Unapproved Working Document

Local and Metropolitan Area Networks– Part 16:

Standard Air Interface for Fixed Broadband Wireless Access Systems-

Media Access Control Modifications and Additional Physical Layer for 2-11 GHz

Abstract: This document is {potentially the basis of} an amendment to the IEEE 802.16 standard for medium-access and physical layer components that meet the functional requirements of a point-to-multipoint Broadband Wireless Access (BWA) system between 2 and 11 GHz as defined by the IEEE 802.16 Working Group. Detailed logical, electrical, and signal processing specifications are presented that enable the production of interoperable equipment.

Keywords: WirelessMAN™ standards, metropolitan area network, fixed broadband wireless access networks

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Editorial Instructions

NOTE-The editing instructions contained in this amendment/corrigendum define how to merge the material contained herein into the existing base standard and its amendments to form the comprehensive standard.

The editing instructions are shown ***bold italic***. Four editing instructions are used: ***change***, ***delete***, ***insert***, and ***replace***. ***Change*** is used to make small corrections in existing text or tables. The editing instruction specifies the location of the change and describes what is being changed by using strikethrough (to remove old material) and underscore (to add new material). ***Delete*** removes existing material. ***Insert*** adds new material without disturbing the existing material. Insertions may require renumbering. If so, renumbering instructions are given in the editing instruction. ***Replace*** is used to make large changes in existing text, subclauses, tables, or figures by removing existing material and replacing it with new material. Editorial notes will not be carried over into future editions because the changes will be incorporated into the base standard.

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1. Overview

1.1 Scope

In this document, sections marked as “*For future study*” are not necessary for the current version of the specification.

Please add the following subclauses and move the content of clause 1.1’s first paragraph into the first subclause 1.1.1

For the purposes of this document, a “system” consists of an 802.16 MAC and PHY implementation with at least one subscriber station communicating with a base station via a point-to-multipoint (P-MP) radio air interface, along with the interfaces to external networks and services transported by the MAC and PHY protocol layers.

1.1.1 10 - 66 GHz Bands

This standard specifies the air interface, including the medium access control layer (MAC) and physical layer (PHY), of fixed point-to-multipoint broadband wireless access (BWA) systems providing multiple services. The medium access control layer is capable of supporting multiple physical layers optimized for the frequency bands of the application. The standard includes a particular physical layer implementation broadly applicable to systems operating between 10 and 66 GHz.

1.1.2 2-11 Ghz Bands

The 802.16ab MAC and PHY must support point-to-multipoint applications in the 2 to 11 GHz range. Radio communications in this range should be possible in near- and non-line-of-sight situations between a base station and a subscriber station. Operational impairments may include partial blockage by foliage, which contributes to signal attenuation and multipath effects. 802.16ab compliant systems shall be deployable in multiple- cell frequency reuse systems and single cell frequency reuse systems. The range of 802.16ab radios varies with transmission power, channel characteristics, availability requirements, local regulations and atmospheric conditions (see IEEE 802.16.3-00/02r4 “Functional Requirements for the 802.16ab Interoperability Standard”).

The ability to support near- and non-line-of-sight scenarios requires new PHY functionality, such as the support of advanced power management techniques, interference mitigation/coexistence and smart antennae support.

The MAC component must be able to support any new PHY features. Additionaly, the 802.16ab MAC introduces new features of its own to deal with the inherent lossy behavior of the wireless medium. Some of these features include the ability to concatenate MPDUs, to employ ARQ on a per-connection basis and to provide an ettiquette for the coexistance of systems in unlicensed bands.

1.2 Purpose

1.3 IEEE 802 Architectural Conformance

1.4 Reference Model

Please add the following new subclause

1.4.1 License Exempt Mesh Topology Option

The IEEE 802.16b system has an optional mesh topology. Unlike the basic point-to-multipoint (P-MP) mode, there are no clearly separate downlink and uplink subframes in the mesh mode. Each station (BS or SS) is able to create direct communication links to a number of other stations in the network instead of communicating only with the BS. However, in typical installations, there will still be certain nodes which provide the BS function of connecting the mesh network to the backhaul links. In fact, when using the mesh centralized scheduling (described below), these BS nodes perform much of the same basic functions as do the BS in the P-MP mode. Thus, the key difference is that in mesh mode all the SSs may have direct links with other SSs. Further, there is no need to have direct link from a SS to the BS of the mesh network. This connection can be provided via other SSs. Communication in all these links shall be controlled by a centralized algorithm (either by the BS or “decentralized” by all nodes periodically), scheduled in a distributed manner within each node’s extended neighborhood, or a scheduled using a combination of these.

1.4.1.1 Distributed scheduling

The stations with which a station has direct links are called neighbors and shall form a neighborhood. A node’s neighbors are considered to be “one hop” away from the node. A two-hop extended neighborhood contains, additionally, all the neighbors of the neighborhood. In the coordinated distributed scheduling mode, all the stations (BS and SSs) shall coordinate their transmissions in their extended two-hop neighborhood.

The coordinated distributed scheduling mode uses some or the entire control portion of each frame to regularly transmit its own schedule and proposed schedule changes on a P-MP basis to all its neighbors. Within a given channel all neighbor stations receive the same schedule transmissions. All the stations in a network shall use this same channel to transmit schedule information in a format of specific resource requests and grants.

Coordinated distributed scheduling ensures that transmissions are collision-free and scheduled in a manner that does not rely on the operation of a BS, and that are not necessarily directed to or from the BS.

Within the constraints of the coordinated schedules (distributed or centralized), uncoordinated distributed scheduling can be used for fast, ad-hoc setup of schedules on a link-by-link basis. Uncoordinated distributed schedules are established by directed requests and grants between two nodes, and must be scheduled to ensure that the resulting data transmissions (and the request and grant packets themselves) do not cause collisions with the data and control traffic scheduled by the coordinated distributed nor the centralized scheduling methods.

1.4.1.2 Centralized and Decentralized scheduling

In the centralized scheduling mesh mode the BS shall act as a centralized scheduler for the SSs within a certain hop range ($HR_{threshold}$) from the BS. The network connections and topology are just the same as in the distributed scheduling mode described in 1.4.1.1, but the BS shall control some portion of the scheduled transmissions for the SSs less than or equal to $HR_{threshold}$ hops from the BS. This hop range, $HR_{threshold}$, may be determined at the system start up phase or may be dynamic according to considerations such as network density, the proximity of other BSs, and/or the dynamic characteristics of the traffic streams.

In centralized scheduling mode the BS shall provide the schedule for all the SSs less than or equal to $HR_{threshold}$ hops from the BS. The BS determines the schedule from the resource requests from the SSs within the $HR_{threshold}$ hop range. Thus the BS acts just like the BS in P-MP network except that not all the SSs have to be directly connected to the BS and the schedule determined by the BS extends to also those SSs that are not directly connected to the BS but less than $HR_{threshold}$ hops from it. The SS resource requests and the BS schedule are both transmitted during the control portion of the frame.

Decentralized scheduling uses the same scheduling algorithm, but rather than have the BS collect all requests and then broadcast the schedule during each scheduling cycle, the requests themselves are broadcast to all the affected nodes which themselves run the same scheduling algorithm to compute the new schedule. So, no separate schedule messages are needed since all the nodes, including SSs, shall be able to determine their schedule.

Centralized scheduling ensures that transmissions are coordinated to ensure collision-free scheduling over the links in the routing tree to and from the BS, typically in a more optimal manner than the distributed scheduling method for traffic streams (or collections of traffic streams which share links) which persist over a duration that's greater than the cycle time to relay the new resource requests and distribute the updated schedule.

Decentralized scheduling has the additional advantage of lower communication overhead when the routing tree to and from the BS is known by the nodes within $HR_{threshold}$ hops of the BS, and can work well when changes to the network topology are relatively infrequent relative to the scheduling cycle.

4. Abbreviations and acronyms

Note - Temporary section for use in development of specification. Not needed in final Delta draft format.

3-DES two-key triple DES
AK *A*uthorization *K*ey
ARP *A*ddress *R*esolution *P*rotocol
ARQ *A*utomatic *R*epeat re*Q*uest
ATDD *A*daptive *T*ime *D*ivision *D*uplexing
ATM *A*synchronous *T*ransfer *M*ode
BCC *B*lock *C*onvolutional *C*ode
BE *B*est *E*ffort
BNI *B*ase station *N*etwork *I*nterface

BR	*B*andwidth *R*equest
BS	*B*ase *S*tation
BTC	*B*lock *T*urbo *C*ode
BWA	*B*roadband *W*ireless *A*ccess
C/(I+N)	*C*arrier to (*I*nterference plus *N*oise) ratio
C/I	*C*arrier to *I*nterference ratio
C/N	*C*arrier to *N*oise ratio
CA	*C*ertification *A*uthority
CBC	*C*ipher *B*lock *C*haining
CBR	*C*onstant *B*it *R*ate
CCS	*C*ommon *C*hannel *S*ignaling
CCV	*C*lock *C*omparison *V*alue
CG	*C*ontinuous *G*rant
CID	*C*onnection *ID*entifier
CLP	*C*ell *L*oss *P*riority
CPE	*C*ustomer *P*remise *E*quipment
CPS	*C*ommon *P*art *S*ublayer
CRC	*C*yclic *R*edundancy *C*heck
CS	*C*onvergence *S*ublayer
ChID	*Ch*annel *ID*entifier
DAMA	*D*emand *A*ssign *M*ultiple *A*ccess
DCD	*D*ownlink *C*hannel *D*escriptor
DES	*D*ata *E*ncryption *S*tandard
DHCP	*D*ynamic *H*ost *C*onfiguration *P*rotocol
DIUC	*D*ownlink *I*nterval *U*sage *C*ode
DIX	*D*EC-*I*ntel-*X*erox
DL	*D*own*L*ink
DSA	*D*ynamic *S*ervice *A*ddition
DSC	*D*ynamic *S*ervice *C*hange
DSD	*D*ynamic *S*ervice Deletion
DSx	*D*ynamic *S*ervice Addition, Change, or Deletion
EC	*E*ncryption *C*ontrol
ECB	*E*lectronic *C*ode *B*ook
EDE	*E*ncrypt-*D*ecrypt-*E*ncrypt
EIRP	*E*ffective *I*sotropic *R*adiated *P*ower
EKS	*E*ncryption *K*ey *S*equence
ETSI	*E*uropean *T*elecommunications *S*tandards *I*nstitute
EUI	*E*xtended *U*nique *I*dentifier
EVM	*E*rror *V*ector *M*agnitude
FC	*F*ragmentation *C*ontrol
FDD	*F*requency *D*ivision *D*uplex
FEC	*F*orward *E*rror *C*orrection
FSH	*F*ragmentation *S*ub-*H*eader
FSN	*F*ragment *S*equence *N*umber
GF	*G*alois *F*ield)
GM	*G*rant *M*anagement
GPC	*G*rant *P*er *C*onnection
GPSS	*G*rant *P*er *S*ubscriber *S*tation
HCS	*H*eader *C*heck *S*equence
HEC	Header *E*rror *C*heck
HL-MAA	*H*igh *L*evel *M*edium *A*ccess *A*rbitration
HMAC	*H*ashed *M*essage *A*uthentication *C*ode
HT	*H*eader *T*ype
IE	*I*nformation *E*lement

IGMP	*I*nternet *G*roup *M*anagement *P*rotocol
IP	*I*nternet *P*rotocol
ITU	*I*nternational *T*elecommunication *U*nion
IUC	*I*nterval *U*sage *C*ode
IWF	*I*nter*W*orking *F*unction
KEK	*K*ey *E*ncryption *K*ey
LAN	*L*ocal *A*rea *N*etwork
LFSR	*L*inear *F*eedback *S*hift *R*egisters
LL-MAA	*L*ow *L*evel *M*edium *A*ccess *A*rbitration
LLC	Logical Link Control
LMDS	*L*ocal *M*ultipoint *D*istribution *S*ervice
LOS	*L*ine *O*f *S*ight
lsb	*l*east *s*ignificant *b*it
LSB	*L*east *S*ignificant *B*yte
MAA	*M*edium *A*ccess *A*rbitration
MAC	*M*edium *A*ccess *C*ontrol
MAN	*M*etropolitan *A*rea *N*etwork
MIB	*M*anagement *I*nformation *B*ase
MIC	*M*essage *I*ntegrity *C*heck
MMDS	*M*ultichannel *M*ultipoint *D*istribution *S*ervice
MPEG	*M*oving *P*ictures *E*xperts *G*roup
MPLS	*M*ulti-*P*rotocol *L*abel *S*witching
msb	*m*ost *s*ignificant *b*it
MSB	*M*ost *S*ignificant *B*yte
MTG	*M*odulation *T*ransition *G*ap
NNI	*N*etwork to *N*etwork *I*nterface (or Network Node Interface)
nrtPS	*n*on-*r*eal-*t*ime *P*olling *S*ervice
OID	*O*bject *ID*entifier
OOB	*O*ut-of-band or *O*ut-of-*B*lock
PBR	*P*iggy*B*ack *R*equest
PCI	*P*rotocol *C*ontrol *I*nformation
PDH	*P*lesiochronous Digital *H*ierarchy
PDU	*P*rotocol *D*ata *U*nit
PHS	*P*ayload *H*eader *S*uppression
PHSF	*P*ayload *H*eader *S*uppression *F*ield
PHSI	*P*ayload *H*eader *S*uppression *I*ndex
PHSM	*P*ayload *H*eader *S*uppression *M*ask
PHSS	*P*ayload *H*eader *S*uppression Size
PHSV	*P*ayload *H*eader *S*uppression *V*alid
PHY	*PHY*sical layer
PI	*P*HY *I*nformation element
PKM	*P*rivacy *K*ey *M*anagement
PLME	*P*HY *L*ayer *M*anagement *E*ntity
PM	*P*oll-*M*e bit
PMD	*P*hysical *M*edium *D*ependent
ppm	*p*arts *p*er *m*illion
PPP	*P*oint-to-*P*oint *P*rotocol
PRBS	*P*seudo *R*andom *B*inary *S*equence
PS	*P*hysical *S*lot
PSH	*P*acking *S*ub-*H*eader
PTI	*P*ayload *T*ype *I*ndicator
PVC	*P*ermanent *V*irtual *C*onnection
QoS	*Q*uality *o*f *S*ervice
rtPS	*r*eal-*t*ime *P*olling *S*ervice

RS	*R*eed-*S*olomon
RSSI	*R*eceive *S*ignal *S*trength *I*ndicator
Rx	*R*eception
SA	*S*ecurity *A*ssociation
SAID	*S*ecurity *A*ssociation *ID*entifier
SAP	*S*ervice *A*ccess *P*oint
SDH	*S*ynchronous *D*igital *H*ierarchy
SDU	*S*ervice *D*ata *U*nit
SF	*S*ervice *F*low
SFID	*S*ervice *F*low *ID*entifier
SHA	*S*ecure *H*ash *A*lgorithm
SI	*S*lip *I*ndicator
SNI	*S*ubscriber station *N*etwork *I*nterface
SS	Subscriber *S*tation
SVC	*S*witched *V*irtual *C*onnection
TC	*T*ransmission *C*onvergence
TCP	*T*ransmission *C*ontrol *P*rotocol
TDD	*T*ime *D*ivision *D*uplex
TDM	*T*ime *D*ivision *M*ultiplex
TDMA	*T*ime *D*ivision *M*ultiple *A*ccess
TEK	*T*raffic *E*ncryption *K*ey
TFTP	*T*rivial *F*ile *T*ransfer *P*rotocol
TLV	*T*ype-*L*ength-*V*alue
TOS	*T*ype *O*f *S*ervice
Tx	*T*ransmission
UCD	*U*plink *C*hannel *D*escriptor
UDP	*U*ser *D*atagram *P*rotocol
UGS	*U*nsolicited *G*rant *S*ervice
UIUC	*U*plink *I*nterval *U*sage *C*ode
UL	*U*p*L*ink
UNI	User to Network Interface
UTC	*C*oordinated *U*niversal *T*ime
VC	*V*irtual *C*hannel
VCI	Virtual Channel Identifier
VLAN	*V*irtual *LAN*
VP	*V*irtual *P*ath
VPI	*V*irtual *P*ath *I*dentifier
XOR	Logical *E*xclusive *Or*

6. MAC Sublayer - Common Part

Change the first paragraph of this clause to the following:

A network that utilizes a shared medium must provide a mechanism to efficiently share it. Two-way point-to-multipoint and mesh topology wireless networks are good examples of shared media: here the media are the space through which the radio waves propagate.

6.2.2 MAC PDU Formats

6.2.2.1 Message Formats

Please make the following sentence the first sentence of this subclause :

Note: This section does not apply to Sub-11 GHz. Instead see subclause 6.2.7.7. through 6.2.7.10

6.2.2.3.1 Downlink Channel Descriptor (DCD) Message

Please make the following sentence the first sentence of this subclause :

Note: This section does not apply to Sub-11 GHz SC PHY. Instead see subclause 6.2.7.8

6.2.2.3.2 Uplink Channel Descriptor (UCD) Message

Please make the following sentence the first sentence of this subclause :

Note: This section does not apply to Sub-11 GHz SC PHY. Instead see subclause 6.2.7.8

6.2.2.3.3 Downlink Map (DL-MAP) message

Please make the following sentence the first sentence of this subclause :

Note: This section does not apply to Sub-11 GHz. Instead see subclause6.2.7.7 through 6.2.7.10.

6.2.2.3.4 Uplink Map (UL-MAP) message

Please make the following sentence the first sentence of this subclause :

Note: This section does not apply to Sub-11 GHz. Instead see subclause 6.2.7.7 through 6.2.7.10.

6.2.2.3.6 Ranging Response (RNG-RSP) message

Add at end of subclause.

Ranging Code :

Indicating the CDMA code sent by the SS. A required parameter if the SS used CDMA ranging code for initial ranging,in this case the RNG-RSP message will be sent using broadcast CID,and the combination of Ranging Symbol,Ranging sub-channel and Ranging Code shall be used to address the sending SS.

Ranging Symbol

Indicating the OFDMA symbol used by the SS. A required parameter if the SS used CDMA ranging code for initial ranging,in this cas the RNG-RSP message will be sent using broadcast

CID,and the combination of Ranging Symbol,Ranging sub-channel and Ranging Code shall be used to address the sending SS.

Ranging sub-channel

Identifies the Ranging sub-channel used by the SS to send the CDMA code. A required parameter if the SS used CDMA ranging code for initial ranging,in this case the RNG-RSP message will be sent using broadcast CID,and the combination of Ranging Symbol,Ranging sub-channel and Ranging Code shall be used to address the sending SS.

6.2.2.4.33 Mesh Schedule with Distributed Scheduling (MSH-DSCH) Message

A Mesh Schedule with Distributed Scheduling (MSH-DSCH) message shall be transmitted in a mesh mode when using distributed scheduling. In coordinated distributed scheduling, all the stations (BS and SS) shall transmit a MSH-DSCH in a P-MP fashion at a regular interval to inform all the neighbors of the schedule of the transmitting station. The MSH-DSCH message shall be used in parallel also to convey resource requests to the neighbors. Each station shall regularly transmit its MSH-DSCH message in a collision-free manner within its extended neighborhood. In uncoordinated distributed scheduling, the stations shall transmit the MSH-DSCH in a directed fashion to an intended neighbor. The MSH-DSCH message format is given in Table 1, including all of the following parameters:

Frame Number
Incremental counter identifying the MAC frame

Hop Number
Indicates the number of hops to the BS. 0xF indicates 15 hops or greater, or no nearby BS detected.

No. Grants
Number of Grant IEs in the message

No Requests
Number of Request IEs in the message

Table 145—MSH-DSCH Message Format

Syntax	Size	Notes
MSH-DSCH_Message_Format() {		
Generic_MAC_Header()	48 bits	
Management Message Type = TBD	8 bits	
Frame Number	12 bits	
Hop Number	4 bits	
No Requests	4 bits	
No Grants	4 bits	
for (i=0; i< No_Requests; ++i) {		
Neighbor ID	8 bits	
Start Frame Offset	4 bits	
Direction	1 bit	
Channel	3 bits	
Position	8 bits	
Duration	6 bits	
Priority	2 bits	

Table 145—MSH-DSCH Message Format

Syntax	Size	Notes
}		
for (i=0; i< No_Grants; ++i) {		
Neighbor ID	8 bits	
Start Frame Offset	4 bits	
Direction	1 bit	
Channel	3 bits	
Position	8 bits	
Duration	6 bits	
Persistence	2 bits	
}		

The Requests and Grants carried in the MSH-DSCH message shall include all of the following parameters:

Neighbor ID
The ID assigned by the transmitting node to the neighbor that this request or grant involves.

Start Frame Offset
Start frame identifier as frame offset.

Direction
0= From requester (i.e. to granter)
1= To requester (i.e. from granter)

Position
The start position of the reservation (PHY slot as time unit)

Duration
The number of slots reserved

Channel
Logical channel number

Persistence
Persistency field for grants

Priority
Priority field for requests

6.2.2.4.34 Mesh Schedule with Centralized Scheduling (MSH-CSCH) Message

A Mesh Schedule with Centralized Scheduling (MSH-CSCH) message shall be created by a BS in mesh mode when using centralized scheduling. The BS will send (unicast or broadcast) the MSH-CSCH message to all its neighbors, and all the SSs within the $HR_{threshold}$ hop range shall forward the MSH-CSCH message to their neighbors that are further away from the BS (i.e. more hops to the BS). The BS shall generate MSH-CSCHs in the format shown in Table 3, including all of the following parameters:

Flow Scale
Determines scale of the granted bandwidth

NumAssignments
Number of 8-bit assignment fields followed

UpstreamAssignment

Base of the granted bandwidth as bits/s for the ingress traffic of the node in the BS's routing tree

DownstreamAssignment

Base of the granted bandwidth as bits/s for the egress traffic of the node in the BS's routing tree

The actual granted bandwidth shall be calculated as

BW = **UpstreamAssignment** * ($2^{\mathbf{FlowScale}}$), for ingress traffic
BW = **DownstreamAssignment** * ($2^{\mathbf{FlowScale}}$), for egress traffic

The nodes in the list are ordered according to a (higher-layer) routing protocol's ordering of the current routing tree to and from the BS, known to all nodes in the network.

Table 146—MSH-CSCH Message Format

Syntax	Size	Notes
MSH-CSCH_Message_Format() {		
Generic_MAC_Header()	48 bits	
Management Message Type = TBD	8 bits	
Flow Scale	4 bits	
NumAssignments	8 bits	
for (i=0; i< NumAssignments; ++i) {		
UpstreamAssignment	4 bits	
DownstreamAssignment	4 bits	
}		
}		

6.2.2.4.35 Mesh Network Configuration (MSH-NCFG) Message

Mesh Network Configuration (MSH-NCFG) messages provide a basic level of communication between nodes in different nearby networks whether from the same or different equipment vendors or wireless operators. All the nodes (BS and SS) in the mesh network shall transmit MSH-NCFGs as described in clause 6.2.7.6.1.1.4.

Table 147—MSH-NCFG Message Format

Syntax	Size	Notes
MSH-DSCH_Message_Format() {		
Generic_MAC_Header()	48 bits	
Management Message Type = TBD	8 bits	
Frame Number	12 bits	
Hop Number	4 bits	
Sequence	8 bits	
Net Entry Address	32 bits	
Power & antenna	4 bits	
Channel	4 bits	
Next Xmt Time	5 bits	
Xmt Holdoff	3 bits	
NumFullNbrEntries	4 bits	
NumCompNbrEntries	4 bits	
for (i=0; i< NumFullNbrEntries; ++i) {		
Nbr MAC Adr	32 bits	
Node Identifier	8 bits	
Nbr Link Info	24 bits	
}		
for (i=0; i< NumCompNbrEntries; ++i) {		
Node Identifier	8 bits	
Nbr Link Info	24 bits	
}		

All the nodes shall generate MSH-NCFGs in the format shown in Table 147, including all of the following parameters:

Frame Number
Incremental counter identifying the MAC frame

Hop Number
Indicates the number of hops to the BS

Sequence
Sequence number used by neighbors to detect missed transmissions

Net Entry Address

MAC address of the new node which this node is supporting in entering the network, or 0xFFFFFFFF if a neighbor node is either entering the network or sponsoring a network entry, or 0x00000000 if no nearby node is attempting to enter the network

Power & antenna

Transmit power & antenna settings used for this message

Channel

The base channel being used in this node's network

Next Xmt Time

This node's next transmission time for MSH-NCFG

Xmt Holdoff

This node's transmit holdoff delay (rounded up to the nearest compressed value)

NumFullNbrEntries

Number of entries in the list of full neighbor information

NumCompNbrEntries

Number of entries in the list of compressed neighbor information

The list of neighbors is selected in a round-robin manner from the node's 1-hop neighbors. The neighbor entries shall include the following parameters:

Nbr MAC Adr

32-bit MAC address, present only in full neighbor information list

Node Identifier

This node's neighbor ID for this physical neighbor

Nbr Link Info

Contains precise information about link status and quality. Consists of several subfields and the format described below.

A node shall generate **Nbr Link Info** field in the format shown in Table 5, including all of the following subfields:

Xmt Holdoff Time

The holdoff time for this neighbor

The **Xmt Holdoff Time** transmitted in the packet shall be quantized to 3 bits with a range of 16 to 2048 MSH-NCFG transmission opportunities, using the following formula (where x is the value transmitted in the packet):

$$\text{Xmt Holdoff Time} = 2^{(x + 4)}$$

Next Xmt Time

The next transmit time for this neighbor

Next Xmt Time shall be compressed in MSH-NCFG packets to 5 bits giving the **Next Xmt Time** "block." The block size is the number of MSH-NCFG opportunities and is related to the value of "x" used in the corresponding Xmt Holdoff Time by the following formula:

$$\text{Next Xmt Time Block Size} = 2^{x}$$

So, if x equals 0 (corresponding to a Xmt Holdoff Time of 16), then the block size is 1 and the **Next Xmt Time** value indicates the actual Next Xmt Time opportunity. If x equals 1, then the block size is two, and the **Next Xmt Time** actual refers to two possible transmit opportunities given by the value passed in the **Next Xmt Time** field times two, and that value plus 1.

For the above scheduling and Mesh Election algorithm, a neighbor node should be considered to be transmitting for any MSH-NCFG opportunity within its Next Xmt Time block. If the Next Xmt Time field is set to 0x1F (all ones), then the neighbor should be considered to be transmitting from the time indicated by this value and every MSH-NCFG opportunity thereafter.

Propagation delay

The propagation delay estimate for this neighbor in time slots

Rcv Link Quality

Measure of the receive link quality from this neighbor

Rcv PHY

PHY mode for this neighbor to use for initial packet transmissions over this link

Rcv Xmt Power

The transmit power for this neighbor to use for this link

Reserved

Reserved for future use, set to 0

Table 148—Contents of the “NBR Link Info” Field

Syntax	Size	Notes
Next Xmt Time	5 bits	
Xmt Holdoff Time	3 bits	
Propagation Delay	4 bits	
Rcv Link Quality	4 bits	
Rcv PHY	3 bits	
Rcv Xmt Power	3 bits	
Reserved	2 bits	Set to 0

The following procedure is used to select the list of physical neighbors to report in the compressed neighbor section of the MSH-NCFG message:

- Any neighbors reported in the round-robin (full neighbor entry) list are excluded.
- All neighbor entries with the “Reported Flag” set are excluded.
- The remaining neighbor entries are ordered by the **Next Xmt Time**, and the NumCompNbrEntries entries with the **Next Xmt Time** the furthest in the future are reported in this MSH-NCFG packet. (In general, learning of nodes with **Next Xmt Times** furthest into the future is more valuable than learning of nodes with **Next Xmt Times** approaching soon, since the neighbors will have more time to use this ineligibility information before it’s stale.)

The “Reported Flag” for all neighbors in either of the above neighbor lists is set to TRUE upon transmission of this MSH-NCFG packet.

6.2.2.4.36 Mesh Network Entry (MSH-NENT) Message

Mesh Network Entry (MSH-NENT) messages provide the means for a new node to gain synchronization and initial network entry into a mesh network. The MSH-NENT message format is given in Table 149, including all of the following parameters:

Frame Number

Incremental counter identifying the MAC frame

Hop Number

Indicates the number of hops to the BS

Sponsor Address

Address of sponsor node

Sequence

Sequence number used by neighbors to detect missed transmissions

Release Flag

Set to 1 for the final MSH-NENT packet transmitted by this node at the completion of the network entry process

Xmt Power

Transmit power used for this message

Reserved

Reserved for future use, set to 0

Table 149—MSH-NENT Message Format

Syntax	Size	Notes
MSH-DSCH_Message_Format() {		
Generic_MAC_Header()	48 bits	
Management Message Type = TBD	8 bits	
Frame Number	12 bits	
Hop Number	4 bits	
Sponsor Address	32 bits	
Sequence	8 bits	
Release Flag	1 bit	
Xmt Power	3 bits	
Reserved	4 bits	Set to 0
}		

6.2.2.4.37 Mesh Centralized Request (MSH-CRQS) Message

SSs in mesh network can use Centralized Request (MSH-CRQS) messages to request bandwidth from the BS. The de-centralized requests and request distribution also use the MSH-CRQS message format. Each node reports the individual traffic demand requests of each “child” node in its subtree from the BS. The nodes in the subtree are those in the current routing tree to and from the BS, known to all nodes in the network, and ordered by address. The MSH-CRQS message format is given in Table 150.

Table 150—MSH-CRQS Message Format

Syntax	Size	Nodes
MSH-DSCH_Message_Format() {		
Generic_MAC_Header()	48 bits	
Management Message Type = TBD	8 bits	
Usage	4 bits	
Flow Scale	4 bits	
NbrDemands	8 bits	
for (i=0; i< NbrDemands; ++i) {		
UpstreamRequest	4 bits	
DownstreamRequest	4 bits	
}		
}		

The parameters in the message are:

Usage
0=Request message to the BS when using centralized or decentralized scheduling
1=Request message summary from the BS when using decentralized scheduling

Flow Scale
Determines scale of the requested bandwidth

NbrDemands
Number of entries in the list of demands followed

UpstreamRequest
Base of the requested bandwidth as bits/s for the ingress traffic

DownstreamRequest
Base of the requested bandwidth as bits/s for the egress traffic

The actual requested bandwidth shall be calculated as

BW = **UpstreamRequest*** $(2^{\textbf{Flow Scale}})$, for ingress traffic
BW = **DownstreamRequest***$(2^{\textbf{Flow Scale}})$, for egress traffic

6.2.4 ARQ - 2-11 GHz Bands Only

Please remove the current clause and replace it with the following subclauses

The ARQ mechanism is part of the MAC layer and can be enabled on a per-connection basis. The per-connection ARQ and associated parameters should be specified and negotiated during connection creation or change. A connection cannot have a mixed ARQ and non-ARQ traffic. Similar to other properties of the MAC protocol the scope of a specific instance of ARQ is limited to one unidirectional connection.

The ARQ feedback information can be sent as a standalone MAC management message on the appropriate basic management connection, or as piggybacked sub-headers on an existing connection. ARQ feedback cannot be fragmented. The implementation of ARQ is optional.

The term MPDU (MAC Protocol Data Unit), used throughout this document, refers to a MAC PDU with a single MAC header, zero or more optional main or packing sub-headers and a payload, where the presence of sub-headers is indicated by the TYPE field in the generic MAC header. An MPDU may carry one or more whole or fragmented MAC SDUs.

6.2.4.1 Block Numbering Scheme

An ARQ block is a uniquely identifiable entity on which the ARQ algorithm operates. Each ARQ block is identified by an ARQ block number, which is assigned to it by the MAC. ARQ block numbers are assigned in increasing order, modulo ARQ_MAX_BSN, where ARQ_MAX_BSN is 2048 (2^{11}). When the MAC decides to transmit a certain MAC SDU for the first time, it assigns it block numbers starting from the current block index, and according to the ARQ_BLOCK_SIZE parameter, that will determine how many ARQ blocks are contained in the MAC SDU. The last block of an MAC SDU may be of size less than the ARQ_BLOCK_SIZE. Note that the ARQ numbering is merely a numbering scheme that identifies both the MAC SDU transmission order, and the order of the ARQ blocks comprising each MAC SDU. Note the ARQ block numbering implies nothing on the order and size of MPDU transmission. The ARQ_BLOCK_SIZE shall be between 4 to 2048 bytes, with a resolution of one byte. The block size is negotiated between the peers during the connection creation/change. A sequence of blocks following a MAC header or sub-header must have contiguous block numbers.

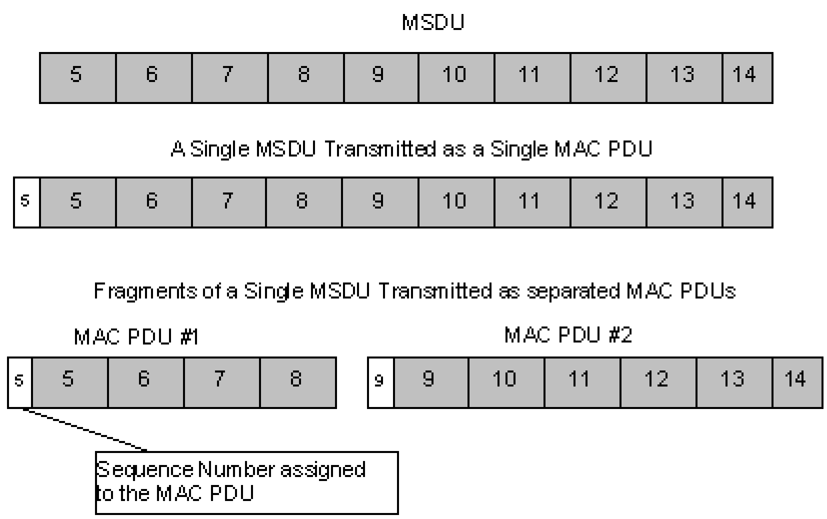


Figure 130—MSDU encapsulation in MAC PDUs

6.2.4.2 ARQ Acknowledgement, Sub-header and Type fields

6.2.4.2.1 Acknowledgment Message Format

Table 151shows the basic ARQ acknowledgment information element used by the receiver to signal positive or negative acknowledgments. This information element may be a transported as part of the ARQ feedback sub-header or as a payload in a standalone MAC PDU.

Table 151—Acknowledgement information element

Syntax	Size	Notes
ARQ_feedback_IE () {		
CID	16 bits	The ID of the connection being referenced
LAST	1 bit	0 = More ARQ feedback IE in the list1 = Last ARQ feedback IE in the list
ACK Type	2 bit	00 = Selective ACK entry01 = Cumulative ACK entry
BSN	11 bits	Block sequential number for the acknowledged ARQ block
Number of 16 bits ACK Maps	2 bits	00 = 16 bits 01 = 32 bits 10 = 48 bits 11 = 64 bits
If (ACK Type == 00) {		
ACK MAP	16 bits	Each bit set to one means the corresponding ARQ block has been received without errors. The first bit corresponds to the ARQ block whose number is the BSN above.
}		
}		

6.2.4.3 Updated Generic MAC header type field encoding

The presence of the sub-headers is indicated by the value of the TYPE field in the generic MAC header. The table below lists the encoding of the TYPE field. The ARQ feedback sub-header enables piggybacking of ARQ feedback information elements. When ARQ-feedback is present, it is always the last sub-header preceding the fragmentation and packing sub-headers that always precede an MAC SDU or fragment. Figure 131 illustrated the piggybacked ARQ feedback as a variable size sub-header.

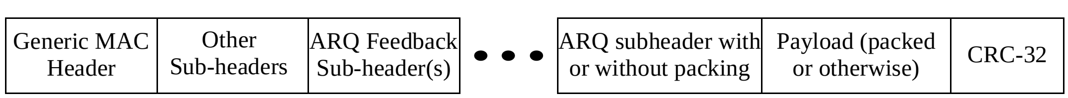


Figure 131—Example MAC PDU with ARQ feedback as piggybacked sub-header

Table 152—Downlink type encoding

Type	Description
0x00	No sub-header present
0x01	Reserved
0x02	ARQ sub-header with packing or TG1 packing subheader present
0x03	Reserved
0x04	ARQ sub-header without packing or TG1 Fragmentation sub-header present
0x05	Reserved
0x06	Reserved
0x07	Reserved
0x08	ARQ-feedback sub-header present
0x09	Reserved
0x0A	ARQ-feedback and packing sub-headers present
0x0B	Reserved
0x0C	ARQ-feedback and fragmentation sub-headers present
0x0D - 0x3F	Reserved

Table 153—Uplink type encoding

Type	Description
0x00	No sub-headers present
0x01	Grant management sub-header present
0x02	ARQ sub-header with packing or TG1 packing sub-header present
0x03	Grant management and packing sub-headers present
0x04	ARQ sub-header without packing or TG1 Fragmentation sub-header present

Table 153—Uplink type encoding

Type	Description
0x05	Grant management and fragmentation sub-headers present
0x06	Reserved
0x07	Reserved
0x08	ARQ-feedback sub-header present
0x09	ARQ-feedback and grant management sub-headers present
0x0A	ARQ-feedback and packing sub-headers present
0x0B	ARQ-feedback and packing and grant management sub-headers present
0x0C	ARQ-feedback and fragmentation sub-headers present
0x0D	ARQ-feedback and fragmentation and grant management sub-headers present
0x0E - 0x3F	Reserved

6.2.4.4 ARQ sub-header without packing

In this case each MPDU will contain a whole MAC SDU or fragment of an MAC SDU. Knowledge of the BSN of the first ARQ block, the length of the MAC SDU or fragment (conveyed in the MAC header) and the **ARQ_BLOCK_SIZE** parameter enable the calculation of the range of ARQ blocks contained in the MAC PDU. The ARQ with fragmentation sub-header position and its contents is shown in Figure 132.

Generic MAC Header	ARQ Sub-headers	Payload (one MSDU or fragment of an MDU)	CRC-32

Figure 132—MAC PDU with ARQ sub-header without packing

Table 154—Format of ARQ sub-header with no packing

Syntax	Size	Notes
Fragmentation_and_ARQ_Sub_Header_Format() {		
FC	2 bits	Fragmentation Control Indicates the fragmentation state of the payload: 00 = no fragmentation 01 = last fragment 10 = first fragment 11 = continuing (middle) fragment
Reserved	2 bits	
ACK Request (“a-bit”)	1 bit	Receiver must send an acknowledgement when this bit is set
BSN	11 bits	Block Sequence number for the first ARQ block in the MAC SDU fragment
}		

6.2.4.5 ARQ sub-header with packing

In this case each MPDU may contain multiple MAC SDUs or fragments thereof. Each of the packed MAC SDU or MAC SDU fragments requires its own ARQ sub-header, as some of them may be transmissions while other are re-transmissions. Knowledge of the BSN of the first ARQ block, the length of the each MAC SDU fragment (conveyed in the packing sub-header) and the **ARQ_BLOCK_SIZE** parameter enable the calculation of the range of ARQ blocks contained in each of the packed message. The ARQ with packing sub-headers position and the contents of an ARQ with packing sub-header is shown below. Note that the A-bit is not present in this sub-header.

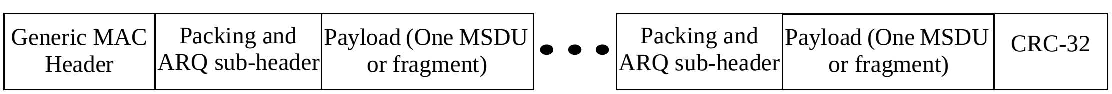


Figure 133—Structure of the MAC PDU with ARQ sub-header with packing

Table 155—Format of ARQ sub-header with packing

Syntax	Size	Notes
Packing_and_ARQ_Sub_Header_Format() {		
FC	2 bits	Fragmentation Control Indicates the fragmentation state of the payload: 00 = no fragmentation 01 = last fragment 10 = first fragment 11 = continuing (middle) fragment
Length	11 bits	The length in bytes of the MAC SDU or MAC SDU fragment, including the three-byte Packing_and_ARQ sub-header
BSN	11 bits	Block Sequence number for the first ARQ block in the MAC SDU fragment
}		

6.2.4.6 ARQ Feedback Sub-header

The ARQ feedback sub-header concatenates one or more ARQ feedback information elements. Therefore the ARQ feedback information element can be "piggybacked" on any connection in the form of a sub-header. Several information elements may be present within the same sub-header. The LAST flag (Table 151) of the information element indicates whether this is the last information element or not, within this sub-header.

6.2.4.7 ARQ Parameters

6.2.4.7.1 ARQ_BLOCK_SIZE

ARQ_BLOCK_SIZE is the basic retransmission unit and it should be negotiated during connection setup. The concept of blocks is described in subclause 6.2.4.1.

6.2.4.7.2 ARQ_WINDOW_SIZE

ARQ_WINDOW_SIZE must be less than or equal to half of the **ARQ_MAX_BSN**.

6.2.4.7.3 ARQ_BLOCK_LIFETIME

ARQ_BLOCK_LIFETIME is the maximum time interval beyond which a transmitter shall discard unacknowledged ARQ blocks.

6.2.4.7.4 ARQ_RETRY_TIMEOUT

ARQ_RETRY_TIMEOUT is the minimum time interval a transmitter shall wait before retransmitting an unacknowledged ARQ block.

6.2.4.7.5 ARQ_SYNC_LOSS_TIMEOUT

ARQ_SYNC_LOSS_TIMEOUT is the minimum time interval after which the ARQ synchronization shall be considered lost.

6.2.4.8 ARQ Procedures

6.2.4.8.1 ARQ State Machine Variables

6.2.4.8.1.1 Transmitter Variables

ARQ_TX_WINDOW_START: All BSN up to (*ARQ_TX_WINDOW_START* - 1) have been acknowledged.

ARQ_TX_NEXT_BSN: BSN of the next block to send. This value shall be between *ARQ_TX_WINDOW_START* and (*ARQ_TX_WINDOW_START* + **ARQ_WINDOW_SIZE).**

6.2.4.8.1.2 Receiver Variables

ARQ_RX_WINDOW_START: All BSN up to (*ARQ_RX_WINDOW_START* - 1) have been correctly received.

ARQ_RX_HIGHEST_BSN: BSN of the highest block received, plus one. This value shall be between *ARQ_RX_WINDOW_START* and (*ARQ_RX_WINDOW_START* + **ARQ_WINDOW_SIZE).**

6.2.4.9 ARQ Connection Setup and Negotiation

Connections are set and defined either statically through the configuration file, or dynamically through the DSA/DSC class of messages. CRC-32 shall be used for error detection of MAC PDUs for all ARQ connections. All the ARQ parameters (subclause 6.2.4.7) shall be set when an ARQ connection is set up. The transmitter and receiver variables (defined in subclause 6.2.4.8.1) shall be reset on connection setup. This section describes the TLV fields for the ARQ algorithm that are required for both static and dynamic connection creation methods.

6.2.4.9.1 ARQ_SUPPORT

This field indicates whether or not ARQ is available for the connection that is being setup. A value of 0 indicates the non-availability of ARQ support and a value 1 indicates otherwise. The DSA-REQ/DSC-REQ shall contain the request to use ARQ or not. The DSA-RSP/DSC-RSP message shall contain the acceptance or rejection of the request. ARQ shall be enabled for this connection only if both sides support it

Table 156—ARQ_SUPPORT TLV

Type	Length	Value	Scope
[24/25]	1	0 = ARQ Not Supported 1 = ARQ Supported	DSx-REQ DSx-RSP Configuration file

6.2.4.9.1.1 ARQ_BLOCK_SIZE

This parameter is negotiated upon connection setup. The DSA-REQ/DSC-REQ shall contain the suggested value of this parameter. The DSA-RSP/DSC-RSP message shall contain the confirmation value or an alternate value for this parameter. The smaller of the two shall be used as the **ARQ_BLOCK_SIZE**.

Table 157—ARQ_BLOCK_SIZE TLV

Type	Length	Value	Scope
[24/25]	2	4 - 2048	DSx-REQ DSx-RSP Configuration file

6.2.4.9.1.2 ARQ_WINDOW_SIZE

This parameter is negotiated upon connection setup. The DSA-REQ/DSC-REQ message shall contain the suggested value for this parameter. The DSA-RSP/DSC-RSP message shall contain the confirmation value or an alternate value for this parameter. The smaller of the two shall be used as the **ARQ_WINDOW_SIZE**.

Table 158—ARQ_WINDOW_SIZE TLV

Type	Length	Value	Scope
[24/25]	2	1 - (ARQ_MAX_BSN/2)	DSx-REQ DSx-RSP Configuration file

6.2.4.9.1.3 ARQ_RETRY_TIMEOUT

The ARQ retry timeout should account for the transmitter and receiver processing delays and any other delays relevant to the system.

TRANSMITTER_DELAY: This is the total transmitter delay, including sending (e.g., MAC PDUs) and receiving (e.g., ARQ feedback) delays and other implementation dependent processing delays. If the transmitter is the BS, it may include other delays such as scheduling and propagation delay.

RECEIVER_DELAY: This is the total receiver delay, including receiving (e.g., MAC PDUs) and sending (e.g., ARQ feedback) delays and other implementation dependent processing delays. If the receiver is the BS, it may include other delays such as scheduling and propagation delay.

The DSA-REQ/DSC-REQ and DSA-RSP/DSC-RSP messages shall contain the values for these parameters, where the receiver and transmitter each declare their capabilities. When the DSA/DSC handshake is completed, each party shall calculate **ARQ_RETRY_TIMEOUT** to be the sum of TRANSMITTER_DELAY and RECEIVER_DELAY. The table below lists the relevant TLVs.

Table 159—ARQ_RETRY_TIMEOUT TLV

Name	Type	Length	Value	Scope
TRANSMITTER_DELAY	[24/25]	2	0 - 65535 (microseconds)	DSx-REQ DSx-RSP Configuration file
RECEIVER_DELAY	[24/25]	2	0 - 65535 (microseconds)	DSx-REQ DSx-RSP Configuration file

6.2.4.9.1.4 ARQ_BLOCK_LIFETIME

The BS shall set this parameter. The DSA-REQ/DSC-REQ or DSA-RSP/DSC-RSP messages shall contain the value of this parameter as set by the BS.

Table 160—ARQ_BLOCK_LIFETIME TLV

Type	Length	Value	Scope
[24/25]	2	0 - 65535 (microseconds)	DSx-REQ DSx-RSP Configuration file

6.2.4.9.1.5 ARQ_SYNC_LOSS_TIMEOUT

The BS shall set this parameter. The DSA-REQ/DSC-REQ or DSA-RSP/DSC-RSP messages shall contain the value of this parameter as set by the BS.

Table 161—ARQ_SYNC_LOSS_TIMEOUT TLV

Type	Length	Value	Scope
[24/25]	2	0 - 65535 (microseconds)	DSx-REQ DSx-RSP Configuration file

6.2.4.9.2 ARQ Operation

6.2.4.9.2.1 ARQ Block Usage

The section describes the use of blocks for ARQ. A MAC SDU is logically divided into blocks of given **ARQ_BLOCK_SIZE**. The last block of a MAC SDU may be smaller than **ARQ_BLOCK_SIZE**. Once defined, the block never changes.

A set of blocks selected for transmission or retransmission is encapsulated into a MAC PDU. A MAC PDU may contain blocks that are transmitted for the first time as well as retransmitted blocks. If fragmentation is enabled for this connection, the fragmentation shall occur only on ARQ block boundaries. Note that a sequence of blocks following a MAC header or sub-header must have contiguous block numbers.

Each ARQ sub-header contains a BSN, which is the sequence number of the first ARQ block in the sequence of blocks following this sub-header. It is a matter of transmitter's policy whether a set of blocks once transmitted as a single MAC PDU should be retransmitted also as a single MAC PDU or not. Figure 134 illustrates the use of blocks for ARQ transmissions and retransmissions.

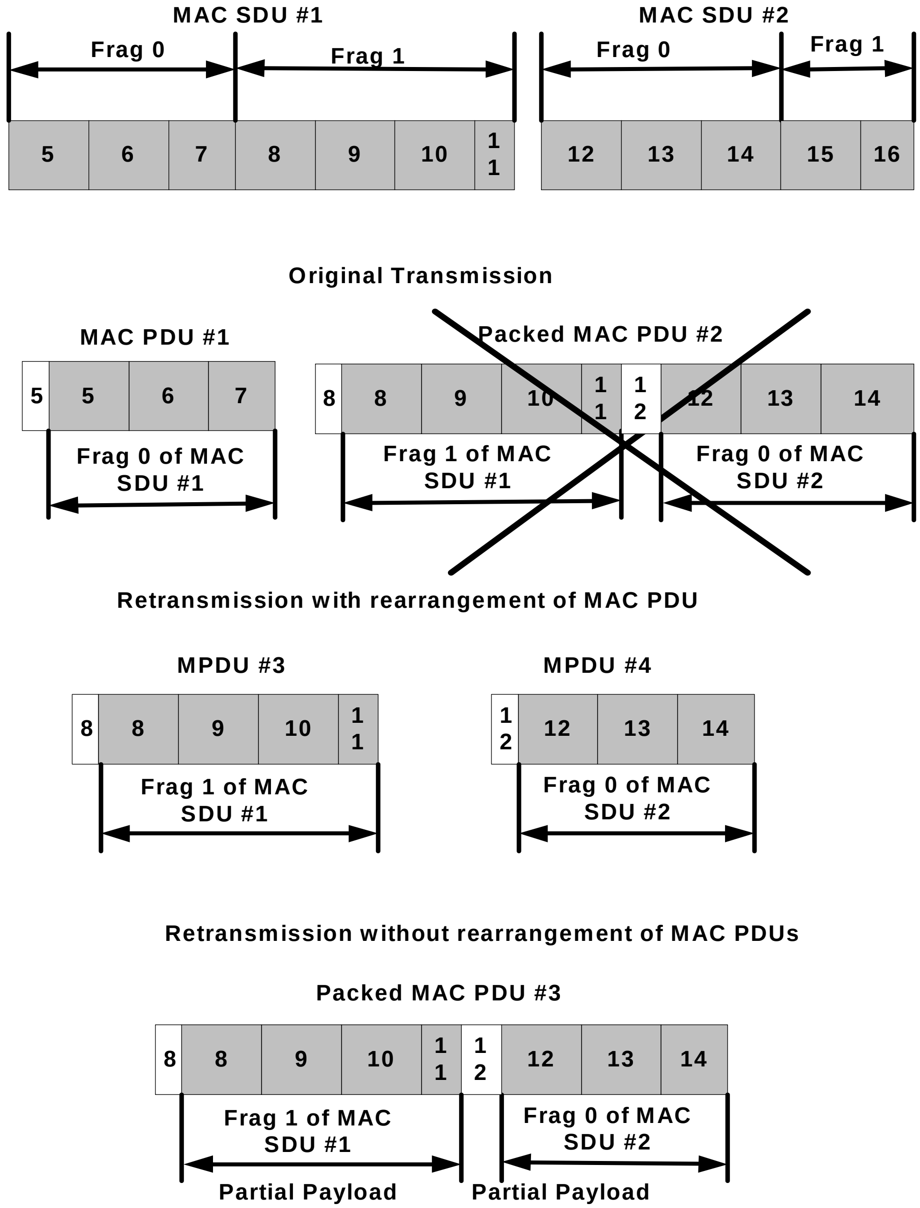


Figure 134—Block usage for ARQ transmissions and retransmissions

6.2.4.9.3 Transmitter State Machine

An ARQ block may be in one of the following four states, *not-sent*, *outstanding*, *discarded* and *waiting-for-retransmission*. Any ARQ block begins as *not-sent*. After it is sent it becomes *outstanding* for a period of time termed **ACK_RETRY_TIMEOUT**. While a block is in *outstanding* state, it either is acknowledged and is *discarded*, or transitions to *waiting-for-retransmission* after **ACK_RETRY_TIMEOUT**. An ARQ block can become *waiting-for-retransmission* before the **ACK_RETRY_TIMEOUT** period expires if it is negatively acknowledged. An ARQ block may also change from *waiting-for-retransmission* to *discarded* when an ACK message for it is received or after a timeout **ARQ_BLOCK_LIFETIME**. The specification of timeout values is outside the scope of the ARQ specification.

The transmitter policy is that if any *waiting-for-retransmission* ARQ blocks exist, they should be given precedence over *not-sent* packets for the same connection. ARQ blocks that are *outstanding* or *discarded* should never be transmitted. When blocks are retransmitted, the block with the lowest BSN shall be retransmitted first.

The ARQ block state sequence is shown below (Figure 135).

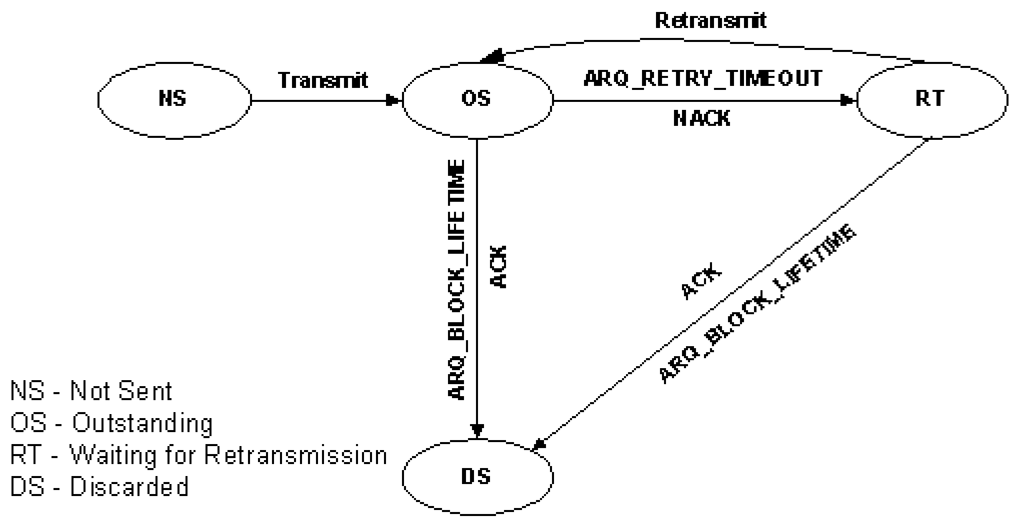


Figure 135—ARQ block states

The transmitter checks (*ARQ_TX_WINDOW_START* + **ARQ_WINDOW_SIZE** - *ARQ_TX_NEXT_BSN)* to see how many ARQ blocks can be transmitted, and creates a full or partial MAC PDU that does not exceed this value. The state variable *ARQ_TX_NEXT_BSN* is copied into the BSN field before transmission, and *ARQ_TX_NEXT_BSN* is incremented after transmission by the number of blocks in the full or partial MAC PDU. If the **ARQ_WINDOW_SIZE** limit is reached due to the transmission of MAC PDU, then the A-bit must be set to 1. Otherwise, the choice of setting A-bit or not is implementation dependent.

When an acknowledgement is received, the transmitter shall check the validity of BSN. A valid BSN is one in the range [*ARQ_TX_WINDOW_START*, *ARQ_TX_NEXT_BSN*]. If BSN is not valid, the transmitter shall ignore the acknowledgement.

If BSN is valid and the acknowledgement is a cumulative, then the transmitter shall consider all blocks in the range [*ARQ_TX_WINDOW_START*, BSN) as acknowledged, set *ARQ_TX_WINDOW_START* to BSN. All timers associated with acknowledged blocks shall be cancelled.

On receiving a valid selective acknowledgement message, the transmitter shall consider all blocks with the corresponding bit set to 1 in the bitmap as acknowledged and those with the corresponding bit set to 0 as negatively acknowledged. Note that an MAC PDU may consist of ARQ blocks transmitted for the first time as well as retransmitted ARQ blocks.

6.2.4.9.4 Receiver State Machine

When an MPDU is received, its integrity is determined based on the CRC-32 checksum. If an MPDU passes the checksum, it is unpacked and de-fragmented, if necessary. The receiver maintains a sliding-window defined by *ARQ_RX_WINDOW_START* state variable and the **ARQ_WINDOW_SIZE** parameter. When an ARQ block with a number that falls in the range defined by sliding window is received, the receiver shall accept it. ARQ block numbers outside the sliding window shall be rejected as out of order. The receiver should discard duplicate ARQ blocks (i.e. ARQ blocks that where already received correctly) within the window.

The sliding window is maintained such that the *ARQ_RX_WINDOW_START* variable always points to the lowest numbered ARQ block that has not been received or has been received with errors. When an ARQ block with a number corresponding to the *ARQ_RX_WINDOW_START* is received, the window is advanced (i.e. *ARQ_RX_WINDOW_START* is incremented modulo **ARQ_MAX_BSN**) such that the *ARQ_RX_WINDOW_START* variable points to the next lowest numbered ARQ block that has not been received or has been received with errors. The timer associated with **ARQ_SYNC_LOSS_TIMEOUT** shall be reset.

If ARQ blocks are being received, yet the *ARQ_RX_WINDOW_START* variable has been pointing to a specific ARQ block for more than **ARQ_SYNC_LOSS_TIMEOUT**, the ARQ synchronization shall be considered lost. In such a case, the window shall slide until an ARQ block that has been correctly received is found. The *ARQ_RX_WINDOW_START* shall point to the next lowest numbered ARQ block that has not been received or has been received with errors.

For each ARQ block accepted fully and without errors (including duplicates), an acknowledgment message may be sent to the transmitter. Acknowledgments may be either for specific ARQ blocks (i.e. contain information on the acknowledged ARQ block numbers), or cumulative (i.e. contain the highest ARQ block number below which all ARQ blocks have been received correctly). Acknowledgments shall be sent in the order of the ARQ block numbers they acknowledge. The frequency of acknowledgement generation is not specified here and is implementation dependent. The receiver shall respond with an acknowledgement, whenever an ARQ sub-header is received with the A-bit set.

An MAC SDU is handed to the upper layers when all the ARQ blocks of the MAC SDU have been correctly received within the timeout values defined.

6.2.4.9.5 Standalone ARQ Feedback

The ARQ feedback message may take the format of a stand-alone MAC message as shown in Table 162. It can be used to signal a cumulative ACK or several selective ACKs similar to the piggybacked sub-header mechanism. This feedback shall be sent as a MAC management message on the appropriate basic management connection (i.e. it cannot be fragmented).

Table 162—Standalone ACK Feedback

Syntax	Size	Notes
ACK_Message_Format() {		
Management Message Type = ?	8 bits	
for (i=1; I<n; i++) {		Repeat as many times as required
ARQ_feedback_IE ()	16 bits	The connection ID being referenced
}		
}		

6.2.7 MAC Support of PHY Layers

6.2.7.6 MAP Relevance and Synchronization

Please insert the following new subclauses

6.2.7.6.1.1.4 Mesh Mode Schedule Relevance and Synchronization

Only TDD is supported in mesh mode. On contrary to the basic P-MP mode, there are no clearly separate downlink and uplink subframes in the mesh mode. Stations shall transmit to each other either in scheduled channels or in random access channels just like in P-MP mode. The basic frame structure is also similar to the one in P-MP mode.

In all scheduling modes, transmission scheduling obeys the following frame structure:

Time is divided into physical slots of duration 2^X microseconds (X integer).
- Using 20 MHz channelization, the default slot duration (T_{dslot}) is 32 microseconds.
- Using 10 MHz channelization, the default slot duration (T_{dslot}) is TBD microseconds.

Slots are then grouped into frames of length 256 slots.

Frames are further grouped into super-frames of length 2048*T_{dslot} microseconds[1].
- Using 20 MHz channelization, the super-frame length is 65536 microseconds, fitting 8 default frames.
- Using 10 MHz channelization, the super-frame length is TBD microseconds, fitting 8 default frames.

For the first frame in each super-frame, the period of 32*T_{dslot} at the start of the frame form the control portion of the frame and super-frame. This control period is used for the network configuration packets detailed in clause 6.2.2.4.35. For other frames, the first N_{slot} (integer) slots of each frame constitute the "control" portion of the frame (or "control slots"). The default size of the control portion (N_{dslot}) of the frame is 32 slots.The remaining (non-control) slots in each frame (256-N_{slot}) constitute the "data" portion of the frame, or the "data slots."

The control portion of frames other than those at the start of the super-frame may be used for the transmission of distributed and centralized scheduling control packets.

In all scheduling modes, data packets are scheduled for transmission during the data portion of the frame. The precise frame structure (e.g., number of microseconds per slot, number of slots in a frame) may vary as a configuration option, but shall be static during normal system operation.

6.2.7.6.1.1.4.1 Physical Neighborhood List

All the basic functions like scheduling and network synchronization are based on the neighbor information all the nodes in the mesh network shall maintain. Each node (BS and SS) maintains a physical neighborhood list with each entry containing the following fields:

MAC Address
32-bit MAC address of the neighbor
Distance

[1] The super-frame length is fixed to ensure interoperability of network configuration packets between mesh systems.

Indicates distance in hops of this neighbor from the present node. If a packet has been successfully received from this neighbor recently (defined further below), it is considered to be 1 hop away.

Node Identifier

8- or 16-bit Number used to identify this node in a more efficient way in MSH-NCFG messages.

Xmt Holdoff Time

The minimum number of frames between MSH-NCFG message transmissions by this node

Next Xmt Time

The super-frame and slot number before which this node is guaranteed not to transmit a MSH-NCFG message. This is initialized to MSH_NEXT_XMT_TIME_NOW. As part of the Aging procedure, and to avoid roll-over problems, this **Next Xmt Time** is also reset to this value whenever this **Next Xmt Time** plus the node's **Xmt Holdoff Time** is equal to or less than the current time.

Earliest Subsequent Xmt Time

The earliest time that this neighbor can transmit its subsequent MSH-NCFG message (following the node's **Next Xmt Time**).

Reported Flag

Set to TRUE if this **Next Xmt Time** has been reported by this node in a MSH-NCFG packet. Else set to FALSE.

For direct (one-hop) neighbors the Node Identifier field shall contain:

Nbr ID

8-bit number indicating the neighbor number which this node has assigned to this neighbor

For indirect (two-hop) neighbors the Node Identifier field shall contain:

Rep ID

Nbr ID for the neighbor that is reporting this two-hop neighbor

Rep Nbr ID

The **Nbr ID** used by the direct (reporting) neighbor to identify this two-hop neighbor node

6.2.7.6.1.1.4.2 Schedule Relevance with Distributed Scheduling

When using coordinated distributed scheduling all the stations in a network shall use the same channel to transmit schedule information in a format of specific resource requests and grants in Mesh Mode Schedule Messages with Distributed Scheduling (MSH-DSCH). A station shall indicate its own schedule by transmitting a MSH-DSCH regularly. The MSH-DSCH messages shall be transmitted during the control portion of the frame. Relevance of the MSH-DSCH is variable and entirely up to the station. An example case is given in Figure 136, in which super-frame size of eight frames has been assumed.

MSH-DSCH messages are transmitted regularly throughout the whole mesh network to distribute nodes' schedules and (together with network configuration packets) provide network synchronization information. A SS that has a direct link to the BS shall synchronize to the BS while a SS that is at least two hops from the BS shall synchronize to its neighbor SSs that are closer to the BS.

The control portion of the first frame in each super-frame is reserved for communication of mesh network configuration packets (MSH-NCFG), as detailed in clause [REF]6.2.2.4.35. The MSH-NCFG packets shall be used to convey information about network status and configuration such as:

Synchronization across multiple mesh networks,
Communication of channels in use across multiple networks, and
Support of network entry for new or mobile nodes.

6.2.7.6.1.1.4.3 Schedule Relevance with Centralized Scheduling

When using centralized scheduling the BS shall act as a centralized scheduler for the SSs within a certain hop range ($HR_{threshold}$) from the BS. The BS shall control all the scheduled transmissions for the SSs less than or equal to $HR_{threshold}$ hops from the BS.

While in distributed scheduling mode all the stations within each two-hop neighborhood shall exchange their schedules in MSH-DSCH messages, in centralized scheduling mode the BS shall indicate all the SSs less than or equal to $HR_{threshold}$ hops from the BS their schedule. BS shall use the Mesh Mode Schedule Messages with Centralized Scheduling (MSH-CSCH) message for that purpose. The MSH-CSCH shall apply to a certain fixed period called an Epoch. An Epoch consists of a variable number of frames. The number of frames in an epoch can be configured during system installation, and can occasionally adapt due to considerations like network size, but shall generally remain static during system operation. This is illustrated in Figure 137, in which an Epoch consists of four frames and a super-frame is equal to eight frames. One should note, that the figure doesn't show messages like MSH-CRQSs required for the successful scheduling. Further, it's a simplified snapshot from the BS's perspective: no MSH-CSCH messages forwarded by the SSs in the network are shown in the figure137.

The BS determines the schedule from the resource requests received from the SSs within the $HR_{threshold}$ hop range. Intermediate SSs are responsible for forwarding these requests for SSs that are further from the BS (i.e. more hops from the BS) as needed. Thus the BS acts just like the BS in P-MP network except that not all the SSs have to be directly connected to the BS and the schedule determined by the BS extends to also those SSs that are not directly connected to the BS but less than or equal to $HR_{threshold}$ hops from it. All the SSs within the $HR_{threshold}$ hop range shall listen and install the schedule for the next Epoch indicated in the MSH-CSCH message. Further, they shall forward the MSH-CSCH message to their neighbors that are further away from the BS.

Additionally, as with distributed scheduling, the control portion of the first frame in each super-frame is reserved for communication of mesh network configuration packets (MSH-NCFG).

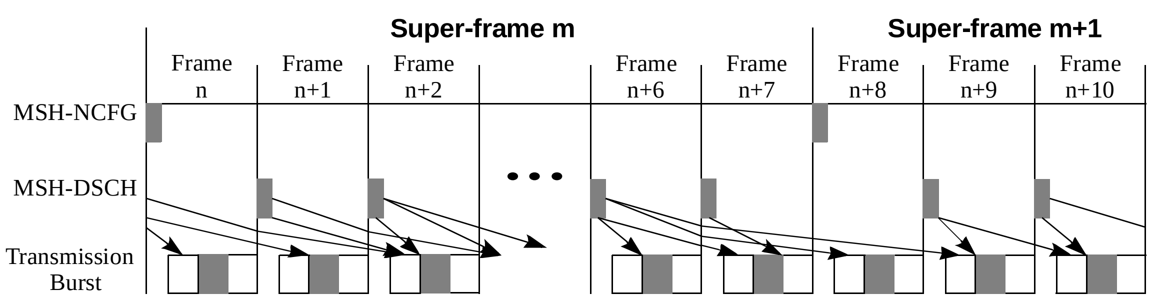


Figure 136—Time Relevance of MSH-DSCH in Distributed Scheduing Mode

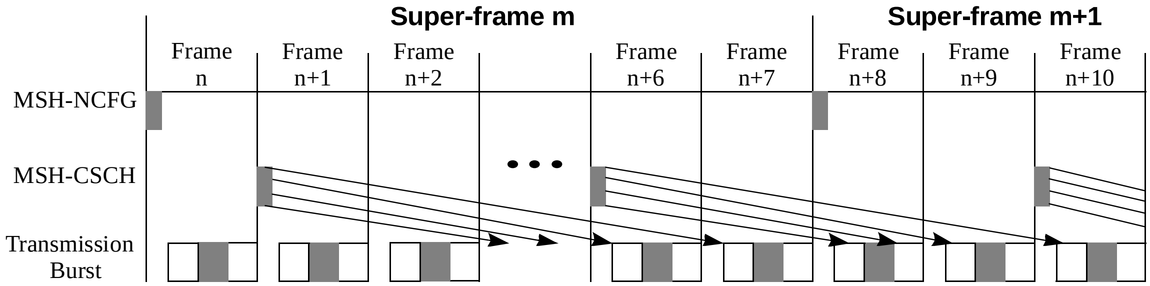


Figure 137—Time Relevance of MSH-CSCH in Centralized Scheduing Mode

6.2.7.6.1.1.4.4 Mesh Network Synchronization

Network configuration (MSH-NCFG) and network entry (MSH-NENT) packets provide a basic level of communication between nodes in different nearby networks whether from the same or different equipment vendors or wireless operators. This communication is used to support basic configuration activities such as:

synchronization between nearby networks used, for instance, for multiple, co-located BSs to synchronize their upstream and downstream transmission periods,
communication and coordination of channel use by nearby networks, and
discovery and basic network entry of new nodes.

6.2.7.6.1.1.4.4.1 MSH-NCFG/MSH-NENT Transmission Timing

MSH-NCFG and MSH-NENT packets are scheduled for transmission during the control portion of the first frame in each super-frame. So that all nearby nodes receive these transmissions, the channel used is cycled through the available channels in the band, with the channel selection being based on the super-frame number. So, for super-frame number i, the channel is determined by the array lookup:

netConfigChannel = channelList[i % channelListLen];

Where the channelList and channelListLen are configuration parameters, which shall be the standard channel selections for the band.

MSH-NCFG and MSH-NENT packets are transmitted at the most robust modulation level. With 20 MHz channelization the default duration of the control portion of the frame used for MSH-NCFG and MSH-NENT packets is $32*T_{dslot}$ = 1,024 microseconds. This is divided as follows:

256 microseconds reserved for the changing to the netConfigChannel channel[1]
144 microseconds reserved for MSH-NENT “network entry” transmissions by new nodes with transmission of preamble commencing at 280 microseconds into the frame.
184 microseconds for first opportunity for MSH-NCFG transmissions by other nodes with transmission of preamble commencing at 416 microseconds into the frame.
184 microseconds for second opportunity for NetConfig transmissions by other nodes, with transmission of preamble commencing at 600 microseconds into the frame.
256 microseconds reserved for returning to the appropriate network channel.

[1] If the particular equipment requires more time than this to change the channel, then it will need to schedule for the channel change to commence at the appropriate time during the previous frame. A similar statement applies to the channel change required at the end of the MSH-NCFG control slots.

For other channelization schemes both the duration of the control portion of the frame and its subparts shall be determined accordingly.

6.2.7.6.1.1.4.4.2 MSH-NCFG Reception Procedure

When a MSH-NCFG packet is received from a neighbor, the following is performed:The distance of the transmitting node is updated to 1-hop (direct) if necessary.

For each node reported in this packet which is not a direct 1-hop neighbor, the distance to the reported node is updated to 2.

The **Next Xmt Time** and **Xmt Holdoff Time** of the transmitting node and all reported nodes are updated. Also, the Earliest Subsequent Xmt Time is updated to equal the neighbor's **Next Xmt Time** plus its **Xmt Holdoff Time**.

If any reported neighbor is found with a **Next Xmt Time** equal to the present node's **Next Xmt Time**, then the MSH_SKIP THIS NCFG_XMT flag is set. (This could occur as a transient condition with topology changes due to channel dynamics or mobility.)

The "Reported Flag" for each entry in the Physical Neighbor Table which was modified is set to FALSE.

If the Node Identifier for any reported node in the compressed neighbor list cannot be resolved to a neighbor entry (with MAC address) using the information in the Physical Neighbor List(see 6.2.7.6.1.1.4.1), then the corresponding neighbor entry is skipped.

6.2.7.7 Common PHY support elements for systems between 2 and 11 GHz

This clause describes the PHY support components that are common for all systems between 2-11 GHz. Clauses 6.2.7.8, 6.2.7.9 and 6.2.7.10 describe the specific components that support each of the individual PHY's for systems between 2-11 GHz. Additionally, components are specified to support licensed-exempt operation in 6.2.7.11 and to support advanced antenna systems (AAS) in 6.2.7.12.

6.2.7.7.1 Downlink and uplink Operation

Two modes of operation have been defined for the point-to-multi-point downlink channel:

- Mode A: supports a continuous transmission stream format (FDD), and
- Mode B: support a burst transmission stream format (FDD or TDD).

Standard-compliant stations are required to support at least one (A or B) of these modes in the downlink and shall only support mode B in the uplink. A Mode B compliant frame can be configured to support either TDM or TDMA transmission formats; i.e. a Mode B burst may consist of a signle user's data, or a concatenation of several users' data.

Having this separation allows each format to be optimized according to its respective design constraints, while resulting in a standard that supports various system requirements and deployment scenarios. This single mode of operation is sufficient for the upstream, since the upstream transmissions are point-to-point burst transmissions between each transmitting subscriber station (SS) and each receiving base station (BS).

6.2.7.7.1.1 Mode A - Continuous Downlink

Mode A is a downlink format intended for continuous transmission. The Mode A downlink physical layer first encapsulates MAC packets into a convergence layer frame as defined by the transmission convergence sublayer. Modulation and coding which is adaptive to the needs of various SS receivers is also supported within this framework.

In Mode A, the downstream channel is continuously received by many SSs. Due to differing conditions at the various SS sites (e.g., variable distances from the BS, presence of obstructions), SS receivers may observe significantly different SNRs. For this reason, some SSs may be capable of reliably detecting data only when it is derived from certain lower-order modulation alphabets, such as QPSK. Similarly, more powerful and redundant FEC schemes may also be required by such SNR-disadvantaged SSs. On the other hand, SNR-advantaged stations may be capable of receiving very high order modulations (e.g., 64-QAM) with high code rates. Collectively, let us define the adaptation of modulation type and FEC to a particular SS (or group of SSs) as 'adaptive modulation', and the choice of a particular modulation and FEC as an 'adaptive modulation type.' Mode A supports adaptive modulation and the use of adaptive modulation types.

A MAC Frame Control header is periodically transmitted over the continuous Mode A downstream, using the most robust supported adaptive modulation type. So that the start of this MAC header may be easily recognized during initial channel acquisition or re-acqusition, the PHY inserts an uncoded, known (but TBD) QPSK code word, of length TBD symbols, at a location immediately before the beginning of the MAC header, and immediately after a Unique Word. (See PHY framing clause for more details on the Unique Word). Note that this implies the interval between Frame Control headers should be an integer multiple of F (the interval between Unique Words).

Within MAC Frame Control header, a PHY control map (DL_MAP) is used to indicate the beginning location of adaptive modulation type groups which follow. Following this header, adaptive modulation groups are sequenced in increasing order of robustness. However, the DL_MAP does not describe the beginning locations of the payload groups that immediately follow; it describes the payload distributions some MAC-prescribed time in the future. This delay is necessary so that FEC decoding of MAC information (which could be iterative, in the case of turbo codes) may be completed, the adaptive data interpreted, and the demodulator scheduling set up for the proper sequencing.

Note that adaptive modulation groups or group memberships can change with time, in order to adjust to changing channel conditions.

In order that disadvantaged SNR users are not adversely affected by transmissions intended for other advantaged SNR users, FEC blocks end when a particular adaptive modulation type ends. Among other things, this implies that the FEC interleaver depth is adapted to accommodate the span of a particular adaptive modulation type.

6.2.7.7.1.2 Mode B - Burst Downlink

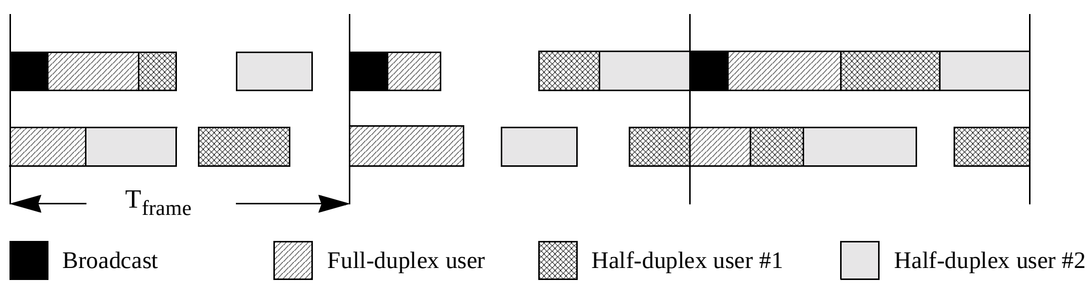


Figure 138—Example of burst FDD Bandwidth Allocation

Mode B is a downlink format intended for burst transmissions, with features that simplify the support for both TDD systems and half-duplex terminals. A Mode B compliant frame can be configured to support either TDM or TDMA transmission formats; i.e., a Mode B burst may consist a single user's data, or a concatenation of several users' data. What's more, Mode B supports adaptive modulation and multiple adaptive modulation types within these TDMA and TDM formats.

A unique (acquisition) preamble is used to indicate the beginning of a frame, and assist burst demodulation. This preamble is followed by PHY/MAC control data. In the TDM mode, a PHY control map (DL_MAP) is used to indicate the beginning location of different adaptive modulation types. These adaptive modulation types are sequenced within the frame in increasing order of robustness (e.g., QPSK, 16-QAM, 64-QAM), and can change with time in order to adjust to the changing channel conditions.

In the TDMA mode, the DL_MAP is used to describe the adaptive modulation type in individual bursts. Since a TDMA burst would contain a payload of only one adaptive modulation type, no adaptive modulation type sequencing is required. All TDMA format payload data is FEC block encoded, with an allowance made for shortening the last codeword (e.g., Reed Solomon codeword) within a burst.

The Mode B downlink physical layer goes through a transmission convergence sublayer that inserts a pointer byte at the beginning of the payload information bytes to help the receiver identify the beginning of a MAC packet.

6.2.7.7.1.3 Uplink

The uplink mode supports TDMA burst transmissions from an individual SSs to a BS. This is functionally similar (at the PHY level) to Mode B downlink TDMA operation. As such, for a brief description of the Physical Layer protocol used for this mode, please read the previous clause on Mode B TDMA operation.

Of note, however, is that many of the specific uplink channel parameters can be programmed by MAC layer messaging coming from the base station in downstream messages. Also, several parameters can be left unspecified and configured by the base station during the registration process in order to optimize performance for a particular deployment scenario. In the upstream mode of operation, each burst may carry MAC messages of variable lengths.

6.2.7.7.2 Multiplexing and Multiple Access Technique

The uplink physical layer is based on the combined use of time division multiple access (TDMA) and demand assigned multiple access (DAMA). In particular, the uplink channel is divided into a number of 'time slots.' The number of slots assigned for various uses (registration, contention, guard, or user traffic) is controlled by the MAC layer in the base station and can vary over time for optimal performance.

As previously indicated, the downlink channel can be in either a continuous (Mode A) or burst (Mode B) format. Within Mode A, user data is transported via time division multiplexing (TDM), i.e., the information for each subscriber station is multiplexed onto the same stream of data and is received by all subscriber stations located within the same sector. Within Mode B, the user data is bursty and may be transported via TDM or TDMA, depending on the number of users which are to be borne within in burst.

6.2.7.7.2.1 Duplexing Technique

Several duplexing techniques are supported, in order to provide greater flexibility in spectrum usage. The continuous transmission downlink mode (Mode A) supports frequency division duplexing (FDD) with adaptive modulation; the burst mode of operation (Mode B) supports FDD with adaptive modulation or time division duplexing (TDD) with adaptive modulation. Systems in the licensed-exempt bands shall use TDD only. Furthermore, Mode B in the FDD case can handle (half duplex) subscribers incapable of transmitting and receiving at the same instant, due to their specific transceiver implementation.

6.2.7.7.2.1.1 Mode A: Continuous Downstream for FDD Systems

In a system employing FDD, the uplink and downlink channels are located on separate frequencies and all subscriber stations can transmit and receive simultaneously. The frequency separation between carriers is set either according to the target spectrum regulations or to some value sufficient for complying with radio channel transmit/receive isolation and de-sensitization requirements. In this type of system, the downlink channel is (almost) "always on" and all subscriber stations are always listening to it. Therefore, traffic is sent in a broadcast manner using time division multiplexing (TDM) in the downlink channel, while the uplink channel is shared using time division multiple access (TDMA), where the allocation of uplink bandwidth is controlled by a centralized scheduler. The BS periodically transmits downlink and uplink MAP messages, which are used to synchronize the uplink burst transmissions with the downlink. The usage of the mini-slots is defined by the UL-MAP message, and can change according to the needs of the system. Mode A is capable of adaptive modulation.

6.2.7.7.2.1.2 Mode B: Burst Downstream for Burst FDD Systems

A burst FDD system refers to a system in which the uplink and downlink channels are located on separate frequencies but the downlink data is transmitted in bursts. This enables the system to simultaneously support full duplex subscriber stations (ones which can transmit and receive simultaneously) and, optionally, half duplex subscriber stations (ones which cannot transmit and receive simultaneously). If half duplex subscriber stations are supported, this mode of operation imposes a restriction on the bandwidth controller: it cannot allocate uplink bandwidth for a half duplex subscriber station at the same time that the subscriber station is expected to receive data on the downlink channel.

In order to simplify the bandwidth allocation algorithms, the uplink and downlink channels are divided into fixed sized frames. A full duplex subscriber station must always attempt to listen to the downlink channel. A half duplex subscriber station must always attempt to listen to the downlink channel when it is not transmitting on the uplink channel.

6.2.7.7.2.1.3 Mode B: Burst Downstream for TDD Systems

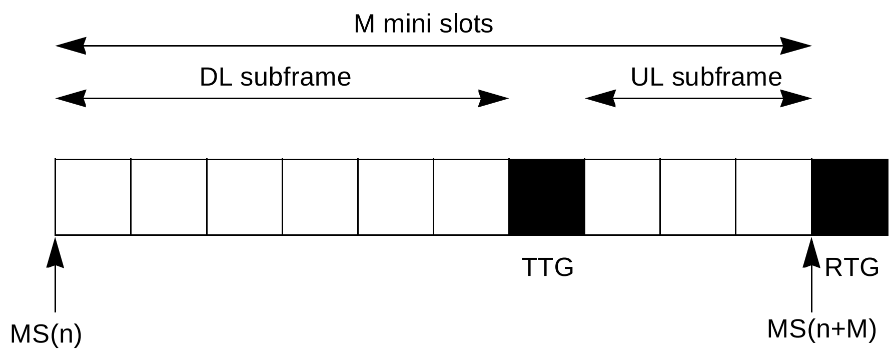


Figure 139—TDD Frame

In the case of TDD, the uplink and downlink transmissions share the same frequency, but are separated in time (Figure 139). A TDD frame also has a fixed duration and contains one downlink and one uplink subframe. Allocation of bandwidth within a frame is performed in terms of mini-slots (MS). Mini-slots are defined in terms of a finer resolution entity called a Physical Slot. The relationship between mini-slots and Physical Slots is given by:

$$\text{Mini-slot} = \text{Physical Slot} \cdot 2^m \quad \text{when} \quad m=0,1,2,3,4,5,6,7$$

The definition of a Physical slot is dependent on the underlying PHY. The split between uplink and downlink is a system parameter, expressed as a number of mini-slots, which occurs at a mini-slot boundary within the frame and is controlled at higher layers within the system.

For OFDM based systems, the Physical Slots are defined as: $\text{Physical Slot} = 4 \cdot \text{Sample time}$.

For SC based systems, the Physical Slots are defined as: $\text{Physical Slot} = 4 \cdot \text{Symbol Duration}$

6.2.7.7.2.1.3.1 Tx / Rx Transition Gap (TTG)

The TTG is a gap between the Downlink burst and the Uplink burst. This gap allows time for the BS to switch from transmit mode to receive mode and SSs to switch from receive mode to transmit mode. During this gap, the BS and SS are not transmitting modulated data, but it simply allows the BS transmitter carrier to ramp down, the Tx / Rx antenna switch to actuate, and the BS receiver clause to activate. After the TTG, the BS receiver will look for the first symbols of uplink burst. The TTG has a configurable duration, which is an integer number of mini slots. The TTG starts on a mini slot boundary.

6.2.7.7.2.1.3.2 Rx / Tx Transition Gap (RTG)

The RTG is a gap between the Uplink burst and the Downlink burst. This gap allows time for the BS to switch from receive mode to transmit mode and SSs to switch from transmit mode to receive mode. During this gap, BS and SS are not transmitting modulated data but simply allowing the BS transmitter carrier to ramp up, the Tx / Rx antenna switch to actuate, and the SS receiver section to activate. After the RTG, the SS receivers will look for the first symbols of QPSK modulated data in the downlink burst. The RTG is an integer number of mini slots. The RTG starts on a mini slot boundary.

6.2.7.7.2.1.4 Mode B: Downlink Data

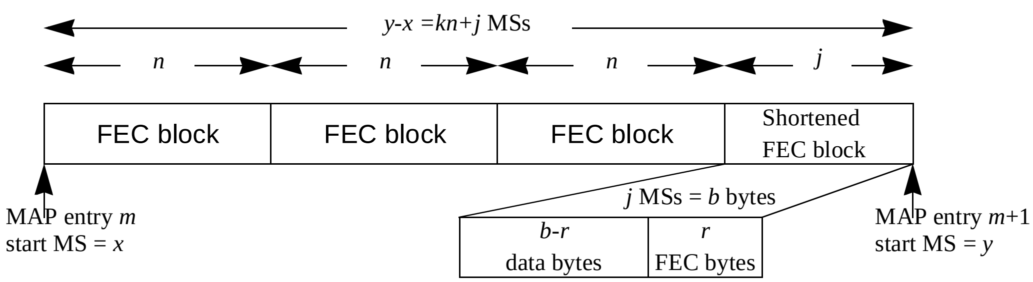


Figure 140—DL-MAP usage and shortened FEC blocks

The downlink data clauses are used for transmitting data and control messages to specific SSs. This data is always FEC coded and is transmitted at the current operating modulation of the individual SS. In the burst mode cases, data is transmitted in robustness order in the TDM portion. In a burst TDMA application, the data is grouped into separately delineated bursts, which do not need to be in modulation order. The DL-MAP message contains a map stating at which mini slot the burst profile change occurs. If the downlink data does not fill the entire downlink sub-frame and Mode B is in use, the transmitter is shut down. The DL-MAP provides implicit indication of shortened FEC (and/or FFT) blocks in the downlink. Shortening the last FEC block of a burst is optional (see clause 11.1.2.2????). The downlink map indicates the number of MS, p allocated to a particular burst and also indicates the burst type (modulation and FEC). Let n denote the number of MS required for one FEC block of the given burst profile. Then, p= kn + j, where k is the number of integral FEC blocks that fit in the burst and j is the number of MS remaining after integral FEC blocks are allocated. Either k or j, but not both, may be zero. j denotes some number of bytes b. Assuming j is not 0, it must be large enough such that b is larger than the number of FEC bytes r, added by the FEC scheme for the burst. The number of bytes available to user data in the shortened FEC block is b - r. These points are illustrated in Figure 140. Note that a codeword may not possess less than 6 information bytes.

In the TDM mode of operation, SSs listen to all portions of the downlink burst to which they are capable of listening. For full-duplex SSs, this implies that a SS shall listen to all portions that have a adaptive modulation type (as defined by the DIUC) which is at least as robust as that which the SS negotiates with the BS. For half-duplex SSs, the aforesaid is also true, but under an additional condition: an SS shall not attempt to listen to portions of the downlink burst that are coincident---adjusted by the SS's Tx time advance---with the SS's allocated uplink transmission, if any.

In the burst TDMA mode of operation, bursts are individually identified in the DL_MAP. Hence, a SS is required to turn on its receiver only in time to receive those bursts addressed to it. Unlike the TDM mode, there is no requirement that the bursts be ordered in order of decreasing robustness.

6.2.7.7.2.1.5 Frame duration Codes

Table 163 indicates the various frame durations that are allowed for the downlink mode B. The actual frame time used by the downlink channel can be determined by the periodicity of the frame start preambles.

Table 163—Frame Duration Codes

Code(N)	Frame duration (T_F)	
	PMP	**Mesh**
0	Unspecified, the frame lasts up to the arrival of the next DL-MAP message	Reserved
1-10	*N/2*	*N*
11-15	*N*	*N*
16-255	Reserved	Reserved

For OFDM and OFDMA PHY, the frame is an integer multiple of the minislot duration, such that the actual frame duration is nearest to the nominal frame duration listed in Table 163

6.2.7.7.3 MAC support of AAS.

6.2.7.7.3.1 Channel state feedback (CSF) messages

6.2.7.7.3.1.1 CSF-REQ message

The Channel State Feedback Request (CSF-REQ) message shall be sent by the BS from time to time, to signal the SS that channel state information should be updated. The time between requests is an internal parameter of the BS MAC, and should not be limited to any specific value. The SS should perform channel estimations on a regular time basis, in order to be able to provide up-to-date estimations upon request.

Table 164—CSF-REQ message format

Syntax	Size	Notes
CSF-REQ_Message_Format() {		
Management Message Type = X	8 bits	
Uplink Channel ID	8 bits	
TLV Encoded Information	variable	
}		

The CID used in the header will be the basic CID of the SS that is addressed.

The following parameters may be included in the TLV encoded information of the message:

Frequency adjust information
Power adjust information
Timing adjust information

6.2.7.7.3.1.2 CSF-REP message

The Channel State Feedback Reply (CSF-REP) message shall be sent by the SS as a response to a CSF-REQ sent by the BS. In some regulatory domains DFS is a mandatory functionality that is required to detect e.g. primary users of the band, and avoid usage of the frequencies occupied. The SS reply shall be the most up-to-date estimation of the channel, obtained during a **Channel Estimation Interval** (CEI). The Channel Estimation Age field shall be used to indicate the number of CEI periods elapsed since the channel estimation was performed. Any value of Channel Estimation Age field, greater then zero, indicates to the BS that the channel information send by SS is not up to date.

The value of CEI shall be predefined according to channel stability over time (a typical value is 20 msec), The BS is responsible to determine the actual value of CEI, and for the distribution of this value to all SSs.

Table 165—CSF-RSP message format

Syntax	Size	Notes
CSF-RSP_Message_Format() {		
Management Message Type = X	8 bits	
Channel Estimation Age	8 bits	
Channel Estimation Data	variable	
}		

The Channel Estimation Data is a stream of data bits captured by the SS PHY. The definition of this stream is left to the PHY, since it may be different for different PHY types. As an example only, this data stream may represent 64 consecutive complex samples (of 8 bits I and Q) of the received preamble or synchronization signal.

6.2.7.8 MAC support of 2-11 GHz SC PHY

6.2.7.8.1 Uplink Burst Subframe Structure

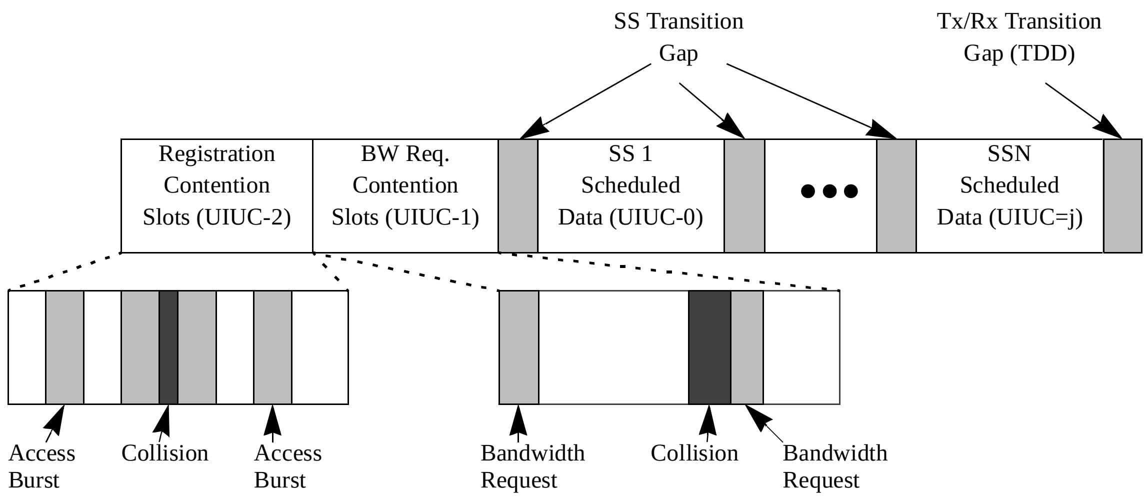


Figure 141—Uplink Subframe Structure

The structure of the uplink subframe used by the SSs to transmit to the BS is shown in Figure 141. There are three main classes of bursts transmitted by the SSs during the uplink subframe:

- Those that are transmitted in contention slots reserved for station registration.
- Those that are transmitted in contention slots reserved for response to multicast and broadcast polls for bandwidth needs.
- Those that are transmitted in bandwidth specifically allocated to individual SSs.

6.2.7.8.1.1 Mode A and Mode B: Uplink Burst Profile Modes

The uplink uses adaptive burst profiles, in which different SSs are assigned different modulation types by the base station. In the adaptive case, the bandwidth allocated for registration and bandwidth request contention slots is grouped together and is always used with the parameters specified for Request Intervals (UIUC=1). The remaining transmission slots are grouped by SS. During its scheduled bandwidth, an SS transmits with the burst profile specified by the base station, as determined by the effects of distance, interference and environmental factors on transmission to and from that SS. SS Transition Gaps (STG) separate the transmissions of the various SSs during the uplink subframe. The STGs contain a gap to allow for ramping down of the previous burst, followed by a preamble allowing the BS to synchronize to the new SS. The preamble and gap lengths are broadcast periodically in the UCD message. Shortening of FEC blocks in the uplink is identical to the handling in the downlink as described in 3.2.2.1.4????.

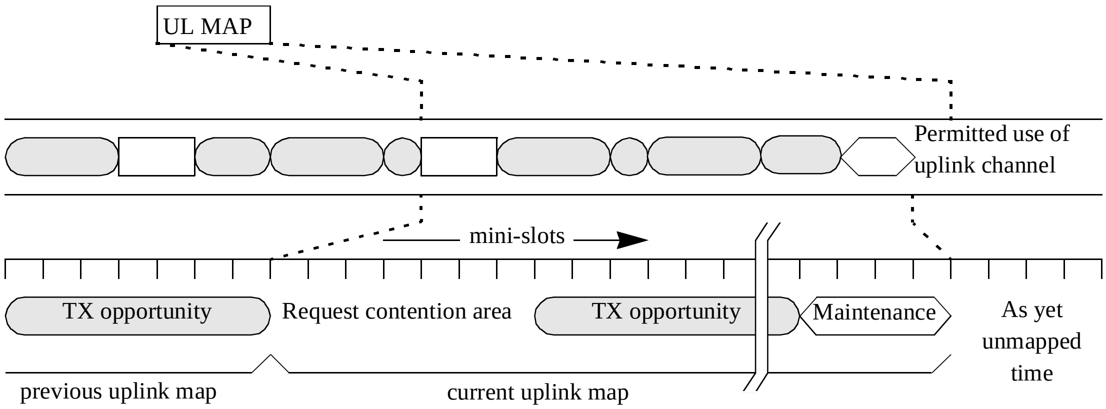


Figure 142—Uplink Mapping in the Continuous Downstream FDD Case

6.2.7.8.2 PHY SAP Parameter Definitions

TBD

6.2.7.8.3 Downlink Physical Layer

This clause describes the two different downlink modes of operation that have been adopted for use in this proposal. Mode A has been designed for continuous transmission, while a Mode B has been designed to support a burst transmission format. Subscriber stations must support at least one of these modes.

6.2.7.8.3.1 Physical layer type (PHY type) encodings

The value of the PHY type parameter (X.X.X) as defined must be reported as shown in the Table 166.

Table 166—PHY Type Parameter encoding

Mode	value	Comment
A(FDD)	2	Continuous downlink
B(FDD)	1	Burst downlink in FDD mode
B(TDD)	0	Burst downlink in TDD mode

6.2.7.8.3.2 Mode A: Continuous Downlink Transmission

This mode of operation has been designed for a continuous transmission stream, using a single modulation/coding combination on each carrier, in an FDD system. The physical media dependent sublayer has no explicit frame structure. Where spectrum resources allow, multiple carriers may be deployed, each using different modulation/coding methods defined here.

6.2.7.8.3.3 Downlink Mode A: Message field definitions

6.2.7.8.3.3.1 Downlink Mode A: Required channel descriptor parameters

The following parameters shall be included in the UCD message:

TBD

6.2.7.8.3.3.2 Mode A: Required DCD parameters

The following parameters shall be included in the DCD message:

TBD

6.2.7.8.3.3.2.1 Downlink Mode A: DCD, Required burst decriptor parameters

TBD.

6.2.7.8.3.3.3 Mode A: DL-MAP

For PHY Type = 2, no additional information follows the Base Station ID field.

6.2.7.8.3.3.3.1 Mode A: DL-MAP PHY Synchronization Field definition

The Synchronization Field, shown in Figure 143 is a 32 bit counter that holds the number of Physical Slots that have elapsed from base station initialization up to the strt of the current frame. When the counter reaches the highest possible value, it wraps around to zero.

Uplink Timestamp [31:16]
Uplink Timestamp [15:0]

Figure 143—PHY Synchronization Field (PHY Type = 2)

6.2.7.8.3.3.4 Mode A: UL-MAP Allocation Start Time definition

The field Allocation Start Time appears in both the downlink (DL-MAP) and uplink (UL-MAP) map messages The value specifies a mini-slot bondary that is the reference point for all mini-slot offset values appearing in the same map message. The value is expressed as the elapsed time in units of Physical Slots from base station initialization to the start of the mini-slot of interest.

6.2.7.8.3.3.5 UL-MAP Ack Time definition

The Ack Time Field value specifies the transmission time of the last subscriber information processed by the base station. The value is expressed as the elapsed time in units of physical slots from base station initialization to the start of the mini-slot following the last information processed by the base station.

6.2.7.8.3.4 Mode B: Burst Downlink Transmission

This mode of operation has been designed to support burst transmission in the downlink channel. In particular, this mode is applicable for systems using adaptive modulation in an FDD system or for systems using TDD, both of which require a burst capability in the downlink channel. In order to simplify phase recovery and channel tracking, a fixed frame time is used. At the beginning of every frame, a preamble is transmitted in order to allow for phase recovery and equalization training. A description of the framing mechanism and the structure of the frame is further described in 3.2.4.5.1????.

6.2.7.8.3.4.1 Mode B: Downlink Framing

In the burst mode, the uplink and downlink can be multiplexed in a TDD fashion as described in 3.2.2.1.3???, or in an FDD fashion as described in 3.2.2.1.2???. Each method uses a frame with a duration as specified in 3.2.5.1???. Within this frame are a downlink subframe and an uplink subframe. In the TDD case, the downlink subframe comes first, followed by the uplink subframe. In the burst FDD case, uplink transmissions occur during the downlink frame. In both cases, the downlink subframe is prefixed with information necessary for frame synchronization.

The available bandwidth in both directions is defined with a granularity of one mini slot (MS). The number of mini slots within each frame is independent of the symbol rate. The frame size is selected in order to obtain an integral number of MS within each frame. For example, with a 10 us MS duration, there are 500 MS within a 5-ms frame, independent of the symbol rate.

The structure of the downlink subframe used by the BS to transmit to the SSs, using Mode B, is shown in Figure 144. This burst structure defines the downlink physical channel. It starts with a Frame Control Header, that is always transmitted using the most robust set of PHY parameters. This frame header contains a preamble used by the PHY for synchronization and equalization. It also contains control clauses for both the PHY and the MAC (DL_MAP and UL_MAP control messages) that is encoded with a fixed FEC scheme defined in this standard in order to ensure interoperability. The Frame Control Header also may periodically contain PHY Parameters as defined in the DCD and UCD.

There are two ways in which the downstream data may be organized for Mode B systems:

- Transmissions may be organized into different modulation and FEC groups, where the modulation type and FEC parameters are defined through MAC layer messaging. The PHY Control portion of the Frame Control Header contains a downlink map stating the MSs at which the different modulation/FEC groups begin. Data should be transmitted in robustness order. For modulations this means QPSK followed by 16-QAM, followed by 64-QAM. If more than 1 FEC is defined (via DCD messages) for a given modulation, the more robust FEC/modulation combination appears first. Each SS receives and decodes the control information of the downstream and looks for MAC headers indicating data for that SS.
- Alternatively, transmissions need not be ordered by robustness. The PHY control portion contains a downlink map stating the MS (and modulation/ FEC) of each of the TDMA sub-bursts. This allows an individual SS to decode a specific portion of the downlink without the need to decode the whole DS burst. In this particular case, each transmission associated with different burst types is required to start with a short preamble for phase re-synchronization.

There is a Tx/Rx Transition Gap (TTG) separating the downlink subframe from the uplink subframe in the case of TDD

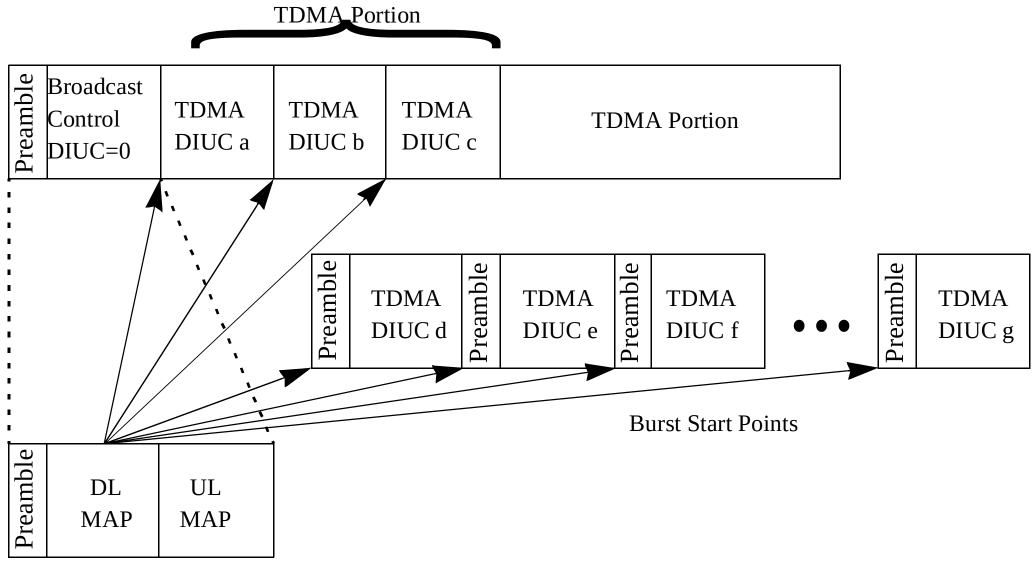


Figure 144—Mode B Downlink Subframe Structure

6.2.7.8.3.4.2 Frame Control

The first portion of the downlink frame is used for control information destined for all SS. This control information must not be encrypted. The information transmitted in this section is always transmitted using the well known DL Burst Type with DIUC=0. This control section must contain a DL-MAP message for the channel followed by one UL-MAP message for each associated uplink channel. In addition it may contain DCD and UCD messages following the last UL-MAP message. No other messages may be sent in the PHY/MAC Control portion of the frame.

6.2.7.8.3.4.3 Downlink Mode B: Required DCD parameters

The following parameters shall be included in the DCD message:

TBD

6.2.7.8.3.4.3.1 Downlink Mode B: DCD, Required burst decriptor parameters

Each Burst Descriptor in the DCD message shall include the following parameters:

TBD

6.2.7.8.3.4.4 Downlink Mode B: Required UCD parameters

The following parameters shall be included in the UCD message:

TBD

6.2.7.8.3.4.5 Downlink Mode B: DL-MAP elements

For PHY Type = {0, 1}, a number of information elements as defined as in Figure ???? follows the Base Station ID field. The MAP information elements must be in time order. Note that this is not necessarily IUC order or connection ID order.

6.2.7.8.3.4.6 Mode B: DL-MAP PHY Syncronization Field definition

Uplink Timestamp [31:16]
Uplink Timestamp [15:0]

Figure 145—PHY Synchronization Field (PHY Type = {0,1})

The jitter includes inaccuracy in timestamp value and the jitter in all clocks. The 500ns allocated for jitter at the Downlink Transmission Convergence Sublayer output must be reduced by any jitter that is introduced by the Downlink Physical Media Dependent Sublayer.

6.2.7.8.3.4.7 UL-MAP Allocation Start Time definition

6.2.7.8.3.4.8 UL-MAP Ack Time definition

The Ack Time Field value specifies the transmission time of the last subscriber information processed by the base station. The value is expressed as the elapsed time in units of Physical Slots from base station initialization tot eh start of the mini-slot following the last information processed by the base station.

6.2.7.8.3.5 Downlink MAP (DL-MAP) message

This clause voids clause 6.2.2.3.3 Downlink MAP (DL-MAP) message

Table 167—DL-MAP message format

Syntax	Size	Notes
DL-MAP_Message_Format() {		
Management Message Type = 2	8 bits	
PHY Synchronization Field	32 bits	
Base Station ID	64 bits	
No. DL-MAP elements: No_Els	16 bits	
Allocation_Start_Time	32 bits	
for (i=0; i< No_Els; i++) {		
Connection_ID	16 bits	
DUIC	4 bits	
Offset	12 bits	
}		
}		

A BS shall generate DL-MAP messages in the format shown in Table 167, including all of the following parameters:

Length
: If the length of the DL-MAP message is a non-integral number of bytes, the Length field in the MAC header is rounded up to the next integral number of bytes. The message must be padded to match this length but the SS must disregard the 4 pad bits.

DCD Count
: Matches the value of the configuration change count of the DCD which describes the burst parameters that apply to this map..

PHY Synchronization
: The PHY Synchronization field is dependent on the PHY layer used. The encoding of this field is given in each PHY separately.

Base Station ID
: The Base Station ID is a 64 bit long field identifying the BS. The Base Station ID may be programmable.

Alloc Start Time
: Effective start time of the uplink allocation defined by the DL-MAP in units of mini-slots. The start time is relative to the start of a frame in which DL-MAP message is transmitted.

Number Of Elements
: The number of Information Elements that follows.

MAP Information Elements
: Each Information Element (IE) consists of three fields:

i) Connection Identifier
ii) Downlink Interval Usage Code
iii) Offset

6.2.7.8.3.6 Uplink MAP (UL-MAP) message

This clause voids clause 6.2.2.3.4 Uplink MAP (UL-MAP) message

Table 168—UL-MAP message format

Syntax	Size	Notes
UL-MAP_Message_Format() {		
Management Message Type = 3	8 bits	
Uplink Channel ID	8 bits	
UCD Count	8 bits	
No. UL-MAP elements: No_Els	16 bits	

Table 168—UL-MAP message format

Syntax	Size	Notes
Allocation_Start_Time	32 bits	
Acknowledgement_Time	32 bits	
Ranging Backoff Start	8 bits	
Ranging Backoff End	8 bits	
for (i=0; i< No_Els; i++) {		
Connection_ID	16 bits	
UIUC	4 bits	
Offset	12 bits	
}		
}		

The BS shall generate the UL-MAP with the following parameters:

Uplink Channel ID
The identifier of the uplink channel to which this Message refers.

UCD Count
Matches the value of the Configuration Change Count of the UCD which describes the burst parameters which apply to this map.

Number of Elements
Number of information elements in the map.

Alloc Start Time
Effective start time of the uplink allocation defined by the UL-MAP in units of mini-slots. The start time is relative to the start of a frame in which UL-MAP message is transmitted (PHY Type = {0,1}) or from BS initialization (PHY Type = 2).

Ack Time
Latest time processed in uplink in units of mini-slots. This time is used by the SS for collision detection purposes. The ack time is relative to the start of a frame in which UL-MAP message is transmitted (PHY Type = {0,1}) or from BS initialization (PHY Type = 2).

Ranging Backoff Start
Initial back-off window size for initial ranging contention, expressed as a power of 2. Values of n range 0–15 (the highest order bits must be unused and set to 0).

Ranging Backoff End
Final back-off window size for initial ranging contention, expressed as a power of 2. Values of n range 0–15 (the highest order bits must be unused and set to 0).

Request Backoff Start
Initial back-off window size for contention data and requests, expressed as a power of 2. Values of n range 0–15 (the highest order bits must be unused and set to 0).

Request Backoff End
Final back-off window size for contention requests, expressed as a power of 2. Values of n range 0–15 (the highest order bits must be unused and set to 0).

MAP Information Elements
Each Information Element (IE) consists of three fields:

i) Connection Identifier

ii) Uplink Interval Usage Code

iii) Offset

Information elements define uplink bandwidth allocations. Each UL-MAP message shall contain at least one Information Element that marks the end of the last allocated burst.

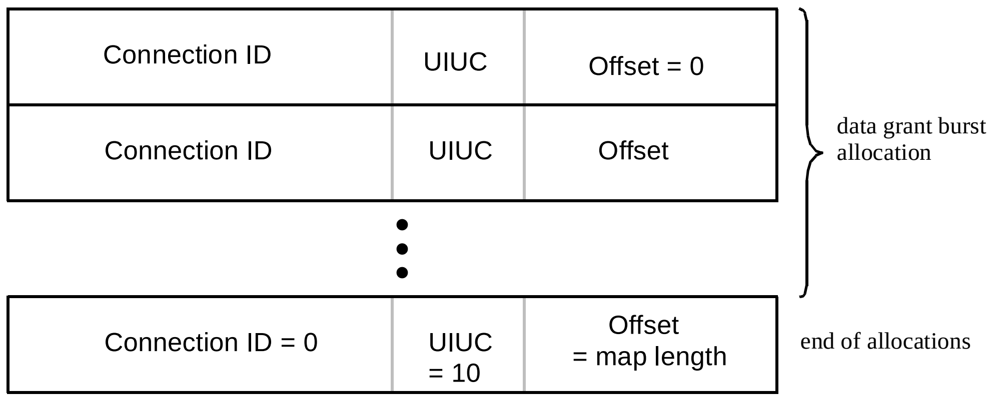


Figure 146—Data grant burst allocation

The Connection Identifier represents the assignment of the IE to either a unicast, multicast, or broadcast address. When specifically addressed to allocate a bandwidth grant, the CID may be either the Basic CID of the SS or a Traffic CID for one of the connections of the SS. A four-bit Uplink Interval Usage Code (UIUC) shall be used to define the type of uplink access and the burst type associated with that access. A Burst Descriptor shall be included for each Interval Usage Code that is to be used in the UL-MAP. The Interval Usage Code shall be one of the values defined in . The offset indicates the start time, in units of minislots, of the burst relative to the Allocation Start Time given in the UL-MAP message. Consequently the first IE will have an offset of 0. The end of the last allocated burst is indicated by allocating a NULL burst (CID = 0 and

UIUC = 10) with zero duration. The time instants indicated by the offsets are the transmission times of the first symbol of the burst including preamble.

Table 169—Uplink Map Information Elements

IE Name	Uplink Interval Usage Code (UIUC)	Connection ID	Mini-slot Offset
Reserved	0	NA	Reserved for future use
Request	1	any	Starting offset of REQ region
Initial Maintenance	2	broadcast	Starting offset of MAINT region (used in Initial Ranging)
Station Maintenance	3	unicast	Starting offset of MAINT region (used in Periodic Ranging)
Data Grant Burst Type 1	4	unicast	Starting offset of Data Grant Burst Type 1 assignment
Data Grant Burst Type 2	5	unicast	Starting offset of Data Grant Burst Type 2 assignment
Data Grant Burst Type 3	6	unicast	Starting offset of Data Grant Burst Type 3 assignment
Data Grant Burst Type 4	7	unicast	Starting offset of Data Grant Burst Type 4 assignment
Data Grant Burst Type 5	8	unicast	Starting offset of Data Grant Burst Type 5 assignment
Data Grant Burst Type 6	9	unicast	Starting offset of Data Grant Burst Type 6 assignment
Null IE	10	zero	Ending offset of the previous grant. Used to bound the length of the last actual interval allocation.
Empty	11	zero	Used to schedule gaps in transmission
Reserved	12-14	any	Reserved
Expansion	15	expanded UIUC	# of additional 32-bit words in this IE

6.2.7.8.3.7 MAP Relevance and Synchronization

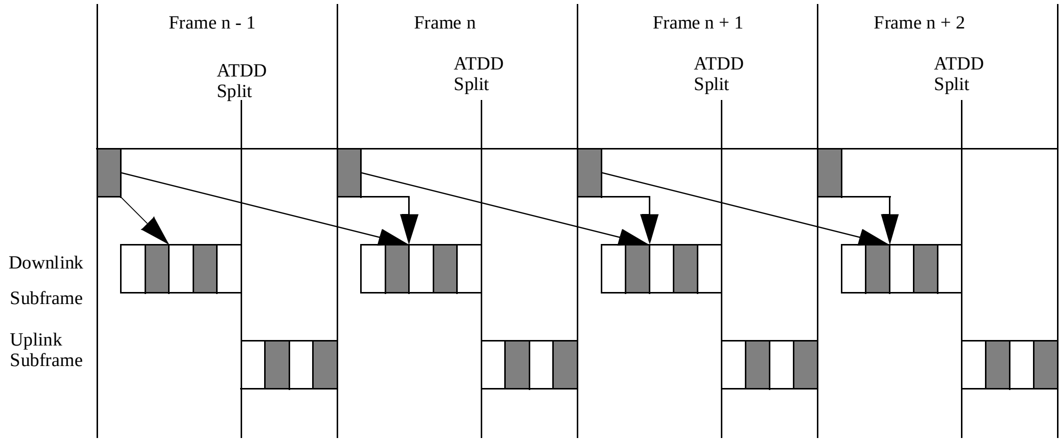


Figure 147—Maximum Time Relevance of PHY and MAC Control Information (TDD)

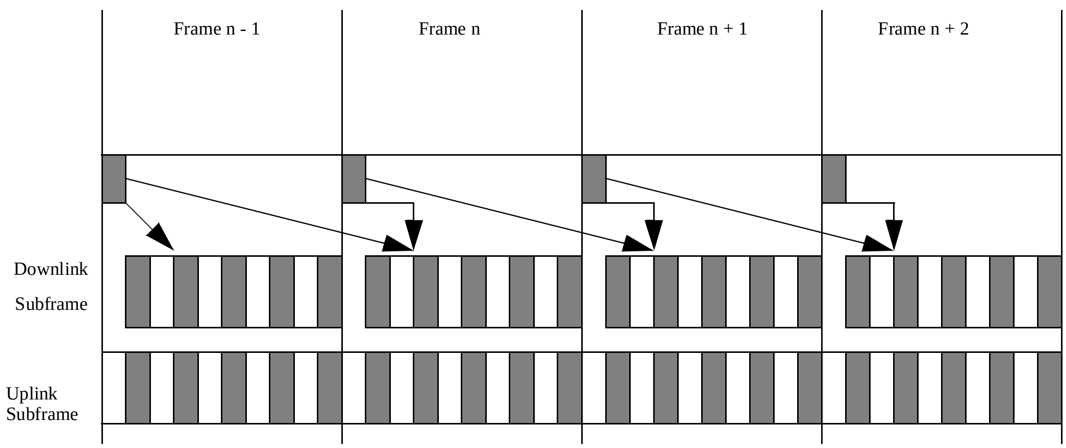


Figure 148—Maximum Time Relevance of PHY and MAC Control Information (FDD)

As shown in Figure 147 and Figure 147, the portion of the time axis described by the MAP is a contiguous area whose duration is equal to the duration of a frame. In the example shown in Figure 147, it consists of a portion of the downstream time of the frame in which the MAP is contained, the upstream time in this frame, followed by a portion of the downstream time in the next frame. The fraction of the downstream time in the current frame (or alternatively, the Allocation Start Time), is a quantity that is under the control of the scheduler.

6.2.7.9 MAC support of 2-11 GHz OFDM PHY

6.2.7.9.1 Uplink Channel Descriptor (UCD) Message Parameters

For Sub-11 OFDM PHY the same UCD format is used as in 6.2.2.3.1 "Uplink Channel Descriptor (UCD) message". The OFDM specific Overall Channel Parameters and Burst profile Parameters are specified in 11.1.1

6.2.7.9.2 Downlink Channel Descriptor (DCD) Message Parameters

For Sub-11 OFDM PHY the same UCD format is used as in 6.2.2.3.2 "Uplink Channel Descriptor (DCD) message". The OFDM specific Overall Channel Parameters and Burst profile Parameters are specified in 11.1.2.

6.2.7.9.3 Mini-slot Definition

As stated in clause 6.2.7.7.2.1.3, Physical Slot (PS) is equal to 4 * Sample Duration. The Mini-Slot Size = PS * 2^M is used as the measurement unit where M = 0 ..7 is broadcasted by the BS in the Mini-Slot Size field of UCD messages.

6.2.7.9.4 Frame Structure

Frame means interval that starts from the beginning of the preamble preceding the downlink FCH burst (see [REF]8.3.4.3.6) that contains at least one DL-MAP or DL-UL-MAP message and lasts up to the start of the preamble preceding the next burst of the same type. This definition does not require the frames to be of the same size.

The frame interval contains both transmissions (PHY PDUs) of BS and SSs and intervals of silence (gaps). The frame length is encoded in the Frame Length Code in the PHY Synchronization Field (see 6.2.7.9.7.1) This field allows for the reception of the next FCH burst. Figure 149 shows the frame structure for TDD

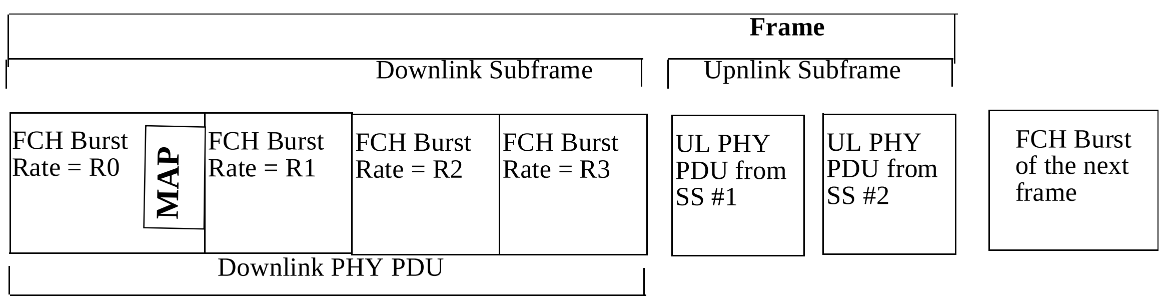


Figure 149—TDD Frame structure

PHY PDU consists of one or several bursts; each one transmitted with fixed PHY parameters. The PHY PDU always starts from a preamble. The bursts may be separated by mid-ambles.

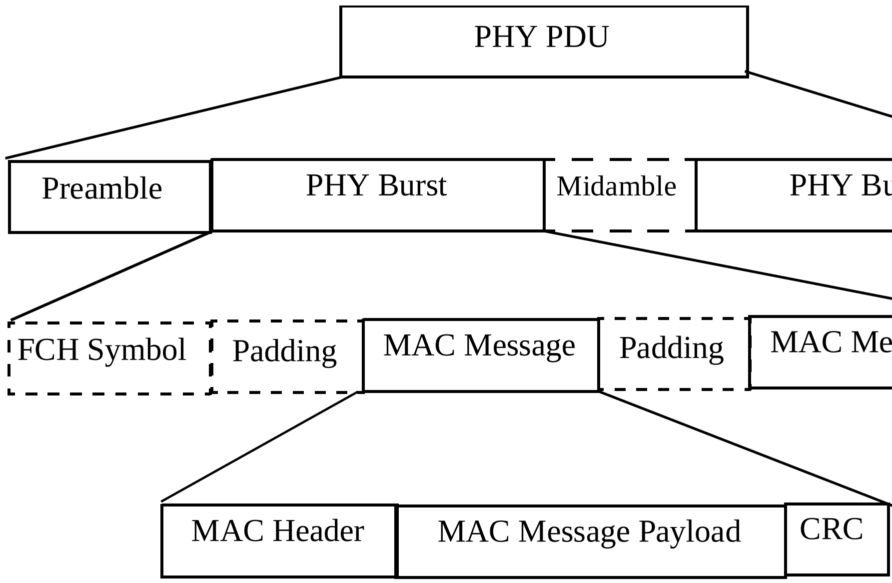


Figure 150—Burst structure

To form an integer number of OFDM symbols, a burst payload may be padded by the bytes 0xFF. The padding may appear in any location between MAC Messages. Then the payload should be scrambled, encoded and modulated using a FEC type and a modulation type specified by this standard.

6.2.7.9.5 Preambles

A burst MAY start from a preamble. See clause 8.3.5.3.3.5 and 8.3.5.4.2.2 for the definition of the correspondent waveforms.

6.2.7.9.6 FCH Burst and DL Frame prefix

A special PHY burst format (FCH or Frame Control Header) is used for DL Frame prefix to enable initial synchronization and acquisition of DL and UL channels parameters. Such a burst always has a preamble and contains a DL Frame prefix. It may also contain padding that includes octets 0xFF to complete the OFDM symbol.

Figure 151—FCH Burst

An FCH burst is one symbol long; it is transmitted at the following well-known modulation/coding: {QPSK, (32,24,4)}

It contains, as a payload, the **DL Frame Prefix** with information on the PHY parameters and length of the burst immediately following the FCH burst. The DL Frame prefix may contain DL-MAP, UL-MAP, DL-UL-MAP, UCD and DCD messages.

Figure 152describes the structure of DL Frame Prefix:

Rate ID (4)	Length (12)	HCS (8)

Figure 152—DL frame prefix

The following are the fields of DL Frame Prefix:

Rate_ID: Field that defines the modulation / coding parameters of the following burst. Encoding is specified in the following table:

Table 170—Rate_ID encoding

Rate_ID	Modulation	Coding Rate	RS Code
0	QPSK	1/2	(32,24,4)
1	QPSK	3/4	(40,36,2)
2	16 QAM	1/2	(64,48,8)
3	16 QAM	3/4	(80,72,4)
4	64 QAM	2/3	(108,96,6)
5	64 QAM	3/4	(120,108,6)

Length: Number of OFDM symbols (PHY payload) in the burst immediately following the FCH burst.

HCS: An 8-bit Header Check Sequence used to detect errors in the DL Frame Prefix. The generator polynomial is $g(D)= D^8 + D^2 + D + 1$

FCH burst may also contain MAP messages.

6.2.7.9.7 MAP Messages

The format of the DL-MAP message is defined in 6.2.2.4.3 Downlink Map (DL-MAP) Message. The format of the UL-MAP message is defined in 6.2.2.4.4 Uplink Map (UL-MAP) Message (Table 15). A single MAP message is defined, that covers both uplink and downlink directions. The following is the format of this message.

Applying Table 171, a new Management Message Type = 33 is added to Table 13 —MAC Management Messages

Table 171— MAC Management Messages

Syntax	Size	Notes
DL-MAP_Message_Format() {		
Generic_MAC_Header()	48 bits	
Management Message Type = 33	8 bits	
PHY Synch. field	32 bits	
DCD count	8 bits	
Base Station ID	48 bits	
No_DL-MAP_elements	8 bits	
No_UL-MAP_elements	8 bits	
UCD count	8 bits	
Allocation start time	32 bits	
for (i=0; i< No_DL-MAP elements; i++) {		
DL-MAP_information_element()	16 bits	
}		
for (i=0; i< No_UL-MAP elements;i++) {		
UL-MAP_information_element()	16 bits	
}		
}		

The meaning of the parameters is the same as in 6.2.2.4.3-6.2.2.4.4.

6.2.7.9.7.1 Synchronization Field

The PHY Synchronization Field of the DL-MAP message is structured as follows.

Table 172— PHY synchronization field

Syntax	Size	Notes
Synchronization_field {		The allowable frame duration Codes are given in Table [TBD]
Frame Duration Code	8 bits	The allowable frame duration Codes are given in Table [TBD]
Frame Number	24 bits	
}		

The frame duration Code values are specified in Table 163.

6.2.7.9.7.2 DL MAP Information Element Format

DL MAP Information Elements have the following format:

Table 173— DL-MAP information element

Syntax	Size	Notes
DL-MAP_information_element() {		
DIUC	4 bits	
Start Time	12 bits	
}		

Downlink Interval Usage Code

A four-bit Downlink Interval Usage Code (DIUC) shall be used to define the burst type associated with that time interval. A Burst Descriptor shall be included into DCD Message for each Interval Usage Code that is to be used in the UL-MAP. The Interval Usage Code shall be one of the values defined in Table 175 contains the DIUC values used in DL MAP Information Element..

Start Time

Indicates the start time, in units of symbol duration, relative to the start of the PHY PDU where the DL-MAP message is transmitted. The end of the last allocated burst is indicated by allocating a NULL burst (CID = 0 and DIUC = 14) with zero duration. The time instants indicated by the Start Time values are the transmission times of the first symbol of the burst including preamble (if present).

6.2.7.9.7.3 UL MAP Information Element Format

The UL-MAP Information Element defines the physical parameters and the start time for UL PHY bursts. The format of UL-MAP elements is shown in Table 174.

Table 174— UL-MAP information element

Syntax	Size	Notes
UL-MAP_information_element() {		
CID	16 bits	
UIUC	4 bits	
Offset	12 bits	
}		

Connection Identifier (CID)
Represents the assignment of the IE to a unicast, multicast, or broadcast address. When specifically addressed to allocate a bandwidth grant, the CID may be either the Basic CID of the SS or a Traffic CID for one of the connections of the SS.

Uplink Interval Usage Code (UIUC)
A four-bit Uplink Interval Usage Code (UIUC) shall be used to define the type of uplink access and the burst type associated with that access. A Burst Descriptor shall be included into an UCD message for each Interval Usage Code that is to be used in the UL-MAP. The Interval Usage Code shall be one of the values defined in Table 175.

Offset
The offset indicates the start time, in units of mini-slots, of the burst relative to the Allocation Start Time given in the UL-MAP message. Consequently the first IE will have an offset of 0. The end of the last allocated burst is indicated by allocating a NULL burst (CID = 0 and UIUC = 10) with zero duration. The time instants indicated by the offsets are the transmission times of the first symbol of the burst including preamble (if present).

6.2.7.9.7.4 DIUC Allocation

Table 175 contains the DIUC values used in **DL MAP Information Element.**

Table 175—DIUC values

DIUC	Usage
0	Preamble
1-12	Burst Profiles
13	Gap
14	End of Map
15	Extended DIUC

6.2.7.9.7.5 UIUC allocation

Table 176 contains the UIUC values used in **DL MAP Information Element**

Table 176—UIUC values

UIUC	Usage
0	Preamble
1-12	Burst Profiles
13	Gap
14	End of Map
15	Extended UIUC

When a power change for the SS is needed, the extended UIUC = 15 may be used with an additional extended UIUC 4-bit index value that for power change should be "0000" and with 8-bit Power control value.

The power control value is an 8-bit signed integer expressing the change in power level (in 0.25 dB units) that the SS should apply to correct it's current transmission power.

The CID used in the Information Element should be the Basic CID of the SS.

6.2.7.9.7.6 MAP Relevance and Synchronization

All the timing information in DL-MAP, UL-MAP, DL-UL-MAP is relative. The following time instants are used as a reference for the timing information

- DL-MAP and the correspondent part of DL-UL-MAP: the start of the first symbol (including the preamble if present) of the burst where the message is transmitted.
- UL-MAP and the correspondent part of DL-UL-MAP: the start of the first symbol (including the preamble if present) of the burst where the message is transmitted + Allocation Start Time value in minislots.

6.2.7.10 MAC support of 2-11GHz OFDMA PHY

6.2.7.10.1 OFDMA Basic parameters

6.2.7.10.1.1 OFDMA Slot Definition

The OFDMA access scheme defines an access scheme of a two dimensional grid that combines time and frequency division access techniques. As defined in clause 8.3.5.3.4.1,each OFDMA symbol is segmented into subcarriers, which are grouped into sub-channels. The mini-slot duration is used as a time symbol reference. In addition, for each time symbol reference, a sub-channel reference should be provided for OFDMA access resolution. The unit of granularity and allocation is termed OFDMA Slot, which is a pair {*N*,*m*}that represent the combination of mini-slot *N* (as a time reference)and sub-channel number *n* (as a frequency unit).

6.2.7.10.1.2 Region and PHY Burst

For both Uplink and Downlink transmissions, several consequtive sub-channels may be aggregated for several consequtive (OFDM) symbol duration intervals. Such an aggregation is figured by a rectangle **Region** at the sub-channel (frequency)--mini-slot (time)domain.

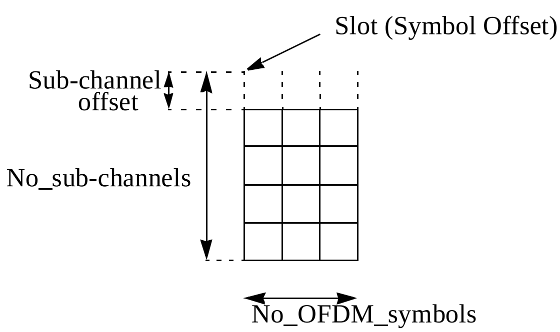


Figure 153—OFDMA allocation example

A Region can be assigned in the UL to a specific SS (or a group of subscribers) or can be transmitted in the DL by the BS as a transmission to a (group of) SS(s). The SS's transmission at the Region is called **PHY Burst.** The BS 's transmission at the Region is called **DL PHY Burst.** The reference point for the first subchannel in the first OFDM symbol of each frame shall be {0,0}

6.2.7.10.2 OFDMA Frame Structure

In the OFDMA working mode,there are two possibilities to transmit the frame control information (DL MAP or DL+UL MAP messages):

1) The frame control information is transmitted at the beginning of the frame,using all or part of the sub-channels (see Figure 154).
2) Taking advantage of the option of forward power control,the transmission of the frame control information is done by using 1-2 sub-channels for the duration of the whole frame while power boosting the used carriers (see Figure 155).

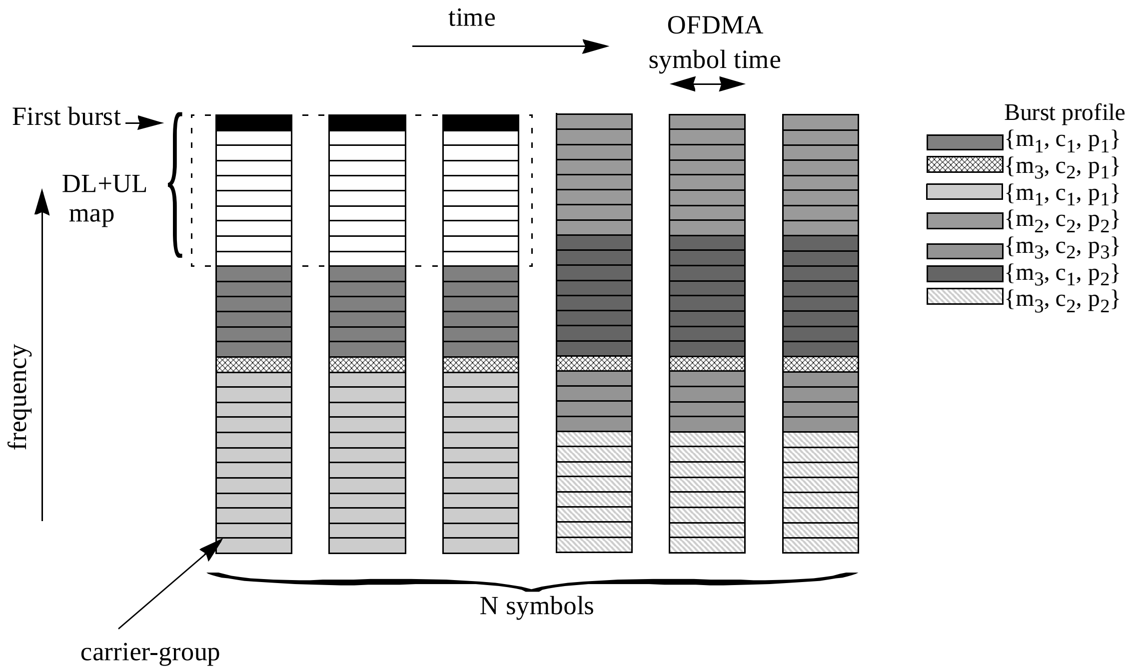


Figure 154—OFDMA DL DL+UL map location method #1

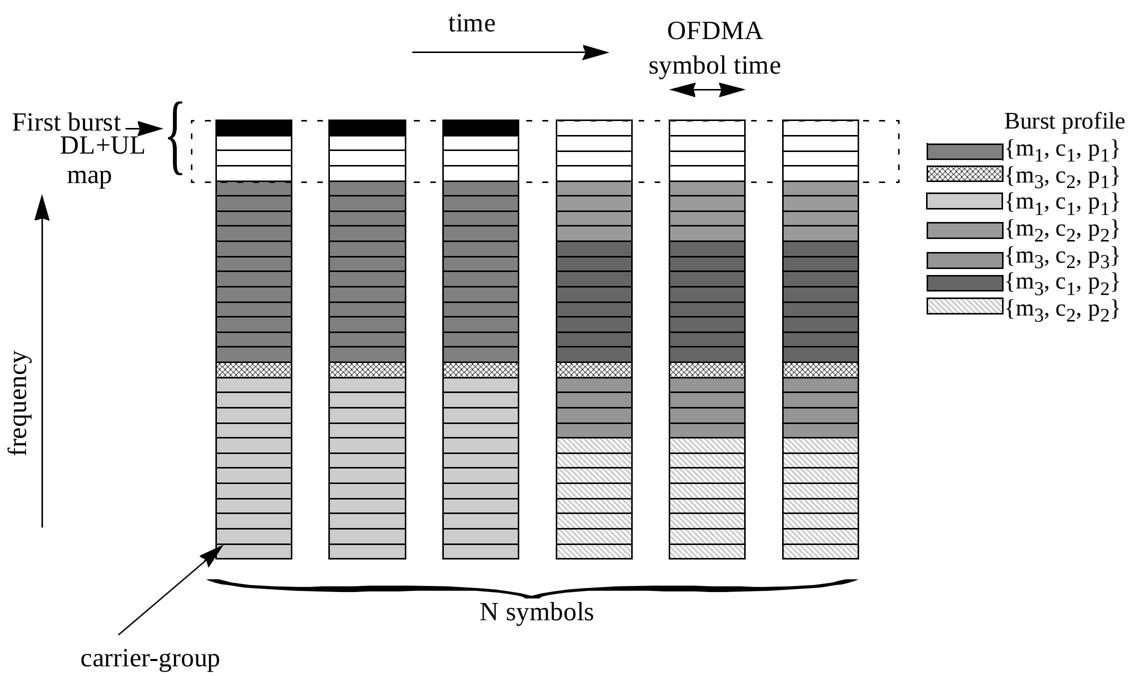


Figure 155—OFDMA DL+UL map location method #2

The frame control information is transmitted at the beginning of each frame.The first burst of the frame control information shall always contain the DL-MAP_prefix field of the DL-MAP. The DL-MAP_prefix is send with the lowest modulation order and coding rate specified.

6.2.7.10.2.1 MAP Messages

6.2.7.10.2.1.1 OFDMA Downlink MAP message

The Downlink Map (DL-MAP) message defines the access to the downlink information. If the length of the DL-MAP message is a non-integral number of bytes, the LEN field in the MAC header is rounded up to the next integral number of bytes. The message must be padded to match this length but the SS must disregard the 4 pad bits. A BS shall generate DL-MAP messages in the format shown in Table 177.

Table 177—DL-MAP message format

Syntax	Size	Notes
DL-MAP_Message_Format() {		
Management Message Type = 2	8 bits	
DL_MAP_prefix() {		
DUIC	8 bits	
DL_MAP_Message_Rectangle() {		Defines the OFDMA Slot {N,n}. The message always starts at {0,0}
No_OFDM_Symbols	10 bits	
No_Sub_channels	6 bits	
}		
Prefix_CS	8 bits	Checksum of the DL_MAP_prefix
}		
PHY_Synchronization_field(){		
Frame_Duration_Code	8 bits	
Frame Number	24 bit	
}		
DCD Count	8 bits	
Base_Station_ID	48 bits	
Allocation_Start_Time	16 bits	
Number DL-MAP Elements: No_Els	16 bits	
for (i=0; i< No_Els; ++i) {		
DL-MAP_Information_Element()	38 bits	Definitinion in {time,sub-channels} grid used to carry specific burst
}		
if (!byte boundary)		
Padding Nibble	4 bits	Padding zeroes till byte boundary.
}		

Rate_ID

Enumerated field that describes the modulation/coding of the DL-MAP message. Encoding values of the Rate_ID field are defined in Table 1.

No_OFDMA_Symbols

Indicates the number of OFDMA symbols for the DL_MAP message starting from first symbol of the frame.

No_Sub_Channels

Indicates the number of sub_channels for the DL_MAP message starting from sub_channel 0.

Prefix CS

An 8-bit checksum for the DL-MAP prefix fields, with the generator polynomial g(D)=D^8+D^2+D+1

Frame Duration Code

Indicates the frame duration as per table 156.

Frame Number

A free-running MAC frame number. The Frame Number is incremented by one on each frame and wraps to zero when maximum value is reached.

DCD Count

Matches the value of the Configuration Change Count of the DCD, which describes the burst parameters that apply to this map.

Base Station ID

The Base Station ID is a 48 bit long field identifying the BS.The Base Station ID shall be programmable.The most significant 24 bits shall be used as the operator unique ID.

Allocation Start Time.

The Allocation Start Time is the effective start time of the downlink allocation defined by the DL-MAP in units of OFDMA symbols. The start time is relative to the start of the frame in which the DL-MAP message is transmitted.

Number Of Elements

The number of DL information Elements that follows.

6.2.7.10.2.1.2 DL-MAP_Information_Element Format

The OFDMA DL-MAP Information Element defines a two-dimensional allocation pattern as defined in the Table 178:

Table 178—DL-MAP_Information_Message format

Syntax	Size	Notes
DL-MAP_Information_Element() {		
DUIC	4 bits	
OFDMA Symbol Offset	10 bits	
Sub-channel Offset	8 bits	
No. OFDMA Symbols	10 bits	
No. Sub-channels	6 bits	
}		

DIUC

Downlink interval usage code used for the burst.

OFDMA Symbol offset

The offset of the OFDMA symbol in which the burst starts,measured from the start of the MAC frame.

Sub-channel offset

The lowest index OFDMA sub-channel used for carrying the burst.

No. OFDMA Symbols

The number of OFDMA symbols that are used (fully or partially)to carry the DL PHY Burst.

No. of sub-channels

The number OFDMA sub-channels with subsequent indexes,used to carry the burst.

6.2.7.10.2.1.3 OFDMA Uplink MAP message

The Uplink Map (UL-MAP) message allocates access to the uplink channel. If the length of the UL-MAP message is a non-integral number of bytes, the LEN field in the MAC header is rounded up to the next integral number of bytes. The message must be padded to match this length but the SS must disregard the 4 pad bits. The BS shall generate the UL-MAP in the format shown in Table 179

Table 179—DL-MAP_Message format

Syntax	Size	Notes
UL-MAP_Message_Format() {		
Management Message Type=3	8 bits	
Uplink Channel ID	8 bits	
UCD Count	8 bits	
No. OFDMA Symbols	10 bits	
No. Sub-channels	6 bits	
}		
Number UL-MAP Elements: No_Els	16 bits	
Allocation Start Time	16 bits	
for (i=0; i< No_Els; ++i) {		
UL-MAP_Information_Element()	52 bits	Definitinion in {time,sub-channels} grid used to carry specific burst
}		
if (!byte boundary)		
Padding Nibble	4 bits	Padding zeroes till byte boundary.
}		

Uplink Channel ID

The identifier of the uplink channel to which this Message refers.

UCD Count

Matches the value of the Configuration Change Count of the UCD, which describes the burst parameters which apply to this map.

No. UL-MAP Elements

Number of information elements in the map.

Allocation Start Time

The Allocation Start Time is the effective start time of the uplink allocation defined by the UL-MAP in units of OFDMA symbols. The start time is relative to the start of the frame in which the UL-MAP message is transmitted.

6.2.7.10.2.1.4 UL MAP Information Element Format

6.2.7.10.2.1.4.1 Normal allocation UL MAP Information Element Format

The OFDMA UL-MAP Information Element defines a two-dimensional allocation pattern for the UL bursts. Information elements define uplink bandwidth allocations.Each UL-MAP message shall contain at least one Information Element that marks the end of the last allocated burst.The Information Elements shall be in strict chronological order within the UL-MAP. The Connection Identifier represents the assignment of the IE to either a unicast,multicast,or broadcast address. A Uplink Interval Usage Code (UIUC)shall be used to define the type of uplink access and the burst type associated with that access.A Burst Descriptor shall be included in the UCD for each UIUC to be used in the UL-MAP. The format of the UL-MAP IE is defined in Table 180

Table 180—UL-MAP_Information_Element format

Syntax	Size	Notes
UL-MAP_Information_Element() {		
CID	16 bits	
UIUC	4 bits	
OFMDA Symbol offset	10 bits	
Sub-channel offset	6 bits	
No. OFDMA Symbols	10 bits	
No. Sub-channels	6 bits	
}		

CID (Connection Identifier)
Represents the assignment of the IE.

UIUC
Uplink interval usage code used for the burst.

OFDMA Symbol offset
The offset of the OFDMA symbol in which the burst starts,the offset value is defined in units of OFDMA symbols and is relevant to the Allocation Start Time field given in the UL-MAP message.

Sub-channel offset
The lowest index OFDMA sub-channel used for carrying the burst.

No. OFDMA Symbols
The number of OFDMA symbols that are used to carry the UL Burst.

No. sub-channels
The number OFDMA sub-channels with subsequent indexes,used to carry the burst.

The end of the last allocated burst is indicated by allocating a NULL burst (CID =0 and UIUC =10)with zero duration.The time instants indicated by the offsets are the transmission times of the first symbol of the burst including preamble.

6.2.7.10.2.1.4.2 CDMA allocation UL-MAP Information Element Format

Table 181defines the UL-MAP_Information_element for allocation BW for a user that requested bandwidth using Request Code. This uplink MAP IE is identified by UIUC =14.

Table 181—CDMA_UL-MAP_Information_Element format

Syntax	Size	Notes
CDMA_UL-MAP_Information_Element() {		
Ranging Code	6 bits	
Ranging Symbol	12 bits	
UIUC=14	4 bits	
OFDMA Symbol offset	10 bits	
Sub-channel offset	6 bits	
No. OFDMA Symbols	10 bits	
No. Sub-channels	6 bits	
Ranging sub-channel	6 bits	
}		

Ranging Code
Indicating the CDMA Code sent by the SS.
Ranging Symbol
Indicating the OFDMA symbol used by the SS.
UIUC
Uplink interval usage code used for the burst.
OFDMA Symbol offset
The offset of the OFDMA symbol in which the burst starts,the offset value is defined in units of OFDMA symbols and is relevant to the Allocation Start Time field given in the UL-MAP message.
Sub-channel offset
The lowest index OFDMA sub-channel used for carrying the burst.
No. OFDMA Symbols.
The number of OFDMA symbols that are used to carry the UL Burst.
Number of sub-channels
The number OFDMA sub-channels with subsequent indexes,used to carry the burst.
Ranging sub-channel
Identifies the Ranging sub-channel used by the SS to send the CDMA code.

The end of the last allocated burst is indicated by allocating a NULL burst (CID =0 and UIUC =10)with zero duration.The time instants indicated by the offsets are the transmission times of the first symbol of the burst including preamble.

6.2.7.10.2.2 DIUC Allocation

Table 182 defines the DIUC encoding that should be used in the UL-MAP Information Elements.

Table 182—UL-MAP_Information_Element DIUC values

DIUC	Usage
0-12	Different burst profiles
13	Gap
14	End of gap
15	Extended

6.2.7.10.2.3 UIUC Allocation

The following table defines the UIUC encoding that should be used in the UL-MAP Information Elements.

Table 183—UL-MAP_Information_Element UIUC values

UIUC	Usage
0	Reserved
1-9	Different burst profiles
10	Null Information Element
11	Empty
12	ARQ
13	Power Control
14	CDMA Allocation Information Element
15	Extended

6.2.7.10.3 Bandwidth Request Using CDMA Codes

This section describes a CDMA code based bandwidth reservation mechanism.

6.2.7.10.3.1 CDMA Bandwidth Request mechanism

Clause 8.3.5.3.4.3.1 defines a mechanism of allocating several tones of the OFDMA symbol for modulating special PN codes.The allocated sub-channels are grouped to a Ranging Sub-Channel and the modulated codes are referenced as Ranging Codes.

Specifically, a subset of ranging codes is defined as bandwidth request codes (Request Codes). , which are used by the SS to request fast bandwidth allocation on a bursty and contentious basis.

Figure X4 describe the messages sequence for CDMA bandwidth request:

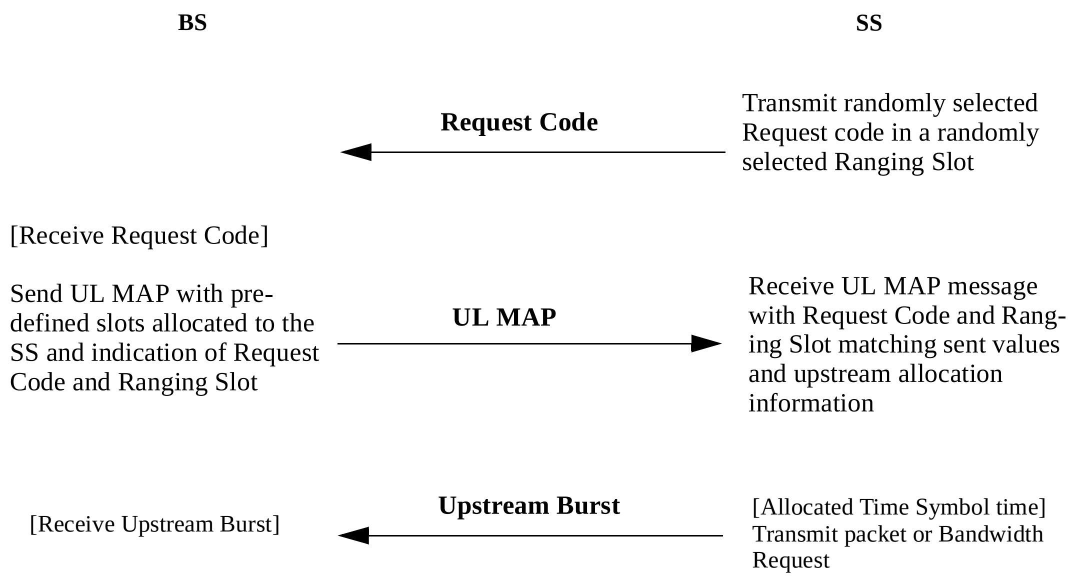


Figure 156—Bandwidth Request in OFDMA modes

The SS,upon a need to request for transmission slots,shall access the air interface without the need to be polled and with reduced collision risk by transmitting a Request Code. Several request codes sent by several SS can be transmitted simultaneously without collision (with limitation on the number of parallel codes).

The BS,when demodulating the ranging slots,and when receiving a request code,shall allocate a pre-defined (and configurable)number of bytes to the SS,the addressing of the allocation shall be done by attaching the indication of the Ranging Slot and Request Code. The SS will use the unique allocation either to send packet or bandwidth request.

6.2.7.10.4 OFDMA Based Ranging

Clause 8.3.5.3.4.3.1 defines a mechanism of allocating several tones of the OFDMA symbol for modulating special PN codes.The allocated sub-channels are grouped to a Ranging Sub-Channel and the modulated codes are referenced as Ranging Codes.

This section describes the OFDMA based ranging mechanism using Ranging Codes.

The basic OFDMA allocation unit (e.g.*slot*)is a combination of a time symbol and a sub-channel.The current OFDMA (OFDM)based PHY specification defines several working modes,those modes defines two upstream access schemes:

1) Each OFDMA (OFDM)symbol will carry either data or ranging slots.
2) Each OFDMA (OFDM)symbol will carry both data and ranging slots.

Figure 157 illustrates the concept of access scheme 1 for TDD mode.

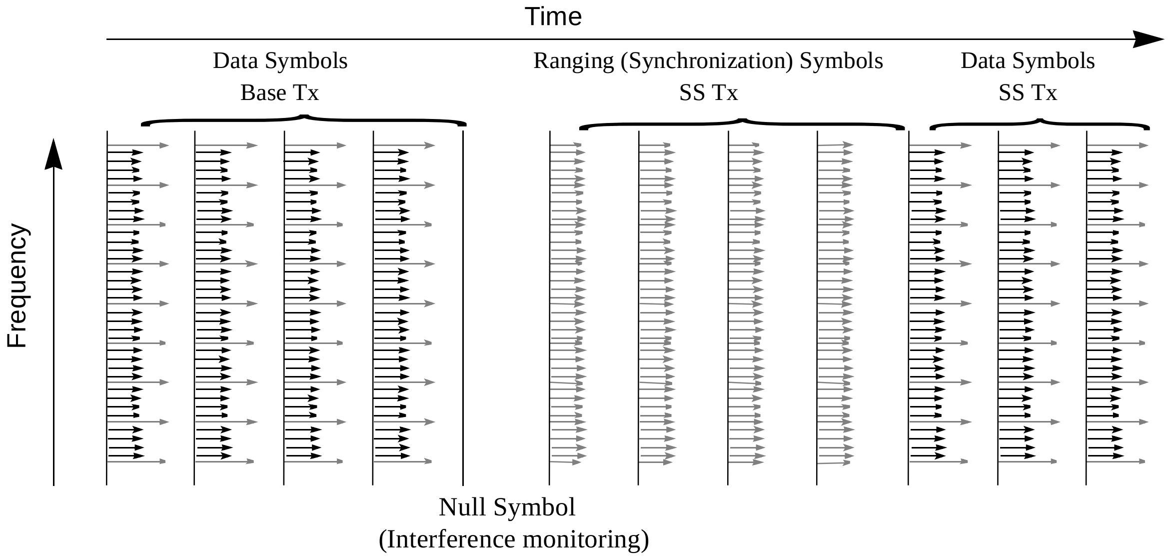


Figure 157—Ranging symbol allocation, method #1, (TDD mode)

Figure 158 illustrates the concept of access scheme 2.

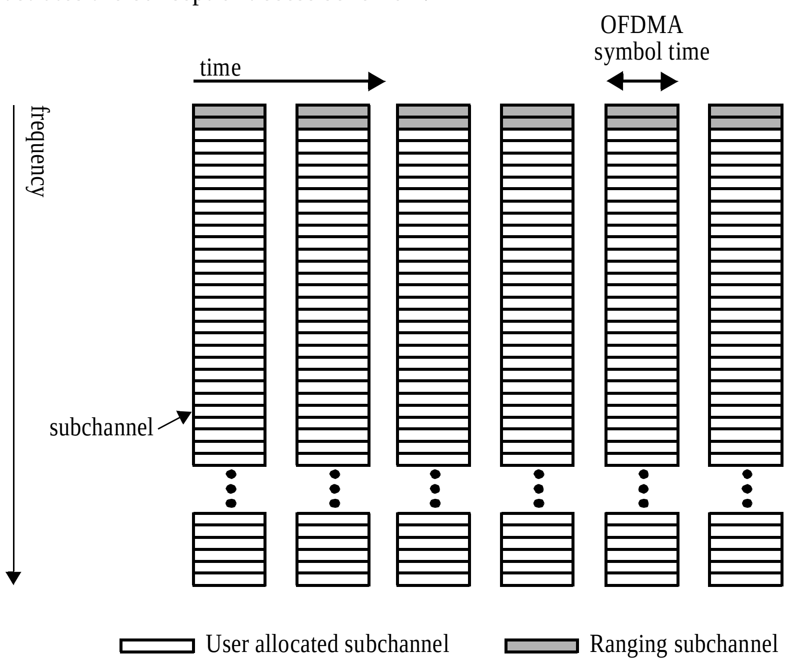


Figure 158—Ranging subchannel allocation, method #2

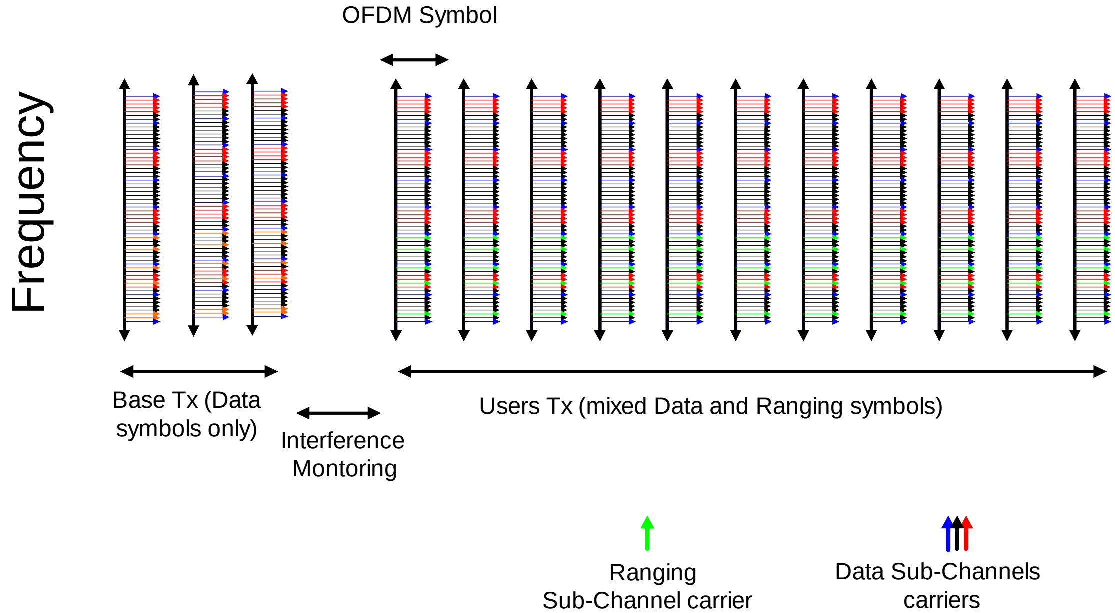


Figure 159—Ranging symbol allocation, method #2, (TDD mode)

On network entry or during at maintenance period,the SS that whishes to perform ranging must select randomly a Ranging Code (Long or Short),which will be transmitted on a Ranging Sub-Channel in a randomly chosen OFDMA symbol.

6.2.7.10.4.1 Description of OFDMA Based Ranging Mechanism

The ranging is the process of acquiring the correct timing offset and power corrections such that the SS 's transmissions are aligned to a symbol that marks the beginning of a burst(s)boundary with the required power.

- The SS,after acquiring downstream synchronization and upstream transmission parameters,shall choose randomly a Ranging Slot (with the use of a binary truncated exponent algorithm to avoid of possible re-collisions) as the time to perform the ranging,then it chooses randomly a Ranging Code (from the Initial Ranging domain) and sends it to the BS (as a CDMA code).
- The BS upon successfully receiving a Ranging Code sends a Ranging Response message that addressed the sending SS by supplying the Ranging Code and Ranging Slot in the message.The Ranging Response message contains all the needed adjustment (e.g.time,power and possibly frequency corrections)and a status notification.
- Upon receiving Ranging Response message with continue status,the SS shall continue the ranging process as done on the first entry with ranging codes randomly chosen from the Secondary Ranging domain.

The following message flow charts (Figure 160 and Figure 161)describes the ranging adjustments process in the two access modes.

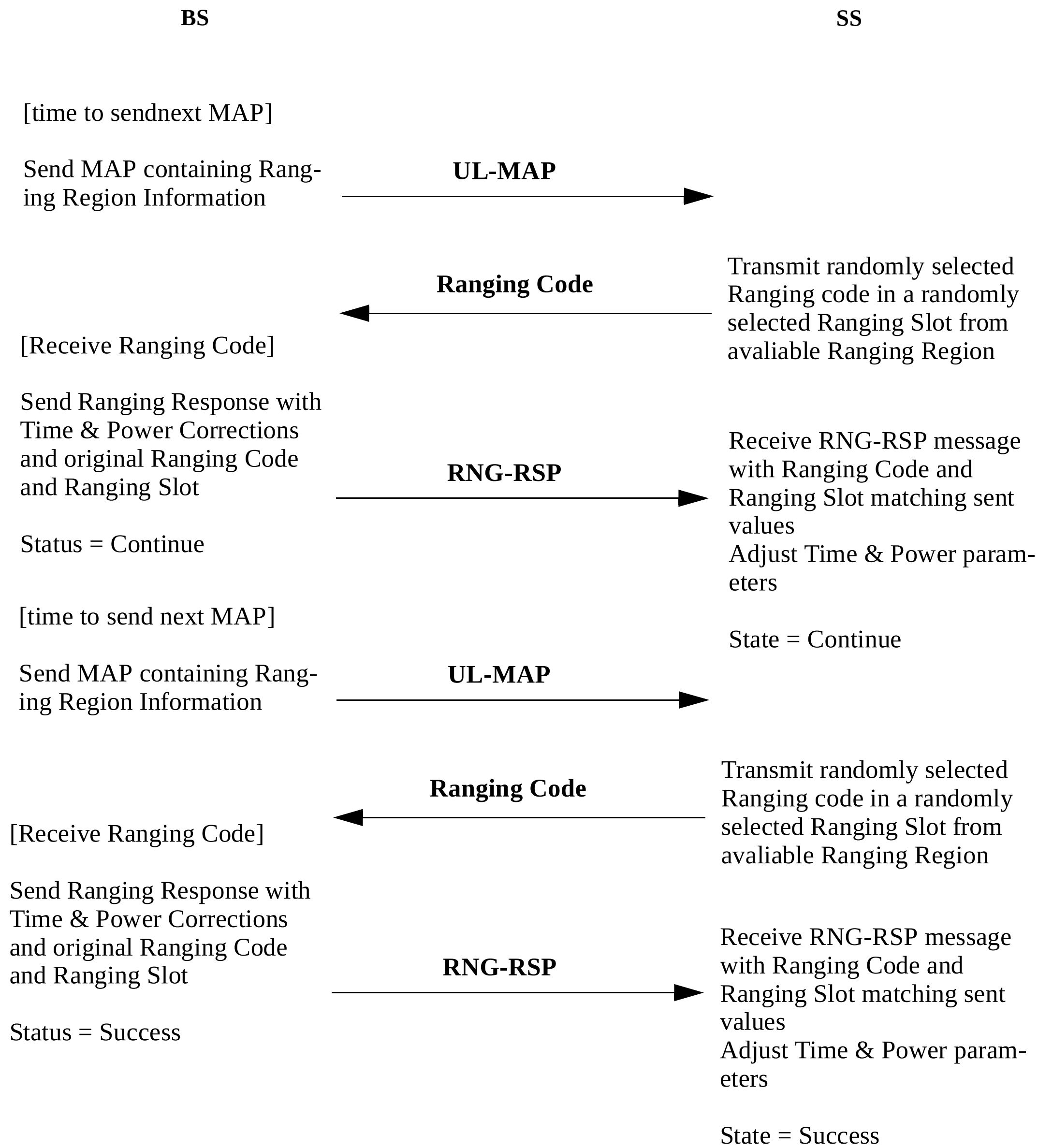


Figure 160—Ranging and automatic adjustments procedure for access scheme 1.

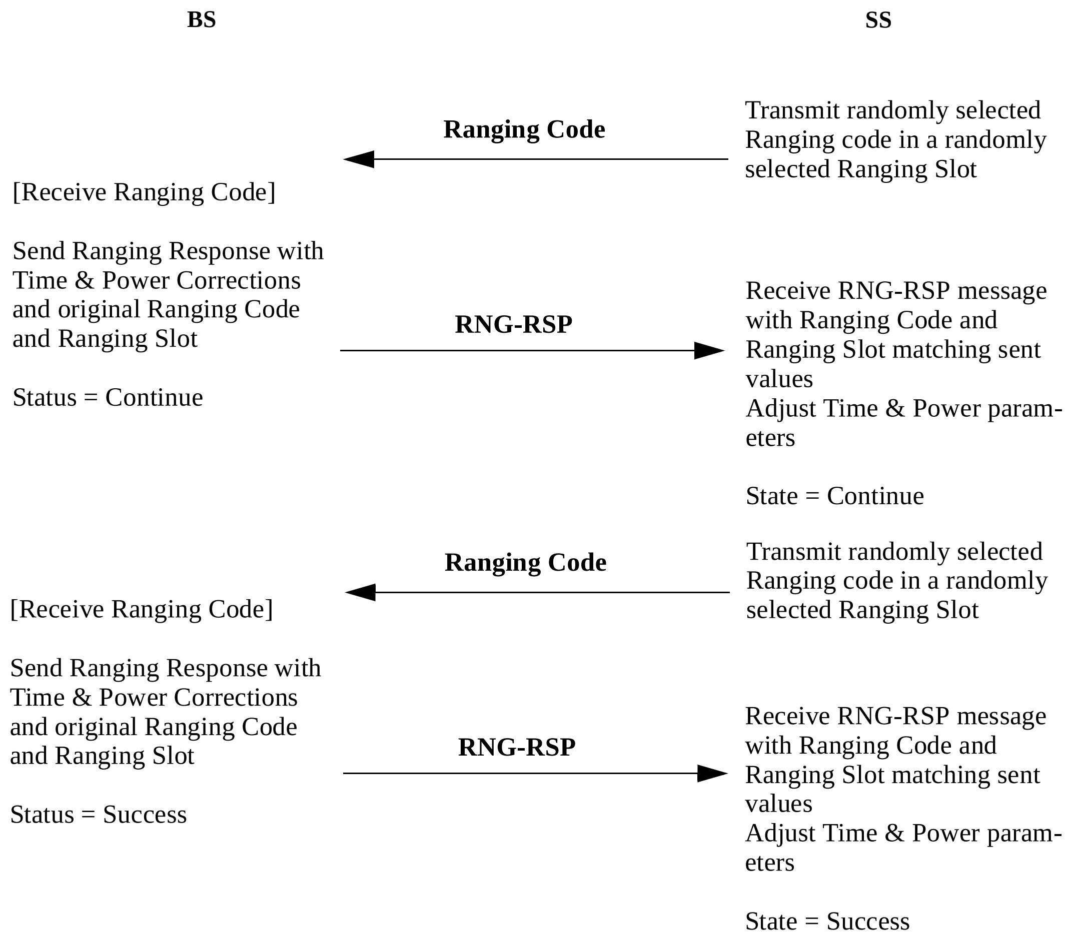


Figure 161—Ranging and automatic adjustments procedure for access scheme 2.

6.2.7.11 MAC support of 2-11GHz License Exempt operation

6.2.7.11.1 License Exempt Dynamic Frequency Selection

DFS is the process that is used to assign one of several possible channels to the SS. DFS may be also used to assign the best quality channel to each link (unicast/multicast/broadcast). The process requires monitoring by the SS and assignment of channels by the upper processing layers of the BS.(Comment: in both Mesh and Directional Antenna Systems the DFS will assign the best quality channels)

6.2.7.11.1.1 Primary User Detection

In some regulatory domains, the 5 GHz license exempt bands have been allocated to certain services on a primary basis. Operation in these bands is allowed only for devices capable of avoiding occupied channels by employing a dynamic frequency selection mechanism. DFS shall be employed to detect interference from other systems. Therefore, the equipment is able to avoid co-channel interference with other systems, notably radar systems. When selecting the channel to operate in, the device shall first assess whether the channel is occupied by a primary user and only after that shall it use other selection criteria, e.g. C/I and RSSI. This is illustrated in the following figure. Figure 162 shows high-level flow diagram of the DFS with primary user detection capability.

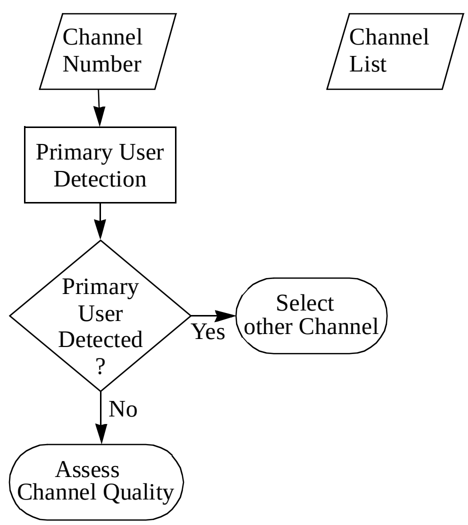


Figure 162—High-level diagram of the primary user detection mechanism of DFS

6.2.7.11.1.2 RSSI and CCI measurement of a DL Channel:

Within the mesh and directive antenna system architectures, each SS, prior to registration, will monitor the available channel spectrum. Typically, the SS will go to each assigned channel (which can be a few as 4) and monitor each channel and compile a list of readable channels. Each channel will be characterized in terms of its RSSI. The RSSI will be determined by the PMD measurement of the preamble bits of the OFDM bursts (in a TBD manner). A similar reading will be made of the Co-Channel Interference (CCI), which is determined by the PMD measurement of a designated OFDM "quiet time" (TBD).

6.2.7.11.1.3 Valid Channels

Valid channels will be considered to be only those channels which have a high enough S/N allowing successful synchronization and demodulation of the MAC Management Messages.

6.2.7.11.1.4 Assignment of DL Channel ID's to RSSI and CCI Measurements.

Valid channels will allow the MAC layer to read the Downlink Channel Descriptor (DCD) and Downlink Access Definition (DL-MAP) messages. These messages are transmitted periodically (see Table 67 in Ref 1) on the channel being monitored.

The DCD will provide the SS with a Downlink Channel ID (1 Byte) and the channel EIRP, which is encoded at a TLV tuple in the DCD (specifically as a Type 2 byte; 1 byte message described as a Downlink Physical Channel Attribute. See (TBD), DCD Channel Encodings)

The DL-MAP will provide the 64 bit Base Station ID.

The Base Station ID; Downlink Channel ID, channel EIRP, RSSI reading and CCI reading will be sent to higher processing layers.

The higher processing layers, not detailed herein, will make a choice concerning the best downlink channel to monitor. The higher processing layers will then tune the PMD to the best channel, and re-synchronize to this channel.

6.2.7.11.1.5 Registration Procedure

The SS will obtain all necessary downlink and uplink parameters as described in clause Sections 6.2.7.2 and 6.2.7.3. This being done, a link will be established with the BS and ranging will be undertaken to finalize any corrections to timing and synchronization; as per Section 6.2.7.5 and 6.2.7.6.

This procedure being completed the SS would then normally proceed with the establishment of IP connectivity, as per Section 6.2.7.8.1. However; in the IEEE 802.16b MAC, this step is delayed; and a new message, a Dynamic Frequency Selection Request Message (DFS-REQ) is transmitted to the BS.

The DFS-REQ is in the standard MAC Management Message Format. The DFS-REQ can be sent by the SS or the BS. A Base Station-originated DFS-REQ message would solicit best-channel information from the particular SS (identified by the Vendor ID in the configuration file). A SS-originated DFS-REQ messages will carry candidate channel information to the BS.

Additionally, there is a MAC management message called DFS-RSP. This message is a BS originated message sent in response to the DFS-REQ message from the SS.

Both the DFS-REQ and DFS-RSP carry TLV encoded information. The TLV tuples will have configuration files having the settings described in the following subclauses.

6.2.7.11.1.5.1 DFS-REQ Message Format

Table 184—DFS-REQ Message Syntax

Syntax	Size	Notes
DFS-REQ_Message_Format() {		
Generic_MAC_Header()	48 bits	Required field
Management Message Type TBD	8 bits	

Table 184—DFS-REQ Message Syntax

TLVCount	8 bits	Number of TLVs present will be a multiple of required TLVs in DFS-REQ operation set
for (i=0; i<TLVCount; i++){		
Either SS or BS **DSF-REQ TLV set**		Set composition depends on whether SS or BS is sender
}		
}		

6.2.7.11.1.5.2 DFS-RSP Message Format

Table 185—DFS-RSP Message Syntax

Syntax	Size	Notes
DFS-RSP_Message_Format() {		
Generic_MAC_Header()	48 bits	Required field
Management Message Type TBD	8 bits	
TLVCount	8 bits	Number of TLVs present will be a multiple of required TLVs in DFS-RSP operation set
for (i=0; i<TLVCount; i++){		
BS **DSF-RSP TLV set**		
}		
}		

6.2.7.11.1.5.3 TLV Set for SS Transmitted DFS-REQ Messages

All uplink DFS-REQ messages sent by the SS to the BS must contain the following TLV settings:

Vendor ID of SS
Base Station ID (current)
Downlink Channel Configuration Setting (current)
Uplink Channel Configuration Setting (current)
Downlink ID
Channel EIRP
Mean RSSI
Mean CCI
CCI variance
RSSI variance
RSSI Fading rate (optional) (current channel)

6.2.7.11.1.5.4 TLV Set for BS Transmitted DFS-REQ Messages

All downlink DFS-REQ messages are sent by the BS to the SS after the SS has successfully registered with the BS. This message is sent in order to interrogate the SS on the quality of all or a subset of the possible received channels. This message is generated by the upper processing layers that are beyond the scope of this specification (such layers would be unique to either the Mesh or Directive Antenna systems). The SS would respond to this message by sending the DFS MAC management message described earlier.

The TLVs for this message would contain:

Vendor ID of SS
Base Station ID
Downlink ID (channel to measure)
Measurement Bandwidth

6.2.7.11.1.5.5 TLV Set for BS Transmitted DFS-RSP Messages

All uplink DFS-RSP messages sent by the BS to the SS shall contain the following TLVs:

Vendor ID of SS
Base Station ID (assigned)
Downlink Channel ID (assigned)
Downlink Channel Configuration Setting (assigned)
Uplink Channel Configuration Setting (assigned)
Uplink EIRP setting (assigned)

Table 186—DFS-REQ and DFS-RSP Information TLVs

Name	Type	Length	Value	Scope
Subscriber Station Vendor ID	tbd	tbd	SSID of registered SS	DFS-REQ DSF-RSP Configuration file
Base Station ID**	tbd	tbd	BSID of	DSF-REQ DSF-RSP Configuration file
Downlink Channel ID**	tbd	tbd	ID of channel being measured	DSF-REQ DSF-RSP Configuration file
Downlink Channel Measurement Bandwidth	tbd	tbd	Amount of bandwidth to use when testing channel	DSF-REQ Configuration files
Downlink Channel Confirguration Setting**	tbd	tbd	Relevant channel settings TBD	DSF-REQ Configuration file
Uplink Channel Configuration Setting**	tbd	tbd	Relevant channel settings TBD	DSF-RSP Configuration file
Uplink EIRP setting (assigned)	tbd	tbd	EIRP setting used by SS	DSF-RSP Configuration file
Mean CCI	tbd	tbd	mean measuerd CCI	DSF-RSP Configuration file
CCI Variance	tbd	tbd	variance of measured CCI	DSF-RSP Configuration file
RSSI Variance	tbd	tbd	variance of measured RSSI	DSF-RSP Configuration file
RSSI Fading Rate**	tbd	tbd	measured fading rate of RSSI	DSF-RSP Configuration file

** = Note that for these TLVs, they may be assignments or reports depending upon the sending entity.

6.2.7.11.2 Interference Mitigation and Co-Existence

The DRFM forms the basis of co-existence. It is required to enable other terminals, operating on different systems, to learn something about the potential interference.

6.2.7.11.2.1 Hierarchical Assumption: First Come/First Claim

In the License-Exempt environment it is proposed that for compliant fixed point to multipoint access systems , the first FWA systems' occupation of a space/frequency zone be respected and protected against co-channel interference from any FWA system installed thereafter. Control would be exercised by an adaptive algorithm that would operate within the BS and set up its RF transmission characteristics in compliance with this general co-existence rule. Such algorithms work best with configurations of oblong microcells arranged in rosette configurations. However, they can work with omnidirectional radiating systems as well.

6.2.7.11.2.2 Downlink Radio Frequency Management (DRFM) Message

This message is sent out periodically (once every 30 seconds to once every minute) on the downstream channel of a base station, which may have multiple antennas. Its purpose is to send the BS RF configuration information to adjacent Base Stations. This message provides the adjacent base stations with information that is useful for the choice of frequencies, radiation patterns, and EIRP's that the adjacent base stations can use in such a way that potential CCI is mitigated. The DRFM is a MAC Management Message of Type 28 (TBD). It begins with a Generic Downlink MAC header and its format is shown in Table

This message will characterize the Radio Frequency Emission properties of the BS and other co-located emitters, which can be other base stations or channels controlled by the primary base station. The purpose of this message is to inform nearby and potentially interfering BS and SS of the radiation of the primary BS.

Each emission from the BS is characterized by giving its channel frequency, EIRP, direction, and beam-width, The following parameters will be included in a DRFM:

Base Station ID - The Base Station ID is a 64 bit long field identifying the BS. The Base Station ID may be programmable or derived from the configuration file used to set up Base Station parameters on installation and activation.

GPS Locator - GPS Location of the BS which can have up to 64 co-located radio emitters which can be either other base stations or a multiple of channels from a single base station. The GPS coordinates are loaded into the configuration file used to set up the Base Station parameters on installation and activation. The resolution of the GPS inputs are to 0.01 minute, and consist of signed latitude and longitudes. The GPS locator field is 7 bytes long and contains reserved bit fields.

Height of BS - The height of a BS in meters above ground level. This is a 10 bit long field allowing the indication of a maximum height of 1024 Meters.

Base Station Emitter Number - The number of distinct channel emissions that are emanating from the BS and its co-located base stations (having the same GPS locator). This is a 6 Bit long field that also defines the number of TLV Downlink Channel Emission (DCE) frames to be read.

Downlink Channel Emission (DCE) Frame - This is a TLV encoded frame that contains information on each emission's radiation characteristics. Up to N=64 emissions can be specified as originating from the location of single BS. Each frame shall contain the frequency of the emission (4 bytes in multiples of Kilohertz); EIRP per emission (in signed units of Power Spectral Density dBm/MHz) 1 Byte; direction of emission with respect to Magnetic North in increments of 2 degrees covering 0-360 degrees azimuth (1 Byte); Beamwidth of emitting antenna in increments of 2 degrees covering 0-360 degrees beamwidth (1 Bytes); and 1 Byte reserved for future use. The DCE frames N={1 to X} will correspond to the emissions from the BS whose ID is given. Emissions from other co-located but independent base stations will be given in N={(X+1) to 64}.

Table 187—DRFM Message Syntax

Syntax	Size	Notes
DRFM_Message_Format() {		
Generic_MAC_Header()	48 bits	Required field
Management Message Type TBD	8 bits	
Base Station ID	64 bits	sending BSID
Latitude Degrees	8 bits	BS GPS Latitude degrees (0 - 90)
Latitude Minutes	8 bits	BS GPS Latitude minutes (0 - 59)
Rsvd	2 bits	
Latitude Minutes Fraction	10 bits	1/100 Fraction (0 - 99)
Rsvd	6 bits	
Longitude Degrees	8 bits	BS GPS Longitude degrees (0 - 90)
Longitude Minutes	8 bits	BS GPS Longitude minutes (0 - 59)
Rsvd	2 bits	
Longitude Minutes Fraction	10 bits	1/100 Fraction (0 - 99)
BS Altitude	10 bits	0 - 1023 meters
BS Emitters	6 bits	1 - 64
Rsvd	6 bits	
for (i=0; i<**BS Emitters**; i++){		one set of the following per emitter required
DCE Emitter Frequency	32 bits	
Emitter EIRP	8 bits	-63 - +64 dBm/MHz
Emitter Direction	8 bits	2 degree steps Magnetic North = {00000000}
Emitter Beamwidth	8 bits	2 degree steps
Rsvd	8 bits	
}		
}		

6.2.7.11.2.3 Reception of the HBS-DRFM

The HBS-DRFM is solely for use by the upper management layers of the BS. It will require the BS to either direct an independent receiver to monitor this message, or it may direct one of its link receivers to undertake monitoring. The BS would have to scan its environment for each adjacent BS and embark on a Scanning and Synchronization procedure as outlined in Section 2.11.2. Once synchronization is achieved and DL-MAP

MAC management messages are received the receiver will have to wait for the HBS-DRFM. This being done, the BS receiver, under control of the upper management layers, will scan another sector until all possible adjacent BS have be identified and characterized through their HBS-DRFM messages.

6.2.7.11.3 Power control information element

When a power change for connection CID is needed, extended UIUC = 15 is used,and a four bit field, the value of "0000" will be defined as the fast-power-control extended UIUC. (see Table 188).

Table 188—Power Control information element

Syntax	Size	Notes
Power_Control_Information_element() {		
CID	16 bits	
UIUC = 15	4 bits	
extended UIUC	4 bits	Fast-power-control = 0X00
Power control	8 bits	Signed integer, which expresses the change in power level (in 0.25 dB units) that the SS should apply to correct its current transmission power.
}		

6.2.7.12 MAC Support of 2-11GHz Advanced Antenna Systems

6.2.7.12.1 Architectural Overview

Adaptive antenna arrays are elements of the BWA system that are used in conjunction with the PHY and MAC, to enhance the performance of the system. Adaptive arrays can improve range and system capacity, and enable a system deployment in Non-Line-of-Sight (NLOS) conditions. This section specifies the general architecture and the detailed mechanism in the MAC by which adaptive array enhancements can be added to the system. A general concept of "Adaptive Array Support" (AAS) is defined in this chapter. The AAS system is capable of delivering the benefits of adaptive arrays and may also be compatible with non-AAS systems. The implementation of adaptive array in a BWA system requires both MAC and PHY to be AAS compliant, therefore it is assumed in this section that the AAS compliant MAC is operating in conjunction with an AAS compliant PHY.

6.2.7.12.1.1 MAC services in AAS systems

The use of adaptive array in the system shall not affect the definition of MAC services at the MAC service access point. When interfacing with higher layers, the AAS MAC appears exactly the same as non-AAS MAC does.

6.2.7.12.1.2 Transition from non-AAS to AAS systems

The architecture of AAS option provides a way to migrate from non-AAS system to AAS system by changing parts of the system first. During the migration phase the system may not be able to gain all AAS benefits, however as the mixture between AAS and non-AAS improves, the system capacity, range, and inter-cell interference performance will significantly increase. The first change in the transition path should be to replace the base-station with an AAS base-station. By enabling coexistence of AAS and non-AAS subscriber stations in the same base-station service area, any mixture of AAS/non-AAS subscriber units can be deployed. At the end, if a system becomes full AAS system, with all its components being AAS compatible (including base-station and all subscriber stations), it can be operated with the AAS option only, thus some of the MAC components that are used in non-AAS base-stations can be omitted. For example, the broadcast MAP used in non-AAS systems to indicate transmission scheduling can be omitted in a full AAS system, since the AAS MAC uses private MAP messages designated to subscriber stations instead of the broadcast MAP.

6.2.7.12.1.3 AAS framing

It is envisioned that AAS is most beneficial for burst-mode PHYs, in particular systems using TDD as the duplexing scheme. During the migration from non-AAS to AAS, each part of the TDD frame (UL part and DL part) is sub-divided into two logical parts. The first part is used for non-AAS subscriber stations, while the second part is used for AAS subscriber stations. For a non-AAS subscriber station, the TDD frame appears like the expected frame, starting with the frame synchronization and control packets (MAP, UCD, DCD, etc.). The downlink burst modes and scheduling is received via DCD and DL-MAP, in the same way as in the non-AAS system. Thus a non-AAS subscriber station can be completely unaware of the fact that it is communicating with an AAS base-station. On the other hand, AAS subscriber stations use a different part of the downlink frame, starting immediately after the first part. The MAC sub-layer within these AAS stations has a special mechanism to schedule transmissions in the uplink and downlink, without using the regular broadcast MAP and DCD messages. The method by which an AAS subscriber station achieves time and frequency synchronization is dependent on the property of the underline AAS PHY, and is beyond the scope of this section.

In order to be able to perform all MAC services, the AAS MAC should have some additional packets in the air interface time frame. These packets are transmitted during the fixed service slot within the AAS part of the frame, and are ignored by non-AAS subscriber stations. Figure 163 illustrates the logical division of the physical frames into non-AAS and AAS parts. For any PHY mode, the division must fall on a boundary indicatable by `the PHY modes map.`

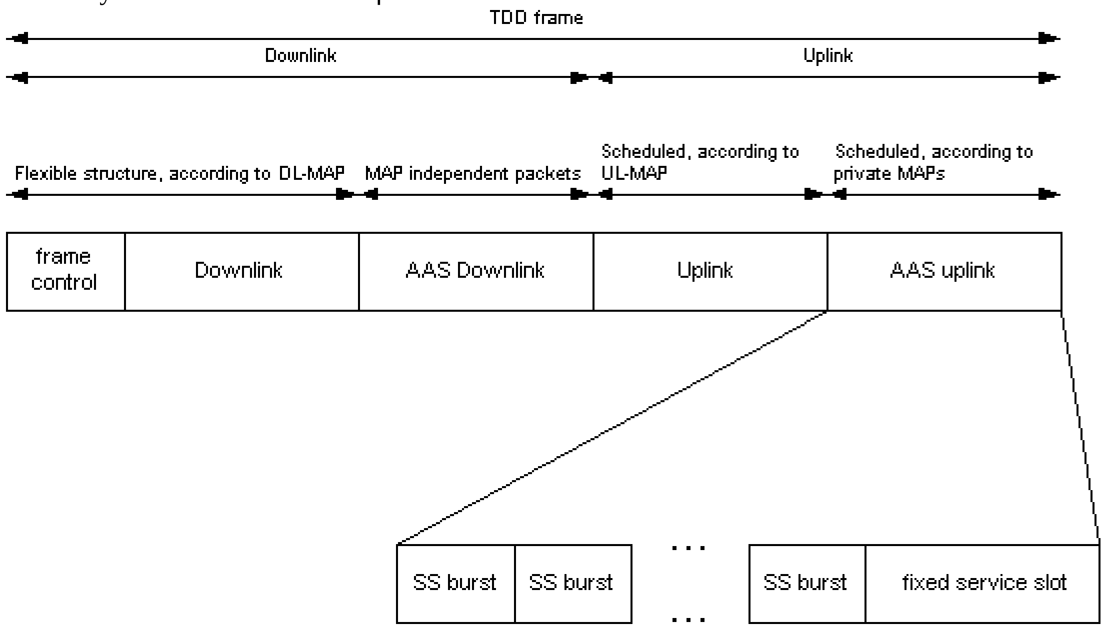


Figure 163—Frame structure with AAS support

6.2.7.12.1.4 Supporting various duplexing schemes

The framing structure shown previously is based on a TDD duplexing scheme. In general, AAS can be applied to all burst-mode air interface schemes, including Time-Division Multiplexing with Time-Division Duplexing (TDM/TDD) and Frequency-Division Duplexing TDM/FDD. When operating in FDD mode, the AAS system cannot rely on the reciprocity of the RF channel (as it is with TDD systems, where the PHY can rely on receiver channel estimations to estimate the transmit channel). Therefore, AAS in FDD systems uses an additional feedback message to support the PHY in performing transmit channel estimation. The additional functions required to support FDD will be described in detail later.

6.2.7.12.1.5 Supporting continuous mode PHY

The AAS option is required to support TDM/FDD and TDM TDD in the burst mode only. Supporting continuous modes is not required.

6.2.7.12.1.6 Supporting different PHY modulation schemes

In general, AAS is independent of the PHY mode in use. The only condition for MAC AAS to be effective is the presence of the necessary AAS functions in the PHY mode and its interface. Thus an AAS capable MAC can be used in conjunction with all modes defined in clause 8.3.

6.2.7.12.1.7 AAS specific functions

From the MAC point of view, the PHY can be equipped with an adaptive array element or not, depending on the system implementation. In the context of this standard, AAS in the MAC sub-layer is defined by MAC protocol functions. The main functions affected by AAS can be divided into three groups as follows:

- MAC control functions: Uplink/Downlink MAP distribution, Channel Description
- MAC utility function: PHY related information provided by MAC

- Registration functions: Initial Synchronization/Ranging

AAS can be implemented in the subscriber station (SS) MAC, which then will be able to interoperate with the MAC of any BS that have AAS at the MAC layer, or in the base-station (BS) MAC.

6.2.7.12.2 Compatability model

AAS is an optional component of the this standard. The AAS option, if present, must comply with the normative clauses specified in this section.

According to the logical division described earlier, non-AAS subscriber stations must be able to operate normally whether or not they receive any signal in the AAS part of the frame, and AAS subscriber stations must be able to operate normally whether or not they receive any signal in the non-AAS part of the frame.

6.2.7.12.3 Logical channels with mapping to physical channels

The mapping of logical channels to physical channels has the same granularity (i.e. mini-slots, OFDM symbols, OFDMA sub-channel) as the non-AAS supporting PHY mode.

The following logical channels exist in non-AAS supporting PHY modes:

1) Broadcast Frame Control Channel: This channel is used for frame control, carrying DL-MAP, UL-MAP, DCD, and UCD
2) Downlink Traffic Channels: This is the part of the physical channel that carries downlink user traffic, as scheduled by the BS
3) Uplink Contention Channel: This channel is used for SS initiated random access, including ranging and bandwidth request
4) Uplink Traffic Channels: This is the part of the physical channel that carries uplink user traffic, as scheduled by the BS

The following logical channels are required for AAS support:

5) Downlink Synchronization Channel: This channel is used for time and frequency synchronization by AAS subscriber stations
6) Downlink Polling Channel: This channel is required for systems where the array adaptation using signals received in the Uplink Contention Channel may not be inadequate to open a Downlink Traffic Channel to a subscriber station
7) Downlink Traffic Channels: This is the part of the physical channel that carries downlink user traffic, as scheduled by the BS. Their availability requires array adaptivation. In contrast to similar channels in the non-AAS systems, multiple simultaneous Downlink Traffic Channels can be open to spatially separated subscriber stations.
8) Uplink Contention Channel: This channel is used for SS initiated random access, including ranging and bandwidth request. Its availability does not require array adaptation.
9) Uplink Traffic Channels: This is the part of the physical channel that carries uplink user traffic, as scheduled by the BS. Their availability requires array adaptation.

In a pure AAS system where all subscriber stations are AAS enabled, only AAS channels shall be required.

6.2.7.12.4 MAC control functions

The DCD, UCD, UL-MAP, and DL-MAP messages for non-AAS subscriber stations are broadcast using the Broadcast CID. Their formats are unchanged by the AAS option, except for the presence of a special value for DIUC and UIUC that mark the AAS part of the frame. Non-AAS subscriber stations shall ignore the intervals associated with these DIUC and UIUC values.

In systems that support only AAS subscriber stations, the use of broadcast messages is not required.

The control of AAS part of the frame is done by unicast Private DCD, UCD, UL-MAP and DL-MAP messages to individual subscriber stations, using the basic CID assigned to that SS. AAS subscriber stations shall ignore all messages associated with the broadcast CID.

The format of Private DCD and UCD messages are the same as broadcast messages, except that the CID must be the basic CID assigned to that AAS subscriber station.

The format of Private DL-MAP and UL-MAP is the same, as shown in the table below:

Table 189—Private DL-MAP and UL-MAP

Field	Size	Notes
Generic MAC Header	6 bytes	Use Basic CID
MAC Message Type	1 byte	
PHY Synchronization	2 bytes	
No. of MAP IE: No_Els	1 byte	
for (i=0; i<No_Els; i++){		
{		
DIUC or UIUC	4 bits	
Allocation_element()		PHY mode dependent
}		

6.2.7.12.5 Subscriber Station Registration Process

The process of registration in AAS systems is different from the regular registration process. This is because the adaptive array operating in the PHY cannot be effective until the MAC and PHY of the BS identify the registering subscriber station. The adaptation of BS antenna array can be accomplished only after the BS has identified the SS. On the other hand, if the BS cannot adapt the array to the new subscriber, there is a chance that the SS will not receive any valid signal from the BS at all. Since the regular registration process requires that the SS receive a valid message first, it is not always possible to rely on this process.

The Uplink Contention Channel and Downlink Polling Channel are designed to solve this problem. The process of registration of a SS to a base-station, where both the SS and the BS use AAS in the MAC is based on the following steps:

SS MAC waits for an indication from PHY that initial synchronization with BS is achieved.

After receiving initial synchronization indication from PHY, SS MAC transmits a registration message TBD using the AAS registration channel (a logical channel that is mapped to a fixed physical slot).

BS PHY receives the registration message and performs channel estimation and delay measurement.

BS MAC receives the registration message from PHY and the corresponding delay. SS then responds with a training sequence to allow BS to perform array adaptation in the correct tones, and thus opens a Downlink Traffic Channel.

BS MAC sends a registration response message containing ranging information, and a private MAP message with an uplink bandwidth allocation to enable SS complete registration sequence.

SS proceeds with the standard process as required to complete all registration operations (power adjustment, rate adaptation, authentication, encryption etc…).

6.2.7.12.6 Broadcast services

6.2.7.12.7 FDD support

Adaptive Arrays use channel state information in the PHY at both downlink and uplink. When channel state of the downlink is required at the BS, there are two ways to obtain it:

- By relying on reciprocity, thus using the uplink channel state estimation as the downlink channel state.
- By using feedback, thus transmitting the estimated channel state from the SS to BS.

The first method is more simple and is well suited for TDD systems, The second method is more suitable for FDD systems, where reciprocity does not apply (due to the large frequency separation between uplink and downlink channels). In this section the special MAC functions that support the second type of channel estimation is described.

Adaptive array support for FDD systems contains two MAC control messages: Request for estimation and a reply. The reply contains channel state information, obtained at the SS. The channel state information shall be computed periodically during Channel Estimation Interval (CEI). The CEI is the time allowed from the arrival of the signal that the SS uses for channel estimation, to the reply send by the SS. The value of CEI shall be determined by the BS and broadcasted to all SSs at registration.

The Channel State Feedback Request and Response (CSF-REQ and CSF-RSP) messages are defined in clause 6.2.7.7.3.1.

6.2.8 Contention resolution

6.2.8.13 Network Entry Procedure in Mesh mode

A new node entering the mesh network obeys the following procedure.

- The new node listens to the channel for a MSH_NET_ENTRY_INITIAL_LISTEN period to overhear a number of MSH-NCFG packets in order to build the node's physical neighbor table, to select a sponsor node based on receive signal quality, and to gain coarse network synchronization using a received MSH-NCFG packet from the selected sponsor.
- The new node transmits a MSH-NENT packet which includes the selected sponsor node's address.
  - If the selected sponsor does not advertise the new node's address in the sponsor's next MSH-NCFG transmission, then the procedure is repeated MSH_SPONSOR_ATTEMPTS times using a random backoff between attempts.
    - If these attempts all fail, then a different sponsor is selected and the procedure repeated (including reinitializing coarse network synchronization).
- If the sponsor advertises this new node's address in its next MSH-NCFG packet, then the sponsor will also include the link information for this new node in the packet's complete neighbor info list, which includes the propagation delay estimate.
- The new node shall adjust its network clock by subtracting half of the propagation delay reported in the packet.
- If the reported propagation delay was not the maximum value (0xF), then network synchronization has been achieved, and the new node may participate in transmission of MSH-NCFG packets and is ready

for higher-layer network entry procedures if any. Otherwise, the node remains in coarse synchronization and shall repeat the above network time correction handshake with the sponsor node.

8. Physical Layer

Insert the following clause.

8.3 Physical Layer for frequencies between 2 and 11 GHz

8.3.1 Introduction

In order to claim compliance of a system with the IEEE 802.16 standard for licensed frequencies between 2 and 11 GHz, its PHY SHALL comply with the Single Carrier (SC) Physical Layer (PHY) as described in clause 8.3.4 or the Orthogonal Frequency Division Multiplexing (OFDM) PHY as described in clause 8.3.5.2 and 8.3.5.3. The system MAY implement both PHYs. It SHALL further comply with all requirements set out in clause 8.3.1 through 8.3.3 that apply to the implemented PHY(s).

In order to claim compliance of a system with the IEEE 802.16 standard for license-exempt frequencies, its PHY SHALL comply with the OFDM Physical Layer (PHY) as described in clause 8.3.5.2 and 8.3.5.4. It SHALL further comply with all requirements set out in clause 8.3.1 through 8.3.3 that apply to the implemented mode.

8.3.1.1 General

8.3.1.1.1 PHY components

Conceptually, the PHY can be described in terms of upper and lower physical layers. As part of the upper physical layer, higher layer (data link, transport, session, etc.) information and PHY control/management data (e.g., training and synchronization) are mapped to symbols. For transmit data, the upper physical layer includes randomization, channel coding, interleaving and modulation to form data symbols, while the lower physical layer maps the data symbols to tones and forms either OFDM symbols or unique words.

The PHY specification addresses the definition of each of the blocks shown in Figure 164. This figure is not meant to imply a specific method or manner of implementation. Neither is it intended to suggest that the same implementation of a block can be used for both an OFDM and SC based PHY.

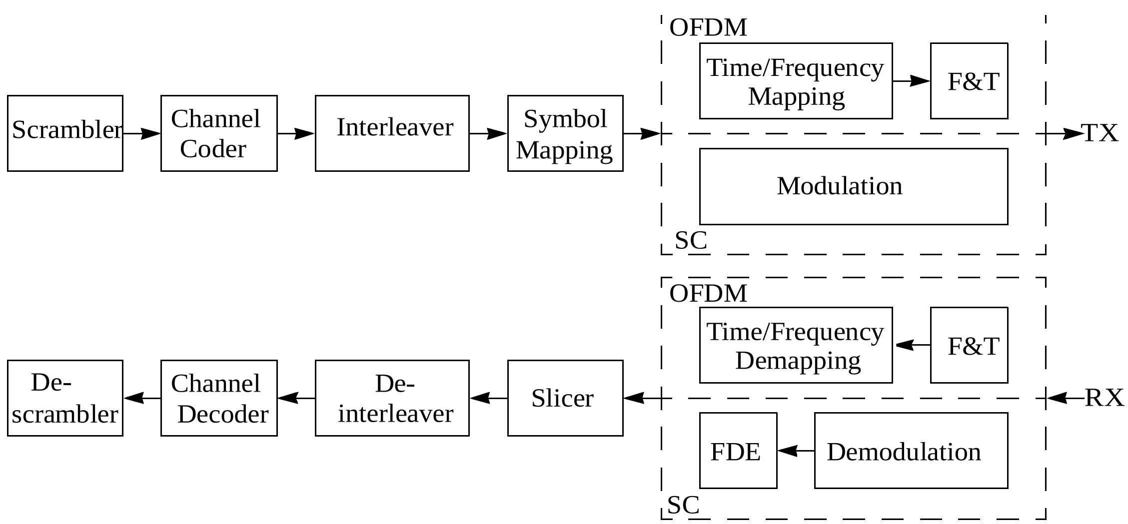


Figure 164—Generic PHY block diagram

8.3.1.1.1.1 Scrambling

The scrambling (randomization) ensures a uniform spectrum and sufficient bit transitions to simplify other PHY functions such as clock recovery and demodulation. Design criteria include the size of the scrambler (i.e., the number of bits), seed size, and how often the seed is set. A concern is how to set the scrambler so as to keep both ends of a communication link synchronized.

8.3.1.1.1.2 Channel coding

The coding performance in different channel conditions (other than average white Gaussian Noise AWGN) is a significant design consideration, especially the performance in frequency selective faded channels. In some cases, coding effect should be understood in the context of other signal processing receiver techniques used by the system (such as diversity, space-time processing etc.). The amount of coding gain required may differ between uplink and downlink due to the different propagation characteristics these channels may have.

8.3.1.1.1.3 Interleaving

Interleaving is used to spread consecutive bits into separate symbols after modulation; the purpose of the interleaver is to prevent a series of consecutive bad symbols, which may occur due to channel conditions.

8.3.1.1.1.4 Modulation

Modulation is the means for mapping digital data to discrete or analog symbols in a manner that efficiently utilizes the available communication channel bandwidth. The goal of modulated data transmission is to transfer data to a distant receiver over a prescribed channel bandwidth, within transmit power, reliability, and receiver complexity constraints. Such modulated data transmission may be implemented using a single carrier or multiple carriers.

In a SC system, data is mapped to symbols and transmitted as a high-speed serial stream that is modulated, i.e., borne, upon a single carrier. At the receiver, an equalizer is used to compensate for any distortion resulting from a non-ideal frequency response of a channel. Of particular importance to the Single Carrier PHY is the Frequency Domain Equalizer (FDE). The FDE provides a low complexity means to compensate for severe multipath and channel impairments (such as NLOS).

In a multi-carrier system, data is mapped to symbols and then multiplexed into a number of simultaneous lower-speed streams, with each stream being modulated, i.e., borne, by a different carrier. The available channel bandwidth is thereby subdivided among these multiple carriers. Although the frequency response over the entire channel bandwidth may be non-ideal (i.e., non-constant), the spacing between the modulated carriers is chosen to be small, so that the frequency response over the signaling bandwidth of any modulated carrier is approximately constant. This facilitates a simple multiplicative method by which each carrier stream may be equalized to compensate for the overall channel non-ideality.

For OFDM, a channel is defined as consisting of all carriers residing within the full signaling bandwidth. Using OFDMA, sub-channels are defined as a fraction of the available carriers within the full signaling bandwidth.

8.3.1.1.1.5 Single carrier - frequency domain equalization (SC-FDE)

The single carrier (SC) system transmits a single carrier, modulated at a high symbol rate. Equalization is often required to compensate the received data for the effects due to multipath propagation, since the multipath creates inter-symbol interference among the received symbols. Time domain equalization is one method used to compensate for multipath effects in a SC system. Frequency Domain Equalization in a SC system is another method of channel equalization. Frequency domain equalization is simply the frequency domain analog of what is done by a conventional linear time domain equalizer. The convolution applied by a linear equalizer in the time domain is replaced by multiplication applied by a frequency domain equalizer in the frequency domain. Since frequency domain equalizer operates upon blocks of data at a time, using computationally efficient fast Fourier transforms (FFTs) and inverse FFTs (IFFTs), it can be computationally more efficient than a long temporal convolution filter, when confronted channels with longer multipath delay spans.

A mixed domain (frequency and time domain) equalizer may also be implemented, to emulate the linear and nonlinear (feedback) functions of a decision feedback equalizer (DFE) and exploits the respective capabilities of each. Such a mixed-domain equalizer is called a frequency domain decision feedback equalizer (FD-DFE), and is depicted in Figure 165. Additional details on a SC-FDE will be presented in clause 8.3.4.

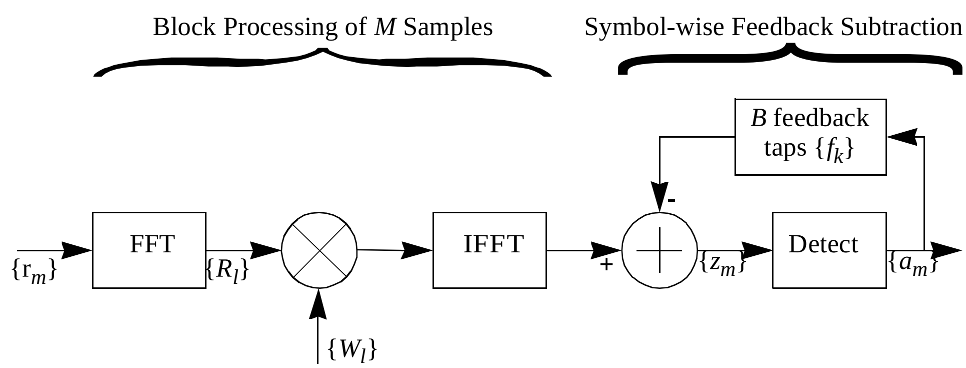


Figure 165—SC-FDE decision feedback equalization at the receiver

Both multi carrier (MC) and SC systems can be enhanced by coding (which is in fact, required for multicarrier systems), adaptive modulation and spatial diversity. In addition, OFDM can be incorporate peak-to-average reduction signal processing to partially (but not completely) alleviate its sensitivity to power amplifier nonlinearities. A SC-FDE can be enhanced by adding decision feedback equalization or maximum likelihood sequence estimation.

8.3.1.1.1.6 Time/frequency map

This block, shown in Figure 166, exists in the OFDM based PHYs only.

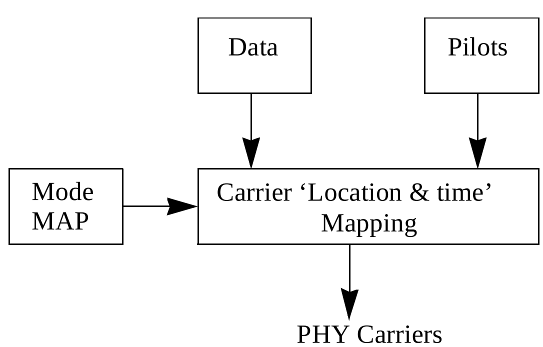


Figure 166—Time/frequency mapping function

The time frequency map takes modulated data and maps it into specific sub-carriers, according to a defined mapping scheme. The time frequency map function should be able to identify the input data origin, in order to be able to perform mapping of a data stream containing data from different sources. As an example: An input data stream may contain MAC originated data bits, coming from different users, and PHY control information altogether. The MAP will identify data origin (user 1, user 2, etc.., PHY control) and MAP each data stream into its specified sub-carriers.

In OFDM mode, the basic resource allocation quantum is an OFDM symbol. The amount of data that fits into an OFDM symbol depends on the constellation and the coding method used within this symbol as well as the number of data carriers per symbol.

In OFDMA mode, the basic resource allocation quantum is a subchannel. For all FFT sizes, each OFDM symbol contains an integer number of subchannels, both on downlink and on uplink. The amount of data that fits into a subchannel depends on the constellation and the coding method used within this subchannel as well as the number of data carriers per subchannel.

In a two-dimensional map, one dimension denotes blocks within the OFDM symbol (frequency domain), and the other denotes the consecutive OFDM symbols (time domain).

The framing structure describes how logical channnels or blocks are mapped into physical layer tones as a function of the symbol number. Logical channels or blocks include payload channels, ranging channels, null channels, access channels, and training channels. Synchronization, pilot tones, and null tones are also mapped into the physical layer tones.

The framing structure is determined by the selection of OFDM or OFDMA and on the differences between the multiple access methodologies used in OFDM and OFDMA. As such, the framing structure takes on different time/frequency maps according to the design selections made by the equipment suppliers.

8.3.1.1.1.7 Frequency and time domain processing (F&T)

This block includes nulling the guard bins, and implementing an inverse transform. In the time domain, it also includes a cyclic prefix operation, and may include windowing, clipping and filtering.

8.3.1.1.1.8 RF transceiver (RF TX and RF RX)

The discrete-time signal is converted to an analog waveform and mixed to a RF frequency. The non-linear distortions introduced as part of the RF conversion can create significant out-of-band interference, and must be reviewed in the context of deployment in specific frequency bands and out-of-band requirements, coexistence with adjacent (in-band and out-of-band) systems (in particular TDD/FDD), and tradeoffs in terms of guard bands, system performance, and system complexity.

8.3.1.2 Key system capabilities

Multiple operational modes are defined. Although the desire is to converge to a limited set of modes, ultimately it will be up to the vendors and operators to decide which modes are supported based on market objectives such as service requirements and cost objectives.

8.3.2 Targeted frequency bands, channel bandwidths and applicable masks

8.3.2.1 Frequency range and the channel bandwidth

This clause is informative, and abstracts regulatory requirements for frequency bands to which this standard may be applicable. The frequency range and the downlink and uplink channel allocations that apply to the PHY system are given in Table 190.

Table 190—Frequency bands and channel allocation

Frequency bands (GHz) (licensed unless noted)		Nominal / typical channel spacing / allocation	Reference
2.305 - 2.320 2.345 - 2.360		1 or 2 x (5 + 5 MHz) or 1 x5 MHz (Can be aggregated in any combinations) Interference Protection to DARS	USA CFR 47 part 27 (WCS) See FCC Docket IB95-91 for potential (increased) interference from DARS repeaters.
2.150 - 2.162 2.500 - 2.690		125kHZ to (n x 6) MHz Single or multiple, contiguous or non-contiguous and combinations. Interference Protection to video and ITFS users	USA CFR 47 part 21.901 (MDS) USA CFR 47 part 74.902 (ITFS, MMDS)
		n x (12 + 12 MHz) (symmetric) and n x (12 + 1.6 MHz) (asymmetric)	CITEL Rec ??? (Proposal by Canada)
2.150-2.160 2.500-2.596 2.686-2.688		1 MHz - (nx6) MHz (1 or 2-way) 25kHz-(nx 25kHz) “return” Contiguous channels preferred	Canada SRSP-302.5 (MCS) MDS service allocated to adjacent sub-bands (incl. separate “return” channels)
2.400 - 2.483.5 (License Exempt)		Frequency Hopping or Direct Sequence Spread Spectrum etc	CEPT/ERC/REC 70-03 USA CFR 47 Part 15, subpart E
3.400 - 4.990	3.410 - 4.200	1.75- 30 MHz paired with 1.75 MHz to 30 MHz Symmetric only. (50 MHz or 100 MHz separation)	ITU-R Rec. 1488 Annex II ETSI EN 301 021, CEPT/ERC Rec. 14-03 E, CEPT/ERC Rec. 12-08 E
	3.400 - 3.700	n x 25 MHz (single or paired) (50 MHz or 100 MHz separation if paired)	ITU-R Rec. 1488 Annex I CITEL PCC.III/REC.47 (XII-99) Canada SRSP-303.4 (FWA)
	3.650 - 3.700	Rulemaking in progress	USA FCC Docket WT00-32
	4.940 - 4.990	Rulemaking in progress	USA FCC Dockets WT00-32 and ET-98-237
5.150 - 5.825 (License Exempt)	5.150 - 5.350	n x 20 MHz (HIPERLAN) Restricted to Indoor Use	CEPT/ERC/REC 70-03
	5.470 - 5.725	n x 20 MHz (HIPERLAN)	
	5.250 - 5.350	100 MHz Max. Restricted to Indoor Use	USA CFR 47 Part 15, subpart E
	5.250 - 5.350	100 MHz Max	
	5.725 - 5.825	100 MHz Max	
10.000 - 10.680		3.5 to 28 MHz paired with 3.5 to 28 MHz. Symmetric only 350 MHz separation	CEPT/ERC/REC. 12-05 ETSI EN 301 021

8.3.2.2 Licensed bands

The ETSI masks are shown in Figure 167. [B18]. The spectral mask for the WCS band is shown in Figure 168 and the spectral mask for the MMDS band is shown in Figure 169.

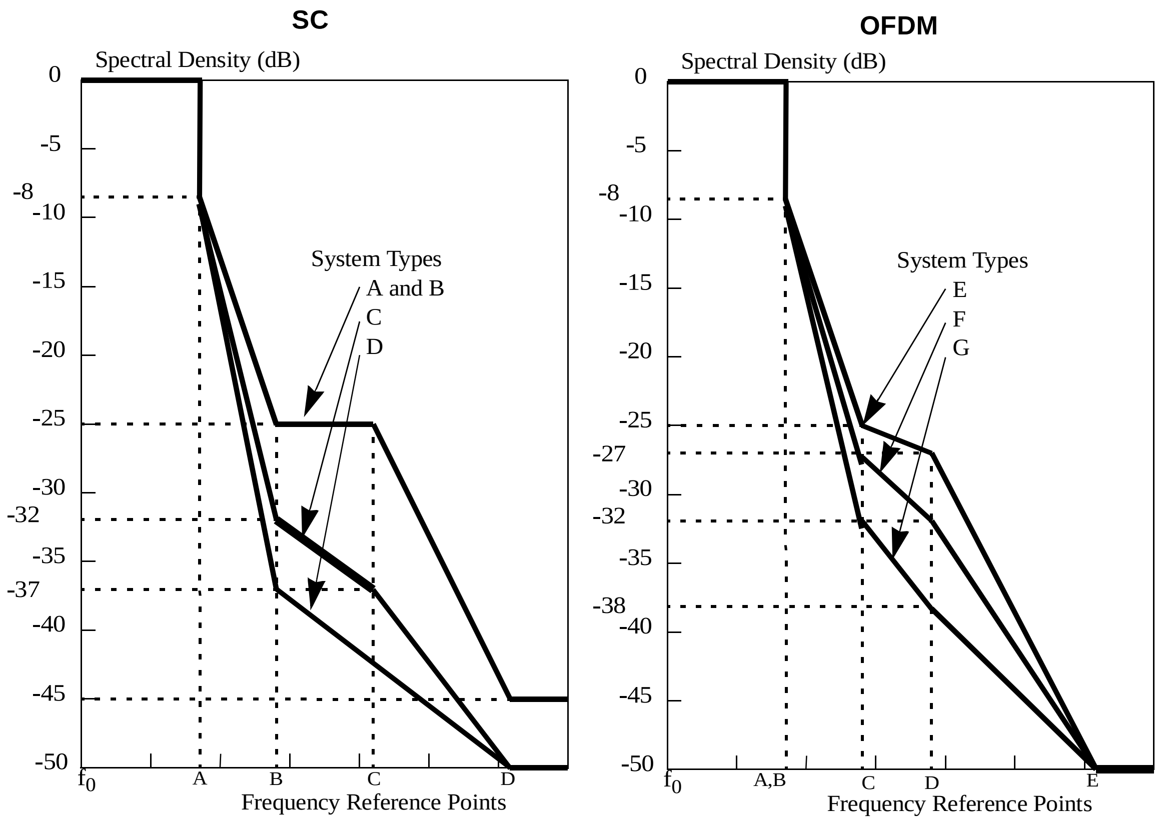


Figure 167—ETSI SC and OFDM spectral masks

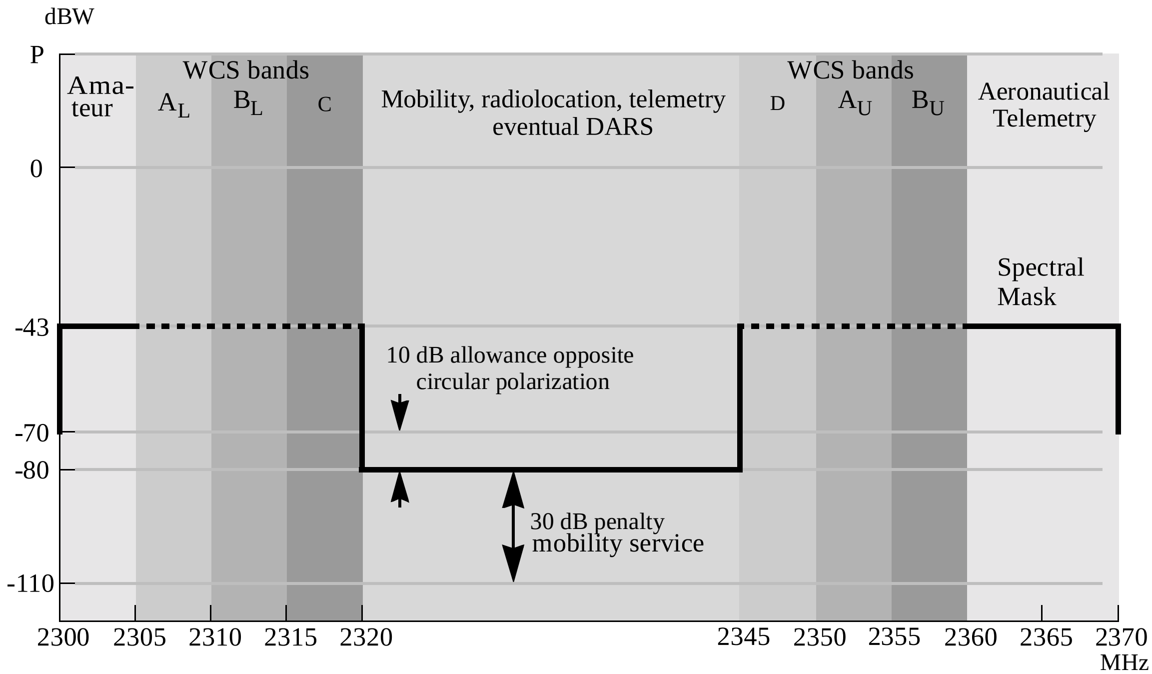


Figure 168—WCS spectral mask

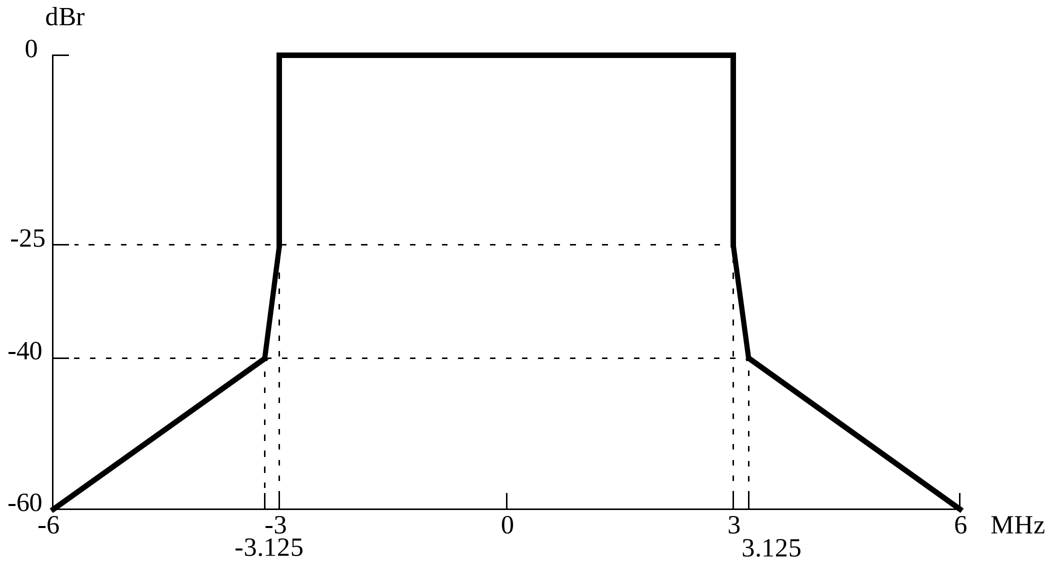


Figure 169—MMDS spectral mask

8.3.2.3 License Exempt Bands

8.3.2.3.1 Introduction

The 802.16 standard for license exempt bands is specifically designed for operation in the 5 GHz band, but may be applicable to other license-exempt bands in the 2-11GHz range. Spectrum allocation in the 5 GHz band is subject to authorities responsible for geographic specific regulatory domains e.g. global, regional, and national. The particular channelization to be used for this standard is dependent on such allocation as well as the associated regulations for use of the allocations. These regulations are subject to revision, or may be superseded.

In some regulatory domains several license-exempt frequency bands may be available for FWA devices. These bands may be contiguous or not, and different regulatory limits may be applicable. A compliant PHY shall support at least one frequency band in at least one regulatory domain.

8.3.2.3.2 USA

License exempt equipment in the USA is regulated by FCC Title 47, Part 15 [B19]. An interpretation of Subpart E, Section 15.407 is provided below for convenience. No rights may be derived from this text.

The 5.15-5.25GHz lower U-NII band is restricted to indoor use only. As at least one device on an FWA link needs to be outdoors (typically the base station), this band is not available for FWA. As a result of this, the rule that the device must meet the maximum -27 dBm/MHz limit below 5250 MHz and above 5350 MHz applies. For the upper U-NII, the limits are maximum -27 dBm/MHz below 5715 MHz and above 5835 MHz, and maximum -17 dBm/MHz in the band 5715 - 5725 MHz and 5825 - 5835 MHz.

In the middle U-NII band, the transmit power is limited to the lesser of 24 dBm (250 mW) or $11+10\log(B_{26dB})$ dBm, with the peak power density (n.b. this is not the peak power) not exceeding 11 dBm/MHz. In the upper U-NII band, the transmit power is limited to the lesser of 30 dBm (1W) or $17+10\log(B_{26dB})$ dBm, with the peak power density not exceeding 17 dBm/MHz. For any multi-point system using directional antenna with gain over 6 dBi, limits for both bands are reduced by the antenna gain in excess of 6dBi.

The maximum allowed output power for this standard's channelization is shown in Table 191.

Table 191—U-NII regulator power limitations

Regulator domain	band	Maximum output Power			Comments
		20 MHz	10 MHz	5 MHz	
USA	U-NII midle	24	21	18	Up to 6 dBi antenna gain, reduction 1 dB per 1dBi exceeding 6
USA	U-NII upper	30	27	24	

The channelization and emission requirements required for compliance with this standard are provided in clause 8.3.5.4.2.3.

8.3.2.3.3 CEPT

The CEPT currently has no allocations for license exempt FWA.

8.3.3 Downlink and uplink channels

8.3.3.1 Introduction

8.3.3.1.1 Duplexing modes

Frequency division duplex (FDD), half-duplex frequency division (H-FDD) and time division duplex (TDD) modes provide for bi-directional operation, except for operation in the license-exempt band, where provision is only made for TDD operation.

TDD flexibility permits efficient allocation of the available bandwidth and hence is capable of efficiently allocating the available traffic transport capacity for applications whose uplink to downlink traffic transport demand ratio can vary with time.

FDD /H-FDD can be used by applications that require fixed asymmetric allocation between their uplink and downlink traffic transport demand.

8.3.3.1.2 Multiple access

In a point to multipoint (P-MP) system, the downlink (DL) and uplink (UL) access to shared resources can be handled differently. In the DL, a base station (BS) can manage (schedule) resources, while in the UL some measure of contention must be supported. In either case, multiple access can be based on one or more orthogonal or nearly orthogonal resources such as divisions in time, frequency, code, and space.

8.3.3.1.3 Transmission stream

Transmissions may be organized in either a burst or continuous mode. In a packet switched system, both DL and UL links operate in a burst mode. Some designs use a continuous mode in the DL, although this approach can be a limitation when incorporating adaptive antenna arrays for spatial processing which can significantly increase cell payload capacity by using simultaneous (non-broadcast) transmissions to multiple customers.

8.3.3.1.4 Scrambling (randomization)

Data randomization is performed on source data transmitted, before FEC encoding, on both the Downlink (DL) and Uplink (UL). Randomization is performed on each allocation (DL or UL) which means that for each allocation of a data block the randomizer shall be used independently.

The bits from the randomizer shall be passed to the channel encoder.

8.3.3.1.5 Channel coding schemes

8.3.3.1.5.1 Downlink channel FEC

A forward error correction code (FEC), consisting of the concatenation of a Reed-Solomon outer code and a rate-compatible convolutional inner code, shall be supported on the downlink. Turbo product coding (TPC) is optional for all modes.

8.3.3.1.5.2 Concatenated reed solomon / convolutional code:

The concatenated Reed-Solomon/ convolutional code FEC is based on the serial concatenation of an outer Reed Solomon code, and an inner convolutional code. The outer code is derived from a Reed Solomon RS (255,239, t=8) 'mother code.' This Reed Solomon 'mother code' may be shortened and punctured to accommodate variable allocation block sizes and/or outer code error correction capabilities. The inner code is derived from a nonsystematic, rate 1/2 convolutional 'mother code', with constraint length K=7, and generator polynomials designated by 171_{OCT} and 133_{OCT}. In addition to rate 1/2, this convolutional code shall also support other rates through puncturing the mother Convolutional code (In addition, in the SC mode, systematic bits, which bypass the inner coder, are used.) , A pragmatic symbol map is used to map convolutionally coded bits to channel symbols. For certain modes, interleaving is defined between the outer and inner encoders.

Figure 170 illustrates the concatenated Reed Solomon/ Convolutional code FEC.

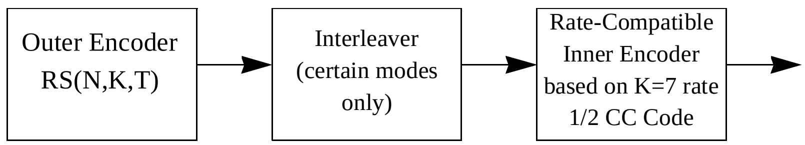


Figure 170—Concatenated Reed Solomon / Convolutional Code Encoder Block.

Encoding begins by passing the source bits through a RS encoder, and encoding data one RS code block at a time. The RS encoder output is interleaved in certain modes. The data is then passed to a rate-compatible binary convolutional encoder, derived from a K=7, rate 1/2 mother code. To achieve convolutional code rates higher than 1/2, the parallel outputs are punctured using puncturing. In the SC mode, not all of the rate increases are achieved by puncturing. It is partially achieved by using systematic bits, which bypass the inner encoder, rather than go through it.

The Reed Solomon code used in the concatenation process is further specified in clause 8.3.3.1.5.2.1. The rate 1/2 convolutional code is further specified in clause 8.3.3.1.5.2.2.

8.3.3.1.5.2.1 Reed Solomon encoding

The Reed Solomon encoding shall be derived from a systematic RS (N=255, K=239, T=8) code. This code can be shortened and punctured to enable variable block sizes and variable error-correction capability, where:

- N overall bytes, after encoding
- K- data bytes before encoding
- T- data bytes that can be fixed

The following polynomials are used for the systematic code:

- Code Generator Polynomial: $gx) = (x+\lambda^0)(x+\lambda^1)(x+\lambda^2)\ldots(x+\lambda^{2T-1}), \lambda = 02_{HEX}$
- Field Generator Polynomial: $p(x) = x^8 + x^4 + x^3 + x^2 + 1$

8.3.3.1.5.2.2 Convolutional encoding

To generate code rates of 2/3, 3/4, 5/6, and 7/8, the 1/2 'mother code' outputs may be punctured.

The binary Convolutional encoder shall have native rate of 1/2, a constraint length equal to K=7, and shall use the following generator polynomials codes to derive its two code bits:

$$G_1 = 171_{OCT} \qquad FOR\ \ X$$
$$G_2 = 133_{OCT} \qquad FOR\ Y \tag{1}$$

The generator is depicted in Figure 171.

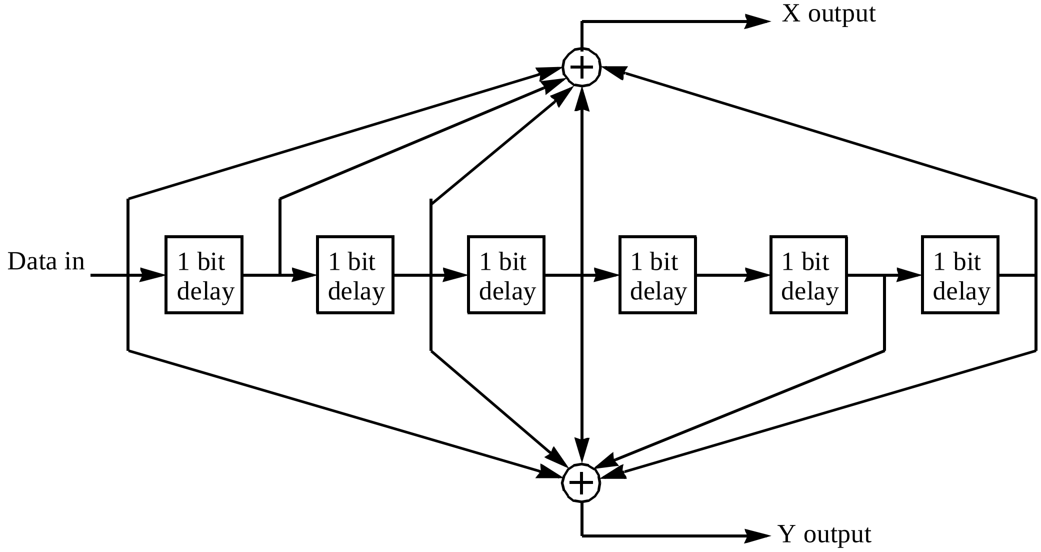


Figure 171—Convolutional encoder of rate 1/2

To generate code rates of 2/3, 3/4, 5/6, and 7/8, the 1/2 'mother code' outputs may be punctured. The binary outputs of the punctured encoder are directly mapped to the constellation for QPSK and BPSK modulated data. They are also directly mapped (following interleaving) to 16-QAM and 64-QAM constellations for the OFDM modes. However, in the SC mode, the punctured encoder is augmented with systematic bits to implement Pragmatic TCM (trellis coded modulation) codes for 16-QAM and higher modulations.

Puncturing patterns and serialization order are described separately for the SC-PHY and the OFDM PHY. In the table, “1” means transmitted bit while “0” denotes removed bit. For the SC PHY the IQ mapping is also given .

Puncturing patterns and serialization order which shall be used to realize the code rates are defined in Table 192. They are defined seperately for the SC-mode, the OFDM modes, and the optional convolutional-only mode in the license-exempt bands. In the notation used by Figure 171, (X, Y) indicates the bit pairs at the output of the Convolutional encoder, with X indicating the top 171_{OCT} polynomial output, and Y indicating the bottom 133_{OCT} output;"1" in a puncture pattern means transmitted bit while "0" denotes non-transmitted bit.

Table 192—The inner Convolutional code with Puncturing Configuration

Mode		Code Rates				
	R	1/2	2/3	3/4	5/6	7/8
	d_{free}	10	6	5	4	3
	X	1	10	101	10101	1000101
	Y	1	11	110	11010	1111010
	XY	X_1Y_1	$X_1Y_1Y_2$	$X_1Y_1Y_2X_3$	$X_1Y_1Y_2X_3Y_4X_5$	$X_1Y_1Y_2Y_3Y_4X_5Y_6X_7$
SC	Required	M	M	M	M	M
OFDM		-	M	M	M	-

8.3.3.1.5.3 Turbo product coding (optional)

Turbo product codes (TPCs) are based on the product of two or more simple component codes. These codes are also commonly called block turbo codes (BTCs). The decoding is based on the concept of soft-in/soft-out (SISO) iterative decoding (i.e., "Turbo decoding"). The component codes shall be binary extended Hamming codes or parity check codes. The main benefit of using the TPC mode is a significant coding gain advantage when compared to the concatenated Reed-Solomon + convolutional codes required in this specification.

TPC is based on using the specified component codes in a two dimensional matrix form, which is depicted in Figure 172. The k_x information bits in the rows are encoded into n_x bits, by using the component block (n_x, k_x) code specified for the respective composite code.

After encoding the rows, the columns are encoded using a block code (ny, ky), where the check bits of the first code are also encoded. The overall block size of such a product code is $n = n_x \times n_y$, the total number of information bits $k = k_x \times k_y$ and the code rate is $R = R_x \times R_y$, where $R_i = k_i / n_i$, i=x, y. The Hamming distance of the product code is $d = d_x \times d_y$.

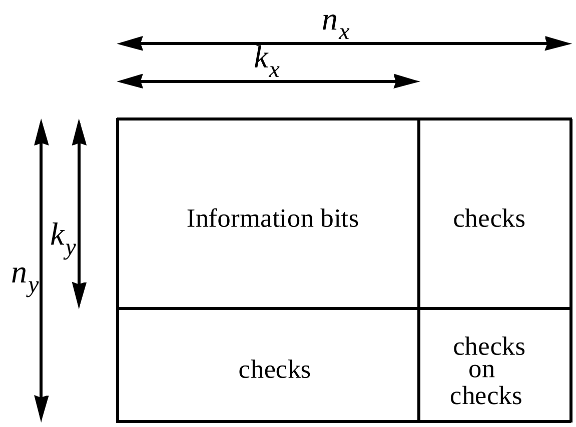


Figure 172—Two-dimensional TPC matrix

8.3.3.1.5.3.1 Encoding of a turbo product code

The encoder for a TPC has near zero latency, and is constructed from linear feedback shift registers (LFSRs), storage elements, and control logic. The constituent codes of TPCs are extended Hamming or parity only codes. Table 193 specifies the generator polynomials for the Hamming Codes.

Table 193—Hamming code generator polynomials

n'	k'	General polynomial
7	4	X^3+X^1+1
15	11	X^4+X^1+1
31	26	X^5+X^2+1
63	57	X^6+X+1

For extended Hamming codes, an overall even parity check bit is added at the end of each code word. Table 194 summarizes the component codes available for use in this specification:

Table 194—TPC component codes

Component code (n,k)	Code type
(64,57)	Extended Hamming Code
(32,26)	Extended Hamming Code
(16,11)	Extended Hamming Code
(8,4)	Extended Hamming Code
(64,63)	Extended Hamming Code
(32,31)	Parity Check Code
(16,15)	Parity Check Code
(8,7)	Parity Check Code
(4,3)	Parity Check Code

Data bit ordering for the composite TPC matrix is the first bit in the first row is the least significant bit (LSB) and the last data bit in the last data row is the most significant bit (MSB).

Figure 173 illustrates an example of a TPC encoded with $(8,4) \times (8,4)$ extended Hamming component codes.

D_{11}	D_{21}	D_{31}	D_{41}	E_{51}	E_{61}	E_{71}	E_{81}
D_{12}	D_{22}	D_{32}	D_{42}	E_{52}	E_{62}	E_{72}	E_{82}
D_{13}	D_{23}	D_{33}	D_{43}	E_{53}	E_{63}	E_{73}	E_{83}
D_{14}	D_{24}	D_{34}	D_{44}	E_{54}	E_{64}	E_{74}	E_{84}
E_{15}	E_{25}	E_{35}	E_{45}	E_{55}	E_{65}	E_{75}	E_{85}
E_{16}	E_{26}	E_{36}	E_{46}	E_{56}	E_{66}	E_{76}	E_{86}
E_{17}	E_{27}	E_{37}	E_{47}	E_{57}	E_{67}	E_{77}	E_{87}
E_{18}	E_{28}	E_{38}	E_{48}	E_{58}	E_{68}	E_{78}	E_{88}

Figure 173—Example of an encoded TPC block

Transmission of the block over the channel shall occur in a linear fashion, with all bits of the first row transmitted left to right followed by the second row, etc. This allows for the construction of a near zero latency encoder, since the data bits can be sent immediately over the channel, with the ECC bits inserted as necessary. For the $(8, 4) \times (8, 4)$ example, the output order for the 64 encoded bits would be: D_{11}, D_{21}, D_{31}, D_{41}, E_{51}, E_{61}, E_{71}, E_{81}, D_{12}, D_{22},..., E_{88}.

Alternatively, a block-based interleaver as specified in mode specific clauses of this document may be used to modify the baseline transmission order.

8.3.3.1.5.3.2 Shortened TPCs

To match packet sizes, TPCs are shortened by removing symbols from the array. In the two-dimensional case rows, columns or parts thereof can be removed until the appropriate size is reached. Unlike one-dimensional codes (such as Reed-Solomon codes), parity bits are removed as part of shortening process.

There are two steps in the process of shortening of product codes. The first is to remove entire rows and/or columns from the 2-dimensional code. This is equivalent to shortening the constituent codes that make up the product code. This method enables a coarse granularity on shortening, and at the same time maintaining the highest code rate possible by removing both data and parity symbols. Further shortening is obtained by removing individual bits from the first row of the 2-dimensional code starting with the lsb.

In the case where the product code specified has a non-integral number of data bytes, the left over msb bits are zero filled by the encoder. After decoding at the receive end, the decoder shall strip off these unused bits and only the specified data payload is passed to the next higher level in the physical layer. The same general method is used for shortening the last code word in a message where the available data bytes do not fill the available data bytes in a code block.

8.3.3.1.5.3.3 Soft decision decoding of turbo product codes

While not specified, it is generally assumed that soft decision decoding will be performed to maximize the decoder performance. Soft decision decoding will provide 2 dB or more performance advantage compared to hard decision decoding.

The soft decision-decoding (soft input - soft output or SISO decoder) algorithm is likewise not specified. Many different SISO decoders are available and described in detail in published academic papers.

8.3.3.1.5.3.4 Iterative Decoding

A decoder iteration is defined here as one complete decoding of all the rows and columns of the TPC. The number of decoder iterations is left to the system provider, keeping in mind the trade off of better performance versus the complexity of the decoder. In any case, the decoder must perform its decoding within the latency constraints of the system design.

8.3.3.1.5.4 Constellation mapping

For modes requiring Gray coding, bits are mapped to symbol constellations using the Gray coding schemes illustrated in Figure 174 and Figure 175. Modes which use a Gray-coded symbol map include all FEC schemes for the OFDM mode; and all modulations---BPSK through 256-QAM---when the single carrier modulation mode is operated without FEC. Selected (but not all) code rates and modulations for the single carrier mode with FEC also use these Gray-coded symbol maps.

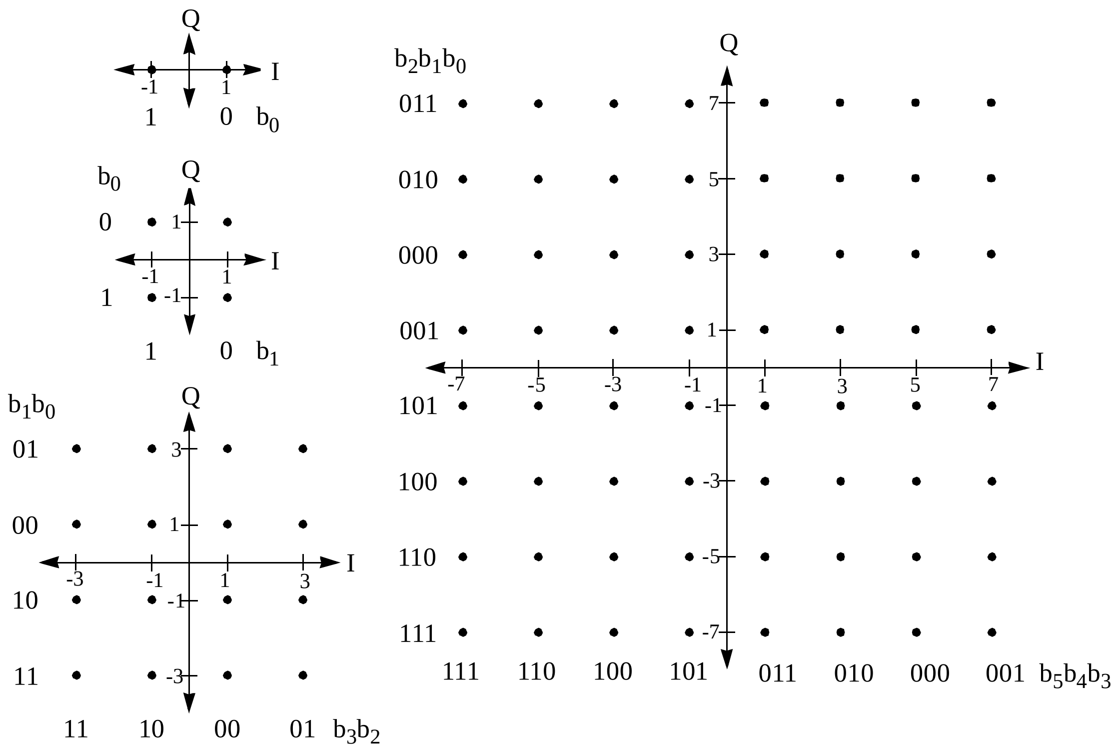


Figure 174—BPSK, QPSK, 16 QAM and 64 QAM constellations

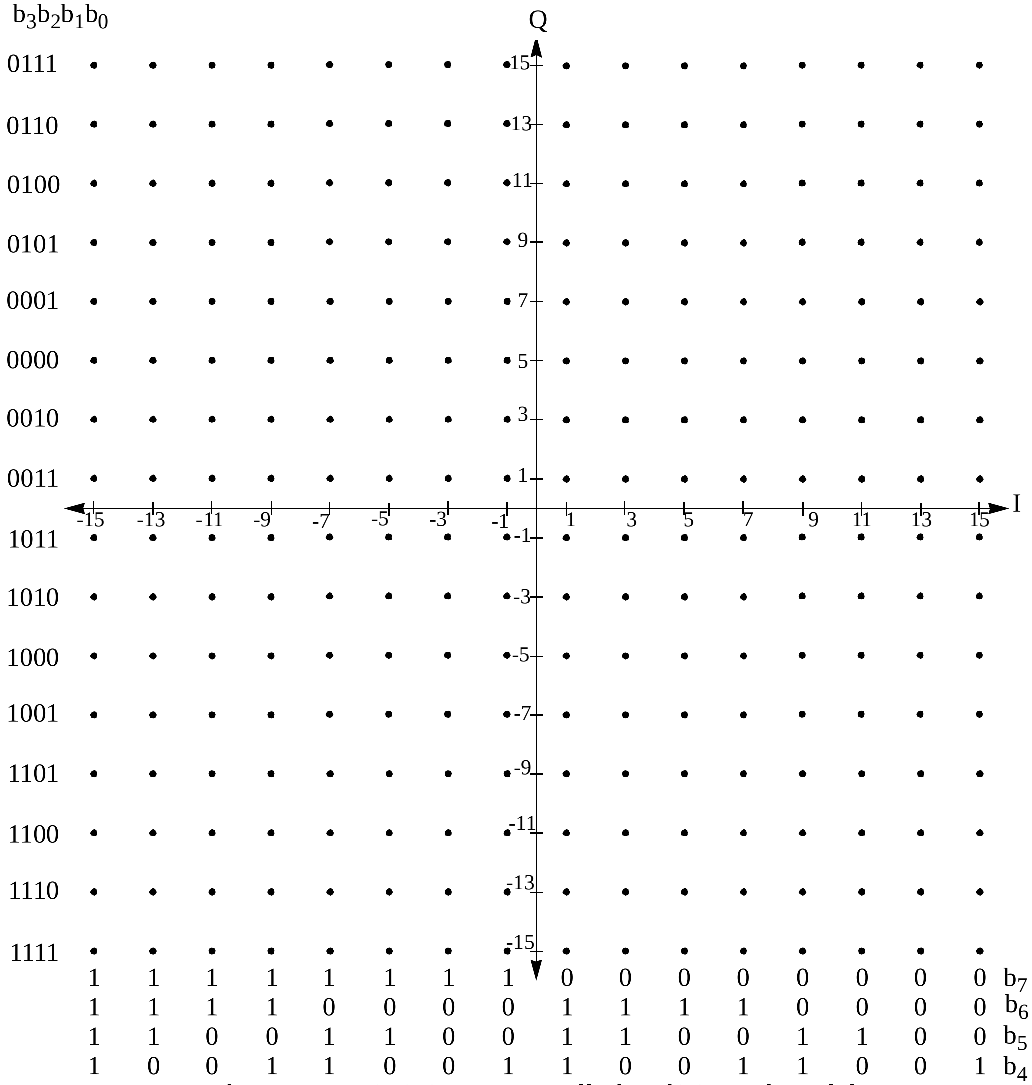


Figure 175—256 QAM constellation (SC mode only)

The constellations as shown in Figure 174 and Figure 175 shall be normalized by multiplying the constellation point with the factor *c* as shown in Table 195.

Table 195—Normalization factors

Modulation scheme	Normalization Factor 6 dB attenuation	Normalization Factor Reference 0dB	Normalization Factor 6 dB boosting
BPSK	$c = 1/2$	$c = 1$	$c = 2$
QPSK	$c = 1/\sqrt{8}$	$c = 1/\sqrt{2}$	$c = \sqrt{2}$
16 QAM	$c = 1/\sqrt{40}$	$c = 1/\sqrt{10}$	$c = 1/\sqrt{5}$
64 QAM	$c = 1/\sqrt{168}$	$c = 1/\sqrt{42}$	$c = 1/\sqrt{21}$
256 QAM	$c = 1/\sqrt{680}$	$c = 1/\sqrt{170}$	$c = 1/\sqrt{85}$

8.3.3.1.6 Adaptive modulations

Adaptive modulation and coding shall be supported in the downlink. The uplink shall support different modulation schemes for each user based on the MAC burst configuration messages coming from the Base Station. Complete description of the MAC / PHY support of adaptive modulation and coding is provided in clause 6.2.7.

8.3.3.2 Downlink

8.3.3.2.1 Downlink multiplexing

Each downlink RF channel is subdivided into fixed frames with which the RF carrier is suitability modulated to provide a digital bit stream. Within each RF channel a frame structure is used to organize and schedule the transmission of voice, video and data traffic.

8.3.3.2.2 Downlink data modulation schemes

The applicable modulation schemes for the downlink are shown in Table 196.

Table 196— Downlink data modulation schemes (M= mandatory, O=optional)

	BPSK	QPSK	16QAM	64QAM	256QAM
Licensed - SC	O	M	M	M	O
Licensed - OFDM	N/A	M	M	O	N/A
License-exempt - OFDM	M	M	M	O	N/A

8.3.3.3 Uplink

TDMA is required in all PHY modes.

8.3.3.3.1 Uplink data modulation schemes

The applicable modulation schemes for the uplink are shown in Table 197.

Table 197—Uplink Data modulation schemes (M= mandatory, O=optional)

	BPSK	QPSK	16QAM	64QAM
Licensed - SC	O	M	M	O
Licensed - OFDM	N/A	M	M	O
License-exempt - OFDM	M	M	M	O

8.3.4 Single Carrier PHY Layer

8.3.4.1 Introduction

8.3.4 and its descending subsections introduce and specify the 802.16 Single Carrier (SC) PHY. Preceding the PHY specification is introductory material, which includes:

- a list of SC PHY features, in 8.3.4.2;
- an introduction to Frequency Domain Equalization (FDE), in 8.3.4.4; and
- a comparison drawing analogies between OFDM processing and SC processing with Frequency Domain Equalization, in 8.3.4.5.

Detailed specification of the single carrier PHY commences in 8.3.4.6.

The intended operating frequency bands for the Wireless MAN PHY range from 2 to 11 GHz. Studies made within the 802.16a standard development process [B32], [B33] suggest that single carrier (SC) FDE technology provide as good or better performance than Orthogonal Frequency Division Modulation (OFDM) technology in addressing Non-Line of Sight (NLOS) multipath channel conditions that may be seen in the 2 to 11 GHz frequency bands. For this reason, equalization with a Frequency Domain Equalizer (FDE) (or SC-FDE) is recommended (but not required) when implementing a SC PHY receiver.

The frame structure associated with the SC PHY fully supports adaptive modulation and coding. Both burst and continuous transmit options are defined for the SC PHY, and, with these options, several modes of TDD and FDD operation are supported. Moreover, the SC PHY is fully compatible with, and leverages the structure of, the 802.16 MAC.

8.3.4.2 Single Carrier PHY Features

The Single Carrier PHY resides within a Broadband Wireless Access (BWA) Point-to-Multipoint communication system that can provide digital two-way voice, data, Internet access, and video services over a wireless air interface. Support of QoS features within the 802.16 MAC enables this BWA system to support such services as packet data and Constant Bit Rate (CBR), as well as T1/E1, POTS, and wide-band audio and video services. This wireless communication system is intended to provide an effective, attractive alternative to traditional wire line (cable or DSL) broadband services.

Key features of the SC PHY include the following:

- Use of single carrier modulation technology and radios to enable low cost implementation of Subscriber Stations (SSs) and Base Stations (BSs).
- Robustness to frequency selective fading and other channel impairments due to the use of a wideband modulation format.
- Full compatibility with the 802.16 MAC.
- Uplink multiple access based on TDMA.
- Downlink multiple access based on broadcast Time Division Multiplexing (TDM).
- Duplexing options that support TDD and FDD operation.
- Symbol-unit packet size granularities, which leads to low overhead, efficient packet transmission.
- Block adaptive modulation and Forward Error Correction (FEC) coding for both the Uplink and Downlink duplex channels, to maximize the service capacity of the system.
- Use of powerful, bandwidth efficient structures for channel estimation.
- Framing structures that facilitate the use of frequency Domain Equalization (SC-FDE), as well as temporal Decision Feedback Equalization.
- Capablity to implement a SC-FDE, which performs at least as well as OFDM in severe multipath environments, with markedly better performance than OFDM when Forward Error Correction is not used.

- Support of high throughput option based on uncoded transmission and ARQ error control; unlike OFDM, does not require Forward Error Correction to provide good performance in multipath environments.
- Roughly the same overall system equalization complexity (with a SC-FDE) as OFDM.
- Support of Transmit and receive diversity options, including Alamouti transmit diversity, delayed transmit diverisity, and Multiple-In Multiple-Out (MIMO) techniques.
- Flexiblity in terms of geographic coverage, use of frequency bands, and capacity allocation.
- Support of power control.
- Capability to use multiple sector antennas at the Base Station.
- Implicit support of smart antenna technologies.
- Potential re-configurability of SC-FDE PHY receiver (via ‘hardware and/or software reuse’) to support OFDM demodulation.
- Potential to provide complexity reduction and subscriber station power efficiency gains via use of mixed mode operation of Downlink OFDM/uplink single carrier rather than downlink OFDM/uplink OFDM.

8.3.4.3 SC-FDE Wireless Access System Model

Figure 176 illustrates a Single carrier modulation (SCM) system and Figure 177 illustrates an OFDM-compatible single carrier modulation system.

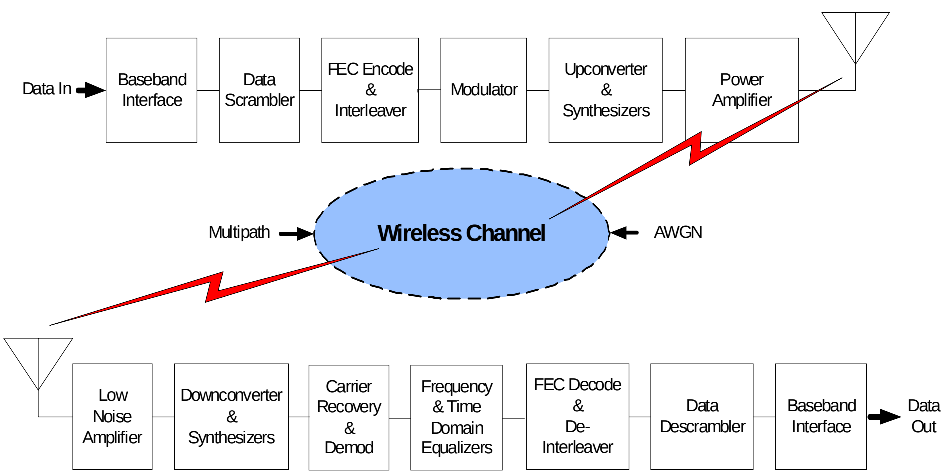


Figure 176—SCM system block diagram

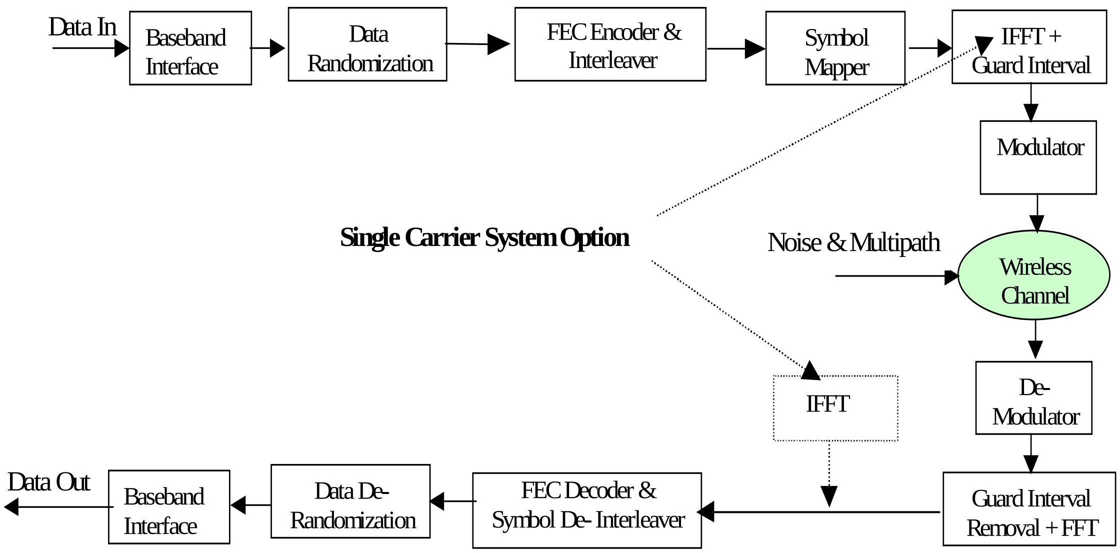


Figure 177—Block Diagram for an OFDM Compatible SCM System

8.3.4.4 Single-Carrier with Frequency Domain Equalization (SC-FDE) Scheme

The 2-11 GHz based fixed wireless systems may be operated in Non-Line-of-Sight (NLOS), severe multi-path environments. Delay spread varies with environment and characteristics of transmit and receive antennas. In typical MMDS operating conditions, the average delay spread may be on the order of 0.5 us. However, 2% of measured delay spreads may be greater than approximately 8-10 us ([B21], [B22], [B33]).

Multi-path delay spread is a major transmission problem, which affects the design of modulation and equalization. Single Carrier Modulation with Frequency Domain equalization is one method that is computationally efficient, cost effective, and robust in extended delay spread environments.

Figure 178 illustrates Single Carrier with Frequency Domain Equalization (SC-FDE) with Linear Equalization at the receiver end.

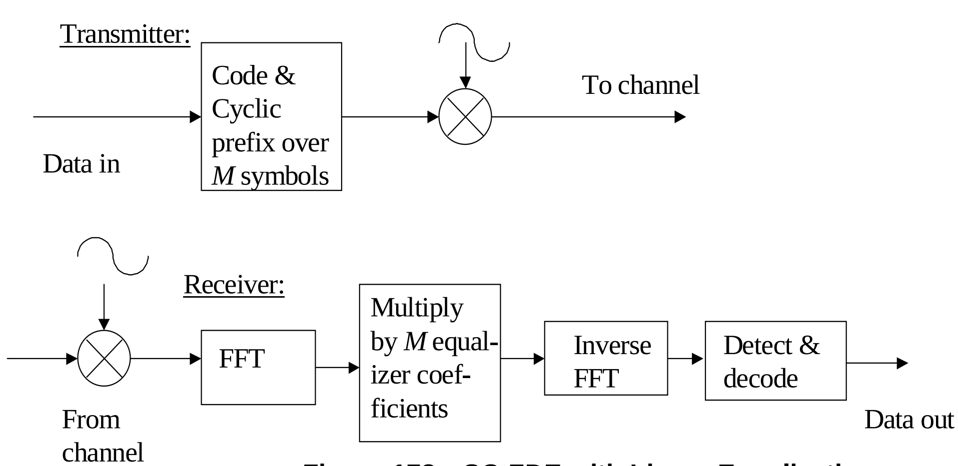
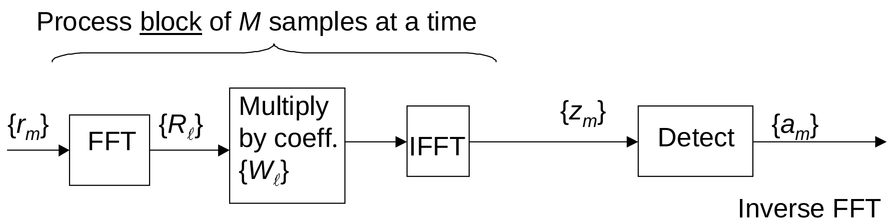


Figure 178—SC-FDE with Linear Equalization

The system of Figure 178 is analogous to a conventional, time-domain linear equalizer, using a transversal filter with M tap coefficients, but in this instance, the filtering done is in the frequency domain. The typical FFT block length (M) suitable for equalizing typical MMDS symbol rates and channels would range between 128 and 1024 points, for both OFDM and Single-Carrier FDE systems using this type of equalizer.



$$\text{Linear equalizer (LE) output} = z_m = \underbrace{\frac{1}{M}\sum_{\ell=0}^{M-1} W_\ell R_\ell \exp\left(j\frac{2\pi}{M}\ell m\right)}_{\text{Inverse FFT}}$$

$$\text{where } R_\ell = \underbrace{\sum_{m=0}^{M-1} r_m \exp\left(-j\frac{2\pi}{M}\ell m\right)}_{\text{FFT}}$$

$$\text{Error } e_m = z_m - a_m. \quad (\text{Minimize } E(|e_m|^2).)$$

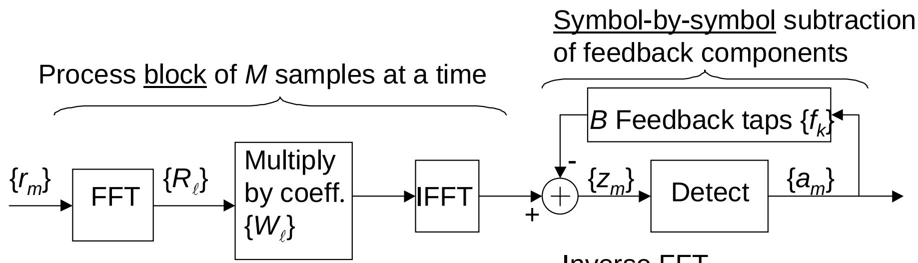
Figure 179—SC-FDE with Linear Equalization - Details

The single carrier Linear equalizer of Figure 179 uses approximately $\log_2$ M multiplies per symbol, which is similar to the equalization complexity required by OFDM.

Figure 180 summarizes the implementation of another single carrier equalizer using mixed-domain techniques, the SC-FDE with decision feedback (abbreviated ‘SC-DFE’). An SC-DFE generally offers better equalization performance than a SC-FDE, and is only slightly greater in complexity if the feedback element component of the equalizer is sparse, containing one to a few taps.

Since the block length, M, and the number of symbols that might be used as a cyclic prefix are similar to those for OFDM, the SC-FDE and SC-DFE both potentially have approximately the same computational complexity as an OFDM equalizer. Moreover, use of the single carrier format does not incur the power back-off penalty associated with OFDM [B22], [B23], [B24], [B28]. An added benefit is that with a programmable receiver possessing Frequency Domain processing elements may be capable of processing both OFDM and Single Carrier Modulated signals.

Many researchers in the 1970s and 1980s made contributions to the technology development of Single Carrier modulation with Frequency Domain Equalization (SC-FDE) (cf. [B21], [B28], [B29], [B30], [B31]). A contributor of particular note is Hikmet Sari, who introduced the concept of Cyclic prefix to simplify equalization processing, and was also the first to explicitly compare the performance of SC-FDE with OFDM [B21].



Inverse FFT

$$\text{DFE output} = z_m = \frac{1}{M}\sum_{\ell=0}^{M-1} W_\ell R_\ell \exp(j\frac{2\pi}{M}\ell m) - \sum_{k\in F_B} f_k^* a_{m-k}$$

$$\text{where}\;\; R_\ell = \underbrace{\sum_{m=0}^{M-1} r_m \exp(-j\frac{2\pi}{M}\ell m)}_{\text{FFT}}$$

F_B is a set of B feedback tap delays corresponding to the B largest channel Impulse response postcursors.

Error $e_m = z_m - a_m$. (Minimize $\text{MSE} = \text{E}(|e_m|^2)$.)

Figure 180—SC-FDE with Decision Feedback Equalizer (FD-DFE)

8.3.4.5 Relationship of OFDM to SC-FDE

OFDM transmits multiple modulated subcarriers in parallel. Each occupies only a very narrow bandwidth. Since only the amplitude and phase of each subcarrier is affected by the channel, compensation of frequency selective fading is done by compensating for each subchannel's amplitude and phase. OFDM signal processing is carried out relatively simply, by using two fast Fourier transforms (FFT's), at the transmitter and the receiver, respectively.

The single carrier (SC) system transmits a single carrier, modulated at a high symbol rate. Frequency domain equalization in a SC system is simply the frequency domain analog of what is done by a conventional linear time domain equalizer. For channels with severe delay spread frequency domain equalization is simpler than the corresponding time domain equalization for the same reason that OFDM is simpler: because of the FFT operations and the simple channel inversion operation.

The main hardware difference between OFDM and SC-FDE is that the transmitter's inverse FFT block is moved to the receiver. The overall system complexities are therefore roughly same. A dual-mode system could be designed to handle either OFDM or SC-FDE by simply interchanging the IFFT block between the transmitter and receiver at each end (see Figure 181).

Both systems can be enhanced by coding (which is in fact required for OFDM systems), adaptive modulation and spatial diversity. In addition, OFDM can incorporate peak-to-average reduction signal processing to partially (but not completely) alleviate its high sensitivity to power amplifier nonlinearities. SC-FDE can be enhanced by adding decision feedback equalization or maximum likelihood sequence estimation.

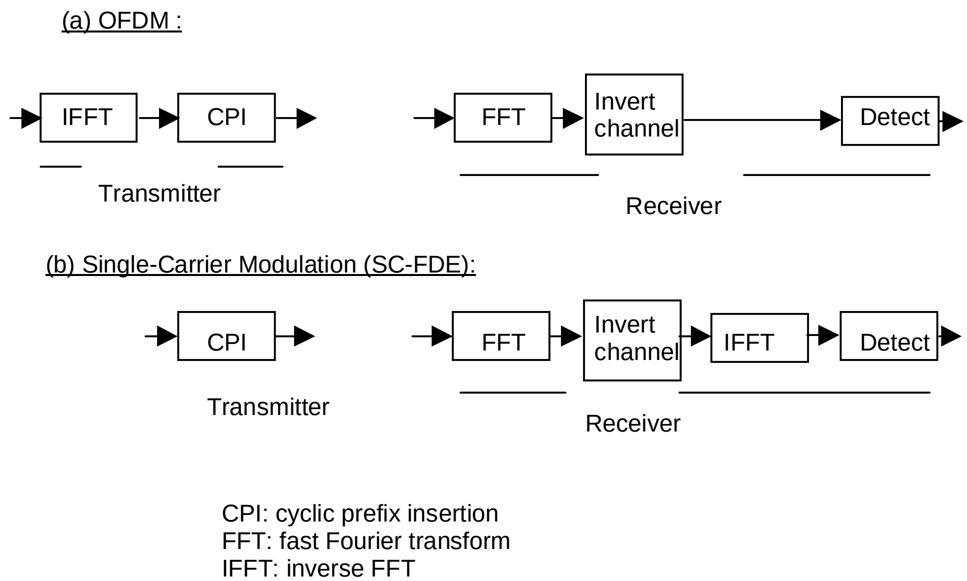


Figure 181—OFDM and SC-FDE relation

8.3.4.6 Downlink Channel

Specification of the Single Carrier PHY commences with specification of its downlink channel elements in 8.3.4.6. The uplink channel is specified in 8.3.4.7; details on framing, multiple access, and duplexing for both the uplink and downlink channels are provided in 8.3.4.8.

8.3.4.6.1 DL Multiple Access

Time Division Multiplexing (TDM) and/or Time Division Multiple Access (TDMA) may be used on the downlink channel, depending on the mode of operation selected by a system operator. The continuous format mode of operation, described in 8.3.4.9 uses TDM, while the burst mode of operation, described in 8.3.4.10 uses either TDM or TDMA.

8.3.4.6.2 DL Modulation Formats

Support of QPSK, 16QAM, and 64-QAM operation on the downlink is mandatory. BPSK and 256 QAM operational modes are also defined, but the support of each of these modes is optional.

The modulation type may change within a continguous downlink transmission (e.g., when messages intended for multiple users are multiplexed together, in a single transmission), or may change in consecutive downlink transmissions. With such an adaptive modulation scheme, an operator may support both low SNR and high SNR subscribers on the same downlink channel, yet still optimize the channel's information-bearing capacity.

8.3.4.6.3 DL Transmit Processing

Figure 182 is a functional block diagram of downlink transmit processing. Transmit processing begins in the MAC, which builds a frame of source bits. In a TDM scheme, these source bits may be composed of several blocks of bits multiplexed together, and intended for several different downlink subscribers. The frame of source bits are sent through a randomizer, which XORs the source bits with a random PN-generated pattern.

The randomized bits are then sent to a Forward Error Correction (FEC) encoder block, where redundancy is added, to increase the immunity of the transmitted data to noise and other transmission impairments.

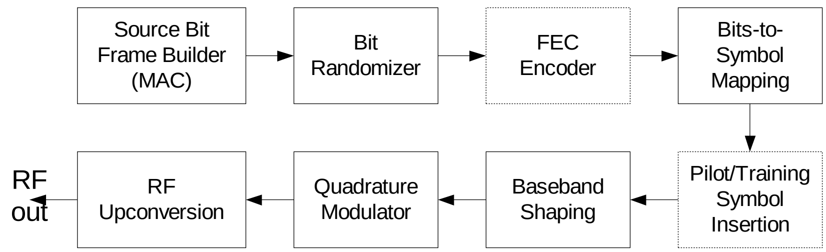


Figure 182—Functional Diagram of Downlink Transmit Processing

The FEC encoder block shown in Figure 182 is dashed, because, although an FEC decoder in the subscriber unit is mandatory, an optional mode exists wherein the transmitter can send uncoded data over the downlink channel, and rely on the MAC's Automatic Repeat ReQuest (ARQ) mechanism for error control. When uncoded transmission is desired, the FEC encoding function is suppressed, and bits flow directly to the next block, which maps bits to elements with a channel symbol constellation.

After symbol mapping, optional extra symbols, such as preamble and pilot symbols, may be inserted into the symbol stream, to aid the demodulation task at the receiver. The In-phase (I) and Quadrature (Q) components of the resulting symbol stream are then sent through identical baseband transmit filters, to interpolate between the symbol samples, and confine the occupied bandwidth of the resulting signal. The filtered Inphase and Quadrature waveforms are then Quadrature modulated, and upconverted to the desired RF carrier frequency for transmission over the air interface.

8.3.4.6.4 Source Bit Randomization for Energy Dispersal

Source bits, i.e., the original information bits prior to FEC encoding, shall be randomized on downlink transmissions. This randomization is performed to ensure sufficient bit transitions to support clock recovery, and to minimize the appearance of the unmodulated carrier when idle or unchanging source data is transmitted over the channel.

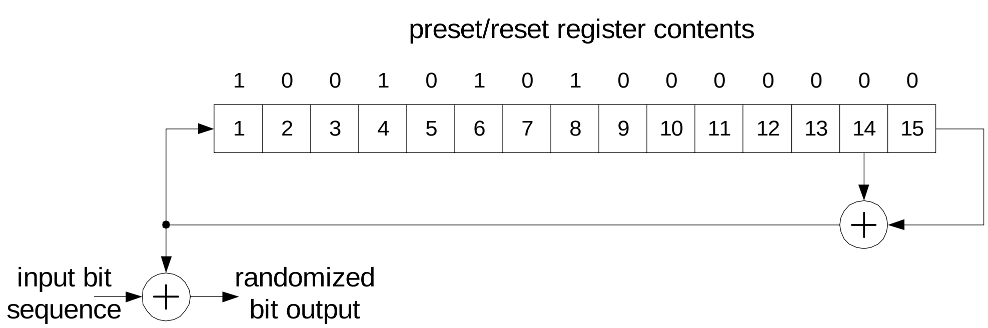


Figure 183—Randomizer for Energy Dispersal

As Figure 183 illustrates, source bit randomization shall be performed by modulo-2 addition (XORing) source (information) data with the output of Linear-Feedback Shift Register (LFSR) possessing characteristic polynomial $1 + X^{14} + X^{15}$. In a burst mode transmission, the LFSR shall be preset at the beginning of each burst to the value 100101010000000. In a continuous mode transmission, the LFSR shall be preset to 100101010000000 at the beginning of each frame.

Note that only information bits are randomized; elements that are not a part of the source data, including preambles, pilot symbols, parity bits generated by the FEC, etc., are not randomized.

8.3.4.6.5 DL FEC

Various modulation formats and Forward Error Correction (FEC) code rates are specified for the downlink channel, to enable reliable and bandwidth efficient downlink communication over a wide range of SNRs. Moreover, as directed by DL_MAP messages from the MAC, the downlink PHY allows the assignment of a particular modulation format and FEC code on a subscriber level basis. With such an adaptive modulation and coding scheme, an operator may support both low SNR and high SNR subscribers on the same downlink channel, yet still optimize the channel's information-bearing capacity.

Broadcast messages, such as system control messages, must be received by all subscribers---including subscribers attempting to initially acquire the downlink channel. For this reason, downstream broadcast messages are always sent with a fixed, known, and robust combination of modulation type and FEC coding. The robust modulation type is QPSK, and the robust FEC is a concatenated code consisting of 1/2 convolutional (inner) code and a Reed Solomon (outer) code, shortened to the appropriate block length for the broadcast message. Further details on adaptive modulation, including its sequencing within a transmission may be found in 8.3.4.9.3

Two Forward error correction (FEC) coding schemes are defined for the downstream:

- A (Mandatory) Concatenated FEC scheme, with codes constructed from Reed-Solomon and Convolutional codes, described in 8.3.4.6.5.1;
- An (Optional) Turbo Product Coding scheme, described in 8.3.4.6.5.3.

In addition, the provision of suppressing all FEC and operating using the ARQ mechanism in the 802.16 MAC for error control is a defined option.

8.3.4.6.5.1 Concatenated Reed-Solomon + Convolutional Code

A standard FEC for the single carrier downlink (and uplink) is the concatenation of an outer Reed Solomon code and an inner trellis code derived from a convolutional code. Figure 184 illustrates the general topology for the concatenated FEC. As Figure 184 demonstrates, source bits are encoded by the outer encoder, optionally interleaved (in the downlink case), encoded again by the inner encoder, and mapped to the I and Q components of complex signaling constellation using a bits-to-constellation signal map. Details on the outer FEC are found in 8.3.4.6.5.1.1; the inner FEC, in 8.3.4.6.5.1.3; the optional interleaver in 8.3.4.6.5.1.2; and the bits-to-symbols maps (for BPSK, QPSK, 16-QAM, 64-QAM, and 256-QAM) in 8.3.4.6.5.1.3.

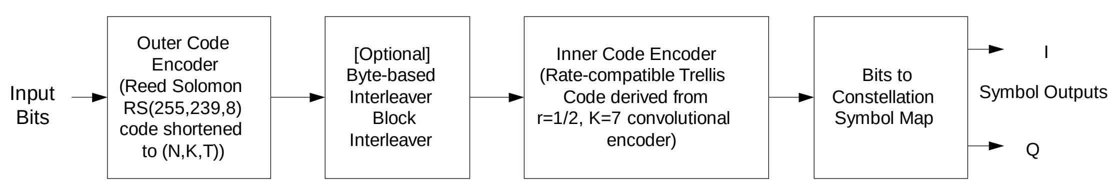


Figure 184—General topology for concatenated FEC used by single carrier mode

8.3.4.6.5.1.1 Outer FEC

The outer FEC is based on a systematic Reed Solomon RS(255,239) code. As this description implies, the baseline Reed-Solomon encoder takes a source block of 239 bytes and encodes it into the code block of 255 bytes, with a minimum distance error correction capability of T=8 bytes. Since the option exists to independently encode user allocations, and many allocations may require fractions of the base block size to be delivered, the baseline RS(255,239) code may be shortened and punctured to an arbitrary RS(N,K) at the end of an allocation, to encapsulate a fractionally-sized block.

The following polynomials are used for the systematic RS(255,239,8) code:

- Code generator polynomial:

$$g(x) = (x+\lambda^0)(x+\lambda^1)(x+\lambda^2)...(x+\lambda^{2T-1}), \lambda = 02_{hex}$$

- Field Generator polynomial:

$$p(x) = x^8 + x^4 + x^3 + x^2 + 1$$

8.3.4.6.5.1.2 [Optional] Block Interleaver

Interleaving is an option on the downstream. If performed, the interleaving is performed on byte-sized words, before they are fed to the inner encoder. If used, this interleaving must be block-based, and must accommodate variable block sizes. The interleaver address generation algorithm is TBD. It is not necessarily a simple row-column block interleaver.

8.3.4.6.5.1.3 Inner FEC

The inner FEC is a rate-compatible pragmatic TCM (Trellis Coded Modulation) code based on the rate 1/2, constraint length 7 binary convolutional ‘mother code’ described in 8.3.3.1.5.2.2. A pragmatic TCM code is constructed from both nonsystematic coded bits (which are derived from the outputs of the rate 1/2 binary convolutional encoder) and from systematic uncoded bits (which are not derived from the output of the rate 1/2 binary convolutional encoder).

The modulation types and code rates supported by the pragmatic TCM inner FEC are listed in Table 198. As the last column of Table 198 indicates, the encoder constructions for the various code rates of are found in through 8.3.4.6.5.1.3.7. The code termination method for the inner FEC is found in 8.3.4.6.5.1.3.8, and the bit to I-Q constellation maps for the various code rates and signaling constellations are found in 8.3.4.6.5.2.

.References for pragmatic TCM codes include [B46] and [B47].

Table 198—Modulations and Code Rates for Single Carrier Inner FEC

Modulation	Code Rates	Bits/symbol	Location of Encoder Description(s)
BPSK [optional]	1/2, 3/4	1/2, 3/4	
QPSK	1/2, 2/3, 3/4, 5/6, 7/8	1, 4/3, 3/2, 5/3, 7/4	
16-QAM	1/2, 3/4	2, 3	8.3.4.6.5.1.3.2, 8.3.4.6.5.1.3.3
64-QAM	2/3, 5/6	4, 5	8.3.4.6.5.1.3.4, 8.3.4.6.5.1.3.5
256-QAM [optional]	3/4, 7/8	6, 7	8.3.4.6.5.1.3.6, 8.3.4.6.5.1.3.7

8.3.4.6.5.1.3.1 Encoding for BPSK and QPSK Modulations, All Rates

For BPSK, the binary outputs of the punctured binary encoder may be directly sent to the symbol mapper for BPSK, using the multiplexed output sequence shown in the 'XY'-headed row of Table 192. For QPSK, the multiplexed output sequence in Table 192 is alternately assigned to the I and Q coordinate QPSK mappers, with the I coordinate receiving the first assignment. The bits-to-constellation maps for BPSK and QPSK utilize Gray code maps, which are depicted in Figure 174 of 8.3.3.1.5.4.

8.3.4.6.5.1.3.2 Encoding for Rate ½ 16-QAM

The rate ½ pragmatic TCM encoder for 16-QAM, which delivers 2 source bits per 16-QAM symbol, is illustrated in Figure 185. Note that the baseline rate ½ binary convolutional encoder first generates a two-bit constellation index, b_3b_2, associated with the I symbol coordinate. Provided the next encoder input, it generates a two bit constellation index, b_1b_0, for the Q symbol coordinate. The I index generation should precede the Q index generation. Note that one might want to interpret this pragmatic TCM encoder for rate 1/2 16-QAM as a rate 2/4 encoder, because it generates one 4 bit code symbol per two input bits. For this reason, input records that are divisible by two are required for operation of this encoder.

The bits-to-constellation map for the rate 1/2 16-QAM encoder output is a Gray code map, which is depicted in Figure 174 of 8.3.3.1.5.4.

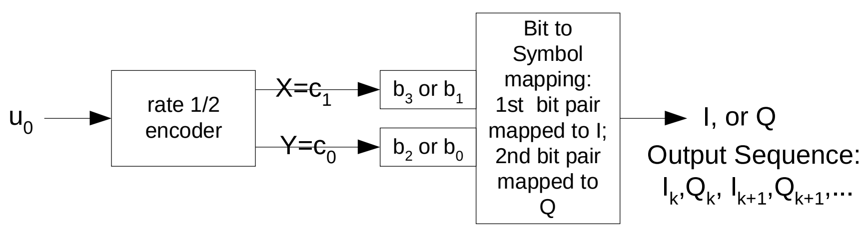


Figure 185—Pragmatic TCM encoder for rate ½ 16-QAM

8.3.4.6.5.1.3.3 Encoding for Rate 3/416-QAM

The rate 3/4 pragmatic TCM encoder for 16-QAM, which delivers 3 source bits per 16-QAM symbol, is illustrated in Figure 186. Note that this encoder uses the baseline rate ½ binary convolutional encoder, along with two systematic bits that are passed directly from the encoder input to the encoder output. With this structure, the encoder is capable of simultaneously generating 4 output bits per three input bits. The sequence of arrival for the $u_2u_1u_0$ input into the encoder is u_2 arrives first, u_1 second, u_0 last. During the encoding process, the encoder generates a two bit constellation index, b_3b_2, for the I symbol coordinate, and simultaneously generates another two bit constellation index, also designated b_1b_0, for the Q symbol coordinate. Note that whole symbols must be transmitted, so the number of bits in an input record to be encoded by the rate ¾ 16-QAM encoder must be evenly divisible by 3.

The bits-to-constellation map for the rate 3/4 16-QAM encoder output is a Pragmatic code map, which is depicted in Figure 191 of 8.3.4.6.5.2.

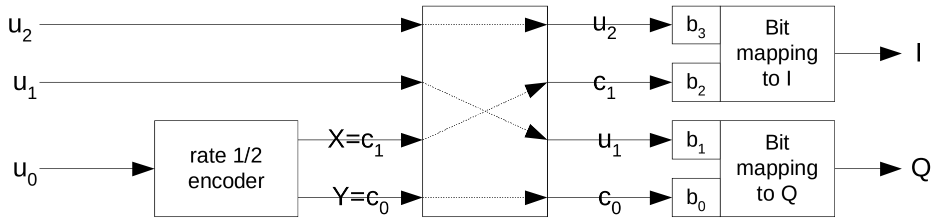


Figure 186—Pragmatic TCM encoder for rate 3/4 16-QAM

8.3.4.6.5.1.3.4 Encoding for Rate 2/3 64-QAM

The rate 2/3 pragmatic TCM encoder for 64-QAM, which delivers 4 source bits per 64-QAM symbol, is illustrated in Figure 187. Note that this encoder uses the baseline rate ½ binary convolutional encoder, along with one systematic bit that is passed directly from the encoder input to the encoder output. The sequence of arrival for the u_1u_0 input into the encoder is u_1 arrives first, u_0 last. The encoder (as a whole) then generates a three bit constellation index, $b_5b_4b_3$, which is associated with the I symbol coordinate. Provided another two-bit encoder input, the encoder generates another three bit constellation index, $b_2b_1b_0$, which is associated with the Q symbol coordinate. The I index generation should precede the Q index generation. Note that one might want to interpret the pragmatic TCM encoder for rate 2/3 64-QAM as a rate 4/6 encoder, because it generates one six bit code symbol per four input bits. For this reason, the number of bits in an input record to be encoded by the rate 4/6 64-QAM encoder must be evenly divisible by 4.

The bits-to-constellation map for the rate 2/3 64-QAM encoder output is a Pragmatic code map, which is depicted in Figure 191 of 8.3.4.6.5.2.

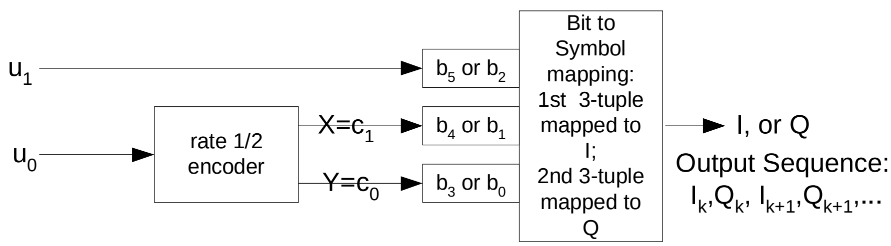


Figure 187—Pragmatic TCM encoder for rate 2/3 64-QAM

8.3.4.6.5.1.3.5 Encoding for Rate 5/6 64-QAM

The rate 5/6 pragmatic TCM encoder for 64-QAM, which delivers 5 source bits per 64-QAM symbol, is illustrated in Figure 193. Note that this encoder uses a rate ¾ punctured version of the rate baseline rate ½ binary convolutional encoder, along with two systematic bits that are passed directly from the encoder input to the encoder output. The rate ¾ punctured code is generated from the baseline rate 1/2 code using the rate 3/4 puncture mask definition in Table 192 of 8.3.3.1.5.2.2. Puncture samples are sequenced c_3 first, c_2 second, c_1 third, and c_0 last. The sequence of arrival for the $u_4u_3u_2u_1u_0$ input into the encoder is u_4 arrives first, u_3 arrives second, u_2 arrives third, u_1 arrives next to last, and u_0 arrives last. During the encoding process, the pragmatic encoder generates a three bit constellation index, $b_5b_4b_3$, for the I symbol coordinate, and simultaneously generates another three bit constellation index, $b_2b_1b_0$, for the Q symbol coordinate. Note that whole symbols must be transmitted, so the number of bits in an input record to be encoded by the rate 5/6 64-QAM encoder must be evenly divisible by 5.

The bits-to-constellation map for the rate 5/6 64-QAM encoder output is a Pragmatic code map, which is depicted in Figure 191 of 8.3.4.6.5.2.

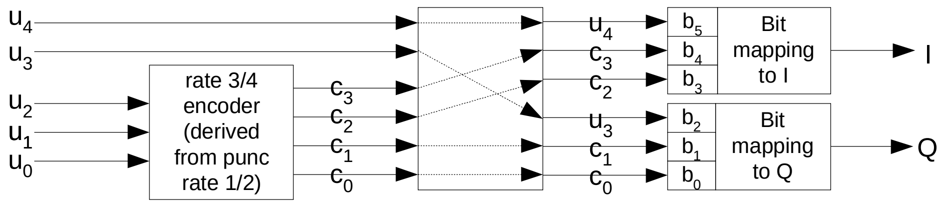


Figure 188—Pragmatic TCM encoder for rate 5/6 64-QAM

8.3.4.6.5.1.3.6 Encoding for Optional Rate 3/4 256-QAM

An optional rate 3/4 pragmatic TCM encoder for 256-QAM, which delivers 6 source bits per 256-QAM symbol, is illustrated in Figure 189. Note that this encoder uses the baseline rate ½ binary convolutional encoder, along with two systematic bits that are passed directly from the encoder input to the encoder output. The sequence of arrival for the $u_2u_1u_0$ input into the encoder is u_2 arrives first, u_1 next, u_0 last. Note that the encoder (as a whole) first generates a four bit constellation index, $b_7b_6b_5b_4$, which is associated with the I symbol coordinate. Provided another four bit encoder input, it generates a four bit constellation index, $b_3b_2b_1b_0$, which is associated with the Q symbol coordinate. The I index generation should precede the Q index generation. Note that one might want to interpret this encoder as a rate 6/8 encoder, because it generates one eight bit code symbol per six input bits. For this reason, the number of bits in an input record to be encoded by the rate 6/8 256-QAM encoder must be evenly divisible by 6.

The bits-to-constellation map for the rate 3/4 256-QAM encoder output is a Pragmatic code map, which is depicted in Figure 192 of 8.3.4.6.5.2.

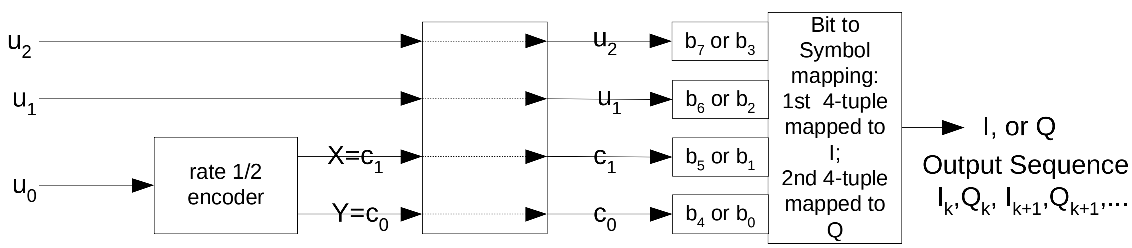


Figure 189—Optional pragmatic TCM encoder for rate ¾ 256-QAM

8.3.4.6.5.1.3.7 Encoding for Optional Rate 7/8 256-QAM

An optional rate 7/8 pragmatic TCM encoder for 256-QAM, which delivers 7 source bits per 256-QAM symbol, is illustrated in Figure 190. Note that this encoder uses a rate ¾ punctured version of the rate baseline rate ½ binary convolutional encoder, along with two systematic bits that are passed directly from the encoder input to the encoder output. The rate ¾ punctured code is generated from the baseline rate 1/2 code using the rate 3/4 puncture mask definition in Table 192 of 8.3.3.1.5.2.2. Puncture samples are sequenced c_3 first, c_2 second, c_1 third, and c_0 last. The sequence of arrival for the $u_6u_5u_4u_3u_2u_1u_0$ input into the encoder (as a whole) is u_6 arrives first, u_5 arrives second, u_4 arrives third, u_3 arrives fourth, u_2 arrives fifth, u_1 arrives next to last, and u_0 arrives last. During the encoding process, the encoder generates a four bit constellation index, $b_7b_6b_5b_4$, for the I symbol coordinate, and simultaneously generates another four bit constellation index, $b_3b_2b_1b_0$, for the Q symbol coordinate. Note that whole 256-QAM symbols must be transmitted, so the number of bits in an input record to be encoded by the rate 7/8 256-QAM encoder must be evenly divisible by 7.

The bits-to-constellation map for the rate 7/8 256-QAM encoder output is a Pragmatic code map, which is depicted in Figure 192 of 8.3.4.6.5.2.

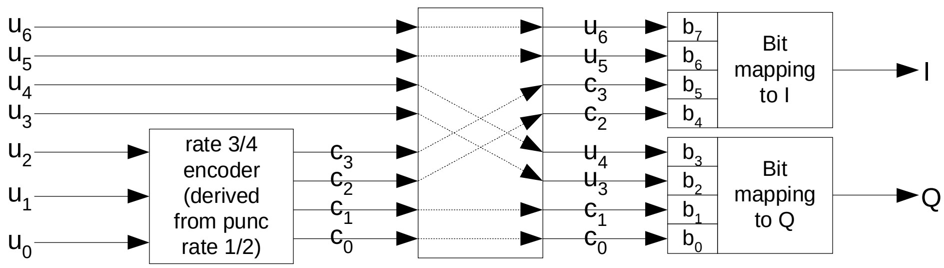


Figure 190—Optional pragmatic TCM encoder for rate 7/8 256-QAM

8.3.4.6.5.1.3.8 Inner Code Termination

Inner code blocks are to be terminated in transitions between modulation types, between allocations, at the beginning and ends of bursts, or as instructed by the 802.16 MAC. Two termination methods are defined:

- Tail biting;
- Zero-state termination.

Tail biting shall be supported, with zero-state termination being optional.

When using tail biting, no extra termination bits are required. The initial state (i.e., the 6-bit value in the shift register) of the baseline rate ½ convolutional encoder is established so that it is the same as the final state of the encoder, at the end of a block. To implement this function in an encoder, at the beginning of a block, the shift registers in baseline rate 1/2 convolutional encoder are initialized with the last 6 non-systematic binary inputs in the transmitted block that would have been fed to the rate ½ convolutional encoder. Note that these bits are not necessarily consecutive input bits, if the pragmatic TCM encoder incorporates systematic bit inputs (i.e., bits that do not enter the rate 1/2 encoder), as well.

When using zero state termination, the basic rate ½ convolutional encoder is initialized with its registers in the all-zeros state. Inner encoding begins from this state, by accepting data inputs. To zero state terminate at the end of the code block, a sufficient number of zero inputs are fed the baseline rate ½ binary convolutional encoder so that its register memory is flushed, i.e., its state memory is driven to zero. This requires a minimum of 6 zero-valued inputs into the K=7 binary convolutional encoder, regardless of whether puncturing is performed or not. Once the first bit is used to begin flushing the binary convolutional encoder memory, all input bits, including the systematic input bits that are parallel to the binary convolutional encoder inputs in the pragmatic TCM encoder, should be set to zero. However, the systematic input bits that are set to zero do not count toward the minimum 6 bit total of binary convolutional encoder bits requisite to flush the encoder memory. Note that the input bits associated with zero state termination should be accounted when computing the code rate-induced record size granularities for a pragmatic TCM encoder.

8.3.4.6.5.2 Constellation Mapping

For the concatenated Reed Solomon/trellis code FEC, code bits will be mapped to I and Q symbol coordinates using either a pragmatic trellis and/or Gray code symbol map, depending on the code rate and modulation scheme. All BPSK and QPSK code rates and the rate 1/2 16-QAM code shall use the Gray coded constellation maps depicted in Figure 174 of 8.3.3.1.5.4. The rate 3/4 16-QAM code, and all code rates for 64-QAM shall use the pragmatic constellation map depicted in Figure 191. All code rates for 256-QAM shall use the pragmatic constellation map depicted in Figure 192. In all of these figures, the constellation can be normalized by a multiplicative factor so that the average signal energy of the constellation is constrained to be 1. These multiplicative normalization factors are tabulated in 8.3.3.1.5.4.

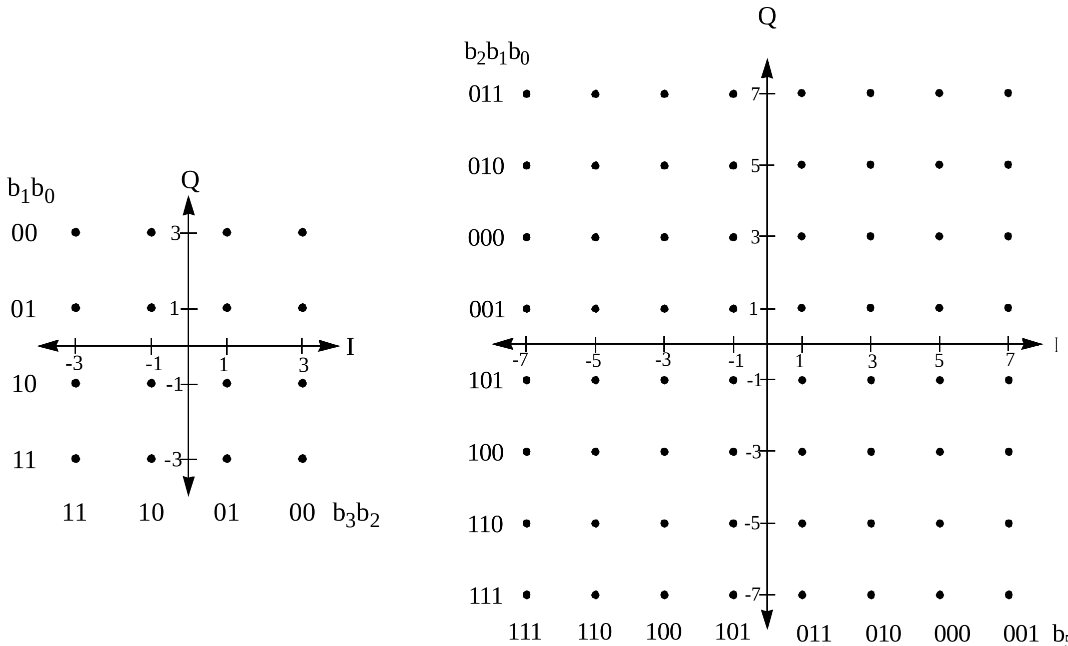


Figure 191—rPragmatic constellation maps for 64-QAM and rate 3/4 16 QAM

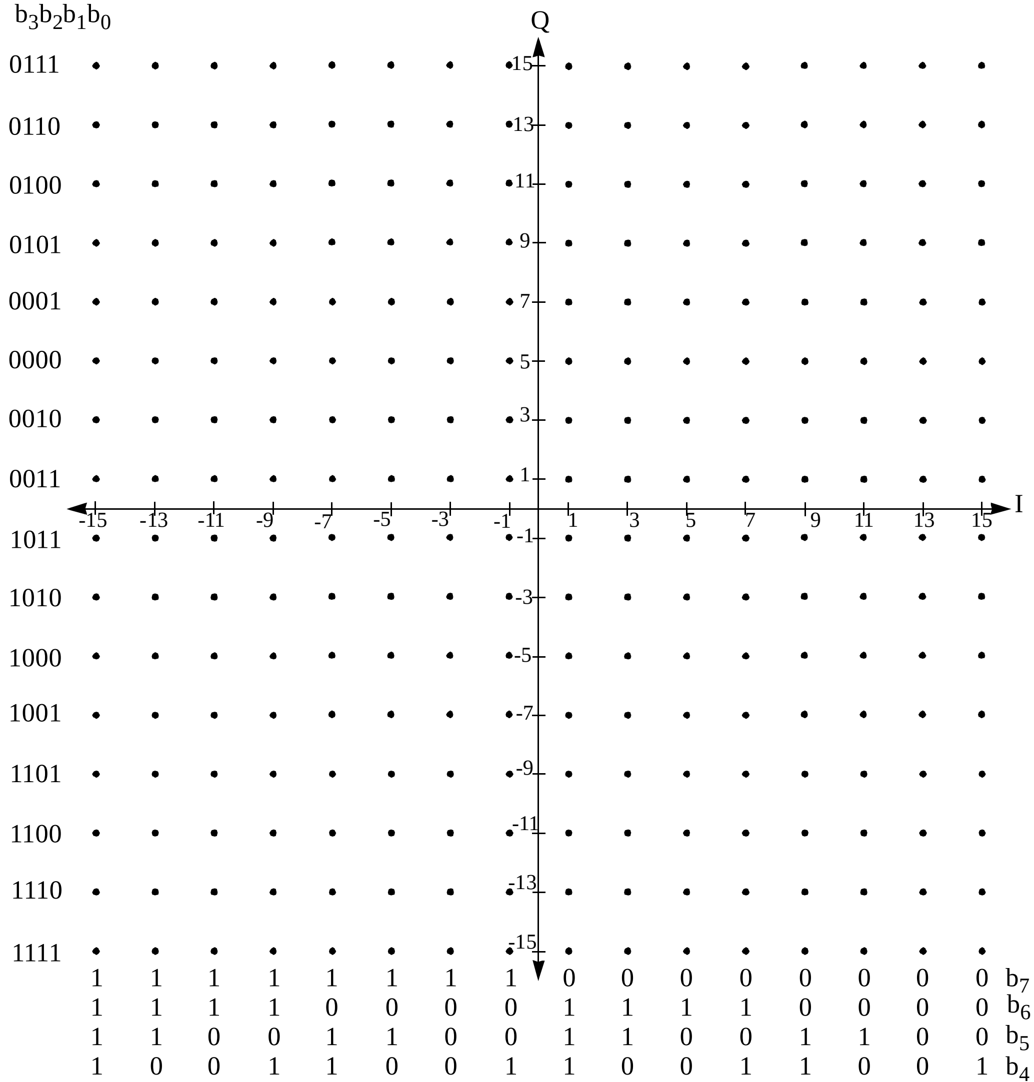


Figure 192—Pragmatic constellation map for 256-QAM

8.3.4.6.5.3 Turbo Product Code

Turbo Product Codes are defined as an optional FEC; in addition to the sections on their bit Interleaving (8.3.4.6.5.3.1) and Symbol Mapping (8.3.4.6.5.3.2), which follow, more general specification details may be found in clause 8.3.3.1.5.4. The codes and related parameters in Table 199 are recommended; however, any code meeting the requirements of clause 8.3.3.1.5.4 may be utilized.

Table 199— Recommended TPC Codes

Data Block Size (Bytes)	Code Rate	Constituent Codes	Code Parameters
15	~1/2	(16,11)(16,11)	I_x=0,I_y=0,B=1
20	~1/2	(32,26)(32,26)	I_x=13,I_y=13,B=9
57	~3/5	(32,26)(32,26)	I_x=2,I_y=7,B=0
54	~3/5	(32,26)(32,26)	I_x=2,I_y=8,B=0
128	~2/3	(64,57)(64,57)	I_x=25,I_y=25,B=0
188	~5/7	(64,57)(64,57)	I_x=25,I_y=10,B=0
188	~5/7	(64,57)(64,57)	I_x=17,I_y=17,B=0
392	~4/5	(64,57)(64,57)	I_x=1,I_y=1,B=0

8.3.4.6.5.3.1 TPC Bit Interleaving

Three options on bit interleavers are provided. In all cases, encoding is done in the standard manner specified in clause 8.3.3.1.5.4 and read out of the encoded array for transmission as follows:

- Type 1 (no interleaver): In this mode bits are written row-by-row and read row-by-row. No additional latency is imposed in this mode.
- Type 2 (block interleaver): Encoded bits are read from the encoder only after all first k2 rows are written into the encoder memory. The bits are read column-by-column from top position in the first column. This interleaver imposes one block of additional latency.
- Type 3 (permutation interleaver): Reserved. Possibilities include helical interleaving, which improves burst error performance or other methods that when combined with M-QAM signaling provides better performance. This interleaver would impose one block of additional latency.

8.3.4.6.5.3.2 TPC Constellation Mapping

The downstream channel supports both continuous and burst mode operation and the FEC incorporates Turbo Product Codes, for each of these applications. In order to provide the desired flexibility and the required QoS, TPCs are used in conjunction with adaptive modulation scheme where different modulation formats and TPC's are specified on a frame-by-frame basis. Mapping of the encoded bits into the desired modulation is arranged in Gray code format, as shown in Figure 193.

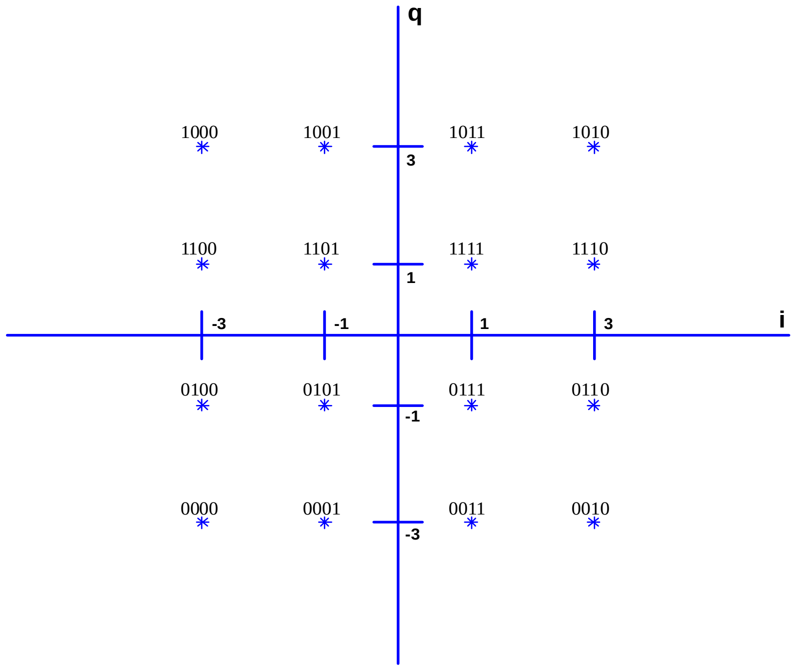


Figure 193—16 QAM Signal Mapping

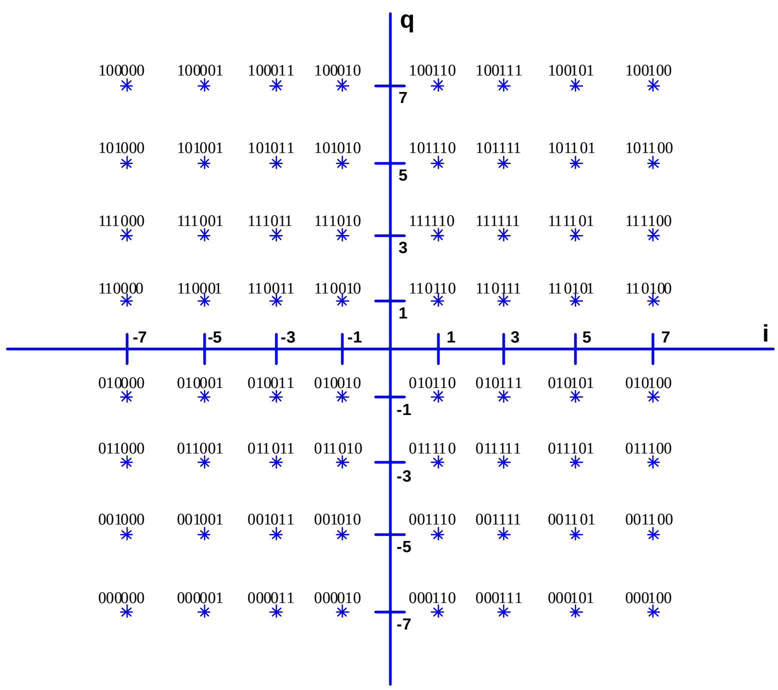


Figure 194—64 QAM Signal Mapping

An additional, optional mode of mapping, known as pragmatic turbo coded modulation may be implemented [B20] at the subscriber station. This mode does not require any new turbo coding schemes, however, by modifying the implementation of the mapping table, an additional coding gain between 0.5dB to 0.75 dB for a range of coding rates and modulation techniques can be achieved. The following example illustrates the procedure.

Consider first that we have a (63,56)2 TPC code described in Table 199. This has rate 0.79 and when combined with 16QAM in Gray code mapping fashion provides 0.79 (log216 = 3.16 bits/symbol/Hz of channel efficiency.

Now consider the (39,32)2 2-dimensional TPC from Table 199. This code has shorter block length, its performance is not as good as the performance of the larger code, however it can be implemented with less complexity and reduced absolute latency (Note: that the latency of TPC codes is similar to the conventional RS codes). When combined with 16QAM in a Gray code manner it provides 2.69 bits/symb/Hz. Figure 195 describes the basic scheme for the TPC in a TCM scheme.

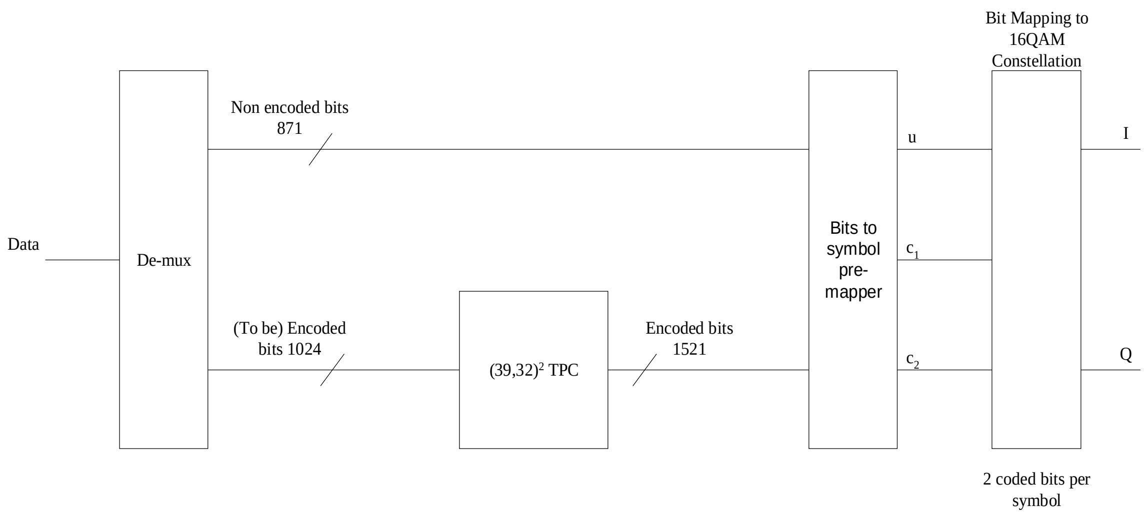


Figure 195—(39,32)2 TPC TCM Encoder

Looking at the throughput of this system we have 1024+871=1895 bits entering the system and (1521+871)/log216= 598 symbols emanating from the modulator. Thus the channel efficiency of this system will be 1895/598=3.17 bits/symb/Hz (similar to the channel efficiency of the coding scheme with larger block length), while both the encoder and decoder latency remains as for shorter (39,32)2 codes. It is apparent that this scheme is applicable to all TPC codes described in this section, and the variation of number of uncoded bits will allow additional flexibility in system development and deployments.

8.3.4.6.6 DL Baseband Pulse Shaping

Prior to modulation, I and Q signals shall be filtered by square-root raised cosine. A roll-off factor of 0.25 shall be supported, with 0.15 and 0.18 being optional, but defined modes. The ideal square-root cosine is defined by the following transfer function H(f):

$$H(f) = 1 \qquad for \quad |f| < f_N(1-\alpha)$$
$$H(f) = \left\{ \frac{1}{2} + \frac{1}{2}\sin\frac{\pi}{2f_N}\left[\frac{f_N - |f|}{\alpha}\right] \right\}^{1/2} \qquad for \quad f_N(1-\alpha) \le |f| \le f_N(1+\alpha)$$
$$H(f) = 0 \qquad for \quad |f| \ge f_N(1+\alpha)$$

Where:

$$f_N = \frac{1}{2T_S} = \frac{R_S}{2}$$

f_N is the Nyquist frequency, and T_s is the modulation symbol duration.

8.3.4.7 Uplink Channel

8.3.4.7.1 UL Multiple Access

The uplink multiple access method shall be Time Division Multiple Access (TDMA). Unlike the downstream (which may time division multiplex several messages together), uplink messages are always transmitted as TDMA bursts, with only one modulation and code rate selection used per burst.

8.3.4.7.2 UL Modulation Formats

Support of QPSK and 16QAM operation on the uplink is mandatory. BPSK, 64QAM, and 256 QAM operational modes are also defined, but the support of each is optional.

Burst parameters, including modulation type, error correction technique and code rate, number and spacing of pilot and/or training symbols, do not change within an uplink burst, but they can change on a burst to burst basis. The Base Station (BS) and its downstream control messages mandate the burst parameters to be used by each Subscriber Station (SS) using the uplink. These parameters may vary from SS to SS, and message type to message type.

8.3.4.7.3 UL Transmit Processing

The uplink transmit processing is identical in concept to that described for the downlink in 8.3.4.6.3. However, unlike the downstream (which may time division multiplex several messages together), upstream messages are always transmitted as TDMA bursts, with only one modulation and code format used per burst. The modulation type and coding can vary from burst to burst, if such a change is authorized by the base station in its downstream UL_MAP messages, or if, for example, an upstream contention channel is used to request more bandwidth after a previous granted transmission.

The payload length may also vary from burst to burst. The length of an uplink payload is constrained to proper codeword sizes that include granularities and overheads associated with the Transmission Convergence Layer, and the number of pilot and training symbols used by a particular burst profile.

8.3.4.7.4 UL Source Bit Randomization for Energy Dispersal

Source bits, i.e., the original information bits prior to FEC encoding, shall be randomized on uplink transmissions. This randomization is performed to ensure sufficient bit transitions to support clock recovery, and to minimize the appearance of the unmodulated carrier when idle or unchanging source data is transmitted over the channel.

The method of randomization for the uplink channel using a Linear Feedback Shift Register (LFSR), and is the same as that of the downstream channel; a description of the downstream randomization is found in 8.3.4.6.4. The LFSR shall be preset at the beginning of each upstream burst to the value 100101010000000.

8.3.4.7.5 UL FEC

Two Forward error correction (FEC) coding schemes are defined for the uplink channel:

A Concatenated FEC scheme, with codes constructed from Reed-Solomon and Convolutional codes, described in 8.3.4.6.5.1;
An (Optional) Turbo Product Coding scheme, described in 8.3.4.6.5.3.

In addition, the provision of suppressing all FEC and operating using the ARQ mechanism in the 802.16 MAC for error control is a defined option.

Except that interleaving is not used with the concatenated FEC scheme, and that 64-QAM support is optional, the uplink FEC is the same as the downlink FEC described in 8.3.4.6.5.

8.3.4.7.6 UL Baseband Pulse Shaping

Prior to modulation, I and Q signals shall be filtered by square-root raised cosine filter. A roll-off factor of 0.25 shall be supported, with 0.15 and 0.18 being optional, but defined modes. The square-root cosine filter characteristic, with parameterized roll-off factor, is defined in 8.3.4.6.6.

8.3.4.8 Framing, Multiple Access, and Duplexing

8.3.4.8 and its descending subsections describe framing elements used to realize the multiple access and duplexing formats supported by the single carrier PHY.

8.3.4.8.1 Overview of Frame Formats and Their Application

Two fundamental block format options are available for the SC PHY:

Type A, which is used for continuous transmissions;
Type B, which is used for burst transmissions.

The Type A (continuous) transmission format is specified in 8.3.4.9 and the Type B (burst) transmission format is specified in 8.3.4.10.

As demonstrated in 8.3.4.11.1.1, Type A, the continuous transmission format, is used (on the downlink) by an FDD system using a continuous (always transmitted) downlink.

Type B, the burst transmission format is found on

- the uplink of a FDD system (see 8.3.4.11.1);
- the downlink of a burst-FDD system (see 8.3.4.11.1.2); and
- the uplink and downlink of a TDD system (see 8.3.4.11.2).

The burst format may be further categorized into two subformats:

- a TDMA burst, and
- a TDM burst.

A TDMA burst contains information intended for one audience. This audience could be a single user, or a group of users receiving a broadcast message. In contrast a TDM burst generally contains multiplexed, concatenated information addressed to multiple audiences. A TDMA burst may, in fact, be interpreted as a TDM burst that multiplexes only one message.

8.3.4.9 Continuous Transmission Format

As its name implies, the continuous transmission format is utilized for a continuously transmitted channel, which may be monitored by all of the Subscriber Stations (SSs) within a Base Station (BS) cell sector. A continuous FDD downlink channel, such as that described in 8.3.4.11.1.1, uses this transmission format. Although the channel may be monitored at all times by all subscribers, the application of adaptive modulation is still possible, through the use of appropriate frame structure elements.

8.3.4.9.1 Frames and Frame Preambles: Requirements and Usage

Continuous data shall be formatted into frames that are aligned with MAC frames. The boundaries between these frames shall be indicated by insertion of a sequence of predetermined symbols known as a Frame Preamble.

8.3.4.9.1.1 Frame Preamble Requirements

As illustrated in Figure 196, a Frame Preamble is a contiguous sequence of length H symbols that are periodically repeated, once per frame. The interval between the end of one of these Frame Preambles and the commencement of the next is I symbols. Both H and I are system parameters, and can be selected (with some restrictions, which will be detailed later) by the system operator. Once the parameters for H and I are set, they should not be changed. In the event that these parameters are changed, resynchronization of the entire system may be necessary.

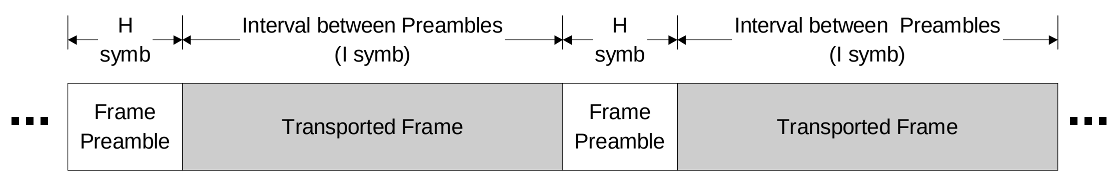


Figure 196—Frame Preamble

The contiguous sequence of symbols composing a Frame Preamble are assumed to be known (or inferred) at the receiver. They are not FEC encoded, and are not a part of the transported frame data. As such, they should be removed by the demodulator prior to FEC decoding.

As illustrated in Figure 197, an H-symbol Frame Preamble is constructed from an integer (1 or greater) number of U-symbol Unique Words, or the last E symbols of a Unique Word followed by an integer (1 or greater) number of Unique Words. This initial fractional part can be useful in some receiver implementations when timing uncertainties exist. Further details on the Unique Word may be found in 8.3.4.12.

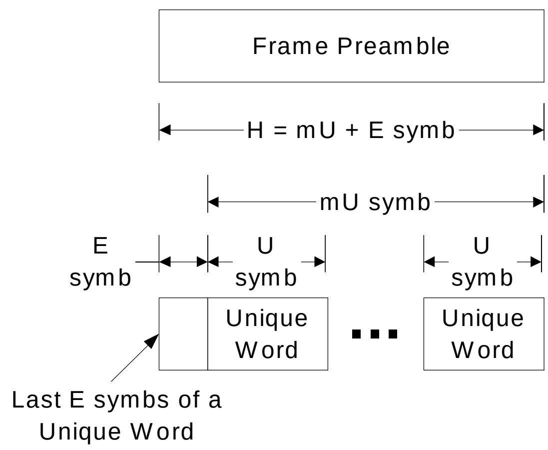


Figure 197— Unique Word Content within the Frame Preamble

So that the Frame Preamble may be uniquely identified (during initial acquisition, for example), the number of whole-numbered Unique Words grouped together in the Frame Preamble must be strictly larger than the number of Unique Words grouped together and used for other purposes (e.g., Pilot Words [see 8.3.4.10]).

8.3.4.9.1.2 Frame Preamble Usage

As 8.3.4.9.1 indicates, MAC frame boundaries are delineated by the Frame Preamble. Location of the beginning of a Frame, which coincides with the location of the Frame Control MAC message, is important during acquisition, because the Frame Control MAC message contains much of the system and frame control information, including MAPs of user data, their lengths, modulation formats, and the FEC used to encode them. Therefore, once the Frame Control MAC message is located and decoded, all ensuing user data that has the CINR to be decodable can be decoded. This begs that the Frame Header Indication Sequence be distinct, so that the location of the frame header may be easily identified, and distinguished from pilot symbols.

Moreover, the Frame Preamble has a another role, outside of aiding initial acquisition. Since the Frame Preamble is constructed from Unique Words, which have optimal autocorrelation properties, the structure and placement of the Frame Preamble also enables re-acquisition and channel estimation before the outset of a subsequent MAC frame. This is important when per-user adaptive modulation is used, because, as indicated in 8.3.4.9.3, user data is sequenced in terms of modulation robustness. Therefore, receivers experiencing low CINRs may not be able to track completely through a MAC frame. The Frame Preamble aids such a receiver in reacquiring, or getting a better, more solid channel estimate, before the appearance of data in the next frame that the receiver has the CINR to successfully decode.

8.3.4.9.2 Pilot Words: Requirements and Usage

The transport data within a continuous data frame may be augmented by the periodic insertion of known Pilot Words. Each Pilot Word is a contiguous sequences of symbols that may be used to assist channel estimation and demodulation at the receiver. Such a feature is particularly useful on a continuous downstream utilizing adaptive modulation.

8.3.4.9.2.1 Pilot Word Requirements

The use of Pilot Words is optional. When used, they must follow the guidelines hereforth described. Figure 198 illustrates some of these guidelines. As Figure 198 illustrates, the first Pilot Word in a frame must occur N symbols after the Frame Preamble. All subsequent Pilot Words are thereupon spaced N symbols apart.

Notice that the final data payload need not be N symbols long. Although not illustrated in Figure 198, if the final Pilot Word would extend into the next frame's Frame Preamble, the overlapping portion of the Pilot Word is excised, and not transmitted. Although N is a system parameter, and may be selected by the system operator, the N used in any given frame must be used in all subsequent frames. In the event that N is changed, resynchronization of the entire system may be necessary.

Likewise, the Pilot Word length, P, is a system parameter, and may be selected by the system operator. However, once a choice for P has been made, it must be used in all future applications. In the event that P is changed, resynchronization of the entire system may be necessary.

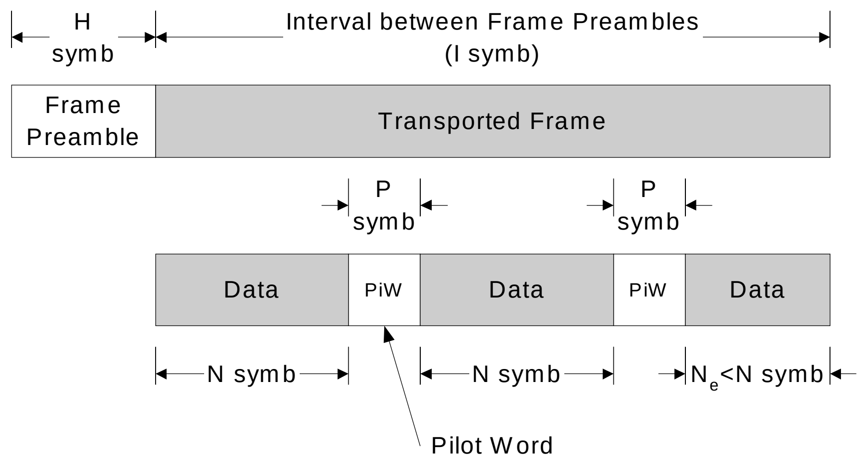


Figure 198—Pilot Words within a Frame

A Pilot Word is constructed from an integer number of U-symbol Unique Words, or the last E symbols of a Unique Word followed by an integer number of Unique Words. In this application, 0 is also an acceptable integer value for the number of whole Unique Words used.

8.3.4.9.2.1.1 Non-conflict of Pilot Words with Frame Preambles

Note that, as prescribed in 8.3.4.9.1.1, the number of whole Unique Words in the Frame Preamble must be unique, and exceed the number used in any other application. Therefore, a system operator must choose the number of whole Unique Words in a Pilot Word to be strictly less than the number of whole Unique Words in the Frame Preamble.

By keeping the number of Unique Words in a Frame Preamble distinct from the number of Unique Words in Pilot Words, a receiver in acquisition mode can determine both the Frame Preamble interval and Pilot Word interval independently---without the need to decode system control messages, or *a priori* knowledge of those system parameters.

8.3.4.9.2.2 Pilot Word Usage

A Pilot Word may be used as pilot symbols, or, given proper parameter choices for N, P, and I, as a cyclic prefix by a frequency domain equalizer.

Pilot symbols are symbols that are known at the receiver. Pilot symbols may assist in the estimation of demodulation parameters, such as equalizer channel coefficients, carrier phase and frequency offsets, symbol timing, and optimal FFT window timing (in a frequency domain equalizer). This assistance from pilot symbols can be quite useful, especially to disadvantaged CINR subscribers attempting to track channel variations on an adaptively modulated continous downlink channel. Even when a subscriber cannot demodulate the payload data, it could potentially maintain tracking lock with the pilot symbols.

If intended to estimate the equalizer channel coefficients, the Unique Word component of Pilot Word should be selected least be as long as the maximum delay spread of the channel. Additional details on Unique Words may be found in 8.3.4.12.

Pilot Words and their intervals may be chosen by a system operator to simplify receivers using frequency domain equalization. settings may simplify receivers using frequency domain equalization. For example, F = N + P symbols can be selected as the block length over which an FFT would be computed by a frequency domain equalizer. With this choice for F, the periodicity of the Pilot Words naturally acts as a cyclic prefix. Note that P must be as long as the delay spread of the channel for the cyclic prefix property to function properly in a delay spread channel. In addition, the frame length I must be constrained such that a frame concludes with a Pilot Word. A further consideration that would reduce the complexity of an FFT engine would be to choose F = N + P as 2 raised to an integer power. However, FFT sizes for frequency domain equalizers do not necessarily have to equal pilot word intervals, since, for example, frequency domain equalizers can also be implemented using overlap save techniques.

8.3.4.9.3 Adaptive Modulation

8.3.4.9.3.1 Concept of Adaptive Modulation

Many Subscriper Stations (SSs) attempt to receive the continuous downlink channel. Due to differing conditions at the various SS sites (e.g., variable distances from the Base Station, presence of obstructions, local interference), SS receivers may experience significantly different CINRs. For this reason, some SSs may be capable of reliably detecting (non-pilot) payload data only when it is derived from certain lower-order modulation alphabets, such as QPSK. Similarly, CINR-disadvantaged SSs may require more powerful and redundant FEC schemes. On the other hand, CINR-advantaged stations may be capable of receiving very high order modulations (e.g., 64-QAM), with high code rates. Obviously, to maximize the overall capacity of the system, the modulation and coding format should be adapted to each class of SS, based on what the SS can receive reliably. Define the adaptation of modulation type and FEC to a particular SS (or group of SSs) as 'adaptive modulation', and the choice of a particular modulation and FEC as an 'adaptive modulation type.' The continuous transmission mode (as does the burst transmission mode) supports adaptive modulation and the use of adaptive modulation types.

8.3.4.9.3.2 Frame Control Header Information and Adaptive Modulation

As Figure 199 illustrates, Frame Control MAC messages are periodically transmitted over the continuous channel, using the most robust adaptive modulation type mandatorily supported, which is QPSK, with a rate 1/2 inner (convolutional code). Among other information, these Frame Control messages provide adaptive modulation type formatting instructions.

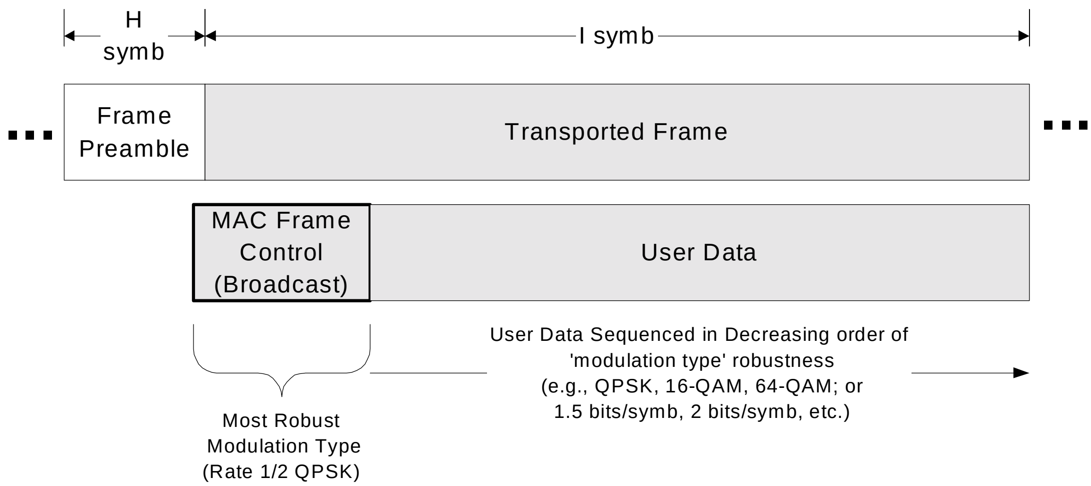


Figure 199—Adaptive Modulation Sequencing within a Continuous Frame

8.3.4.9.3.3 Adaptive Modulation Sequencing

Within the MAC Frame Control Header, a downlink PHY control map (DL_MAP) is used to indicate the beginning location of each of adaptive modulation type payload that follows. However, the DL_MAP does not describe the beginning locations of the payload groups that immediately follow; it describes the payload distributions at some MAC-prescribed time in the future. This delay is necessary so that FEC decoding of MAC information (which could be iterative, in the case of turbo codes) may be completed, the adaptive data interpreted, and the demodulator scheduling set up for the proper sequencing.

As Figure 199 illustrates, following the MAC Frame header, payload groups are sequenced in decreasing order of robustness (e.g., first QPSK, then 16-QAM, then 64-QAM). This robustness sequencing improves receiver performance, because it enables receivers experiencing lower CINRs to track only through the modulation types that they can reliably receive. In transitions between modulation types, this sequencing also allows equalizers with decision feedback elements to make decisions on lower-order modulation types.

8.3.4.9.3.4 Transitions Between Modulation Types

Transitions between modulation types may occur anywhere within a frame that the Frame Control DL_MAP message indicates that they should change.

8.3.4.9.3.5 Per-Adaptive-Modulation-Type FEC Encapsulation

So that disadvantaged-CINR SSs are not adversely affected by transmissions intended for other advantaged-SINR users, FEC blocks end when a particular adaptive modulation type ends. Among other things, this implies that the FEC interleaver depth and code blocks are adapted to accommodate the span of a particular adaptive modulation type. Note, however, that data from several users could be concatenated by the MAC (and interleaved together by the PHY) within the span of a given adaptive modulation type.

8.3.4.9.3.6 MAC Header FEC Encapsulation and Interleaving

So that the MAC header data may be decoded by a receiver that has just acquired (and does not yet know the modulation lengths and distributions of user data), the MAC Frame Control data should be a known block size and separately FEC-encoded from all other user-specifically-addressed data. MAC Frame Control data is not interleaved.

8.3.4.9.4 Processing of Partially Empty Payloads

When data is not available to completely fill a frame for transmission, the empty part of a payload may be stuffed with all-zeros dummy data, and/or the transmitter may lower its power---at the system operator's discretion. However, the transmitter may not lower its power for the entire duration of the empty interval. If Pilot Words are being used, they are always transmitted, so that all listening SSs may track the channel, and maintain synchronization.

8.3.4.10 Burst Transmission Format

In addition to the continuous transmission format, a second transmission format is defined for the Single Carrier PHY: the burst transmission format. As its name implies, the burst transmission format is utilized for burst transmissions, all of which may or may not be monitored by all Subscriber Stations (SSs) within a Base Station (BS) cell sector. In the broadband wireless application, one might see bursts on a multiple-access FDD uplink (8.3.4.11.1), a TDD uplink and downlink (8.3.4.11.2), or a burst-FDD downlink (8.3.4.11.1.2).

The burst transmission format accommodates both TDMA and TDM bursts. Figure 200 compares TDMA and TDM bursts, by way of illustration. A TDMA burst contains information intended for one audience. This audience could be a single user, or a group of users receiving a broadcast message. When adaptive modulation is applied, one modulation type is transmitted in a single TDMA burst, although different bursts may encapsulate different modulation types. In contrast, a TDM burst generally contains multiplexed, concatenated information that is generally addressed to multiple audiences, and may encapsulate multiple modulation types. A TDMA burst may, in fact, be interpreted as a type of TDM burst, addressed to a single audience. For this reason, and for generality, the more comprehensive TDM case is described in all further discussions. However, the reader should recognize that all discussion applies to the more special case of TDMA bursts, as well.

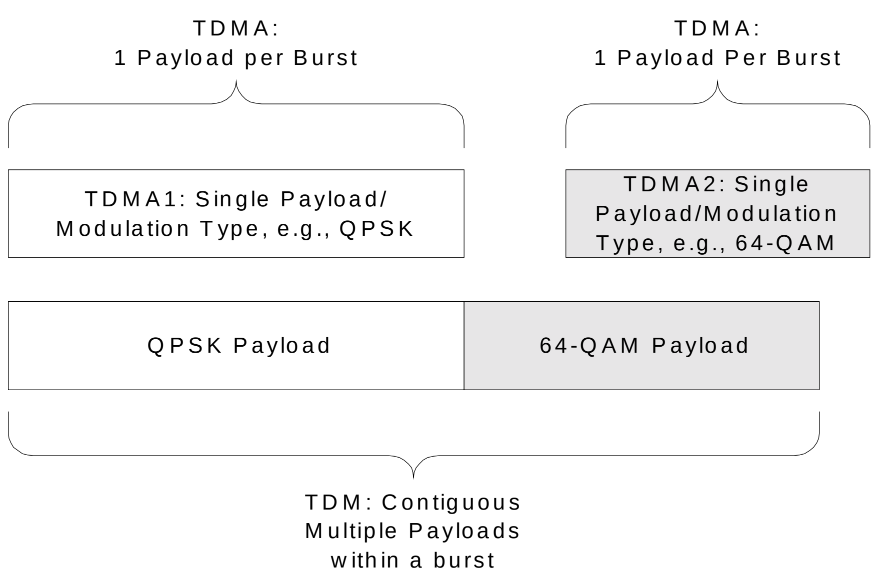


Figure 200—Comparison of TDMA and TDM bursts

8.3.4.10.1 Fundamental Burst Frame Elements

This section describes fundamental elements found in a burst. These fundamental elements are illustrated in Figure 201.

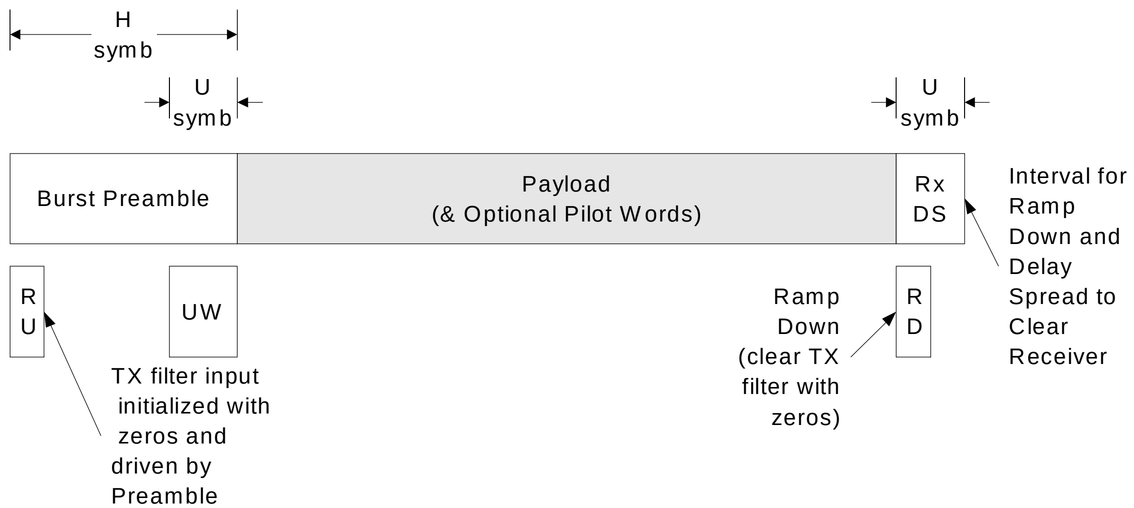


Figure 201—: Fundamental Burst Frame Elements

As illustrated in Figure 201, a burst consists of three fundamental elements: a Burst Preamble, a Payload, and null transmit (quiet) region (RxDS) following the end of a burst.

8.3.4.10.1.1 Burst Preamble

The Burst Preamble enables the receiver to acquire and/or update parameters used to receive a burst. Burst profile parameters delivered by the MAC indicate the length of the Burst Preamble, with the nominal value used in system control messages TBD.

8.3.4.10.1.1.1 Unique Word Content in the Burst Preamble

A compliant H-symbol Frame Preamble must be constructed from an integer (1 or greater) number of U-symbol Unique Words, or the last E symbols of a Unique Word followed by an integer (1 or greater) number of Unique Words. This requirement is illustrated in Figure 202.

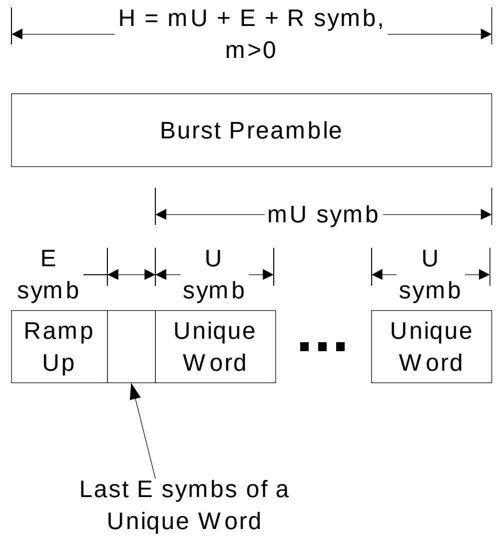


Figure 202—Contents of a Burst Preamble

8.3.4.10.1.1.2 Ramp Up

As both Figure 201 and Figure 202 also indicate, the Burst Preamble also contains a ramp-up region during which the power of the transmitter is ramped up. This ramping may be achieved by initializing the transmit filter memory with zero-valued (null) symbols, and then pushing the desired transmit data symbols into the filter to naturally ramp the filter output (and system power) to its full scale value. The ramp up interval length, R, is TBD. If a ramp-up sequence length shorter than one-half the length of the impulse response of the transmit filter is specified, the transmit filter output samples related to first few symbols may be suppressed from the transmit filter output, and a ramped power buildup achieved by windowing the ramp-up sequence, using a raised-cosine window of the desired length R, for example.

8.3.4.10.1.2 Burst Payload

The Payload block illustrated in Figure 201 contains the data to be transmitted, and may also contain extra pilot symbols, grouped together as Pilot Words, which may periodically repeat at a regular interval within the burst. Note that the most generic burst profile would allow the Payload region may be of any length, even a single symbol in length. Burst profiles may

8.3.4.10.1.3 Null Transmit Tail Region (RxDS)

The null transmit tail region (RxDS) illustrated in Figure 201 is a period over which the transmitter ramps down, and the receiver collects delay-spread versions of symbols at the end of the burst. This RxDS region is mandatory. The RxDS region shall be the length of a Unique Word used by the system. This implies that the RxDS region should be as long as the maximum expected delay spread for the channel in use.

8.3.4.10.1.3.1 Ramp Down

The transmitter must ramp down during this RxDS region by inserting zero inputs into the transmit filter memory following the last intended data symbol, and allowing the natural response of the filter to drive the filter output to zero. This ramp down approach is mandatory.

8.3.4.10.1.4 Guard Interval (TDD Systems)

In a TDD system, switches between receive and transmit, and vice versa, are required. Note that the transmitter may switch over to receive mode after the ramping region concludes; however, the receiver cannot switch over to transmit mode (without receiver performance degradation) until all of the delay spread is collected, and the RxDS region concludes. In a TDD system, a Guard Interval (GI), illustrated in Figure 208 of 8.3.4.11.2 is specified and used to enable this switchover. The length of the Guard Interval, G, is TBD.

8.3.4.10.2 Pilot Words: Requirements and Usage

The transport data within a burst data frame may be augmented by the periodic insertion of known Pilot Words. Each Pilot Word is a contiguous sequence of symbols that may be used to assist channel estimation and demodulation at the receiver.

8.3.4.10.2.1 Pilot Word Requirements

The use of Pilot Words is optional. When used, the requirements for Unique Words are the same as those for the continuous mode of operation described in 8.3.4.9.2.1, with the ‘burst frame payload’ being analogous to the ‘transported payload’ used in continuous mode. Note, however, that the restriction of 8.3.4.9.2.1.1 on the distinctness of Pilot Words from Frame Preambles (in the continuous transmit mode) is not applicable (to the burst transmit mode).

8.3.4.10.2.2 Pilot Word Usage

A Pilot Word may be used as pilot symbols. Pilot symbols are symbols that are known at the receiver. Pilot symbols may assist in the estimation of demodulation parameters, such as equalizer channel coefficients, carrier phase and frequency offsets, symbol timing, and optimal FFT window timing (in a frequency domain equalizer). If intended to estimate the equalizer channel coefficients, the Unique Word component of Pilot Word should be selected least be as long as the maximum delay spread of the channel. Additional details on Unique Words may be found in 8.3.4.12.

Burst profiles with particular Pilot Word length, P, and Pilot Word interval, N, settings may also simplify receivers using frequency domain equalization. For example F = N + P symbols can be selected as the block length over which an FFT would be computed by a frequency domain equalizer. With this choice for F, the periodicity of the Pilot Words serves as a natural cyclic prefix. Note that P must be as long as the delay spread of the channel for the cyclic prefix property to function properly in a delay spread channel. In addition, the burst payload length must be constrained such that a frame concludes with a Pilot Word. A further consideration that would reduce the complexity of an FFT engine would be to choose F = N + P as 2 raised to an integer power. However, FFT sizes for frequency domain equalizers do not have to equal pilot word intervals, since, for example, frequency domain equalizers can also be implemented using overlap save techniques.

8.3.4.10.3 Burst Profile and Frequency Domain Equalization Processing Examples

Figure 203 illustrates a burst of arbitrary length which is equalized by a frequency domain equalizer using an overlap-save type FFT method. Note that although a single FFT length is used in Figure 203, arbitrary payload sizes are accommodated, due to (a), the overlapping FFT sections, and (b), the receiver's use of zero padding at the end of the receive burst, to fill out enough data to complete the final FFT. Mark that the zero padded symbols are not transmitted; they are added at the receiver immediately before computing the final FFT. Use of this arbitrary length format would be specified by a burst profile designating its selection. Note that pilot symbols may be interspersed within the payload as desired; they just are not explicitly used by the FFT processing engine.

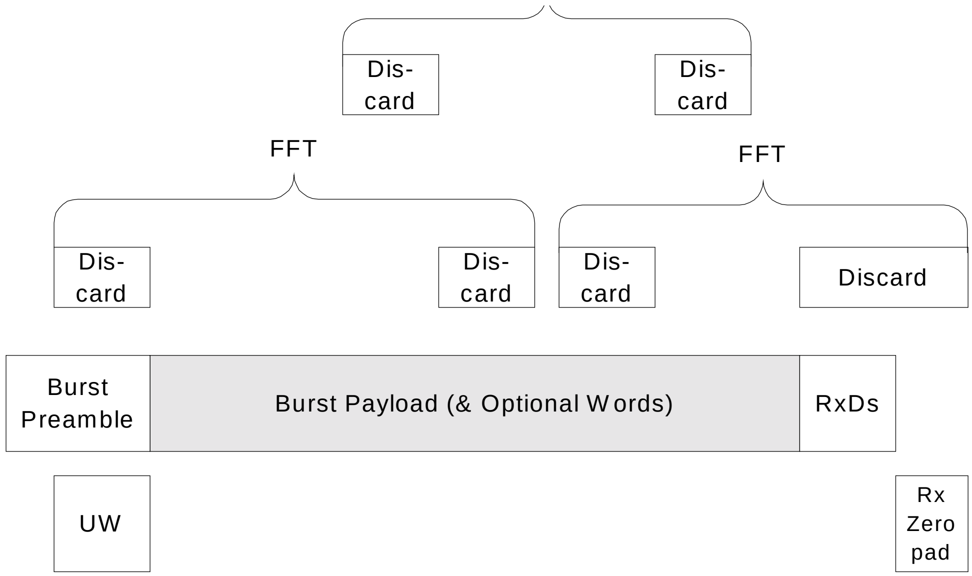


Figure 203—Using overlapping FFTs and receiver-injected zero-pad data

Another burst frame processing technique, which is more efficient in its use of FFT computational resources, but is less efficient in its utilization of channel resources, is illustrated in Figure 204. Note the explicit use of regularly spaced Unique Words (UWs). For this case, the UWs are spaced at intervals that accommodate FFT processing, so that the overlapping of Figure 203 is not necessary. Each FFT shown in Figure 204 spans a payload block and a UW; one can select the each payload sub-block so that the FFT is a power of 2 length that is particularly amenable to efficient FFT processing. This constraint, however, limits the payload size to finite multiples of F - U = N, where F is the FFT size and U is the Unique Word length. T

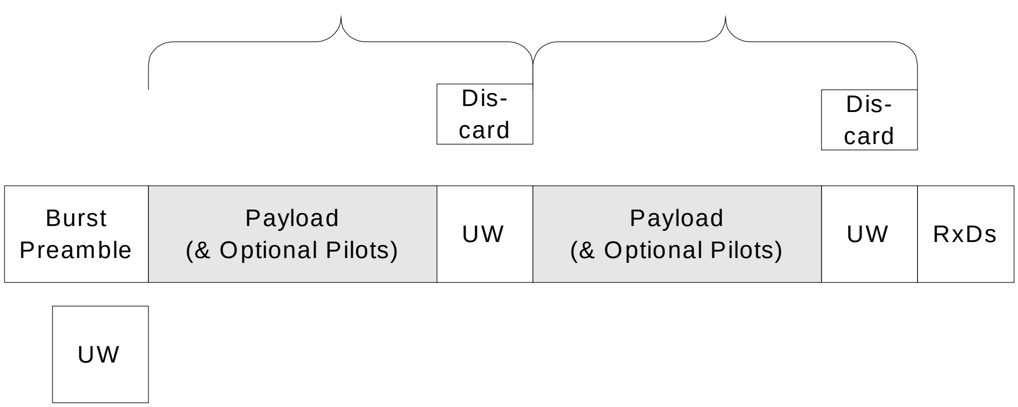


Figure 204—: Burst with UWs spaced to facilitate hardware-efficient FDE

Observe that although the preceding burst formats have been described and formulated in terms of applicability to frequency domain equalization techniques, these formats are amenable to temporal domain equalization techniques, as well.

Note that the capability to decode the burst format of Figure 203 is mandatory; the optional burst profile of Figure 204 may enable pipelined, faster processing in some high symbol rate, hardware-constrained applications.

8.3.4.10.4 Adaptive Modulation

Many Subscriber Station (SS) receivers typically will be tuned to a burst downlink channel. Moreover, many SSs will attempt to transmit to a Base Station (BS) on a burst uplink channel. Due to differing conditions at the various SS sites (e.g., variable distances from the Base Station, presence of obstructions, local interference), communication with different SSs may involve significantly different CINRs. For this reason, some SSs may be capable of communicating with a BS only when data is derived from certain lower-order modulation alphabets, such as QPSK. Similarly, such CINR-disadvantaged transactions may require more powerful and redundant FEC schemes. On the other hand, CINR-advantaged transactions may be capable of communicating with very high order modulations (e.g., 64-QAM) and high code rates. Obviously, to maximize the overall capacity of the system, the modulation and coding format should be adapted to each SS and communication link, based on the CINR that the link can reliably support. Define the adaptation of modulation type and FEC to a particular SS (or group of SSs) as 'adaptive modulation', and the choice of a particular modulation and FEC as an 'adaptive modulation type.' The burst transmission mode supports adaptive modulation and the use of adaptive modulation types.

As Figure 200 illustrates, the modulation borne by a burst may change from burst to burst (as different SS transactions are processed). One would see this with TDMA bursts, which are used on upstream single carrier PHY transmissions, As Figure 200 also illustrates, for the case of Time Division Multiplexed bursts, which one might see on a TDM downstream, the modulation may change during different segments of a single burst.

8.3.4.10.4.1 Frame Control Information and Adaptive Modulation

The distribution of adaptive modulation types for bursts, or within bursts (for TDM bursts) is indicated within Frame Control messages sent by the MAC on the downlink channel.

Frame Control MAC messages are periodically transmitted on the downlink burst channel (but not the uplink channel), using the most robust adaptive modulation type mandatorily supported. This modulation type would be QPSK, with a rate 1/2 inner (convolutional) code. The outer Reed Solomon code is shortened to accommodate the length of the Frame Control message. No interleaving is used.

A Frame Control MAC messages may be transmitted alone, consituting a burst in itself, or it may be an element of a TDM burst. When it is a part of a TDM burst, it must be the first multiplexed element in that burst. In all instances, the FEC used for the Frame Control message must encapsulate the Frame Control message.

Within a down MAC Frame Control message, a PHY control map (MAP) is used to indicate the beginning location of each of adaptive modulation type payload that follows, at some time in the future. This downstream control MAP governs operation of the downstream and upstream transmissions. However, the MAP does not describe the beginning locations of the payload groups that immediately follow this MAP; it describes the payload distributions at some MAC-prescribed time in the future, which may pertain to a different burst. This delay is necessary so that FEC decoding (which could be iterative, in the case of turbo codes) may be completed, the adaptive modulation instructions interpreted, and the demodulator scheduling set up for the proper sequencing. Note that this information containing the distribution of data within a particular burst may be contained in another burst.

8.3.4.10.4.2 Adaptive Modulation Sequencing for TDM bursts

Within a TDM burst, payload groups are sequenced in increasing order of robustness (e.g., first QPSK, then 16-QAM, then 64-QAM). This robustness sequencing improves receiver performance, because it enables receivers experiencing lower SINRs to track only through the modulation types that they can reliably receive.

8.3.4.10.4.3 Per-Adaptive-Modulation-Type FEC Encapsulation (TDM)

So that disadvantaged-SINR SSs are not adversely affected by transmissions intended for other advantaged-SINR users, FEC blocks end when a particular adaptive modulation type ends. Among other things, this implies that the FEC interleaver depth and code blocks are adapted to accommodate the span of a particular adaptive modulation type. Note, however, that data from several users could be concatenated by the MAC (and interleaved together by the PHY) within the span of a given adaptive modulation type.

8.3.4.11 Duplexing: FDD and TDD Operation

In the sections that follow, the framing and MAC messaging mechanisms developed in 8.3.4.9 (for the continuous transmission format) and 8.3.4.10 (for the burst transmission format) are used to generate duplexed communication schemes. 8.3.4.11.1 describes several types of FDD operation, and 8.3.4.11.2 describes TDD operation. In addition to providing operational regulations, some effort is made to demonstrate of how the communicating duplexes within two-way transactions interact, via MAC messages.

8.3.4.11.1 FDD Operation

Frequency Division Duplexing (FDD) segregates the upstream and downstream on different carriers. Base stations transmit on downstreams, while subscriber units transmit on upstreams. Three different FDD formats are possible:

1. Continuous downlink and burst uplink, with multiple transmitters sharing the uplink on a TDMA basis;
2. Burst downlink and uplink, with at one or more transmitters on the downlink, and multiple transmitters sharing the uplink on a TDMA basis.
3. Half-duplex FDD, which is similar to 2), except that the downlink and uplink may not be used at the same time.

8.3.4.11.1.1 FDD with Continuous Downlink

The downlink of an FDD system with a continuously transmitted downlink is illustrated in Figure 205. On the continuous downlink, frames must repeat at regular, constant intervals. Each one of these frames is headed by a Frame Preamble, which identifies the beginning of a frame. The Frame Preamble also aids in the update or acquisition channel parameter estimates.

The Preamble is followed by a MAC message, the MAP, which is encoded using QPSK. The MAP is then followed by payloads addressed to various users, which can be sequenced in modulation types from least robust (e.g., QPSK) to most robust (e.g., 64-QAM). Such robustness sequencing facilitates decision-aided processing, which can, in some cases, reduce the amount of overhead that must be allocated to pilot symbols. (A receiver demodulates what it can, and if it loses lock in trying to modulate data requiring too high of an SNR, it can reacquire using the repetitive Frame Preamble at the beginning of the next frame.)

As the breakout illustration in the middle of Figure 205 illustrates, the MAP itself is composed of several fields. These include a fixed sequence called the MAC Header, a Global Time Stamp (to synchronize network time between the upstream and downstream duplexes), a Downstream Schedule (that contains adaptive modulation information on the multiplexed downstream packets), and an Upstream Schedule for grants given to various users on the upstream. These schedules include the starting location of each packet, as well as the modulation, code rate, and FEC type to be used. The MAP concludes with a ARQ-related field for upstream messages previously received.

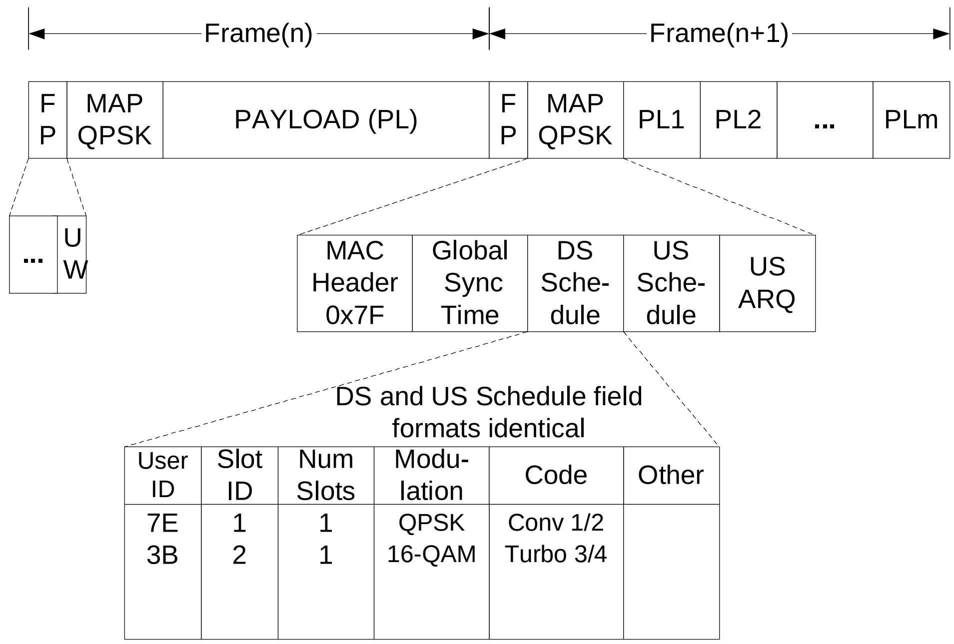


Figure 205—Downstream Duplex of FDD with a Continuous Downstream

Figure 206 juxtaposes the burst upstream, upon which many bursty subscribers transmit, with the continuous downstream. Note that an upstream frame consists of many bursts, some of which are allocated to request bursts, and others allocated to granted payloads. Each burst---whether it be a request or a payload---is a TDMA burst. As such, the burst contains an Burst preamble (and ramp up), a Burst Payload body, and an RxDS (receiver delay spread clear) region. The request bursts may be subcategorized as network registration contention slots, or BW request contention slots. Additional guard symbols (denoted as ‘G’ in Figure 206) are attached to the beginning and end of the network registration slots, to accommodate time uncertainties preceding initial registration and ranging. Note that the Upstream Schedule found in the downstream MAP governs the distribution of granted payload TDMA bursts on the upstream.

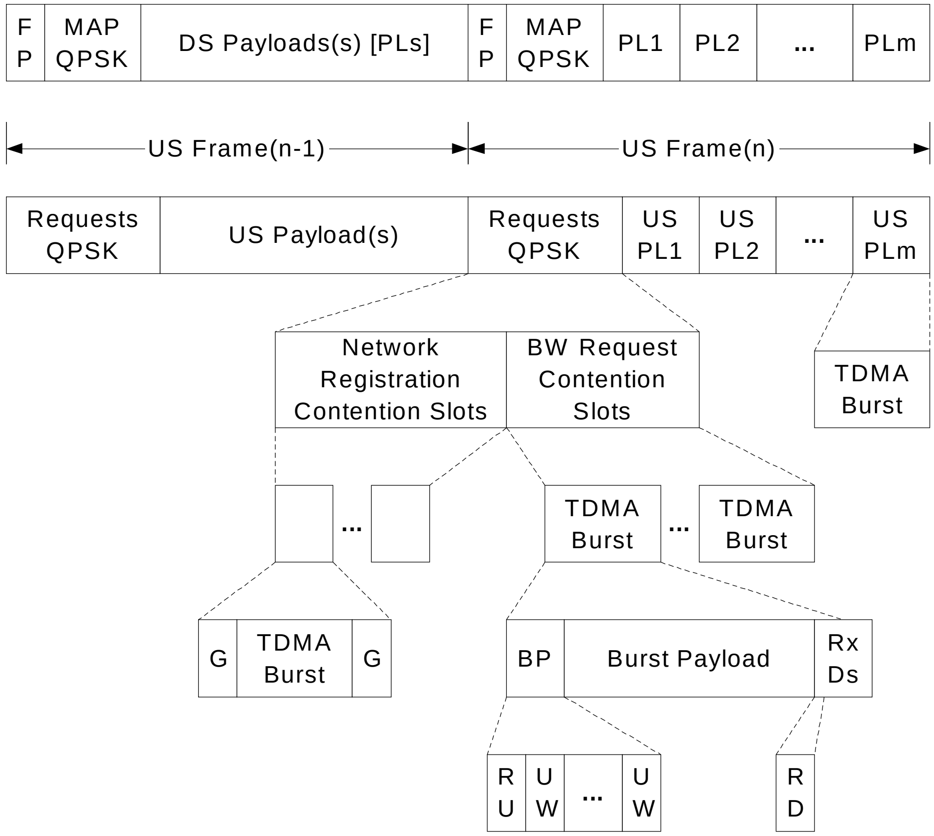


Figure 206— FDD Burst TDMA Upstream Juxtaposed with Continuous Downstream

8.3.4.11.1.2 FDD with Burst Downstream

The only difference between FDD with a continuous downstream and FDD with a burst downstream is that the burst downstream case replaces a continuous frame with a TDM burst frame. As such, the continuous frame Preamble is replaced by a burst acquisition sequence (preamble), and the burst ends with an RxDS region, which allows delay spread to clear in the subscriber unit receivers Figure 207 illustrates the burst FDD downstream case.

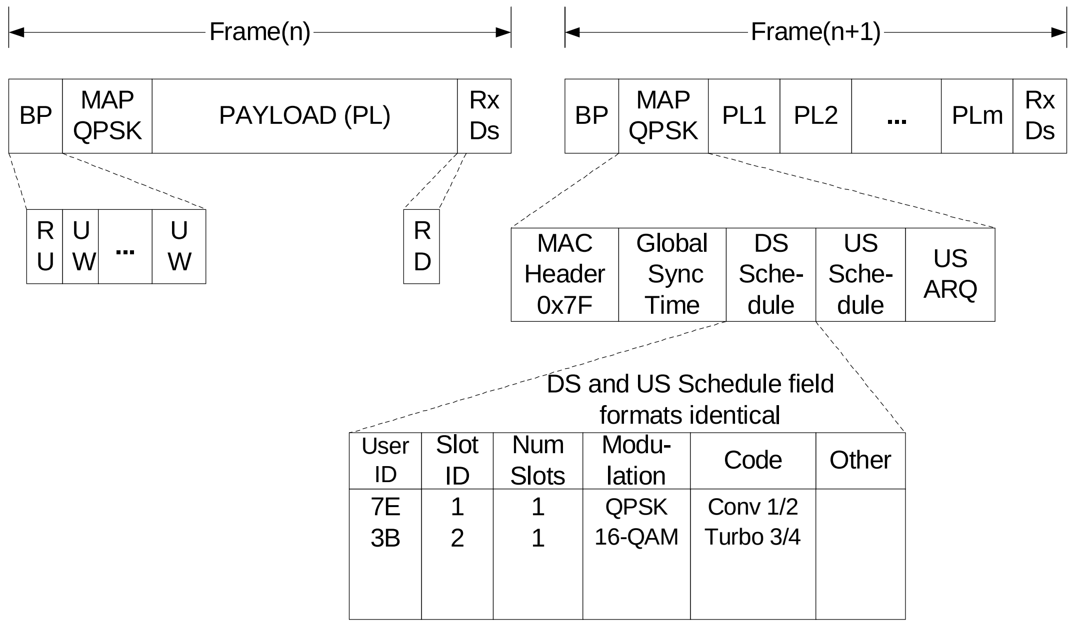


Figure 207—Burst FDD Downstream Frame

8.3.4.11.1.3 Half-duplex FDD Operation

Half-duplex FDD operation is conceptually identical to TDD operation, in that the downstream and upstream switches back and forth between two duplexes. However, these duplexes are transported at different carrier frequencies with half-duplex FDD. Because of this switching between carriers, and the incumbent tuning required, some parameter settings, such as the Duplex Guard Interval (DGI), may differ between half duplex FDD and TDD. Information on TDD operation may found in 8.3.4.11.2.

8.3.4.11.2 TDD Operation

TDD multiplexes both the upstream and downstream on the same carrier, over different time intervals. By adaptively time-sharing the bandwidth between the upstream and downstream according to duplex loading, TDD enables scare bandwidth to be more flexibly (and finely) allocated between subscriber units and base stations. TDD also offers some potential benefits related to channel response reciprocity.

Figure 208 illustrates TDD operation with a single-burst TDM downlink. Note that this variant of TDD quite resembles FDD operation, except that, with TDD, the uplink and downlink alternate between occupying the shared channel. Like the FDD case, a TDD upstream receives its grants from a downlink frame that precedes it. In most respects other than perhaps timing, MAC message formats are almost identical between FDD and TDD.

The only completely new frame element introduced by TDD is the Duplex Guard Interval (DGI). The Duplex Guard Interval separates the duplexes, allows time for a receiver to transition over to become a transmitter, and accounts for propagation delays following reception of the RxDS region which precedes the DGI. The DGI may be assigned a different length on the upstream to downstream transition than the downstream to upstream transition.

Note that Figure 208 illustrates a single TDM burst per downlink duplex frame. This case was chosen for illustrative simplicity; in general, several TDM bursts may occupy the downstream duplex of a TDD frame, with the first burst in the downstream duplex frame containing the MAC Frame Control messages, including the MAP.

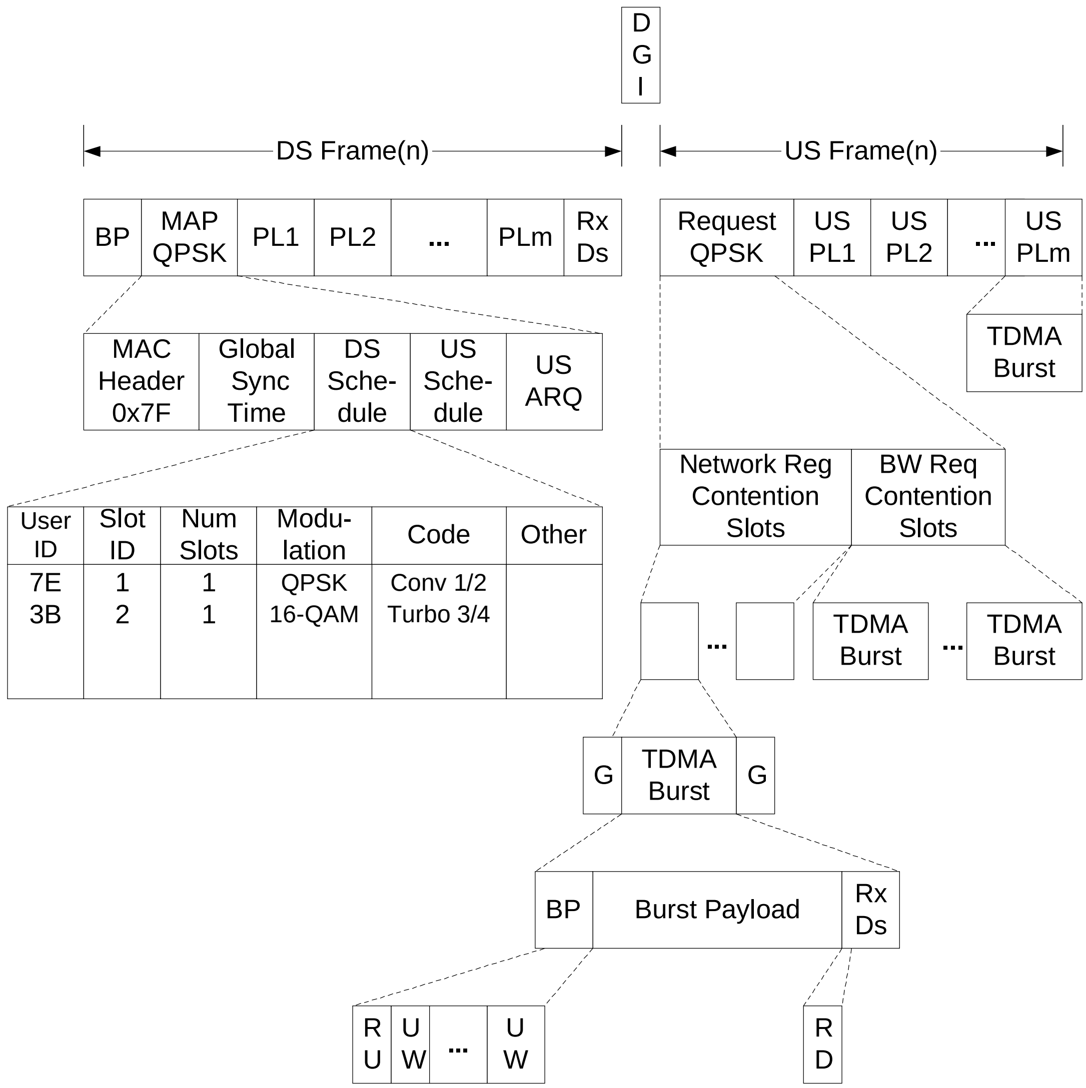


Figure 208—Ilustration of TDD messaging and operation (with TDM downlink)

modifies the description of the design criteria used to select a Unique Word sequence.

8.3.4.12 Unique Word

8.3.4.12.1 Unique Word Sequence Design Criteria

The choice of a structure for the Unique Word is critical, because a Unique Word may be used for channel estimation, and it may also be used as a cyclic prefix element in some frequency domain equalizers implementations. Its cyclic prefix role imposes one constraint: the Unique Word must be at least as long as the maximum delay spread to be experienced by an intended receiver. Its channel estimation role imposes added constraints: the Unique Word should have good periodic correlation properties, and/or equivalently possess a broadband, un-notched frequency response. In addition, since it may be a component within an acquisition preamble and play a role in the initial channel estimation and acquisition of a receiver, the Unique Word should have an symbol magnitude profile that is constant, to minimize AGC requirements. And lastly, since the Unique Word introduces overhead, it should be no longer than it need be; installations that experience less delay spread should not be burdened with the overhead of excessively long Unique Words. This implies that some flexibility in the choice (or construction) of Unique Words is desirable.

8.3.4.12.2 Unique Word Sequence Specification

Frank-Zadoff [B26] and Chu sequences [B27] are two constructions of CAZAC (Constant Amplitude Zero Auto-Correlation) sequences that possess the desired periodic correlation and constant amplitude properties. As Table 200 indicates, support of a Frank-Zadoff sequence of length 64 is mandatory in a compliant device. For applications with longer or shorter delay spreads, an operator may desire to use other, optional sequences of differing lengths. For this reason Table 200 defines optional Frank-Zadoff and Chu sequences of various lengths.

Table 200—UW lengths, Types, and Support Status

Length, U (symbols)	Sequence Type	Support Status
0	---	Optional
8	Chu	Optional
16	Frank-Zadoff	Optional
32	Chu	Optional
64	Frank-Zadoff	Mandatory
128	Chu	Optional
256	Frank-Zadoff	Optional
512	Chu	Optional

The I and Q components of a length U, $0 \le n < U$, Unique Word sequence are generated from

$$\begin{aligned} I[n] &= \cos(\theta[n]) \\ Q[n] &= \sin(\theta[n]) \end{aligned} \tag{2}$$

where $\theta[n] = \theta_{chu}[n]$ when generating a Chu sequence, and $\theta[n] = \theta_{frank}[n]$ when generating a Frank-Zadoff sequence. For a Chu sequence,

$$\theta_{chu}[n] = \frac{\pi n^2}{U} \tag{3}$$

and, for a Frank-Zadoff sequence,

$$\theta_{frank}[n = p + q\sqrt{U}] = \frac{2\pi pq}{\sqrt{U}}$$
$$p = 0, 1, \ldots, \sqrt{U} - 1 \qquad (4)$$
$$q = 0, 1, \ldots, \sqrt{U} - 1$$

The length U = 16, 64, and 256 Unique Word sequences are composed of symbols from QPSK, 8-PSK, and 16-PSK alphabets, respectively. However, the length U = 8, 32, 128, and 512 sequences are derived from polyphase symbol alphabets that may require additional care in a hardware implementation. The error vector magnitude (EVM) computed for Unique Word symbols in a transmitter implementation should conform with the general EVM requirements for transmitted symbol modulation accuracy found in 8.3.5.17.1.5.

8.3.4.13 Framing Recommendations for Antenna Diversity Systems

Diversity techniques are likely to find application in some broadband wireless installations. Non-invasive techniques such as receive diversity do not require that any special considerations on the part of the air interface, or framing. For two-way delay transmit diversity, where two transmit antennas are used and the output of the second antenna is delayed with respect to the first, the considerations are minor. Namely, both receiver equalization and framing must be adequate to accommodate the extra delay spread introduced in the system due to the delayed output of the second transmitter.

However, framing considerations arise when the Alamouti transmit diversity scheme [B32], which achieves 2-way maximal ratio transmit diversity combining, is to be applied. 8.3.4.13.1 describes the Alamouti scheme and provides guidance on the framing used that may be used to implement it. 8.3.4.13.2, which then follows, provides information on other advanced diversity techniques.

8.3.4.13.1 Alamouti Transmit Diversity

The Alamouti transmit diversity scheme may be applied to either the continuous or burst formats, if two consecutive blocks of data are logically coupled, and are jointly processed at both the transmitter and receiver. The technique to be described is particularly amenable to frequency domain equalization.

Figure 209 illustrates the concept of block pairing used by a Alamouti transmit diversity scheme. A two-antenna transmitter system must format data into such logically paired blocks to obtain the promised diversity. Figure 209 also illustrates the insertion of 'Delay spread guard symbols', between the paired blocks so that neither block leaks delayed information onto the other block, or onto the next (or previous) sets of paired blocks. The use of delay spread guard symbols may not be necessary in all frequency domain equalizer implementations, but is conceptually useful to stress that the two blocks should be isolated from each other.

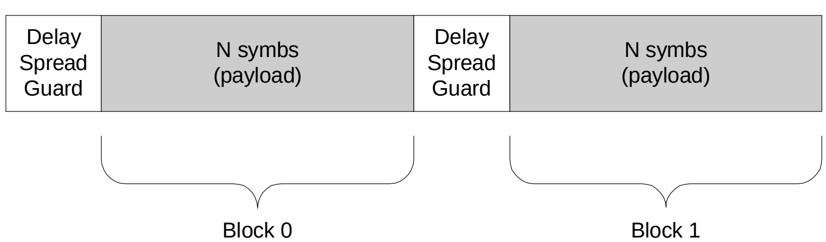


Figure 209—Paired Blocks used for Alamouti transmit diversity combining

Let $\{s_0[n]\}$ and $\{s_1[n]\}$ be two sequences, each of length N symbols ($0 \le n < N$), that are desired to be delivered to a receiver using the Alamouti transmit diversity scheme. Table 201 indicates the block multiplexing structure that a 2-antenna transmitter would use to transmit the two sequences over the paired blocks illustrated in Figure 209. As Table 201 indicates, transmit Antenna 0 would transmit its data sequences in order, according to burst or continuous format specifications, with no modifications (other than the possible insertion of delay spread guard symbols between the blocks). However, Transmit Antenna 1 must not only reverse the order in which the blocks are transmitted, but must also conjugate the transmitted complex symbols and must also time-reverse the sequence of data symbols within each block.

Table 201—Multiplexing arrangement for block Alamouti processing

TX Antenna	Block 0	Block 1
0	$\{s_0[n]\}$	$\{s_1[n]\}$
1	$\{-s_1*[N-n-1]\}$	$\{s_0*[N-n-1]\}$

If $S_0(e^{j\omega})$, $S_1(e^{j\omega})$, $H_0(e^{j\omega})$, $H_1(e^{j\omega})$, $N_0(e^{j\omega})$, and $N_1(e^{j\omega})$ represent the Discrete-time Fourier transforms, respectively, of the symbol sequences $\{s_0[n]\}$ and $\{s_1[n]\}$, channel impulse responses (for the channels associated with each transitter antenna) $\{h_0[n]\}$ and $\{h_1[n]\}$, and additive noise sequences (associated with each block) $\{n_0[n]\}$ and $\{n_1[n]\}$, the received signals associated with each block, interpreted in the frequency domain, are:

$$R_0(e^{j\omega}) = H_0(e^{j\omega})S_0(e^{j\omega}) - H_1(e^{j\omega})S_1(e^{j\omega}) + N_0(e^{j\omega}) \tag{5}$$

$$R_1(e^{j\omega}) = H_0(e^{j\omega})S_1*(e^{j\omega}) - H_1(e^{j\omega})S_0*(e^{j\omega}) + N_1(e^{j\omega}) \tag{6}$$

Assuming that the channel responses $H_0(e^{j\omega})$ and $H_1(e^{j\omega})$ are known, one can use the frequency domain combining scheme

$$C_0(e^{j\omega}) = H_0*(e^{j\omega})R_0(e^{j\omega}) + H_1(e^{j\omega})R_1*(e^{j\omega}) \tag{7}$$

$$C_1(e^{j\omega}) = -H_1(e^{j\omega})R_0*(e^{j\omega}) + H_0*(e^{j\omega})R_1*(e^{j\omega}) \tag{8}$$

to obtain the combiner outputs

$$C_0(e^{j\omega}) = (\left|H_0(e^{j\omega})\right|^2 + \left|H_1(e^{j\omega})\right|^2)S_0(e^{j\omega}) + H_0*(e^{j\omega})N_0(e^{j\omega}) + H_1(e^{j\omega})N_1*(e^{j\omega}) \tag{9}$$

$$C_1(e^{j\omega}) = (\left|H_0(e^{j\omega})\right|^2 + \left|H_1(e^{j\omega})\right|^2)S_1(e^{j\omega}) - H_1(e^{j\omega})N_0*(e^{j\omega}) + H_0*(e^{j\omega})N_1(e^{j\omega}) \tag{10}$$

The combiner outputs of Eq. 9 and Eq. 10 can then be independently equalized using frequency domain equalizer techniques (see [B25], for an example) to obtain estimates for $\{s_0[n]\}$ and $\{s_1[n]\}$.

The channel responses can also be estimated using pilot symbols. In order to demonstrate this, first assume that corresponding pilot symbols are the same in the 0 and 1 blocks, i.e., $S_0^{pilot}(e^{j\omega}) = S_1^{pilot}(e^{j\omega}) = S_{pilot}(e^{j\omega})$, and that $_{pilot}(e^{j\omega})$ is known.

Upon substituting $_{pilot}(e^{j\omega})$ for $S_0(e^{j\omega})$ and $S_1(e^{j\omega})$ in Eq. 5 and Eq. 6, one can show

$$S_{pilot}*(e^{j\omega})R_0^{pilot}(e^{j\omega}) + S_{pilot}(e^{j\omega})R_1^{pilot}(e^{j\omega}) = 2\left|S_{pilot}(e^{j\omega})\right|^2 H_0(e^{j\omega}) \tag{11}$$

$$-S_{pilot}^{*}(e^{j\omega})R_0^{pilot}(e^{j\omega}) + S_{pilot}(e^{j\omega})R_1^{pilot}(e^{j\omega}) = 2\left|S_{pilot}(e^{j\omega})\right|^2 H_1(e^{j\omega}) \quad (12)$$

Note that Eq. 11 and Eq. 12 are combining relations that resemble those found in Eq. 9 and Eq. 10. As such, they can be used to estimate the channels $H_0(e^{j\omega})$ and $H_1(e^{j\omega})$, using received data from subblocks in which contiguous sequences of pilot symbols were transmitted. The channel estimation task is particularly simple since pilot symbols (for single carrier operation) must be derived from the Unique Words of 8.3.4.12, and these Unique Words have a constant frequency domain magnitude, *i.e.*, $\left|S_{pilot}(e^{j\omega})\right|^2 = \left|S_{UW}(e^{j\omega})\right|^2 = 1$.

Figure 210 and Figure 211 two example illustrations of frame structures that accommodate Alamouti transmit diversity signaling.

Figure 210 illustrates a cyclic-prefix-based frame structure, with Pilot Word (Unique Word) repetitions chosen to enable both Alamouti combining and simultaneous estimation (or channel updates) of the two channels arising from the use of two transmit antennas.

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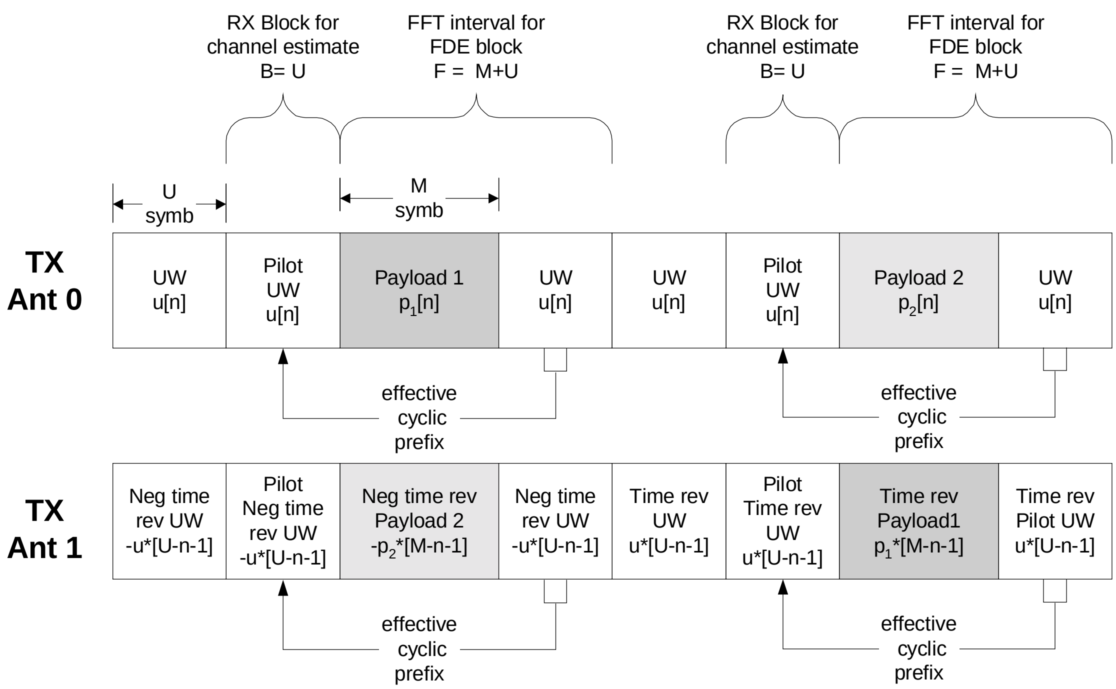

Figure 210—Cyclic prefix-based Alamouti framing with channel estimation

Figure 211 illustrates a cyclic-prefix-based frame structure where channel estimates and/or channel updates are not needed. This case might occur with in burst format applications, where the channels might be estimated with sufficient accuracy using information in the acquisition preamble.

Mark that the framing profiles of Figure 210 and Figure 211 use cyclic prefix structures, and assume the receiver has an equalizer designed for cyclic prefix-based processing. Other profiles are possible---some that may not require cyclic prefixes.

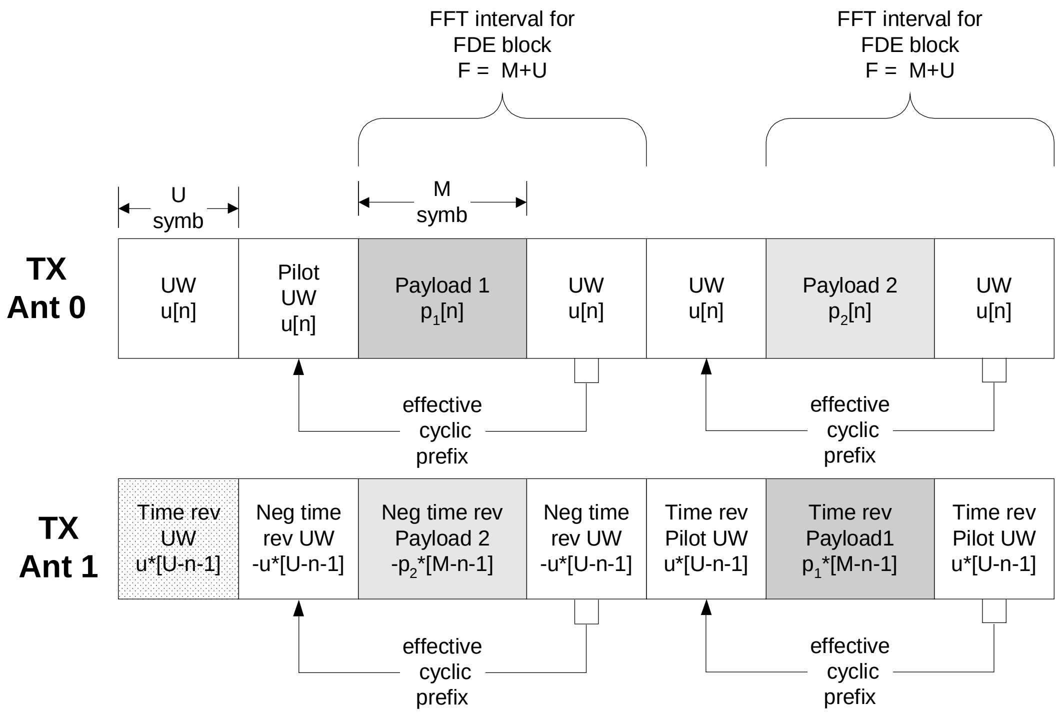

Figure 211—Cyclic prefix-based Alamouti framing without channel estimation

8.3.4.13.2 Application of Advanced Diversity Systems

Multiple antennas can be used at the transmitter and/or receiver to provide added dimension to the communication channel model. Over fading wireless channels, the theoretical channel capacity using multiple antenna diversity (sometimes called ‘Multiple-Input/Multiple-Output’ or ‘MIMO’) technology is greater (and in some cases, much, much greater) than that of conventional Single-Input/Single-Output (called SISO) technology, regardless of the modulation technique utilized---including Single Carrier (SC) modulation.

Use of multiple receive antennas (‘SIMO’ technology) increases the diversity of a system, and therefore increases the channel capacity over fading channels. However, the incorporation of receive diversity increases the complexity of a receiver. Figure 212 illustrates the application of antenna array for Single Carrier systems with three receive antennas.

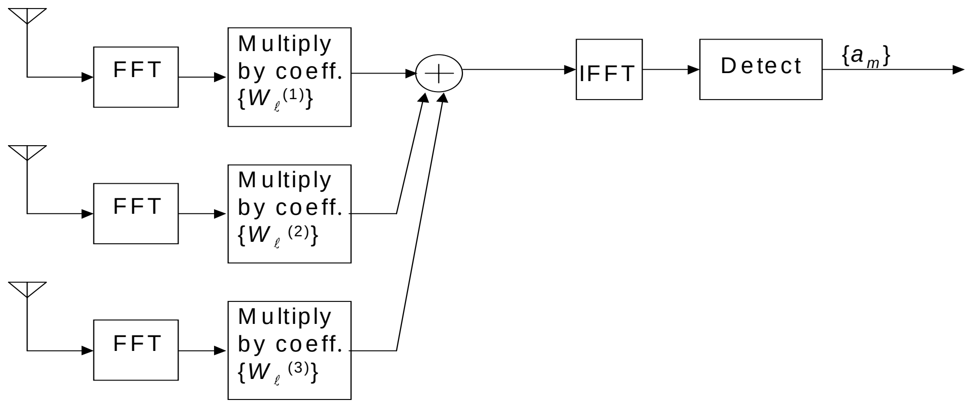

Figure 212—SC-FDE with Smart Antenna Array

The Alamouti transmit diversity technique of 8.3.4.13.1 is a ‘MISO’ (‘Multiple Input, Single Output’) technique, and has the potential to achieve the channel capacity for a 2-way MISO system. What’s more, Alamouti transmit diversity can be combined with receiver diversity to realize a MIMO system.

However, when the level of receiver diversity is greater than 1, Alamouti MIMO system do not achieve the theoretical channel capacity of a MIMO system with the same number of transmit and receive antennas. For this reason, structures that enable incorporation of other advanced and promising MIMO technologies, as they mature, are desirable.

8.3.4.14 Framing Considerations for Adaptive Antenna Systems

8.3.4.14.1 Application of Adaptive Antennas

The PHY layer shall provide mechanisms that enable the future application of adaptive (‘smart’) antennas. A desired smart antenna feature might be the capability to track a target within a predetermined angle of uncertainty, for example, 3 or more degrees. Coupling this active tracking capability of a smart antenna with transmit antenna pattern optimization (*i.e.*, aiming transmissions where particular subscriber stations are located) could potentially provide better coexistence by decreasing interference, while increasing cell coverage radii, and increasing the transport capacity of the system.

8.3.4.15 SC-FDE System Capacity and Modulation Efficiency

8.3.4.15.0.1 System Capacity:

Table 202 lists the system capacity for a SC PHY Downlink and Uplink. The aggregate transmission bit rate is optimized under several constraints. These are:

- The allocated channel bandwidth;
- The modulation level;
- The spectrum shaping filter bandwidth with roll factor of a = 0.25 (mandatory), 0.15 (optional) and 0.18 (optional);
- The FEC coding scheme (Reed-Solomon (n, k) over GF(256);
- The requirement of uplink time tick for the Mini-slots burst duration; and
- Processing power limitation of available chips to be used.

Included in Table 202 is the overhead associated with the use of FEC and a Frequency Domain Equalizer with periodic Unique Word patterning.

Table 202—System Capacity Objectives Example

	Downlink TX Rate (Mbps)		**Uplink TX Rate (Mbps)**	
Channel Spacing	16 QAM 3.38 bps/Hz	64 QAM 5.07 bps/Hz	QPSK 1.46 bps/Hz	16 QAM 2.92 bps/Hz
3.5 MHz	11.02	16.54	4.77	9.54
5 MHz	15.72	23.57	7.44	14.88
6 MHz	18.82	28.21	8.93	17.86
7 MHz	22.03	33.03	9.52	19.05

8.3.4.15.1 SC-FDE System Throughput

For single-carrier systems, system throughput will vary with the operating modes. With frame structure given in Subclause ????, the SC-FDE system throughput is given as:

$$T = R\frac{N-U}{N}r\frac{\log M}{\log 2} \quad (13)$$

If the design with $\frac{U}{2} = R \cdot d$, rounded up to the nearest power of 2, the throughput for SC-FDE system will then equal to:

$$T = R\frac{N - \lceil (R \cdot d) \rceil_2}{N}r\frac{\log M}{\log 2} \quad (14)$$

where $\lceil x \rceil_2$ denotes rounding x up to the nearest power of 2.

Table 203 presents typical channel throughput for SC-DFE system with a 1.75 MHz channel Bandwidth. Similar typical results for higher channel bandwidths will be proportionally larger.

Table 203—Throughput for various Models in 1.75 MHz Channel

System dependent parameters		**Link-Dependent Parameters**		**Traffic Dependent Parameters**			
Symbol [sample] Rate (MS/sec	Design Max Delay Spread (μ s)	QAM States	Conv. Code Rate	FFT Sizes			
				256	512	1024	2048
1.5	4	4	1/2	1.453	1.477	1.488	1.494
			2/3	1.938	1.969	1.984	1.992
			3/4	2.180	2.215	2.232	2.241
			7/8	2.543	2.584	2.604	2.615
		16	1/2	2.906	2.953	2.977	2.988
			2/3	3.875	3.938	3.969	3.984
			3/4	4.359	4.430	4.465	4.482
			7/8	5.086	5.168	5.209	5.229
		64	1/2	4.359	4.430	4.465	4.482
			2/3	5.813	5.906	5.953	5.977
			3/4	6.539	6.645	6.697	6.724
			7/8	7.629	7.752	7.813	7.844
	10	4	1/2	1.395	1.447	1.474	1.487
			2/3	1.859	1.930	1.965	1.982
			3/4	2.092	2.171	2.210	2.230
			7/8	2.440	2.533	2.579	2.602
		16	1/2	2.789	2.895	2.947	2.974
			2/3	3.719	3.859	3.930	3.965
			3/4	4.184	4.342	4.421	4.460
			7/8	4.881	5.065	5.158	5.204
		64	1/2	4.184	4.342	4.421	4.460
			2/3	5.578	5.789	5.895	5.947
			3/4	6.275	6.513	6.631	6.691
			7/8	7.321	7.598	7.737	7.806
	20	4	1/2	1.313	1.406	1.453	1.477
			2/3	1.750	1.875	1.938	1.969
			3/4	1.969	2.109	2.180	2.215
			7/8	2.297	2.461	2.543	2.584
		16	1/2	2.625	2.813	2.906	2.953
			2/3	3.500	3.750	3.875	3.938
			3/4	3.938	4.219	4.359	4.430
			7/8	4.594	4.922	5.086	5.168
		64	1/2	3.938	4.219	4.359	4.430
			2/3	5.250	5.625	5.813	5.906
			3/4	5.906	6.328	6.539	6.645
			7/8	6.891	7.383	7.629	7.752

8.3.4.16 Minimum Performance Requirements

8.3.4.16.1 System Requirements

8.3.4.16.1.1 Channel Frequency Accuracy

The RF channel frequency accuracy for subscriber shall be within +/-15 parts per million (ppm) of the selected RF carrier over a temperature range of –40 to +65 degrees C operational and up to 5 years from the date of manufacture of the equipment manufacture.

The basestation can support the use of highly stable ovenized and/or disciplined oscillators. The frequency accuracy for basestation shall be within +/-4 parts per million (ppm) of the selected RF carrier over a temperature range of –40 to +65 degrees C operational and up to 10 years from the date of manufacture of the equipment manufacture.

8.3.4.16.1.2 Carrier Phase Noise

The transmitter for the downlink shall meet an integrated double sideband (DSB) carrier phase noise of (TBD) degrees RMS from 10 kHz to 2 MHz. The uplink DSB carrier phase noise shall be (TBD) degrees RMS from 10 kHz to 2 MHz. These values should be suitable to meet the detection requirements for the respective highest mandatory modulation indices for the downlink and uplink (downlink is 64-QAM, uplink is 16-QAM).

8.3.4.16.1.3 Symbol Rate

The symbol rate includes considerations for carrier frequency stability, analog filtering / response, and root-raised-cosine (RRC) alpha, as well as spectral mask considerations. The table below identifies the minimum and maximum symbol rates versus RF frequency bandwidth. The assumed RRC filter alpha is 0.25.

Table 204—Maximum Symbol Rates

Channel Bandwidth	Minimum Symbol Rate	Minimum Symbol Rate
7 MHz	(TBD) Msps	(TBD) Msps
6 MHz	(TBD) Msps	(TBD) Msps
3.5 MHz	(TBD) Msps	(TBD) Msps
3 MHz	(TBD) Msps	(TBD) Msps
1.75 MHz	(TBD) Msps	(TBD) Msps
1.5 MHz	(TBD) Msps	(TBD) Msps

8.3.4.16.1.4 Symbol Timing Jitter

The minimum-to-maximum difference of symbol timing over a 2-second period shall be less than 2% of the nominal symbol period. This jitter specification shall be maintained over a temperature range of –40 to +65 degrees C,operational.Additional short-term stability figures can be added for completeness.

8.3.4.16.1.5 Transmitter Minimum SNR and EVM

The transmitted signal shall have an SNR of no less than (TBD) dB at the antenna feed point. The transmitter EVM shall be no greater than (TBD)%.

8.3.4.16.1.6 Transmitter Maximum EIRP

8.3.4.16.1.6.1 Basestation Output Power

The recommended maximum output power is given in the table below for the given bands. The output power is effective isotropic radiated power (EIRP). These values assume a backoff for the minimum modulation index, 4-QAM. It is also assumed that the signal bandwidth is 6 MHz. As a practical matter, the RF output power from a basestation should be such that it can overcome cable and other losses in a tower deployment. It should not be significantly more powerful than the subscriber; otherwise the air interface would be drastically uplink limited. The subscriber side of the air interface is driven by economics that dictate lower cost and power. This would necessitate a lower power PA (as described in the next section).

Table 205—Recommended Subscriber Maximum EIRP (*FCC EIRP limit.)

Band of Interest	EIRP (120 deg Sector)	EIRP (90 deg Sector)	EIRP (60 deg Sector)
2.15-2.162, 2.5-2.69 GHz	(TBD) dBm	(TBD) dBm	(TBD) dBm
3.5 GHz	(TBD) dBm	(TBD) dBm	(TBD) dBm
5.25-5.35 GHz	(TBD) dBm*	(TBD) dBm*	(TBD) dBm*
5.725-5.825 GHz	(TBD) dBm*	(TBD) dBm*	(TBD) dBm*
10.5 GHz	(TBD) dBm ((TBD) dBm from 10.6 to 10.68)	(TBD) dBm ((TBD) dBm from 10.6 to 10.68)	(TBD) dBm ((TBD) dBm from 10.6 to 10.68)

8.3.4.16.1.7 Transmitter Power Level Control

The transmitter shall provide up to (TBD (~50dB)) of power level control with a tolerance of +/-3 dB.

8.3.4.16.1.8 Ramp up/down Requirements

During ramp up and ramp down of burst power, the output power should be within TBD dB of the desired average power within TBD symbols. This settling time should factor into consideration transients due to the transmit filter impulse response.

8.3.4.16.1.9 Spurious Emissions during burst On/Off transients

Each transmitter must control spurious emissions, prior to and during ramp up and during and following ramp down, before and after a burst in a TDM/TDMA scheme. Spec TBD.

8.3.4.16.1.10 Out of Band Spurious Emissions

Out of band spurious emissions should conform with the applicable regulatory spectral masks and bandwidths described in 8.3.2.

8.3.4.16.1.11 Receiver Sensitivity

The maximum sensitivity value for the receiver, referenced to the receiver input, is identified in the following table.

Table 206—Receiver Sensitivity Values

Channel Bandwidth	Data Rate (Mbits/s)	Receiver Sensitivity (dBm)
7 MHz	(TBD)	(TBD)
7 MHz	(TBD)	(TBD)
7 MHz	(TBD)	(TBD)
7 MHz	(TBD)	(TBD)
6 MHz	(TBD)	(TBD)
6 MHz	(TBD)	(TBD)
6 MHz	(TBD)	(TBD)
6 MHz	(TBD)	(TBD)
3.5 MHz	(TBD)	(TBD)
3.5 MHz	(TBD)	(TBD)
3.5 MHz	(TBD)	(TBD)
3.5 MHz	(TBD)	(TBD)
3 MHz	(TBD)	(TBD)
3 MHz	(TBD)	(TBD)
3 MHz	(TBD)	(TBD)
3 MHz	(TBD)	(TBD)
1.75 MHz	(TBD)	(TBD)
1.75 MHz	(TBD)	(TBD)
1.5 MHz	(TBD)	(TBD)
1.5 MHz	(TBD)	(TBD)

8.3.4.16.1.12 Receiver Maximum Input Signal

The basestation shall be capable of receiving a maximum on-channel operational signal of –40 dBm and shall tolerate a maximum input signal of 0 dBm without damage to circuitry. The subscriber shall be capable of receiving a maximum on-channel operational signal of –20 dBm and shall tolerate a maximum input signal of 0 dBm without damage to circuitry.

8.3.4.16.1.13 Receiver Linearity

The receiver at the basestation and subscriber shall have a minimum input intercept point (IIP3) of (TBD (~0)) dBm.

8.3.4.16.1.14 Receiver Signal Power Measurement

The basestation and subscriber shall be able to determine input signal power to within a tolerance of (TBD) dBm, with a resolution of 1 dB.

8.3.4.16.2 Cell Requirements

This section describes the concepts of the standard cell and the extended cell. This section may be added outside of the SC section, as it is universal to OFDM as well as SC. Perhaps it can be contained within section 8.3.2 or 8.3.3.

8.3.4.16.2.1 Frequency Reuse

Frequency reuse shall be (TBD) for 3 sector cells, (TBD) for 4 sector cells, and (TBD) for 6 sector cells.

8.3.4.16.2.2 Standard Cell Structure

The standard cellular structure represents the bulk of the deployments to serve residential, SOHO and SME subscribers. In this deployment schematically basestation and subscriber antennas are used. Antenna heights are assumed to be roughly 100 feet for the basestation antennas and 20 feet for the subscriber. This deployment would be used in higher density deployments such as urban, suburban and perhaps small towns. The cell radii are given below for each of the SUI link model categories.

Table 207—Sector Radii for Standard Cells

Band of Interest	# Sectors	Cell Radius for SUI Category A	Cell Radius for SUI Category B	Cell Radius for UI Category C
2.15 - 2.162, 2.5 - 2.69 GHz	3	(TBD) km	(TBD) km	(TBD) km
	4	(TBD) km	(TBD) km	(TBD) km
	6	(TBD) km	(TBD) km	(TBD) km
3.5 GHz	3	(TBD) km	(TBD) km	(TBD) km
	4	(TBD) km	(TBD) km	(TBD) km
	6	(TBD) km	(TBD) km	(TBD) km

Table 207—Sector Radii for Standard Cells

Band of Interest	# Sectors	Cell Radius for SUI Category A	Cell Radius for SUI Category B	Cell Radius for UI Category C
5.25 - 5.35 GHz	3	(TBD) km	(TBD) km	(TBD) km
	4	(TBD) km	(TBD) km	(TBD) km
	6	(TBD) km	(TBD) km	(TBD) km
5.725 - 5.825 GHz	3	(TBD) km	(TBD) km	(TBD) km
	4	(TBD) km	(TBD) km	(TBD) km
	6	(TBD) km	(TBD) km	(TBD) km
10.5 GHz	3	(TBD) km	(TBD) km	(TBD) km
	4	(TBD) km	(TBD) km	(TBD) km
	6	(TBD) km	(TBD) km	(TBD) km

8.3.4.16.2.3 Extended Cell Structure

The extended cell structure would be used for deployments where subscriber densities are lower, or where cell fringes move from moderate populations to more sparse populations (outskirts of town). In this deployment, basestation antenna heights of 300 feet would be used to support less obstructed link paths. Subscriber antennas would be place as high as practical but shouldn't differ much from the standard cell structure. To support the increased link distance, higher gain antennas (>21 dBi) could be used on the subscribers, and spatially diverse (beamforming) antennas could be used at the basestation. Narrower bandwidth signals could also be used for the fringe subscribers, provided proper filtering is properly employed. These cells could support greater than twice the standard cell radius. The minimum cell radii are given in the table below.

Table 208—Minimum Sector Radii for Extended Cells

Band of Interest	# Sectors	Cell Radius for SUI Category A	Cell Radius for SUI Category B	Cell Radius for UI Category C
2.15 - 2.162, 2.5 - 2.69 GHz	3	(TBD) km	(TBD) km	(TBD) km
	4	(TBD) km	(TBD) km	(TBD) km
	6	(TBD) km	(TBD) km	(TBD) km
3.5 GHz	3	(TBD) km	(TBD) km	(TBD) km
	4	(TBD) km	(TBD) km	(TBD) km
	6	(TBD) km	(TBD) km	(TBD) km

Table 208—Minimum Sector Radii for Extended Cells

Band of Interest	# Sectors	Cell Radius for SUI Category A	Cell Radius for SUI Category B	Cell Radius for UI Category C
5.25 - 5.35 GHz	3	(TBD) km	(TBD) km	(TBD) km
	4	(TBD) km	(TBD) km	(TBD) km
	6	(TBD) km	(TBD) km	(TBD) km
5.725 - 5.825 GHz	3	(TBD) km	(TBD) km	(TBD) km
	4	(TBD) km	(TBD) km	(TBD) km
	6	(TBD) km	(TBD) km	(TBD) km
10.5 GHz	3	(TBD) km	(TBD) km	(TBD) km
	4	(TBD) km	(TBD) km	(TBD) km
	6	(TBD) km	(TBD) km	(TBD) km

8.3.5 OFDM PHY Layers

8.3.5.1 Introduction

This clause is informative only.

The following physical layer (PHY) specifications are designed to meet the functional requirements that have been defined for Broadband Fixed Wireless Access (BFWA) systems. It incorporates many aspects of existing standards in order to leverage existing technology for reduced equipment cost and demonstrated robustness of implementation with modifications to ensure reliable operation in the targeted 2-11 GHz licensed frequency bands. The PHYs in clause 8.3.5.3 were designed with a high degree of flexibility in order to provide operators in different regulatory domains the ability to optimize system deployments with respect to cell planning, cost considerations, radio capabilities, offered services, and capacity requirements. The PHYs in clause 8.3.5.4 have been designed specifically for 5GHz license-exempt operation.

The PHY specified in this clause is based on OFDM (Orthogonal Frequency Division Multiplex) modulation. Depending on the selected parameters in the time/frequency mapping for the different modes, it can support Time Division Multiple Access (TDMA) as well as Orthogonal Frequency Division Multiple Access (OFDMA) [B39], [B40]. This flexibility ensures that the system can be optimized both for short burst type of applications, as well as more streaming type oriented applications and provides a seamless development migration path from various existing OFDM-based standards.

The carrier spacing in frequency is dictated by the multipath characteristics of the channels in which the FWA system is designated to operate. As the channel propagation characteristics depend on the topography of the area and on the cell radius, the amount of carriers into which the channels is subdivided depends on the overall channel width and the carrier spacing. This PHY specification contains the programmability to deal with this range of applications.

8.3.5.1.1 Generic OFDM Symbol description

The OFDM symbol duration, or the related carrier spacing in frequency, is a major design parameter of an OFDM system. The symbol duration is composed of the FFT interval and of the Cyclic Prefix (CP) (see clause 8.3.5.1.2).

The number of carriers utilized, N_{used}, is usually only about 83% of the FFT bins (see 8.3.5.1.3). For implementation reasons, this number is chosen to be about 83% of the nearest power of 2. This choice involves implementation aspects of anti-aliasing filters. Note that the choice of FFT size is an artificial implementation parameter. For example a modulation of less than 256 carriers can be implemented either with a FFT of size 256, or with a FFT of size 512 at double sampling rate. We will stick with the convention, in which OFDM modes are denoted by the "FFT size" which is the smallest power of two above the number of carriers.

The effective bandwidth of the transmitted signal is related to the carrier spacing and the number of carriers.

In order to calculate the sampling frequency for any bandwidth, we define the bandwidth efficiency:

$$BW_{Efficiency} = \frac{F_s}{BW} \cdot \frac{(N_{used}+1)}{N_{FFT}} = \frac{\Delta f \cdot (N_{used}+1)}{BW} \tag{15}$$

in which

BW	Channel bandwidth (Hz)
F_s	Sampling frequency (Hz)
Δf	Carrier spacing (Hz)

$N_{used} + 1$ Number of active carriers used in the FFT (pilot and data carriers) + DC carrier

N_{FFT} FFT size

The Bandwidth efficiency is designed to be in the range of 83-95%, mainly depending on the FFT size, in order to occupy the maximum usable bandwidth but still allow adequate RF filtering. From this notion we can extract the sampling frequency for each BW by:

$$F_s = BW_{Efficiency} \cdot BW \cdot \frac{N_{FFT}}{(N_{used} + 1)} \tag{16}$$

The conversion from carrier modulation values to time domain waveform is typically implemented by a FFT algorithm on blocks of size 2^n. After the FFT, the time domain complex samples are transmitted at rate . The carrier spacing is, therefore,

$$\Delta f = \frac{F_s}{N_{FFT}} \tag{17}$$

The FFT interval duration is related to carrier spacing by

$$T_b = \frac{1}{\Delta f} = \frac{N_{FFT}}{F_s} \tag{18}$$

8.3.5.1.2 Time domain description.

Inverse-Fourier-transforming creates the OFDM waveform; this time duration is referred to as the useful symbol time T_b. A copy of the last samples is inserted before the useful symbol time, and is called the Cyclic Prefix (CP); its duration T_g is denoted as a fraction of the useful symbol time. The two together are referred to as the symbol time T_s Figure 213 illustrates this structure:

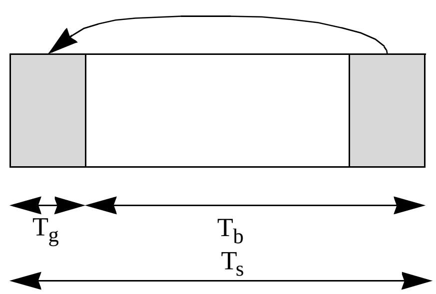

Figure 213—OFDM Symbol time structure

A cyclic extension of T_g μ s is used to collect multipath, while maintaining the orthogonality of the tones. The transmitter energy increases with the length of the guard time while the receiver energy remains the same (the cyclic extension is discarded), so there is a $10\log(1 - T_g/(T_b + T_g))/\log(10)$ dB loss in SNR. Using a cyclic extension, the samples required for performing the FFT at the receiver can be taken anywhere over the length of the extended symbol. This provides multipath immunity as well as a tolerance for symbol time synchronization errors.

The CP overhead fraction can be reduced by using larger FFT intervals (i.e. a larger FFT size). Larger FFT intervals do however, among others, adversely affect the sensitivity of the system to phase noise of the oscillators. To facilitate a choice in this tradeoff, the designed PHY provides for various FFT sizes.

8.3.5.1.3 Frequency Domain Description

The frequency domain description includes the basic structure of an OFDM symbol.

An OFDM symbol is made up from carriers, the amount of carriers determines the FFT size used. There are several carrier types:

- Data carriers - for data transmission
- Pilot carriers - for different estimation purposes
- Null carriers - no transmission at all, for guard bands and DC carrier.

Figure 214 illustrates such a scheme:

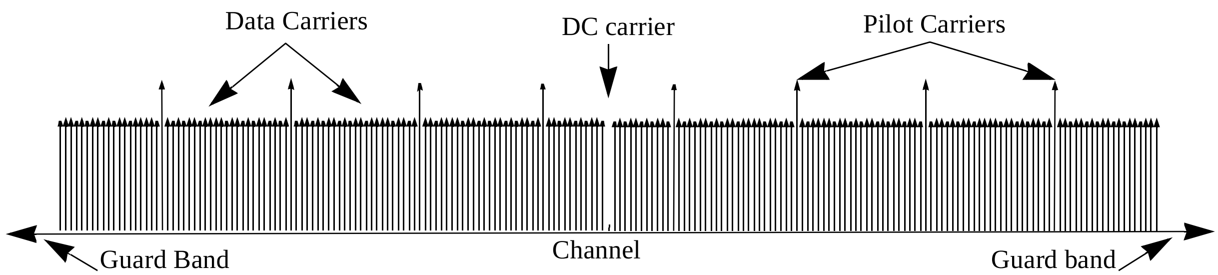

Figure 214—OFDM frequency description (256-FFT example)

The purpose of the guard bands is to enable the signal to naturally decay and create the FFT "brick Wall" shaping.

In the OFDMA mode, only part of all active carriers may be used by the transmitter, the different carriers of which may be intended for different (groups of) receivers. A set of carriers intended for one (group of) receiver(s) is termed a subchannel. The carriers forming one subchannel may, but need not be adjacent. The concept is shown in Figure 215.

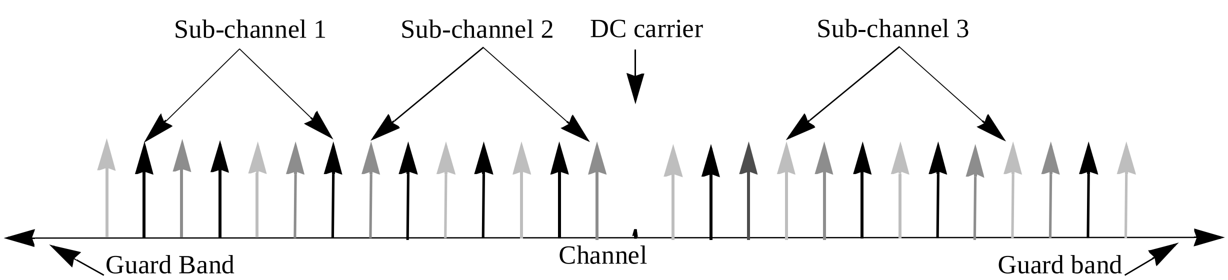

Figure 215—OFDMA frequency description (3 channel schematic example)

The symbol is divided into logical sub-channels to support scalability, multiple access, and advanced antenna array processing capabilities. The sub-channel structure will depend on the purpose for the sub-channelization. For wide-band processing, the mapping is based upon a special permutation code, which distributes consecutive symbols across the available bandwidth.

The number of carriers in the OFDMA mappings assigned to each subchannel is independent of the FFT size. For example doubling the FFT size hence results in twice the number of subchannels which creates a very modular approach.

The usage of OFDMA result in systems that have more implementation complexity, but can provide several advantages.

- Frequency diversity:Possible random spreading of subchannel carriers across the frequency band
- Power concentration: Same power distributed on fewer carriers (most usable on the SS), providing up to 15 dB gain
- Forward Power Control: Digital allocation of different power amplification to the Sub-Channels most usable on the Base-Station side), providing up to 6 dB concentration gain.

8.3.5.1.4 Overview of OFDM Symbol Parameters

The following tables give some calculations of the Carrier Spacing, Symbol Duration and Guard Interval duration for different masks. The sampling frequency is defined as $F_s = BW \cdot 8/7$ (see clause 8.3.5.3.4.1 and 8.3.5.4.4) with the following exceptions. When using 64-FFT in the U-NII band the sampling rate is $F_s = BW$ (see clause 8.3.5.3.3.1, 8.3.5.4.3.1). When using 256 or 512 FFT in a licensed band, $F_s = BW \cdot 7/6$ (see clause 8.3.5.3.3.1)..

Table 209—MMDS Channelization Parameters

			OFDM		**OFDMA**	
	$F_s/(BW)$		**7/6**		**8/7**	
BW(MHz)	N_{FFT}		**256**	512	**2048**	4096
1.5	$\Delta f(kHz)$		**6 51/61**	3 28/67	**36/43**	18/43
	$BW_{Efficiency}$		**91.60%**	91.37%	**94.64%**	94.64%
	$T_b(\mu s)$		**146 2/7**	292 4/7	**1194 2/3**	2389 1/3
	T_g/T_b	1/32	**4 4/7**	9 1/7	**37 1/3**	74 2/3
		1/16	**9 1/7**	18 2/7	**74 2/3**	149 1/3
		1/8	**18 2/7**	36 4/7	**149 1/3**	298 2/3
		1/4	**36 4/7**	73 1/7	**298 2/3**	597 1/3
3	$\Delta f(kHz)$		**13 43/64**	6 51/61	**1 60/89**	36/43
	$BW_{Efficiency}$		**91.60%**	91.37%	**94.64%**	94.64%
	$T_b(\mu s)$		**73 1/7**	146 2/7	**597 1/3**	1194 2/3
	T_g/T_b	1/32	**2 2/7**	4 4/7	**18 2/3**	37 1/3
		1/16	**4 4/7**	9 1/7	**37 1/3**	74 2/3
		1/8	**9 1/7**	18 2/7	**74 2/3**	149 1/3
		1/4	**18 2/7**	36 4/7	**149 1/3**	298 2/3

Table 209—MMDS Channelization Parameters

			OFDM		**OFDMA**	
	$F_s/(BW)$		**7/6**		**8/7**	
BW(MHz)	N_{FFT}		**256**	512	**2048**	4096
6	$\Delta f(kHz)$		**27 11.32**	13 43/64	**3 8/23**	1 60/89
	$BW_{Efficiency}$		**91.60%**	91.37%	**94.64%**	94.64%
	$T_b(\mu s)$		**36 4/7**	73 1/7	**298 2/3**	597 1/3
	T_g/T_b	1/32	**1 1/7**	2 2/7	**9 1/3**	18 2/3
		1/16	**2 2/7**	4 4/7	**18 2/3**	37 1/3
		1/8	**4 4/7**	9 1/7	**37 1/3**	74 2/3
		1/4	**9 1/7**	18 2/7	**74 2/3**	149 1/3
12	$\Delta f(kHz)$		**54 11/16**	27 11/32	**6 39/56**	3 8/23
	$BW_{Efficiency}$		**91.60%**	91.37%	**94.64%**	94.64%
	$T_b(\mu s)$		**18 2/7**	36 4/7	**149 1/3**	298 2/3
	T_g/T_b	1/32	**4/7**	1 1/7	**4 2/3**	9 1/3
		1/16	**1 1/7**	2 2/7	**9 1/3**	18 2/3
		1/8	**2 2/7**	4 4/7	**18 2/3**	37 1/3
		1/4	**4 4/7**	9 1/7	**37 1/3**	74 2/3
24	$\Delta f(kHz)$		**109 3/8**	54 11/16	**13 11/28**	6 39/56
	$BW_{Efficiency}$		**91.60%**	91.60%	**94.64%**	94.64%
	$T_b(\mu s)$		**9 1/7**	18 2/7	**74 2/3**	149 1/3
	T_g/T_b	1/32	**2/7**	4/7	**2 1/3**	4 2/3
		1/16	**4/7**	1 1/7	**4 2/3**	9 1/3
		1/8	**1 1/7**	2 2/7	**9 1/3**	18 2/3
		1/4	**2 2/7**	4 4/7	**18 2/3**	37 1/3

Table 210—ETSI Channelization Parameters

			OFDM		OFDMA	
	F_s/BW		**7/6**		**8/7**	
BW(MHz)	N_{FFT}		**256**	512	**2048**	4096
1.75	$\Delta f kHz)$		**7 79/81**	3 80/81	**83/85**	21/43
	$BW_{Efficiency}$		**91.60%**	91.37%	**94.64%**	94.64%
	$T_b(\mu s)$		**125 19/49**	250 38/49	**1024**	2048
	T_g/T_b	1/32	**3 45/49**	7 51/49	**32**	64
		1/16	**7 41/49**	15 33/49	**64**	128
		1/8	**15 33/49**	31 17/49	**128**	256
		1/4	**31 17/49**	62 34/49	**256**	512
3.5	$\Delta f(kHz)$		**15 77/81**	7 79/81	**1 61/64**	83/85
	$BW_{Efficiency}$		**91.60**	91.37%	**94.64%**	94.64%
	$T_b(\mu s)$		**62 34/49**	125 19/49	**512**	1024
	T_g/T_b	1/32	**1 47/49**	3 45/49	**16**	32
		1/16	**3 45/49**	7 41/49	**32**	64
		1/8	**7 41/49**	15 33/49	**64**	128
		1/4	**15 33/49**	31 17/49	**128**	256
7	$\Delta f(kHz)$		**31 82/91**	15 77/81	**3 29/32**	1 61/64
	$BW_{Efficiency}$		**91.60%**	91.37%	**94.64%**	94.64%
	$T_b(\mu s)$		**31 17/49**	62 34/49	**256**	512
	T_g/T_b	1/32	**48/49**	1 47/49	**8**	16
		1/16	**1 47/49**	3 45/49	**16**	32
		1/8	**3 45/49**	7 41/79	**32**	64
		1/4	**7 41/49**	15 33/49	**64**	128

Table 210—ETSI Channelization Parameters

			OFDM		OFDMA	
	F_s/BW		**7/6**		**8/7**	
BW(MHz)	N_{FFT}		**256**	512	**2048**	4096
14	$\Delta f(kHz)$		**63 77/96**	31 82/91	**7 13/16**	3 29/32
	$BW_{Efficiency}$		**91.60%**	91.37%	**94.64%**	94.64%
	$T_b(\mu s)$		**15 33/49**	31 17/49	**128**	256
	T_g/T_b	1/32	**24/49**	48/49	**4**	8
		1/16	**48/49**	1 47/49	**8**	16
		1/8	**1 47/49**	3 45/49	**16**	32
		1/4	**3 45/49**	7 41/49	**32**	64
28	$\Delta f(kHz)$		**127 29/48**	63 77/96	**15 5/8**	7 13/16
	$BW_{Efficiency}$		**91.60%**	91.37%	**94.64%**	94.64%
	$T_b(\mu s)$		**7 41/49**	15 33/49	**64**	128
	T_g/T_b	1/32	**12/49**	24/49	**2**	4
		1/16	**24/49**	48/49	**4**	8
		1/8	**48/49**	1 47/49	**8**	16
		1/4	**1 47/49**	3 45/49	**16**	32

Table 211—PCS/WCS Channelization Parameters

			OFDM		OFDMA	
	F_s/BW		**7/6**		**8/7**	
$BW(MHz)$	N_{FFT}		**256**	512	**2048**	4096
2.5	$\Delta fkHz)$		**11 35/89**	5 62/89	**1 32/81**	30/43
	$BW_{Efficiency}$		**91.60%**	91.37%	**94.64%**	94.64%
	$T_b(\mu s)$		**87 27/35**	175 19/35	**716 4/5**	1433 3/5
	T_g/T_b	1/32	**2 26/35**	5 17/35	**22 2/5**	44 4/5
		1/16	**5 17/35**	10 34/35	**44 4/5**	89 3/5
		1/8	**10 34/35**	21 33/35	**89 3/5**	179 1/5
		1/4	**21 33/35**	43 31/35	**179 1/5**	358 2/5
5	$\Delta f(kHz)$		**22 70/89**	11 35/89	**2 64/81**	1 32/81
	$BW_{Efficiency}$		**91.60%**	91.37%	**94.64%**	94.64%
	$T_b(\mu s)$		**43 31/35**	87 27/35	**358 2/5**	716 4/5
	T_g/T_b	1/32	**1 13/35**	2 26/35	**11 1/5**	22 2/5
		1/16	**2 26/35**	5 17/35	**22 2/5**	44 4/5
		1/8	**5 17/35**	10 34/35	**44 4/5**	89 3/5
		1/4	**10 34/35**	21 33/35	**89 3/5**	179 1/5
10	$\Delta f(kHz)$		**45 55/96**	22 70/89	**5 47/81**	2 64/81
	$BW_{Efficiency}$		**91.60%**	91.37%	**94.64%**	94.64%
	$T_b(\mu s)$		**21 33/35**	43 31/35	**179 1/5**	358 2/5
	T_g/T_b	1/32	**24/35**	1 13/35	**5 3/5**	11 1/5
		1/16	**1 13/35**	2 26/35	**11 1/5**	22 2/5
		1/8	**2 26/35**	5 17/35	**22 2/5**	44 4/5
		1/4	**5 17/35**	10 34/35	**44 4/5**	89 3/5
15	$\Delta f(kHz)$		**68 23/64**	34 16/89	**8 10/27**	4 5/27
	$BW_{Efficiency}$		**91.60%**	91.37%	**94.64%**	94.64%
	$T_b(\mu s)$		**14 22/35**	29 9/35	**119 7/15**	238 14/15
	T_g/T_b	1/32	**16/35**	32/35	**3 11/15**	7 7/15
		1/16	**32/35**	1 29/35	**7 7/15**	14 14/15
		1/8	**1 29/35**	3 23/35	**14 14/15**	29 13/15
		1/4	**3 23/35**	7 11/35	**29 13/15**	59 11/15

Table 212—U-NII Channelization Parameters

			OFDM		OFDMA
	$F_s/(BW$		**1**	**8/7**	8/7
BW(MHz)	N_{FFT}		**64**	**256**	2048
5 (Optional)	$\Delta fkHz)$		78/18	22 9/28	2 64/81
	$BW_{Efficiency}$		82.81%	89.73%	94.64%
	$T_b(\mu s)$		12 4/5	44 4/5	358 2/5
	T_g/T_b	1/32		1 2/5	11 1/5
		1/16	4/5	2 4/5	
		1/8	1 3/5	5 3/5	
		1/4	3 /15		
10	$\Delta f(kHz)$		**156 1/4**	**44 9/14**	5 47/81
	$BW_{Efficiency}$		**82.81%**	**89.73%**	94.64%
	$T_b(\mu s)$		**6 2/5**	**22 2/5**	179 1/5
	T_g/T_b	1/32		**7/10**	5 3/5
		1/16		**1 2/5**	11 1/5
		1/8	**4/5**	**2 4/5**	
		1/4	**1 3/5**	**5 3/5**	
20	$\Delta f(kHz)$		**312 1/2**	**89 2/7**	11 9/56
	$BW_{Efficiency}$		**82.81%**	**91.60**	94.64%
	$T_b(\mu s)$		**3 1/5**	**11 1/5**	89 3/5
	T_g/T_b	1/32			2 4/5
		1/16		**7/10**	5 3/5
		1/8		**1 2/5**	11 1/5
		1/4	**4/5**	**2 4/5**	

8.3.5.1.5 Basic performance parameters

In Table 213, raw bitrates are shown for typical bandwidths.

Table 213—Raw bitrates (Mbps)

BW (MHz)	T_g / T_b	BPSK 1/2	BPSK 3/4	QPSK 1/2	QPSK 3/4	16-QAM 1/2	16QAM 3/4	64QAM 2/3	64QAM 3/4
OFDM 256-FFT									
6 MHz (MMDS)	1/32	N/A	N/A	5.09	7.64	10.18	15.27	20.36	22.91
	1/16	N/A	N/A	4.94	7.41	9.88	14.82	19.76	22.24
	1/8	N/A	N/A	4.67	7.00	9.33	14.00	18.67	21.00
	1/4	N/A	N/A	4.20	6.30	8.40	12.60	16.80	18.90
7 MHz (ETSI)	1/32	N/A	N/A	5.94	8.91	11.88	17.82	23.76	26.73
	1/16	N/A	N/A	5.76	8.65	11.53	17.29	23.06	25.94
	1/8	N/A	N/A	5.44	8.17	10.89	16.33	21.78	24.50
	1/4	N/A	N/A	4.90	7.35	9.80	14.70	19.60	22.05
20 MHz (U-NII)	1/16	8.07	12.10	16.13	24.20	32.27	48.40	64.54	72.61
	1/8	7.62	11.43	15.24	22.86	30.48	45.71	60.95	68.57
	1/4	6.86	10.29	13.71	20.57	27.43	41.14	54.86	61.71
OFDMA 2048-FFT									
6 MHz (MMDS)		N/A	N/A	4.99	7.48	9.97	14.96	19.95	22.44
		N/A	N/A	4.84	7.26	9.68	14.52	19.36	21.78
		N/A	N/A	4.57	6.86	9.14	13.71	18.29	20.57
		N/A	N/A	4.11	6.17	8.23	12.34	16.46	18.51
7 MHz (ETSI)		N/A	N/A	5.82	8.73	11.64	17.45	23.27	26.18
		N/A	N/A	5.65	8.47	11.29	16.94	22.59	25.41
		N/A	N/A	5.33	8.00	10.67	16.00	21.33	24.00
		N/A	N/A	4.80	7.20	9.60	14.40	19.20	21.60

8.3.5.2 Common elements

8.3.5.2.1 PMP Frame structure

When implementing a TDD system, the frame structure is built from BS and SS transmissions. Each burst transmission consists of one or more OFDM symbols. The cell radius is dependent on the time left open for initial system access. This time should be at least equal to the maximum tolerable round trip delay plus the number of OFDM symbols necessary to transmit the ranging burst. Further, in each frame, the TX/RX transition gap (TTG) and RX/TX transition gap (RTG) need to be inserted between the downlink and uplink and at the end of each frame respectively to allow the BS to turn around (time plan for a single frame is shown in Figure 216). The sum of TTG and RTG should be 2µs plus a multiple of Ts. For license-exempt implementations, TDD is the only duplexing arrangement allowed.

In FDD systems there is no need for TTG and RTG as the downlink and uplink transmit on independent frequencies (for H-FDD terminals, scheduling rules should avoid TX and RX activity of the same terminal within the TTG and RTG gap time).

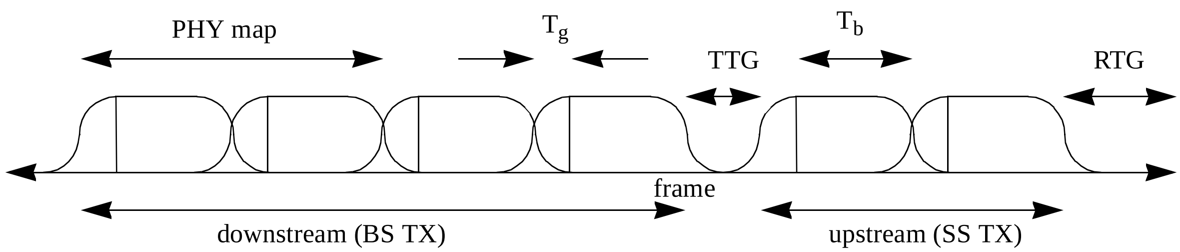

Figure 216—Time Plan - One TDD time frame

8.3.5.2.2 Multiple Antenna Technology (optional)

Employing adaptive antenna arrays can increase the spectral efficiency linearly with the number of antenna elements. This is achieved by steering beams to multiple users simultaneously so as to realize an inter-cell frequency reuse of one and an in-cell reuse factor proportional to the number of antenna elements. An additional benefit is the gain in signal strength (increased SNR) realized by coherently combining multiple signals, and the ability to direct this gain to particular users. This is in contrast to sectored antenna approaches where most users are not in the direction of maximum antenna gain. Another benefit is the reduction in interference (increased signal to interference plus noise ratio, SINR) achieved by steering nulls in the direction of co-channel interferers.

The benefits of adaptive arrays can be realized for both the uplink and downlink signals using retro directive beam forming concepts in TDD systems, and to some extent in FDD systems using channel estimation concepts. These techniques do not require multiple antennas at the SS, although further benefits can be achieved by doing this.

Further benefits can be realized by combining adaptive antenna arrays with frequency spreading. These techniques are based on Stacked Carrier Spread Spectrum implementations.

Adaptive array could be designed to accommodate Narrow Band or Broad Band systems, support for narrow band system is optional and achieved by defining the Sub-Channel carriers to be adjunct. The system inherently supports Broad Band channels, by using any other symbol structure (including the one were carriers of a sub-Channel are allocated adjunct).

When using Broad Band allocations in a Broad Band channel (up to 28MHz) there are several methods used to design adaptive arrays which are well known [B41], this methods could comprise the use of matched receivers (amplitude and phase all over the band). Another method could comprise the use of non-matched receivers were processing could be done in the Base Band (by first sending internal testing signals and tuning the arrays in the Base Band, easily implemented for OFDM modulation, which is a frequency domain processing).

8.3.5.2.2.1 Transmit diversity Alamouti's Space-Time Coding

Alamouti's scheme [B42] is used on the downlink to provide (Space) transmit diversity of 2nd order.

There are two transmit antennas on the BTS side and one reception antenna on the SS side. This scheme requires Multiple Input Single Output -MISO- channel estimation. Decoding is very similar to maximum ratio combining.

Figure 217 shows Alamouti scheme insertion into the OFDM chain. Each Tx antenna has its own OFDM chain, but they have the same Local Oscillator for synchronization purposes.

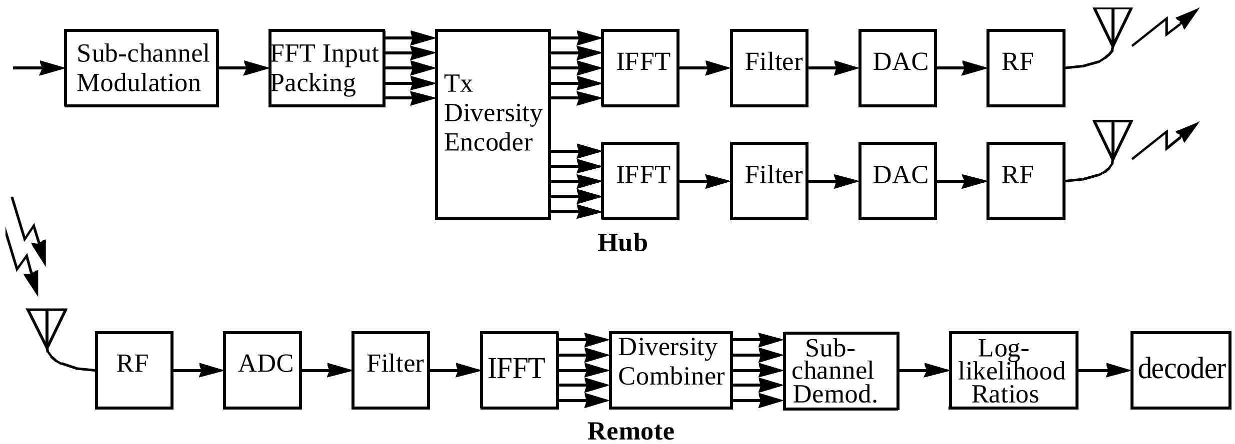

Figure 217—Illustration of the Alamouti STC

Both antennas transmit in the same time 2 different OFDM data symbols. Transmission is performed twice so as to decode and get 2nd order diversity. Time domain (Space-Time) repetition is used.

8.3.5.2.2.2 MISO channel estimation and synchronization

Both antennas transmit in the same time, and they share the same Local Oscillator. Thus, received signal has exactly the same auto-correlation properties as in the 1 Tx mode. Time and frequency coarse and fine estimation can so be performed in the same way as in the 1 Tx mode. The scheme requires MISO channel estimation, which is allowed by splitting some preambles and pilots between the 2 Tx antennas.

8.3.5.2.2.3 Alamouti STC Encoding

(Scheme explanation) The basic scheme [B42] transmits 2 complex symbols s0 and s1, using twice a MISO channel (two Tx, one Rx) with channel values h_0 (for antenna 0) and h_1 (for antenna 1).

First channel use: Antenna0 transmits s_0, antenna1 transmits s_1.

Second channel use: Antenna0 transmits $-s_1*$, antenna1 transmits s_0*.

Receiver gets r_0 (first channel use) and r_1 (second channel use) and computes s_0 and s_1 estimates:

$$\hat{s}_0 = h_0^* \cdot r_0 + h_1 \cdot r_1^* \quad (19)$$

$$\hat{s}_1 = h_1^* \cdot r_0 - h_0 \cdot r_1^* \quad (20)$$

These estimates benefit from 2nd order diversity as in the 1Tx-2Rx Maximum Ratio Combining scheme. OFDM/OFDMA symbols are taken by pairs. (equivalently, 2 Tx symbol duration is twice 1 Tx symbol duration, with twice more data in a symbol.) In the transmission frame , variable location pilots are kept identical for two symbols, that means that the modulo L of the transmission is held the same for the duration of two symbols. Alamouti's scheme is applied independently on each carrier, in respect to pilot tones positions.

Figure 218 shows Alamouti's scheme for OFDMA. Note that for OFDM, the scheme is exactly the same except that a pilot symbol is inserted before the data symbols. Also note that since pilot positions do not change from even to odd symbols, and pilots modulation is real, conjugation (and inversion) can be applied to a whole symbol (possibly in the time domain)

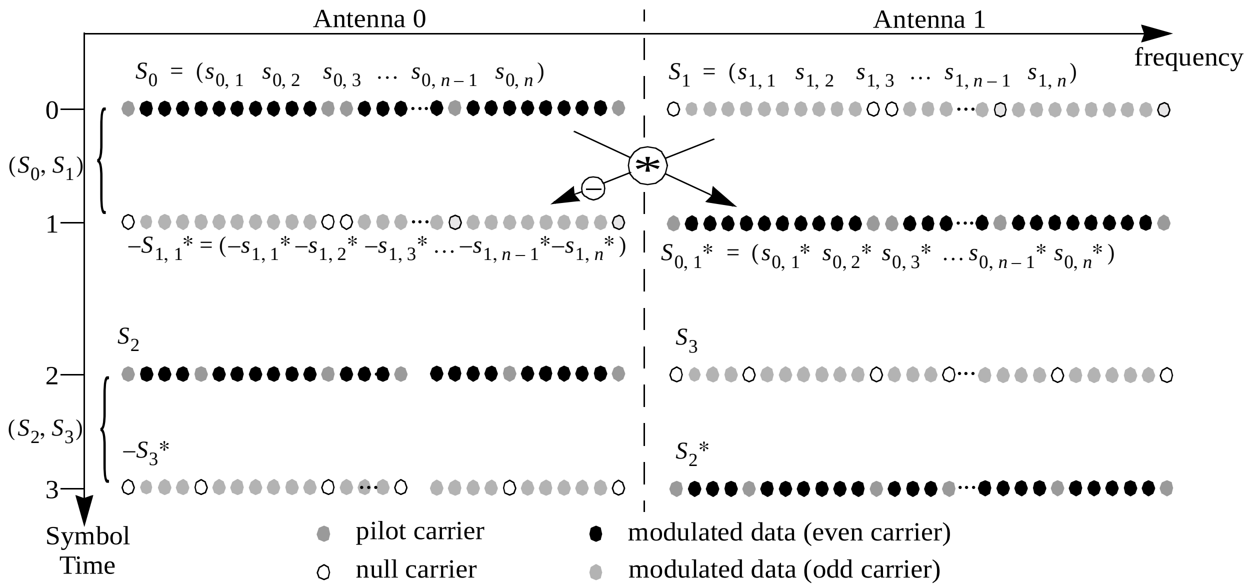

Figure 218—Alamouti Scheme Usage with OFDM/OFDMA

8.3.5.2.2.4 Alamouti STC Decoding

The receiver waits for 2 symbols, and combines them on a carrier basis according to the formula in clause 8.3.5.2.2.3.

8.3.5.3 OFDM PHY Layer for licensed bands

8.3.5.3.1 Introduction

This specification allows for FFT sizes 256, 512, 2048 and 4096. A compliant device shall implement either the mode A_L (256 FFT with TDMA), or alternatively mode B_L (2048 FFT with OFDMA) for any bandwidth. The 512 FFT with TDMA and 4096 FFT with OFDMA modes are optional.

8.3.5.3.2 Common elements

8.3.5.3.2.1 Channel Coding

8.3.5.3.2.1.1 Scrambling (Randomization)

Data randomization is performed on data transmitted on the DL and UL. The randomization is performed on each allocation (DL or UL), which means that for each allocation of a data block (Sub-Channels on the frequency domain and OFDM symbols on the time domain) the randomizer shall be used independently. If the amount of data to transmit does not fit exactly the amount of data allocated, padding of FFx ('1' only) shall be added to the end of the transmission block, up to the amount of data allocated.

The shift-register of the randomizer shall be initialized for each new allocation or for every 1250 bytes passed through (if the allocation is larger then 1250 bytes).

The Pseudo Random Binary Sequence (PRBS) generator shall be $1 + X^{14} + X^{15}$ as shown in Figure 219. Each data byte to be transmitted shall enter sequentially into the randomizer, MSB first. Preambles are not randomized.The seed value must be used to calculate the randomization bit,which is combined in an XOR with the first bit of data of each burst. The randomizer sequence is applied only to information bits.

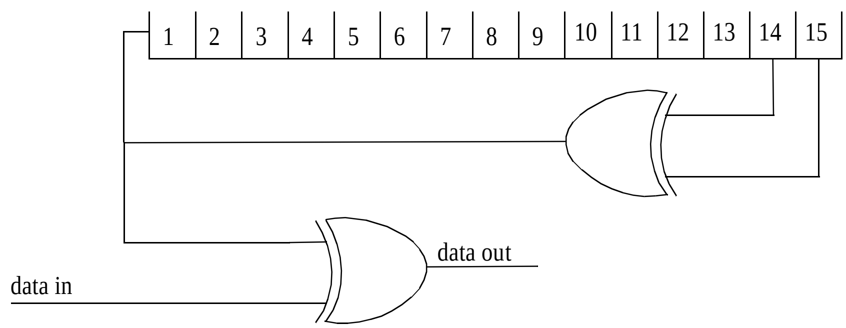

Figure 219—PRBS for Data Randomization

The bit issued from the randomizer shall be applied to the encoder.

In the downlink, the scrambler shall be re-initialized at the start of each frame with the sequence:

1 0 0 1 0 1 0 1 0 0 0 0 0 0 0.

The uplink initialization of the randomizer is defined for OFDM is defined in clause 8.3.5.3.3.2.1. and for OFDMA in clause 8.3.5.3.3.2.1.

8.3.5.3.2.1.2 FEC

Code rates of 1/2, 3/4 for QPSK and 16QAM are required. Additionally, code rates 2/3 and 3/4 shall be implemented when 64QAM (optional modulation) is supported. These coding rates shall be implemented using concatenated Reed Solomon and Convolutional codes. Optionally, Turbo Product Codes (TPC) may be implemented using the extended coding mode, as shown in 8.3.5.3.2.1.3.

The Reed-Solomon-Convolutional coding rate 1/2 shall be used as the coding mode when requesting access to the network.

8.3.5.3.2.1.2.1Tail Biting Code Termination

In order to allow sharing of the ECC decoder, each of the multiple data streams subdivides its data into RS blocks. In this mode, each RS block is encoded by a tail-biting convolutional encoder. In order to achieve a tail biting convolutional encoding the memory of the convolutional encoder shall be initialized with the last data bits of the RS packet (the packet data bits are numbered $b_b..b_n$).

8.3.5.3.2.1.3 Turbo Product Codes (Optional)

The Turbo Product Codes and shortening methods used for the OFDM PHY layer (licensed bands) are generically described in clause 8.3.3.1.5.3, with specific codes provided in clause 8.3.5.3.3.2.2.2 and 8.3.5.3.4.2.2.2.

8.3.5.3.2.1.4 Interleaving

The PRBS generator depicted in Figure 220 is used to achieve the bit interleaver array, it is initialized with the binary value:

0 0 0 1 0 1 1 0 1 0.

The PRBS generator produces an index value, which shall correspond to the new position of the input bit into the output interleaved data burst.

The interleaver shall use the following algorithm:

- The Interleaver indexes range from 1 to N, where N denotes the block size (defined in clause 8.3.5.3.3.2.3 and 8.3.5.3.4.2.3).
- For each input bit, the PRBS shall be rotated, the rotation produces a number, which is the value of the PRBS memory register.
- If the obtained number is bigger than N, it shall be discarded and the PRBS shall be rotated again. The rotation shall continue until an index between 1 to N is produced.
- The obtained index shall be used to address the position of the processed bit into the output interleaved data burst

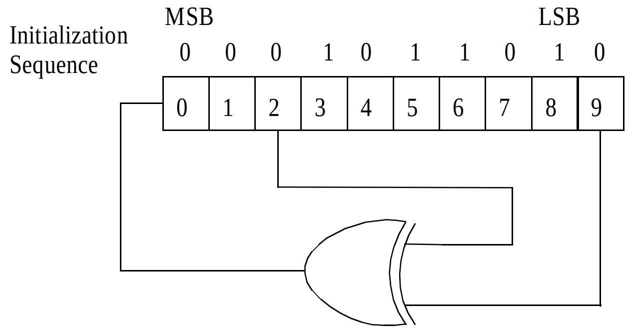

Figure 220—PRBS for Bit-Interleaver Array

8.3.5.3.2.2 Modulation

The modulation used both for the UL and DL data carrier is QPSK, 16QAM and optionally 64QAM. These modulations are used adaptively both in the UL and DL in order to achieve the maximum throughput for each link. The modulation on the DL can be changed for each allocation, to best fit the modulation for a specific user/users. For the UL, each user is allocated a modulation scheme, which is best suited for his needs.

The pilot carriers for the UL and DL are mapped using a BPSK modulation.

8.3.5.3.2.2.1 Data Modulation

After bit interleaving, the data bits are entered serially to the constellation mapper, which is shown in Figure 174. The constellations that must be supported are shown in Table 196 and Table 197. The complex number z in Figure 174, before mapping onto the carriers, shall be normalized to the value c as defined in Table 195.

The normalized constellation-mapped data shall be subsequently modulated onto the allocated data carriers. The data mapping shall be done by sequentially modulating these complex values onto the relevant carriers. The reference-normalizing factor is used for the UL, and the DL defined for 0dB boosting or attenuation. The normalizing factors used for attenuation and boosting are for DL use only, this is defined in the DL parameters for a specific burst type and is used for Forward APC.

8.3.5.3.2.2.2 Pilot Modulation

Pilot carriers shall be inserted into each data burst in order to constitute the Symbol and they shall be modulated according to their carrier location within the OFDM symbol.

The Pseudo Random Binary Sequence (PRBS) generator depicted hereafter, shall be used to produce a sequence, w_k.The polynomial for the PRBS generator shall be $X_{11} + X_2 + 1$.

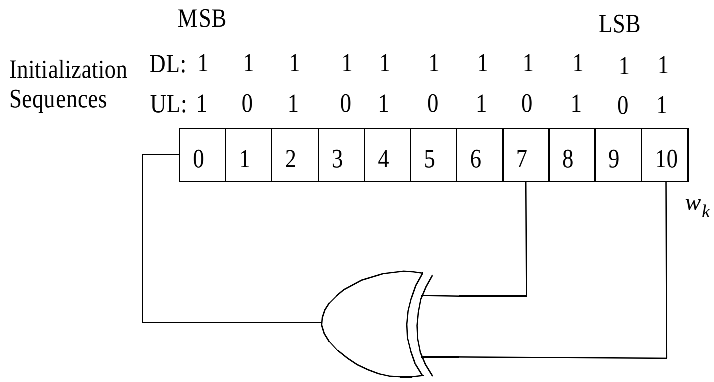

Figure 221—PRBS for pilot modulation

The value of the pilot modulation, on carrier k, shall be derived from w_k.

When using data transmission on the DL the initialization vector of the PRBS is: [11111111111] except in the OFDMA modes where for symbols which include the MAP information the PRBS is initialized with [01010101010]. When using data transmission on the UL the initialization vector of the PRBS will be: [10101010101]. The PRBS shall be initialized so that its first output bit coincides with the first usable carrier. A new value shall be generated by the PRBS on every usable carrier. For the PBRS allocation, the DC carrier and the side-band carriers are not considered as usable carriers.

Each pilot shall be transmitted with a boosting of 2.5 dB over the average power of each data tone. The Pilot carriers shall be modulated according to the following formula:

$$\Re\{C_k\} = \frac{8}{3}\left(\frac{1}{2} - w_k\right) \qquad \Im\{C_k\} = 0 \tag{21}$$

For preambles or midambles, the pilots shall not be boosted an shall be modulated according to the following formula:

$$\Re\{C_k\} = 2\left(\frac{1}{2} - w_k\right) \qquad \Im\{C_k\} = 0 \tag{22}$$

For Mode B, a ranging pilot modulation exception is defined in 8.3.5.3.4.3.1.3.

8.3.5.3.2.3 Framing Structure

The framing structure used for the DL includes the transmission of a PHY control and UL mapping, which is transmitted in the most robust coding and modulation of the system followed by transmission using modulation and coding schemes as defined in the PHY control. The MAC layer also defines the DL transmission frame length and the length of the different transmission parts. Figure 222 illustrates the DL framing:

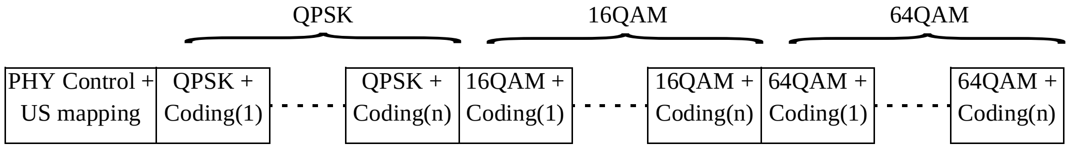

Figure 222—DL Frame Structure

In mode A_L, the transitions between modulations and coding takes place only on OFDM symbol boundaries, in mode B_L and C_L, the transition may take place on carriers within an OFDM symbol.

8.3.5.3.2.4 Control Mechanisms

Ranging for time (coarse synchronization) and power is performed during two phases of operation; during registration of a new subscriber unit either on first registration or on re-registration after a period TBD of inactivity; and second during FDD or TDD transmission on a periodic basis.

8.3.5.3.2.4.1 Synchronization

8.3.5.3.2.4.1.1Network Synchronization

For TDD realizations, all Base-Stations may have the facility to be time synchronized to a common timing signal. For FDD realizations, it is recommended (but not required) that all Base-Stations be time synchronized to a common timing signal. In the event of the loss of the network timing signal, Base-Stations shall continue to operating and shall automatically resynchronize to the network timing signal when it is recovered.

For both FDD and TDD realizations, frequency references derived from the timing reference may be used to control the frequency accuracy of Base-Stations provided that they meet the frequency accuracy requirements of clause 8.3.5.3.2.4.1.4. This applies during normal operation and during loss of timing reference.

8.3.5.3.2.4.1.2 Time Stamp, Frame Timing Reference

Each Base-Station and SS shall maintain a 32 bit system clock which is incremented as described in clause clause ???????.

Each Base-Station and SS shall have a facility to time stamp incoming OFDM or OFDMA symbols. The time stamp shall be an integer in the range from 0 to $2^{Ntimestamp}$-1. The time stamp shall be synchronized to the network timing.

Time stamps shall be automatically reacquired after the loss of time or frequency synchronization. Frame and symbol timing at the Base-Station and SS shall be derived from the synchronized timing epoch and the time stamp. SS cannot transmit payload data until time, frequency, frame and time stamp synchronization is achieved. A provision shall be made for time stamp rollover such that no ambiguity could occur across the network elements. This applies during normal operation and during loss of timing reference.

8.3.5.3.2.4.1.3 Guard Timing and Frame Timing

The Base-Station shall transmit an OFDM or OFDMA symbol coincident with the timing epoch.

The TDD guard timing between Basestation transmission and SS transmission (RTG) shall be adjustable in the range of TBD microseconds to TBD microseconds.

The TDD guard timing between SS transmission and Basestation transmission (TTG) shall be adjustable in the range of TBD microseconds to TBD microseconds.

8.3.5.3.2.4.1.4Subscriber Station Synchronization

For any duplexing all SSs shall acquire and adjust their timing such that all uplink OFDM symbols arrive time coincident at the Base-Station to a accuracy of +/- 30% of the guard-interval or better.

The frequency accuracy of the Base-Station RF and Base-Band reference clocks shall be at least 2ppm. The user reference clock could be at a 20ppm accuracy, and the user should synchronize to the DL and extract his clock from it, after synchronization the RF frequency would be accurate to 2% of the carrier spacing.

8.3.5.3.2.4.2 Ranging

During registration, a new subscriber registers during the random access channel and if successful is entered into a ranging process under control of the base station. The ranging process is cyclic in nature where default time and power parameters are used to initiate the process followed by cycles where (re)calculated parameters are used in succession until parameters meet acceptance criteria for the new subscriber. These parameters are monitored, measured and stored at the base station and transmitted to the subscriber unit for use during normal exchange of data. During normal exchange of data, the stored parameters are updated in a periodic manner based on configurable update intervals to ensure changes in the channel can be accommodated. The update intervals will vary in a controlled manner on a subscriber unit by subscriber unit basis.

Ranging on re-registration follows the same process as new registration. The purpose of the ranging parameter expiry is in support of portable applications capability. A portable subscriber unit's stored parameters will expire and are removed after the expiry intervals no longer consuming memory space and algorithm decision time.

8.3.5.3.3 Mode A_L - OFDM

8.3.5.3.3.1 OFDM Symbol Parameters

For any channel bandwidth *BW*, $F_s = BW \cdot 7/6$ and the mandatory FFT size is 256. FFT size 512 may be implemented.

The data symbol structure is made up of data carriers and constant location pilots. The number of data carriers and pilots depends on the FFT size being employed, but it is the same for up- and down-stream.

In Table 214, the DC carrier is numbered 0, whereas carrier numbers increase from the lowest to the highest frequency.

Table 214—Symbol Parameters

N_{FFT}	Parameter	Value	
256	N_{used}	200	
	Guard Carriers: Left, Right	28	27
	BasicConstantLocationPilots	{-84,-60,-36,-12,12,36,60,84}	
512	N_{used}	394	
	Guard Carriers: Left, Right	59	58
	BasicConstantLocationPilots	{-171,-133,-95,-57,-19,19,57,95,133,171}	

8.3.5.3.3.2 Channel Coding

Channel coding is composed of three steps: randomizer, forward error correction (FEC) and interleaving. They shall be applied in this order at transmission. The complementary operations shall be applied in reverse order at reception.

8.3.5.3.3.2.1 Uplink Scrambling (Randomization) Initialization

The scrambler (see clause 8.3.5.3.2.1.1) is initialized with the following vector.

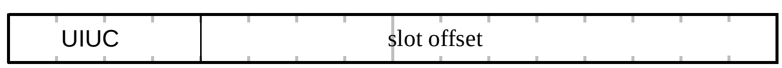

Figure 223—OFDM Randomizer Initialization vector

8.3.5.3.3.2.2 FEC

8.3.5.3.3.2.2.1Concatenated Reed Solomon and Convolutional Coding

The encoding is performed by first passing the data in block format through the RS encoder and then pass it through a tail biting convolutional encoder.

Table 215 gives the block sizes and the code rates used for the different modulations and code rates. As 64 QAM is optional, the codes for this modulation must only be implemented if the modulation is implemented.:

Table 215—Mandatory Channel Coding per Modulation

Modulation	Uncoded Block Size (Bytes)	Coded Block Size (bytes	Overall Coding Rate	RS Code	CC Code Rate
QPSK	24	48	1/2	(32,24,4)	2/3
QPSK	36	48	3/4	(40,36,2)	5/6
16 QAM	48	96	1/2	(64,48,8)	2/3
16 QAM	72	96	3/4	(80,72,4)	5/6
64 QAM	96	144	2/3	(108,96,6)	3/4
64 QAM	108	144	3/4	(120,108,6)	5/6

8.3.5.3.3.2.2.2Turbo Product Codes (Optional)

Table 216 gives the block sizes, code rates, channel efficiency, and code parameters for the different modulation and coding schemes.As 64 QAM is optional, the codes for this modulation must only be implemented if the modulation is implemented.

Table 216—Optional Channel Coding per Modulation

Modulation	DataBlock Size (Bytes)	Coded Block Size (Bytes)	Overal Code Rate	Efficiency (bit/s/Hz)	Constituent Codes	Code Parameter
QPSK	23	48	~1/2	1.0	(32,26)(16,11)	I_x=4,I_y=2,B=8
QPSK	35	48	~3/4	1.5	(8,7)(64,57)	I_x=14,I_y=9,B=1
16 QAM	58	96	~3/5	2.4	(32,26)(32,26)	I_x=0,I_y=8,B=0
16 QAM	78	96	~4/5	3.3	(16,15)(64,57)	I_x=4,I_y=3,B=12
64 QAM	92	144	~2/3	3.8	(64,57)(32,26)	I_x=16,I_y=8
64 QAM	120	144	~5/6	5.0	(32,31)(64,57)	I_x=13,I_y=3,B=7

8.3.5.3.3.2.3 Interleaving

A combination of a bit interleaver and a symbol interleaver is used to interleave the data over the frequency domain.

8.3.5.3.3.2.3.1 Bit Interleaving

Table 217 summarises the bit interleaver sizes as a function of modulation and coding.

Table 217—Number of Coded Bits in OFDM Bit Interleaved Block

96 Symbol Interleaver		N_{FFT}	
		256	**512**
Modulation	Coded bits per Bit Interleaved Block	Bit Interleaved Blocks per OFDM Symbol	
QPSK	192	2	4
16 QAM	384	2	4
64 QAM	576	2	4

8.3.5.3.3.2.3.2 Symbol (Sub-carrier) Interleaving

The symbol interleaver follows the modulation mapper, which follows bit-interleaver.

The symbol interleaving works as follows: data symbols coming from the modulation mapper are divided into N groups of 96 symbols each. Therefore, there will be 2 groups for 256-FFT: group 0 containing from symbol S_0 to Symbol S_{95}, and group 1 with symbols varying from S_{96} to S_{191}. In the case of 512 FFT, there will be 4 groups containing: group 0 symbols from S_0 to S_{95}, group 1 symbols from S_{96} to S_{191}, group 2 symbols from S_{192} to S_{287}, and group 3 symbols from S_{288} to S_{383}.

Once the groups have been formed, the symbols will applied to the IFFT processor assigning one symbol of each group to the available data carriers in the following way: $Carrier(n + N \cdot k) = group(n, k)$ where n=0,1..(N-1). k= 0,1,2...95. (pointer to elements in each group).

For example, for 512-FFT, the symbols will be applied to the carriers in the following way: S_0 ->C_0, S_1->C_4,...,S_{95}->C_{380}, S_{96}->C_1,..,S_{191}->C_{381}, S_{192}->C_2,..,S_{287}->C_{382}, S_{288}->C_3,.., S_{383}->C_{383}. This process is graphically explained in Figure 224.

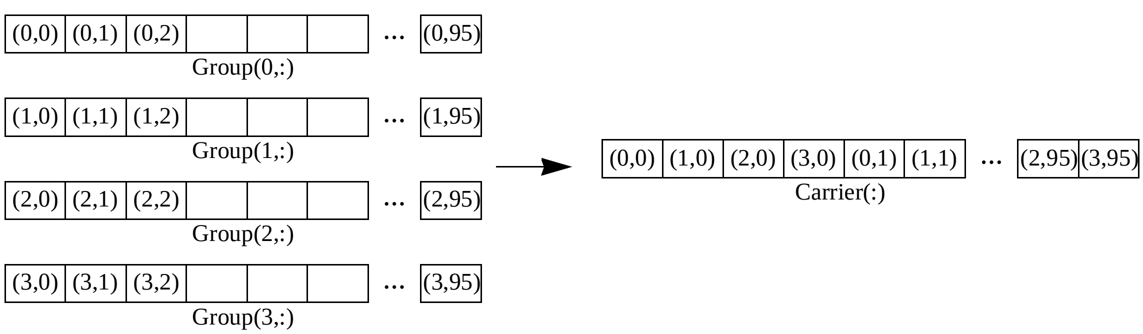

Figure 224—Symbol Interleaver for 512 FFT

8.3.5.3.3.3 Control Mechanisms

8.3.5.3.3.3.1 Ranging

In the OFDM mapping regular uplink bursts shall be used for ranging. The only difference is that an extended header shall be used in order to allow resolving larger timing uncertainty, arising from the propagation delay in large cells.

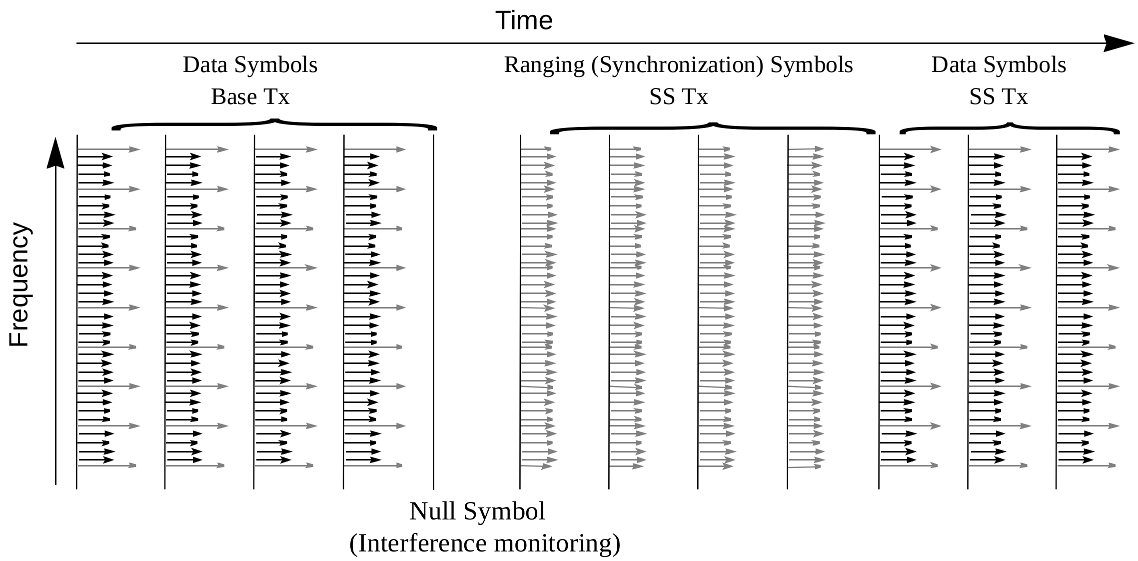

Figure 225—Ranging Symbol Allocation

8.3.5.3.3.3.2 Bandwidth requesting

Bandwidth requests in OFDM are contention based, wherein regular uplink bursts shall be used for bandwidth requests. Bandwidth requests are further provisioned by a piggy-back mechanism provided by the MAC.

The base station shall allocate a number of symbols every frame for bandwidth requests. This number of symbols shall be large enough to contain one or a multiple of long preamble uplink bursts with one OFDM symbol in data. SSs requiring bandwidth may, using a backoff mechanism, use these slots to request bandwidth.

8.3.5.3.3.3.3 Power Control

8.3.5.3.3.4 Frame structure

8.3.5.3.3.4.1 Uplink

The basic allocation for a user UL transmission is made up of a long preamble and an integer number of OFDM data symbols, adding more data symbols prolongs the transmission, while the short preamble is repeated every X data symbols transmission. Therefore the UL mapping is illustrated in Figure 226 (each block represents a symbol as depicted in Figure 225):

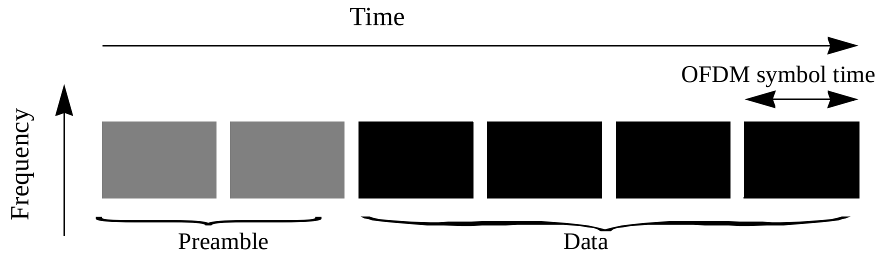

Figure 226—Mode A UL Framing

8.3.5.3.3.4.2 Downlink

Data is encoded as a single stream and the resulting stream is mapped to consecutive OFDM symbols. In every OFDM symbol, only one coding and constellation can be used to transmit data. Figure 227 illustrates a possible two-dimensional transmission mapping (every color represents a different Modulation and coding scheme, see also Figure 222).

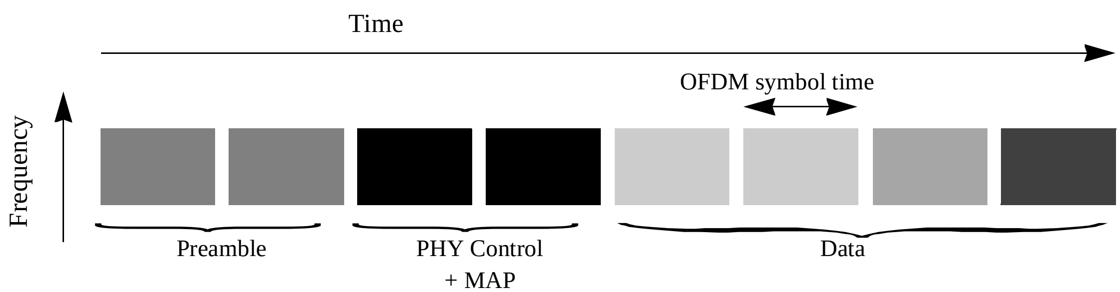

Figure 227—Mode A DL Framing

As shown in Figure 227, the DL frame starts with a preamble consisting of one or more pilot symbols.

8.3.5.3.3.5 Preamble structure

For both the downlink and uplink , the preamble consists of one OFDM symbol preceded by a cyclic prefix whose length is the same as the cyclic prefix in the traffic mode. This is illustrated in the following figure.

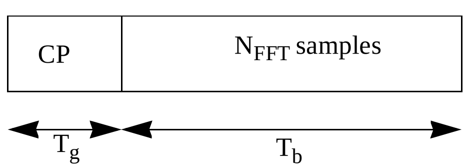

Figure 228—Basic preamble structure

8.3.5.3.3.6 Alamouti STC preambles (optional)

A long preamble is transmitted once, either by one or both antennas. It is used for coarse synchronization.

A short preamble is transmitted once, antenna 0 using even carriers, and antenna 1 odd carriers. This allows fine synchronization and MISO channel estimation. Each channel (0 & 1) is interpolated with very little loss according to channel model.

Another option for short preamble is to transmit it twice alternatively from antenna 0 then antenna 1 . This yields to a preamble overhead, but with better fine synchronization.

Pilots tones are used to estimate phase noise. There are transmitted alternatively (on a symbol basis) from one antenna or the other. Since both antennas have the same LO, there is no penalty on phase noise estimation.

8.3.5.3.4 Mode B_L - OFDMA

8.3.5.3.4.1 OFDMA Symbol Parameters

For 2048 and 4096-FFT, $F_s = BW \cdot 8/7$ for any channel bandwidth *BW*. For any channel bandwidth, the mandatory FFT size is 2048.

8.3.5.3.4.1.1 Downlink

The symbol structure for those FFT sizes is made up of constant and variable location pilots, which are spread all over the symbol, and from data carriers, which are divided into subchannels. The amount of Sub-Channels differs between the different FFT sizes.

First allocating the pilots and then mapping the rest of the carriers to Sub-Channels construct the OFDMA symbol. There are two kinds of pilots in the OFDM symbol:

- Constant location pilots - which are transmitted every symbol
- Variable location pilots - which shift their location every symbol with a cyclic appearance of 4 symbols

The variable pilots are inserted in the locations defined by the next formula: $k = 3L + 12P_v$

$k \in \{0, \ldots, N_{FFT} - 2\}$ Indices of usable carriers minus 1 (excludes DC carriers)

$L \in 0 \ldots 3$ denotes the symbol number with a cyclic period of 4

$P_v \geq 0$ is an integer number

The pilot's locations are illustrated in Figure 229:

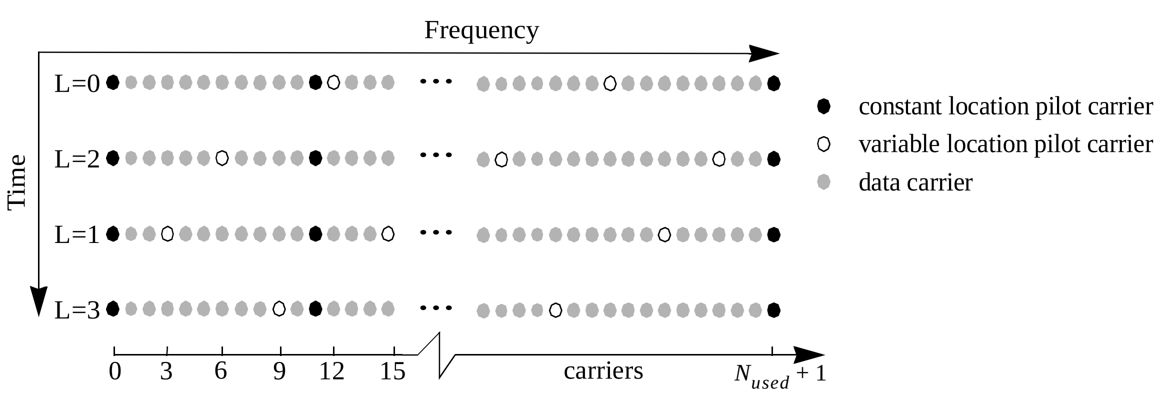

Figure 229—Pilot and data carrier location in DL OFDMA symbol

The symbols are transmitted with the following order L=0,2,1,3.

After mapping the pilots, the rest of the carriers (not including the DC carrier, which is not used) are data carriers scattered all over the usable spectrum (we should mention that the exact location of those carriers changes as a function of the symbol number which is modulo 4).

Allocation of carriers to Sub-Channels is achieved using the permutation algorithm below. ID_{cell} is a parameter which is assigned by the MAC to uniquely identify each cell in the system.

1. The usable carrier space is divided into N_{groups} basic groups. N_{groups} is equal to the number of carriers per subchannel (48 in DL and 53 in UL). Each basic group is made up of adjacent carriers. The number of the carriers in a basic group is equal to the number of possible subchannels. As a result of the carrier allocation procedure, each subchannel is built taking one carrier from each basic group.
2. We define a basic permutation $\{PermutationBase_0\}$, containing $N_{elements}$ elements. $N_{elements}$ is equal to the number of possible subchannels. Different permutations ($\{PermutationBase_s\}$) are achieved by cyclically rotating $\{PermutationBase_0\}$ to the left s times.
3. To get a $N_{subchannel}$ length series ($N_{subchannel}$ being the number of data carriers per subchannel) the permutated series are concatenated, until the concatenated series has at least $N_{subchannel}$ elements.
4. Let $p_s[j]$ (*j* starting from 0) be the *j*-th element of $\{PermutationBase_s\}$. The *k*-th element of the resulting concatenated series, $c_{s[k]}$, is obtained by:

$$c_s[k] = \{p_s[k_{mod(N_{elements})}] + ceil[(k+1)/N_{elements}] \cdot ID_{cell}\}_{mod(N_{elements})} \quad (23)$$

5. The last step achieves the carrier numbers allocated for the specific Sub-Channel with the current ID_{cell}. Using the next formula we achieve the $N_{subchannel}$ carriers (48 in DL, 53 in UL) of the current permutation in the cell:

$$carrier(n, s) = N_{elements} \cdot n + c_s[n] \quad (24)$$

Here carrier(n, s) is the n-th carrier of subchannel number s; n = 0,1...,52.

In order to achieve the DL Sub-Channels, the data carriers are grouped into one space (in acceding order of their indices) and then divided it into 48 basic groups (N_{groups} =48). Each group containing a certain amount of carriers, and then special permutations as described above are used to extract the Sub-Channels.

Table 218—Downlink Symbol Parameters

N_{FFT}	Parameter	Value	
2048 (2K)	N_{used}	1703	
	Guard Carriers: Left, Right	173	173
	Subchannels, data carriers/subchannel	32	48
	BasicConstantLocationPilots	{0,39, 261, 330, 342, 351, 522, 636, 645, 651, 708, 726, 756, 792, 849, 855, 918, 1017, 1143, 1155, 1158, 1185, 1206, 1260, 1407, 1419,1428, 1461, 1530,1545, 1572, 1701}	
	$\{PermutationBase_0\}$	{3, 18, 2, 8, 16, 10, 11, 15, 26, 22, 6, 9, 27, 20, 25, 1, 29, 7, 21, 5, 28, 31, 23, 17, 4, 24, 0, 13, 12, 19, 14, 30}	
4096 (4K)	N_{used}	3406	
	Guard Carriers: Left, Right	345	345
	Subchannels, data carriers/subchannel	64	48
	BasicConstantLocationPilots	{0, 39, 261, 330, 342, 351, 522, 636, 645, 651, 708, 726, 756, 792, 849, 855, 918, 1017, 1143, 1155, 1158, 1185, 1206, 1260, 1407, 1419, 1428, 1461, 1530, 1545, 1572, 1701, 1791, 1860, 1884, 1911, 1950, 2025, 2037, 2058, 2103, 2112, 2154, 2169, 2283, 2298, 2376, 2400, 2586, 2634, 2697, 2757, 2823, 2892, 2958, 3039, 3075, 3096, 3120, 3153, 3219, 3270, 3321, 3381, 3404}	
	$\{PermutationBase_0\}$	TBD	

8.3.5.3.4.1.2 Uplink

A subchannel is made up of 48 usable carriers and 5 pilot carriers. The UL subchannel structure is shown in Figure 230.

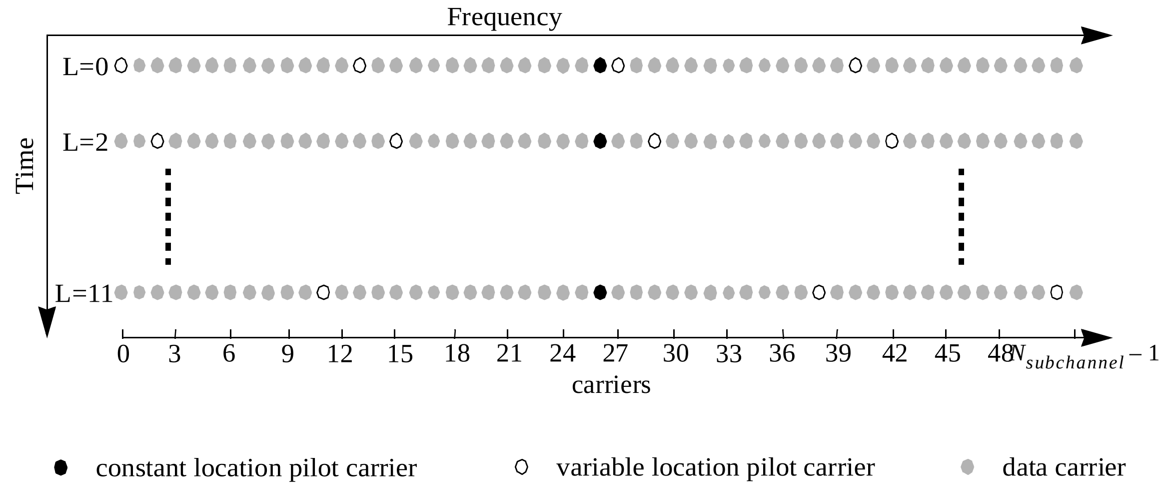

Figure 230—Pilot and data carrier Allocation of UL Sub-channel

The UL data symbol structure is comprised of data carriers and pilot carriers. The data symbols are produced with a modulo 13 repetition (L denotes the modulo 13 index of the symbol with indices 0..12), the location of the variable location pilots are shifted for every symbol produced, the first symbol (L=0) is produced after the all-pilot symbols (preamble), which consist of permutated carriers modulated according to 8.3.5.3.2.2.2. For L=0 the variable location pilots are positioned at indices: 0,13, 27,40 for other L these location vary by addition of L to those position, for example for L=5 variable pilots location are: 5,18, 32, 45. The UL Sub-Channel is also comprised of a constant pilot at the index 26. All other carriers (48) are data carriers, their location changes for every L, the transmission ordering of L is 0,2,4,6,8,10,12,1,3,5,7,9,11.

The whole UL OFDMA symbol is split into Sub-Channels as follows: The number of basic groups is 53 (N_{groups} =53) and they are allocated Y adjunct carriers, from the first usable carrier to the last (not including the DC carrier, which is not used). Then permutations (see clause 8.3.5.3.4.1.1, $N_{subchannel}$ =53) are used to extract the Sub-Channels.

The last method for defining the Sub-Channels involves programming by MAC message the carrier numbers for each Sub-Channel. Table 219 provides the applicable uplink symbol parameters:

Table 219—Uplink Symbol Parameters

N_{FFT}	Parameter	Value	
2048 (2K)	N_{used}	1696	
	Guard Carriers: Left, Right	176	175
	Subchannels, data carriers/subchannel	32	48
	$\{PermutationBase_0\}$	{3, 18, 2, 8, 16, 10, 11, 15, 26, 22, 6, 9, 27, 20, 25, 1, 29, 7, 21, 5, 28, 31, 23, 17, 4, 24, 0, 13, 12, 19, 14, 30}	
4096 (4K)	N_{used}	3392	
	Guard Carriers: Left, Right	352	353
	Subchannels, data carriers/subchannel	64	48
	$\{PermutationBase_0\}$	{TBD}	

8.3.5.3.4.1.3 Permutation Example

This clause is informative only.

For clarity, an example for using the permutation procedure with the UL 2048 mode is given. The relevant parameters characterizing the UL 2048 mode are as follow:

- Number of Sub-Channels: $N_{elements} = 32$
- Number of data carriers in subchannel: $N_{subchannel} = 48$
- Number of carriers in subchannel: $N_{groups} = 53$
- $\{PermutationBase_0\}$ = {3, 18, 2, 8, 16, 10, 11, 15, 26, 22, 6, 9, 27, 20, 25, 1, 29, 7, 21, 5, 28, 31, 23, 17, 4, 24, 0, 13, 12, 19, 14, 30}

Using the procedure defined in clause 8.3.5.3.4.1.1 does the allocating:

1 The basic series of 32 numbers is {3, 18, 2, 8, 16, 10, 11, 15, 26, 22, 6, 9, 27, 20, 25, 1, 29, 7, 21, 5, 28, 31, 23, 17, 4, 24, 0, 13, 12, 19, 14, 30}

2 In order to get 32 different permutation the series is rotated to the left (from no rotation at all up to 31 rotations). For the first permutation ($permutationbase_{s=1}$), we get the following series: {18, 2, 8, 16, 10, 11, 15, 26, 22, 6, 9, 27, 20, 25, 1, 29, 7, 21, 5, 28, 31, 23, 17, 4, 24, 0, 13, 12, 19, 14, 30, 3}

3 To get an $N_{subchannel} = 53$ length series we concatenate the permutated series 2 times (to get a 64 length series) and take the first 53 numbers only: {18, 2, 8, 16, 10, 11, 15, 26, 22, 6, 9, 27, 20, 25, 1, 29, 7, 21, 5, 28, 31, 23, 17, 4, 24, 0, 13, 12, 19, 14, 30, 3, 18, 2, 8, 16, 10, 11, 15, 26, 22, 6, 9, 27, 20, 25, 1, 29, 7, 21, 5, 28, 31, 23, 17, 4, 24, 0, 13, 12, 19, 14, 30, 3}.

4 The concatenation depends on the ID_{cell} (which characterizes the working cell and can range from 0 to 15). For example when using permutation s=1 with $ID_{cell} = 2$

$$c_1[k] = \{p_s[k_{mod(32)}] + 2 \cdot ceil[(k+1)/32]\}_{mod(32)} \qquad \text{with } k = 0, 1, \ldots, 52$$

$c_1[k]$ = {20, 4, 10, 18, 12, 13, 17, 28, 24, 8, 11, 29, 22, 27, 3, 31, 9, 23, 7, 30, 1, 25, 19, 6, 26, 2, 15, 14, 21, 16, 0, 7, 22, 6, 12, 20, 14, 15, 19, 30, 26, 10, 13, 31, 24, 29, 5, 1, 11, 25, 9, 0, 3}

5 The last step achieves the carrier indices allocated for the specific Sub-Channel with the current Cell Id. Using $carrier(n, 1)) = 32n + c_1[n]$,where $n = 0, 1, \ldots, 52$ the current permutation of subchannel 1 is found: {20, 36, 74, 114, 140, 173, 209, 252, 280, 296, 331, 381, 406, 443, 451, 511, 521, 567, 583, 638, 641, 697, 723, 742, 794, 802, 847, 878, 917, 944, 960, 999, 1046, 1062, 1100, 1140, 1166, 1199, 1235, 1278, 1306, 1322, 1357, 1407, 1432, 1469, 1477, 1505, 1547, 1593, 1609, 1632, 1667}.

8.3.5.3.4.2 Channel Coding

8.3.5.3.4.2.1 Uplink Scrambling (Randomization) Initialization

The scrambler (see clause 8.3.5.3.2.1.1) is initialized with the following vector

8LSB of the Slot Offset	Sub-channel Offset

Figure 231—OFDMA Randomizer Initialization Vector

8.3.5.3.4.2.2 FEC

8.3.5.3.4.2.2.1 Concatenated Reed Solomon and Convolutional Coding

The encoding is performed by first passing the data in block format through the RS encoder and then pass it through a tail biting convolutional encoder.

Table 220 gives the block sizes and the code rates used for the different modulations and code rates. As 64 QAM is optional, the codes for this modulation must only be implemented if the modulation is implemented.

Table 220—Mandatory Channel Coding per Modulation

Modulation	Uncoded Block Size (Bytes)	Overall Coding Rate	Coded Block Size (Bytes)	RS Code	CC Code Rate
QPSK	18	1/2	36	(24,18,3)	2/3
QPSK	26	~3/4	36	(30,26,2)	5/6
16 QAM	36	1/2	72	(48,36,6)	2/3
16 QAM	54	3/4	72	(60,54,3)	5/6
64 QAM	72	2/3	108	(81,72,4)	3/4
64 QAM	82	~3/4	108	(90,82,4)	5/6

8.3.5.3.4.2.2.2 Turbo Product Codes (Optional)

Table 221 gives the block sizes, code rates, channel efficiency, and code parameters for the different modulation and coding schemes.

Table 221—Optional Channel Coding per Modulation

Modulation	Data Block Size (Bytes)	Coded Block Size (Bytes)	Overall Coding Rate	Efficiency bit/s/Hz	Constituent Codes	Code Parameters
QPSK	16	36	~1/2	0.9	(32,26)(16,11)	I_x=11,I_y=17,B=6
QPSK	25	36	~2/3	1.4	(8,7)(64,57)	I_x=2,I_y=17
16 QAM	40	72	~3/5	2.2	(32,26)(32,26)	,I_x=8,I_y=8
16 QAM	56	72	~4/5	3.1	(16,15)(64,57)	I_x=4,I_y=16
64 QAM	68	108	~5/8	3.8	(32,26)(32,26)	I_x=0,I_y=5,B=0
64 QAM	88	108	~4/5	4.9	(32,31)(16,15)	I_x=0,I_y=10

8.3.5.3.4.2.3 Interleaving

Table 222 summarises the bit interleaver sizes as a function of modulation and coding.

Table 222—Bit Interleaved Block Sizes

Modulation	Coded Bits per Bit Interleaved Block
QPSK	288
16 QAM	576
64 QAM	864

8.3.5.3.4.3 Control Mechanisms

8.3.5.3.4.3.1 Ranging

Measurements of Time (ranging) and Power are performed by allocating several Sub-Channels to one Ranging Sub-Channel. Users are allowed to collide on this Sub-Channel. Each user randomly chooses one code from a bank of specified binary codes. These codes are modulated by BPSK on the contention Sub-channel. The Base Station can then separate colliding codes and extract timing (ranging) information and power. In the process of user code detection, the Base Station gets the Channel Impulse Response (CIR) of the code, thus acquiring for the Base Station vast information about the user channel and condition. The time (ranging) and power measurements allow the system to compensate for the near/far user problems and the propagation delay caused by large cells.

The usage of the Sub-Channels for ranging is done by the transmission of a Pseudo Noise (PN) code on the Sub-Channel allocated for ranging transmission. The code is always BPSK modulated and is produced by the PRBS described in Figure 232 (the PRBS polynomial generator shall be $1 + X^1 + X^4 + X^7 + X^{15}$):

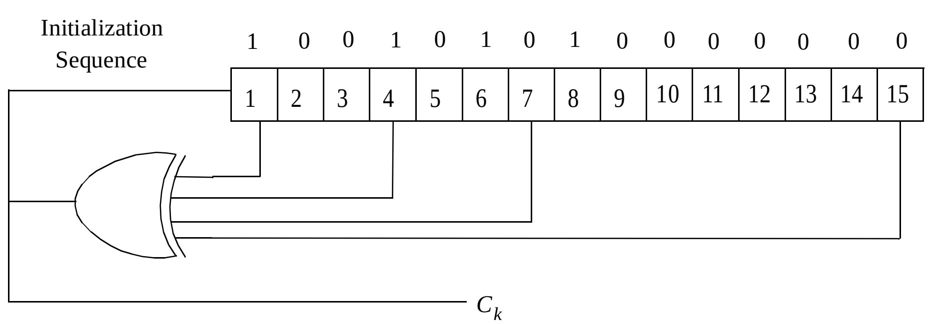

Figure 232—PRBS for Ranging Code Generation

Clocking the PRBS (where each clock produces one bit) subsequently produces the Ranging codes. The length of the ranging codes are multiples of 53 bits long (the default for the 2k mode is 2 Sub-Channels allocated as the ranging Sub-Channel therefore the ranging code length is 106), the codes produced are used for the next purposes:

- The first 16 codes produced are for First Ranging; it shall be used by a new user entering the system.

- The next 16 codes produced are used for maintenance Ranging for users that are already entered the system.
- The last 16 codes produced are for users, already connected to the system, issuing bandwidth requests.

These 48 codes are denoted as Ranging Codes and are numbered 0..47.

The number of active long ranging codes should be specified dynamically by the base station, and the default number should be set to two.

The MAC sets the number of Sub-Channels allocated for Ranging, these ranging Sub-Channels could be used concatenates as orders by the MAC in order to achieve a desired length.

8.3.5.3.4.3.1.1 Long Ranging transmission

The Long Ranging transmission shall be used by any SS that wants to synchronize to the system channel for the first time. A Long Ranging transmission shall be performed during the two first consecutive symbols of the UL frame. The same ranging code is transmitted during each symbol.

Sending for a consecutive period of two OFDMA signals a preamble shall perform the long ranging transmission. The preamble structure is defined by modulating one Ranging Code, up on the Ranging Sub-Channel carriers. There shall not be any phase discontinuity on the Ranging Sub-Channel carriers during the period of the Long Ranging transmission.

This Long Ranging transmission is allowed only on the Ranging Sub-Channel resources defined by the MAC process in the Base Station.

8.3.5.3.4.3.1.2 Short Ranging transmission

The Short Ranging transmission shall be used only by a SS that has already synchronized to the system. The Short Ranging transmission shall be used for system maintenance ranging or for fast bandwidth allocation requests.

To perform a Short Ranging transmission, the SS shall send a preamble for a period of one OFDM/OFDMA symbol in the duration of the ranging interval. The preamble structure is defined by modulating one Ranging Code on the Ranging Sub-Channel. This transmission may occur on any OFDM symbol out of the six available ranging symbols.

This Short Ranging transmission is allowed only on the Ranging Sub-Channel resources defined by the MAC process in the Base Station.

8.3.5.3.4.3.1.3 Ranging Pilot Modulation

When using the ranging Sub-Channels the user shall modulate the pilots according to the following formula:

$$\begin{aligned} \Re\{Carrier_k\} &= (1/2 - C_k)/6 \\ \Im\{Carrier_k\} &= 0 \end{aligned} \tag{25}$$

being, $Carrier_k$ the k^{th} carrier used within the set of carriers allocated for ranging whereas , and C_k depicts the k^{th} bit of the code generated according to clause 8.3.5.3.4.3.1.1

8.3.5.3.4.3.2 Bandwidth Requesting

The usage of the Sub-Channels for fast bandwidth request is done by the transmission of a Pseudo Noise (PN) code on the Sub-Channel allocated for ranging transmission (see clause 8.3.5.3.4.3.1). Bandwidth requests are further provisioned by a piggy-back mechanism provided by the MAC.

8.3.5.3.4.3.3 Power Control

8.3.5.3.4.4 Frame structure

8.3.5.3.4.4.1 Downlink

Each encoded frame of downlink information is transmitted on one subchannel over a period of three consecutive symbols. A downstream frame consists of N symbols, where the first symbol contains the carrier group, PHY control and uplink map. The remaining N-1 symbols containing data are orgainized as an integer number of groups of three symbols.

The transmission of the DL is performed on the subchannels of the OFDMA symbol, the amount of subchannels needed for the different transmissions (modulation and coding) and their mapping is defined in the PHY control. The mapping of the subchannels is performed in a two-dimensional grid, involving the subchannels in the frequency domain and OFDM symbols in the time domain.

8.3.5.3.4.4.2 Uplink

The basic allocation for a user UL transmission is made up of subchannels, a basic user allocation is made up of one Sub-Channel over duration of 4 OFDMA symbols. The first is a preamble and remaining are used for data transmission, adding more data symbols or subchannels increases the amount of data sent by the user, this allocation is presented in Figure 233:

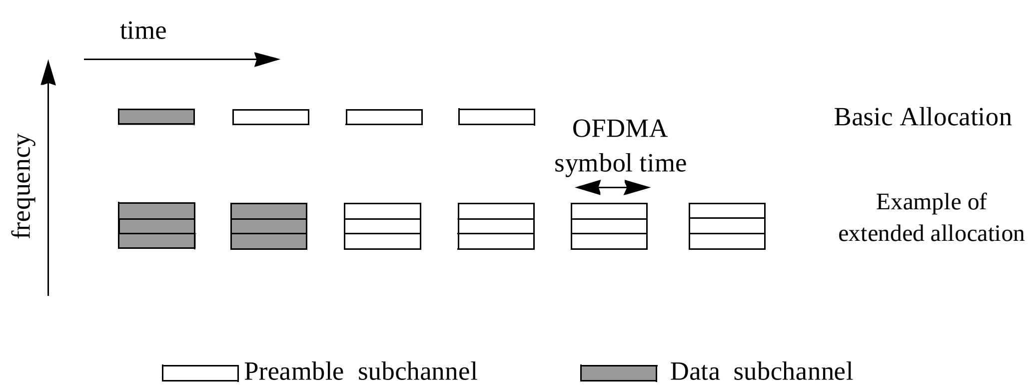

Figure 233—UL bandwidth Allocation

The framing structure used for the UL includes the transmission of a possible symbol for Jamming monitoring, an allocation for Ranging and an allocation for data transmission. The MAC sets the length of the UL framing, and the UL mapping.

The framing for these modes involve the allocation of ranging Sub-Channels within the OFDMA symbols, while the rest of the Sub-channels are used for users transmission, the UL mapping is illustrated in Figure 158. An optional Null symbol may be inserted to facilitate Jamming monitoring.

An example uplink burst showing two different subscribers with different PHY Burst structures and profiles is shown in Figure 234

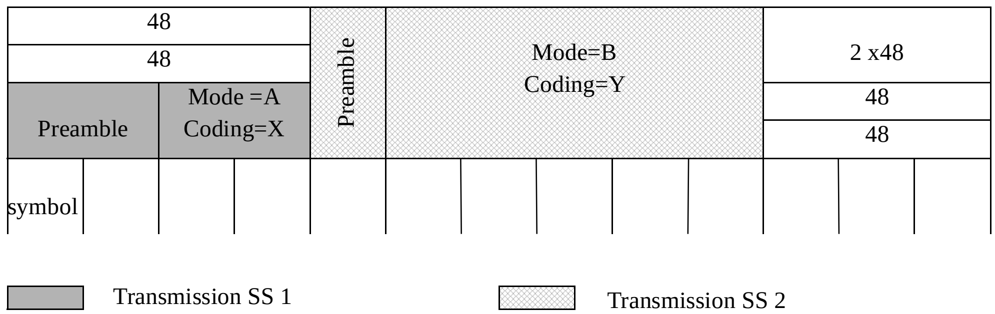

Figure 234—UL Burst definition Example #1

8.3.5.3.4.5 Alamouti STC preamble (optional)

Pilot tones are shared between the two antennas in time.

Again, synchronization, including phase noise estimation, is performed in the same way as with one Tx antenna. The estimation of the two channels is unchanged, but interpolation is more used (in the time domain).

8.3.5.3.5 Mode C_L (optional)

This mode specifies a mapping for advanced antenna array processing. Unless specified differently, clause 8.3.5.3.4 applies.

Mode C_L is based on a subchannel structure with 48 data carriers.

This mapping has the same fundamental subchannel tone utilization as Mode B_L. The main distinction between Mode B_L and Mode C_L is that the symbol data is assigned to adjacent carriers as indicated in the framing figures shown below. With Mode B_L, the framing figures depict logical subchannels since the carriers are actually distributed across the available frequency spectrum to mitigate against frequency selective fading. With Mode C_L, frequency selective fading is mitigated via spatial processing and spectral diversity.

Note that by using spatial processing, intracell (or intra-sector) spectral reuse is possible. Hence, multiple users will be assigned to overlapping OFDM symbols. This provides lower user latency when contention arises and higher system capacity. Spatial processing also provides beamforming gain and interference rejection via null steering. This, provides SINR improvements that result in reduced transmit power requirements or increased cell radii, and reduces the fade margin requirements due to spatial and spectral diversity combining.

8.3.5.3.5.1 Symbol Structure

Relative to Mode B_L, in this mapping the pilot and data carriers are assigned fixed positions in the frequency domain within an OFDM symbol.

8.3.5.3.5.2 Frame Format

8.3.5.3.5.2.1 Downlink

The frame format is described by a two-dimensional layout with subchannels in the frequency domain and OFDM symbols in the time domain. Figure 235 illustrates a generic two-dimensional downlink transmission mapping where the different colors and shading reflect different modulation and coding schemes. Figure 236 shows a specific example as an overlay to a Mode B_L mapping.

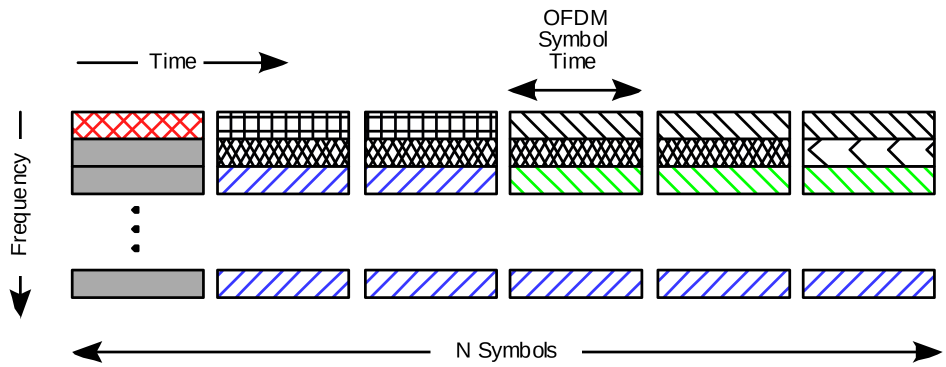

Figure 235—Downlink Framing

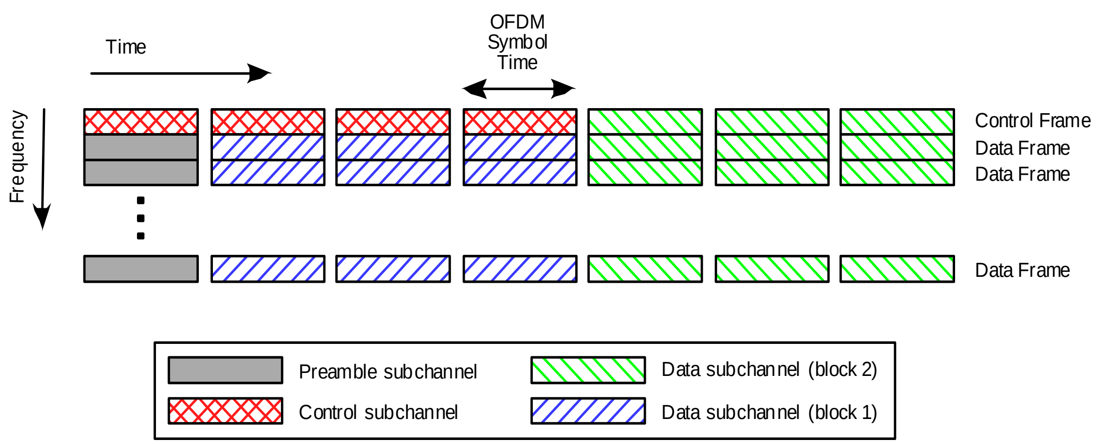

Figure 236—Downlink Framing, using Mode B Framing

8.3.5.3.5.2.2 Uplink

The framing structure is described by a layout with subchannels in the frequency domain and OFDM symbols in the time domain. The mapping shown in Figure 237 shows the generic uplink framing with N OFDM symbols. A frame may be a control frame or a data frame. A control frame has one or more control symbols. A data frame is comprised of a preamble symbol and data symbols. The mapping shown in Figure 238 with four OFDM symbols is one example, where the data frame is identical to the basic allocation in Mode B_L.

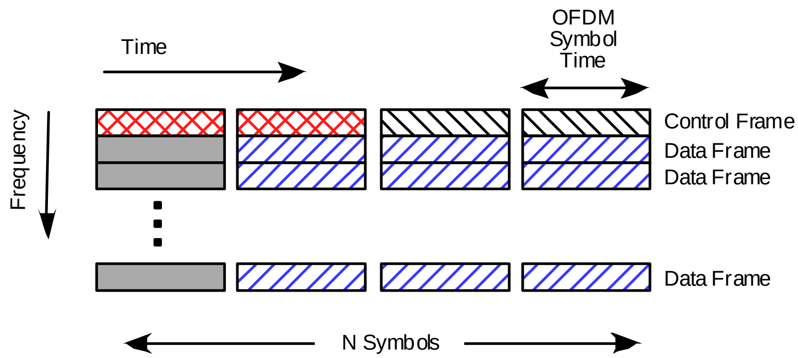

Figure 237—UL Framing

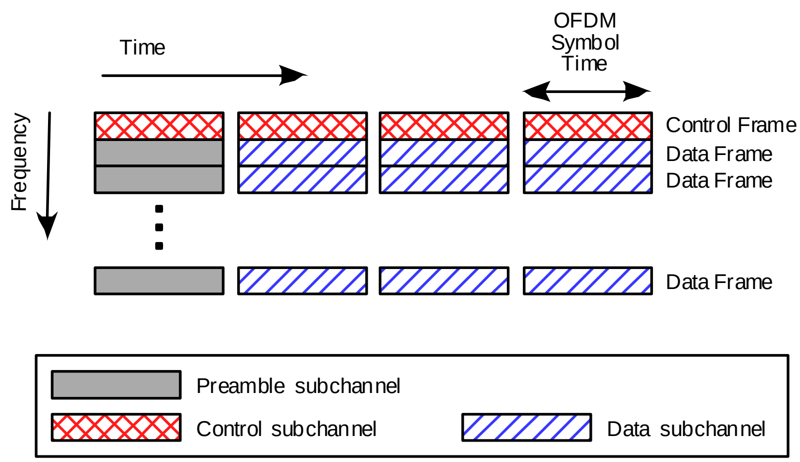

Figure 238—UL Framing Example

8.3.5.3.5.3 Superframe Format

There are two frame structures, a control frame, which contains one or more control symbols, and a data frame, which contains a preamble symbol and one or more data symbols. As shown in Figure 239, a super-frame is defined as a control frame followed by one or more data frames.

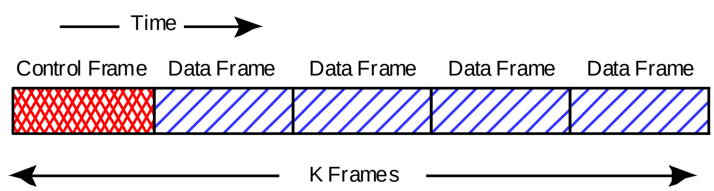

Figure 239—Superframe Structure

This superframe structure can be applied as shown in Figure 240. As with Mode B, the first two subchannels can be reserved for control functions such as ranging and contention based access. For the remaining sub-channels, the superframe structure is offset so that the control frames are distributed throughout time and fre-quency.

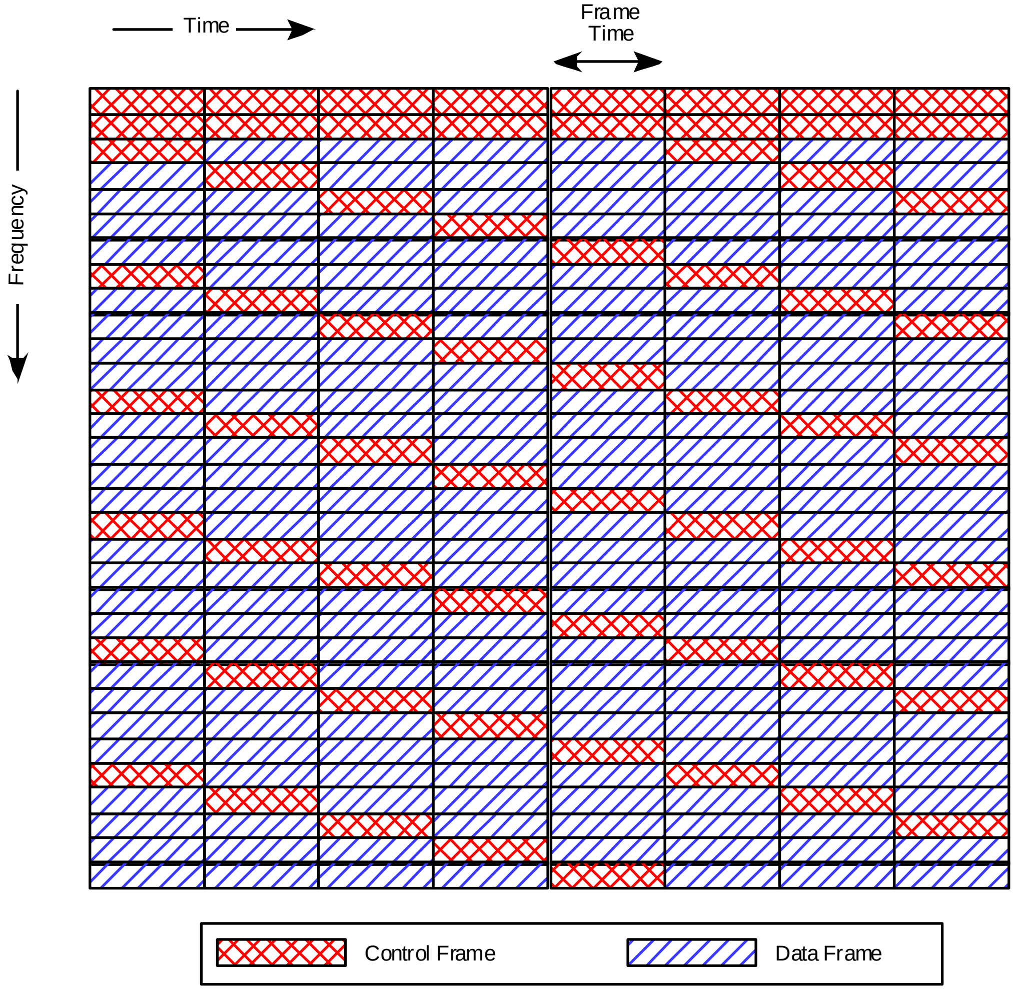

Figure 240—Superframe Layout

8.3.5.4 OFDM PHY Layer for license-exempt bands

8.3.5.4.1 Introduction

The PHY specified in this clause is intended for license exempt operation in the 2 to 11 GHz band in general, and the 5 GHz band in specific. In order to allow different deployment scenarios from dense populated areas (where sectorized environments and the high interference levels may require narrow channels) to sparse populated areas (where wider channels can help delivering better services at the same system cost), the PHY layer is allowed to operate with channel bandwidths of 10 MHz or 20 MHz and optionally 5 MHz. An compliant device must implement 10 MHz and/or 20 MHz channelization and may implement 5MHz channelization (see clause 8.3.5.4.2.3.1).

The PHY defines two mandatory modes 64 and 256 -FFT and one optional mode 2048-FFT. All modes shall only support TDD operation. The mandatory modes employ Time Division Multiple Access (TDMA) while the optional mode employs a combination of TDMA and Orthogonal Frequency Division Multiple Access (OFDMA). The modes are summarized in Table 223.

Table 223—Mandatory and optional modes

Mode	Access method	FFT size	Status
A_E	TDMA	64	Mandatory
B_E	TDMA	256	Mandatory
C_E	OFDMA	2048	Optional

In order for a system to comply with this standard, it shall implement both mode A_E and mode B_E and may implement mode C_E. A compliant device shall be capable of facilitating devices using either mode A_E or mode B_E, but need not be capable of facilitating both modes in the same configuration.

This PHY Layer has been designed to be similar to that described in clause 8.3.5.3. Unless addressed in this clause, clause 8.3.5.3 shall apply.

8.3.5.4.2 Common elements

8.3.5.4.2.1 Symbol Description

The cyclic prefixes T_g (see Figure 213) are fractions 1/4, 1/8, 1/16 1/32 of T_s and must be provided with a minimum time-duration of 750 ns and a maximum time-duration of at most 6 μ s for mode A_E and B_E, and at most 12 μ s for mode C_E. If a fraction provides a time-duration below 750ns or above 6 (respectively 12 for mode C_E) μ s for a given FFT size and channelization, this fraction does not have to be implemented (see Table 212).

In addition to the PMP frame structure in clause 8.3.5.2.1, an optional frame structure (see Figure 241) is defined to facilitate mesh networks.

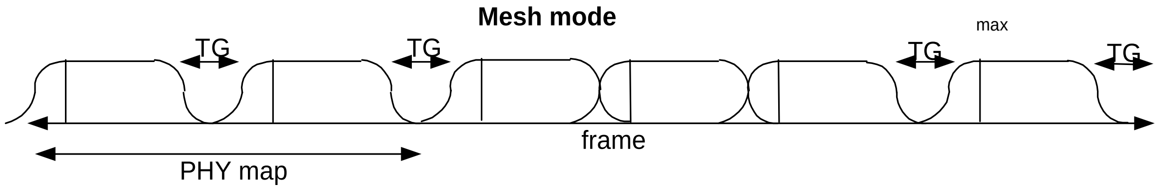

Figure 241—Mesh Frame Structure (optional)

In the optional mesh mode, a PHY map consisting of several control slots are allocated and the frame structure is built from node transmissions. The cell radius is dependent on the Transition GAP (TG), which is inserted before every and after the last PHY map. Random access uses the same method as the PMP mode. The number of PHY maps in the mesh mode shall be a network management variable.

8.3.5.4.2.2 Preambles

Preambles are special training sequences that are prepended to the OFDM symbols carrying data. The receiver uses them for signal detection, AGC convergence, carrier recovery, symbol timing recovery and equalization. The PHY uses a fully featured preamble and shortened versions of it depending on the burst position in the frame. The complete preamble is depicted in Figure 242 and consists of multiple short training symbols and 1 long training symbol.

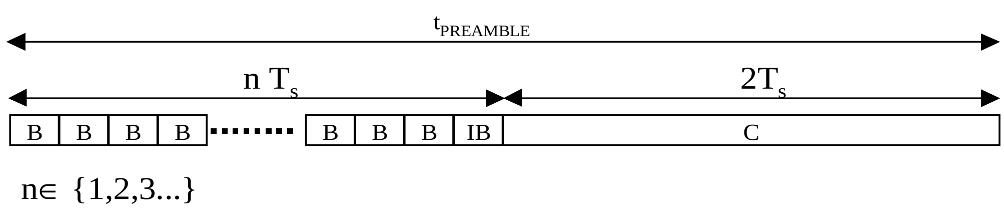

Figure 242—Complete Preamble Structure

A short training symbol (B) has no cyclic prefix and consists of 12 carriers with an FFT size of 16 modulated by the elements of the sequence (to discuss the factor):

$$S16_{-7,7} = \{0, 1+j, -1-j, 1+j, -1-j, -1-j, 1+j, 0, -1-j, -1-j, 1+j, 1+j, 1+j, 1+j, 0\} \quad (26)$$

Equivalently, the same 12 carriers are spaced at 4 times the inter-carrier spacing with an FFT size of 64:

$$S16_{-31,31} = \begin{matrix} \{0, 0, 0, 0, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, \ldots \\ 0, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 0, 0, 0, 0\} \end{matrix} \quad (27)$$

$$S16_{-127,127} = \begin{matrix} \{ \; 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1+j, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, \ldots \\ -1-j, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1+j, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, \ldots \\ -1-j, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1-j, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0\ldots \\ 1+j, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, \ldots \\ -1-j, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1-j, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, \ldots \\ 1+j, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1+j, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, \ldots \\ 1+j, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1+j, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, \ldots \\ 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0\} \end{matrix} \quad (28)$$

The last repetition of the short symbols is a sign-inverted copy of the previous short symbol B, i.e. IB=-B.

Having a period of only 16 samples, short training symbols are suitable for signal detection and for fast AGC. Having enlarged inter-carrier spacing, short training symbols can be used for coarse carrier recovery for an offset up to half of the carrier spacing. Table 224 summarizes the offset recovery capabilities for different channel bandwidths.

Table 224—Offset recovery capabilities

Channel BW (MHz)	Allowed Offset (ppm)
20	?
10	?
5	?

The long training symbol is an OFDM symbol generated with the same FFT size as the data symbols but with a cyclic prefix (guard interval or GI) extended so that the overall length is 2 times the nominal length of a data symbol (TBD). It is BPSK modulated with a known/fixed pattern. It may be used for fine carrier offset recovery, symbol timing recovery and equalization. The first two functions require the extended cyclic prefix; the equalization requires the same cyclic prefix as normal (data) OFDM symbols. For an FFT size of 64, the long training symbol is modulated by the sequence (TBD):

$$S64_{-31,31} = \{0, 0, 0, 0, 0, 1, 1, -1, -1, 1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, 1, 1, 1, 1, 0, \ldots \\ 1, -1, -1, 1, 1, -1, 1, -1, 1, -1, -1, -1, -1, -1, 1, 1, -1, -1, 1, -1, 1, -1, 1, 1, 1, 1, 0, 0, 0, 0, 0\}$$

The preamble usage depends on the burst position within the frame. A shortened preamble that contains only the long training symbol is depicted in Figure 243.

I

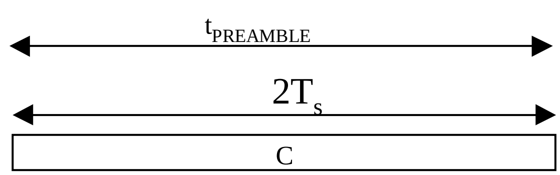

Figure 243—Shortened preamble: Long traing symbol with large GI

8.3.5.4.2.3 Transmitter Requirements

8.3.5.4.2.3.1 Channelization

Channel center frequencies are defined at every integral multiple of 5 MHz above 5 GHz. The relationship between center frequency and channel number is given by the following equation:

Channel center frequency = 5000 + 2.5 n_{ch} (MHz)

where n_{ch} = 0,1,...400. This definition provides a 9-bit unique numbering system of all channels with 2.5 MHz spacing from 5 GHz to 6 GHz to provide flexibility to define channelization sets for all current and future regulatory domains. In USA,current regulations for U-NII permits operation of outdoor fixed wireless devices in both middle and upper U-NII bands. In Europe the current regulations do not allow operation of such devices in the 5-6 GHz band, but efforts are ongoing to modify this. The set of operating channel numbers by regulatory domain is defined in Table 225. The channels in parenthesis are optional, the others are mandatory. Note that the support of the individual bands is not mandatory.

Table 225—Channelizations

Regulatory domain	Band (GHz)	Channelization (MHz)		
		20	10	(5)
USA	U-NII middle 5.25 -5.35	(104), 112, 120, 128, (136)	(102), 106, 110, 114, 118, 122, 126, 130, 134, (138)	(103), (105), (107), (109), (111), (113), (115), (117), (119), (121), (123), (125), (127), (129), (131), (133), (135), (137)
	U-NII upper 5.725-5.825	298, 306, 314, 322, 330[a]	(292), 296, 300, 304, 308, 312, 316, 320, 324,(328),332[a],336[a]	(293), (295), (297), (299), (301), (303), (305), (307), (309), (311), (313), (315), (317), (319), (321), (323), (325), (327),(329)[a],(331)[a], (333)[a],(335)[a]
Europe	CEPT band B[b] 5.47-5.725	200, 208, 216, 224, 232, 240, 248, 256, 264, 272	(194), 198, 202, 206, 210, 214, 218, 222, 226, 230, 234, 238, 242, 246, 250, 254, 258, 262, 266, 270, 274, (278)	(195), (197), (199), (201), (203), (205), (207), (209), (211), (213), (215), (217), (219), (221), (223), (225), (227), (229), (231), (233), (235), (237), (239), (241), (243), (245), (247), (249), (251), (253), (255), (257), (259), (261), (263), (265), (267), (269), (271), (273), (275), (277)
	CEPT band C[a] 5.725-5.875	298, 306, 314, 322, 330, 338	(292), 296, 300, 304, 308, 312, 316, 320, 324, 328, 332, 336, 340 (344)	(293), (295), (297), (299), (301), (303), (305), (307), (309), (311), (313), (315), (317), (319), (321), (323), (325), (327), (329), (331), (333), (335), (337), (339), (341), (343)

[a]Pending FCC action on docket ET 99-231
[b]Current applicable regulations do not allow this standard to be operated in the indicated band.

Figure 244 depicts the 20 MHz channelization scheme listed in Table 225. Optional channels are drawn in gray. Channelization has been defined to be compatible with IEEE 802.11a for interference mitigation purposes, even though this results in inefficient spectrum usage in the middle U-NII band.

The middle U-NII sub-band accommodates 3 channels of 20MHz, while the upper U-NII band supports 4 channels. Both U-NII bands accommodate 8 channels of 10 MHz. Additionally, two optional 20 MHz channels are defined in the middle U-NII band and one 10 MHz channel in each of the bands. The 5 MHz channelization, which is optional, provides 18 channels in each band.

The channels shown as optional, except in the upper U-NII band have been designated such due to the regulatory band-edge requirements that may be tough to meet. The optional channel in the upper U-NII band is currently not available, but the FCC is considering adding this spectrum to the upper U-NII band.

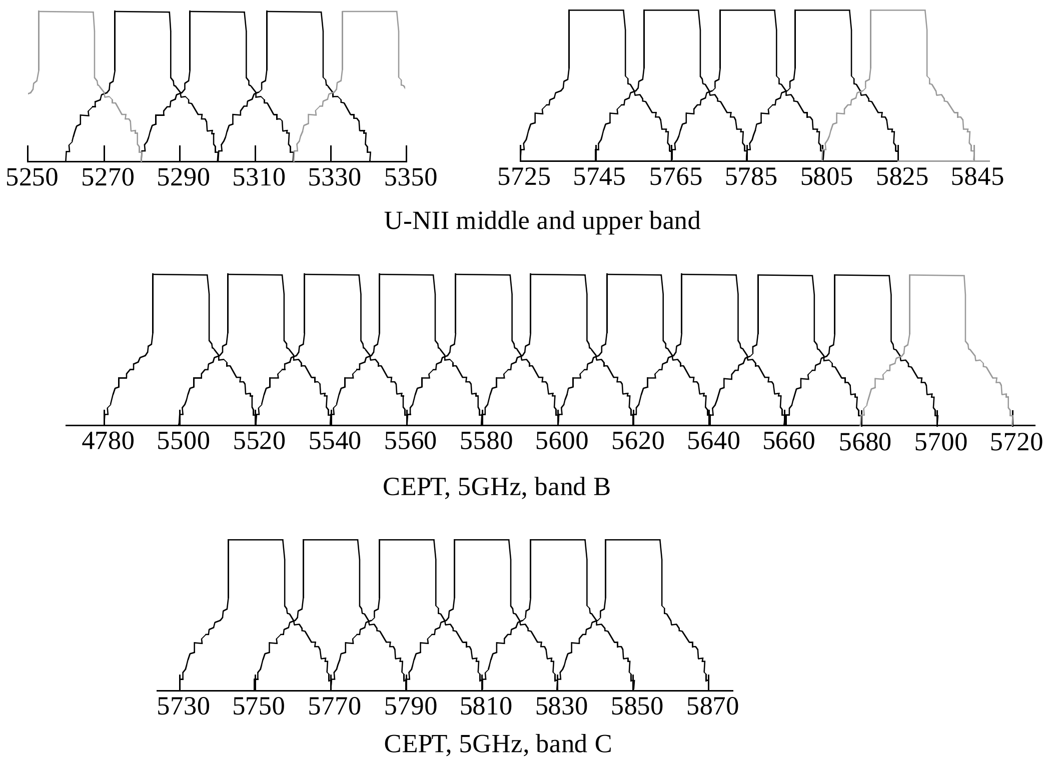

Figure 244—Channelization, 20 Mhz

8.3.5.4.2.3.2 Transmit spectral mask

The transmitted spectral density of the transmitted signal shall fall within the spectral mask as shown Figure 245 and Table 226. The measurements shall be made using 100 kHz resolution bandwidth and a 30 kHz video bandwidth. The 0 dBr level is the maximum power allowed by the relevant regulatory body.

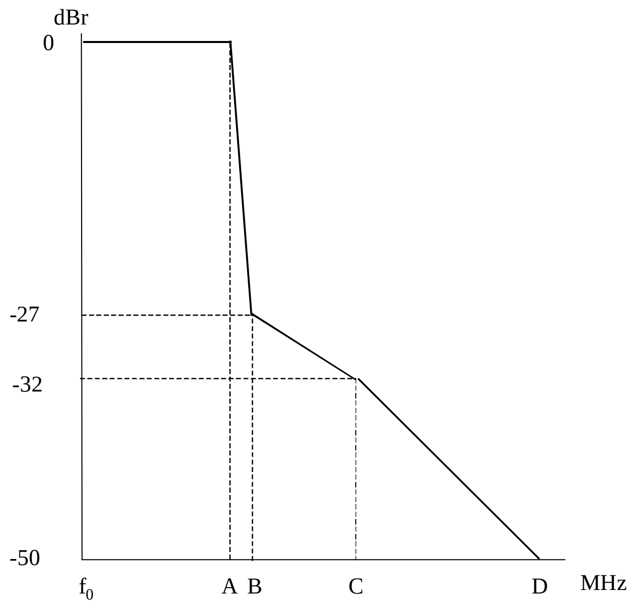

Figure 245—Transmit Spectral Mask (see Table 226)

Table 226—Transmit Spectral Mask Parameters

Chanelization (MHz)	A	B	C	D
20	9.5	10.5	19.5	29.5
10	4.25	TBD	TBD	TBD
5	2.25	TBD	TBD	TBD

8.3.5.4.2.3.3 Transmit Power Level Control

The transmitter shall support monotonic power level control of 45dB minimum with resolution of 3dB.

8.3.5.4.2.3.4 Transmitter Linearity

The transmitter linearity shall be sufficient to ensure minimal distortion of the transmitted OFDM signal. The test method will use a notch test method with the assistance of a test mode to create a notched OFDM signal. The average depth of the notch shall be TBD dB measured at the transmitter output. Use of an EVM may be used as an alternate test method, but all equipment must support all defined test modes.

8.3.5.4.2.3.5 Transmitter Spectral Flatness

The average energy of the constellations in each of the n spectral lines shall deviate no more than the following:

Table 227—Spectral Flatness

Spectral Lines	Spectral Flatness
Spectral lines from -n/2 to -1 and +1 to n/2	+/-2dB from their average energy
Spectral lines from -n to -n/2 and +n/2 to n	+2/-4dB from their average energy

This data will be taken from the channel estimation step.

8.3.5.4.2.3.6 Transmitter Constellation Error and Test Method

This requirement specifies limits for Error Vector Magnitude (EVM) measurements for the constellation elements.

The definition and test method are specified in [B43] clause 17.3.9.6.3. The following addition applies:

For OFDMA modes, measurements will be taken with all subchannels active.

To separate EVM measurements for the BS and SS.

8.3.5.4.2.4 Receiver Requirements

8.3.5.4.2.4.1 Receiver Sensitivity

The packet error rate (PER) shall be less than TBD (%) at the power levels shown below for a standard message and test conditions. The measurement shall be taken at the antenna port or through a calibrated radiated test environment.

Table 228—Receiver Sensitivity

Channel Bandwidth (MHz)	Data Rate (Mbit/s	Maximum Sensitivity (dBm)
20z		
20		
20		
10		
10		
10		
5		
5		
5		

Standard test message: TBD bytes of TBD format (possibly 2 std messages -short and long)

Test Conditions: room temp, no interference, conducted measurement if RF port available, radiated measurement in a calibrated test environment if antenna is integrated, FEC enabled

8.3.5.4.2.4.2 Receiver Adjacent and Alternate Channel Rejection

The adjacent channel rejection and alternate channel rejection shall be measured by setting the desired signal's strength 3dB above the rate dependent receiver sensitivity (see Table 228) and raising the power level of the interfering signal until the specified error rate is obtained. The power difference between the interfering signal and the desired channel is the corresponding adjacent channel rejection. The interfering signal in the adjacent channel shall be a conformant OFDM signal, unsynchronized with the signal in the channel under test. For alternate channel testing the test method is identical except the interfering channel will be any channel other than the adjacent channel.

For the PHY to be compliant, the minimum rejection shall exceed the following:

Table 229—Minimum Adjacent and Non-Adjacent Channel Rejection

Channel Bandwidth (MHz)	Adjacent Channel Rejection (dB)	Non-Adjacent Channel Rejection (dB)
20	40?	50?
10	40?	50?
5	40?	50?

8.3.5.4.2.4.3 Receiver Interference Requirements

Interference may be mitigated through intelligent configuration and control, however it cannot be completely eliminated. The receiver must not degrade more than TBD dB when operating in the presence of the following interference signals:

Table 230—Interference Requirements

Signal Freq	User	Power Level (dB)
	Radar	
	ISM pt-pt	-10

Change clause for out of UNII band rejection and add to table.

8.3.5.4.2.4.4 Receiver Maximum Input Signal

The receiver shall be capable of receiving a maximum on-channel signal of -20dBm, and must tolerate a maximum signal of 0dBm without damage.

Limit may need to be adjusted to account for raditated vs injected measurements. TBD how to test for units with integrated antenna.

8.3.5.4.2.4.5 Receiver Linearity

The receiver shall have a minimum Input Intercept Point (IIP3) of 0dBm.

To change this spec to an IMD measurement and corresponds to the adjacent channel needs.

8.3.5.4.2.4.6 Receiver Gain Control and RSSI Parameters

The minimum RSSI resolution shall be 1dB with accuracy TBDdB.

TBD how to handle this internal spec need (reporting and adjusting power control and AGC loops)

8.3.5.4.2.5 Frequency Control Requirements

8.3.5.4.2.5.1 Transmit/Receive Center Frequency and Symbol Clock Frequency Tolerance

The transmitted center frequency, receive center frequency and the symbol clock frequency shall be derived from the same reference oscillator. At the BS the reference frequency tolerance shall be +/- 20ppm. At the SS, both the transmitted center frequency and the symbol clock frequency shall be synchronized to the BS with a tolerance of maximum 1% of the inter-carrier spacing.

For mesh capable devices, all devices shall have a +/- 20ppm maximum frequency tolerance and achieve synchronization to its neighboring nodes with a tolerance of maximum 3% of the inter-carrier spacing.

During the synchronization period as described in the 802.16 MAC, the SS shall acquire frequency synchronization with the specified tolerance before attempting any uplink transmission. During normal operation, the SS shall track the frequency changes and shall defer any transmission if synchronization is lost.

8.3.5.4.2.5.2 Frequency Lock Detect

All modems will monitor the status of the frequency lock detect and prevent transmission if the oscillators lose synchronization to the base station clock.

8.3.5.4.2.5.3 Phase Noise

Recommended phase noise mask for the SS and BS.

8.3.5.4.2.5.4 General Requirements

8.3.5.4.2.5.5 Temperature Range

To use BellCore temperature ranges:

Table 231—Operational Temperature Classes

Class	Range (^{o}C)	Environment
1	[0,40]	
2	[-20,50]	
3	[-30,70]	
4	[-40,85]	

8.3.5.4.2.5.6 Antenna Interface

Any exposed transmit and receive antenna interface port shall be 50 ohms. It is permissible to integrate the antenna and eliminate any external RF port.

8.3.5.4.2.5.7 Diagnosis Features

??

8.3.5.4.2.6 Channel Coding

Data encoding is composed of three steps: randomizer, forward error correction (FEC) and interleaving. They shall be applied in this order at transmission. The complementary operations shall be applied in reverse order at reception.

8.3.5.4.2.6.1 Data randomizer (scrambler)

The data bytes to be transmitted are converted to a serial bit stream using the MSB first LSB last rule. The serial bit stream shall be passed through a data randomizer that uses the generator polynomial $R(X) = X^7 + X^4 + 1$ and is depicted in Figure 246. The same randomizer is used to scramble data at transmission and de-scramble received data.

In order to avoid retransmission of the same frame with the same initial state of the scrambler, the initial state of the scrambler will be variable, set at the beginning of an OFDM/OFDMA burst to a TBD parameter.

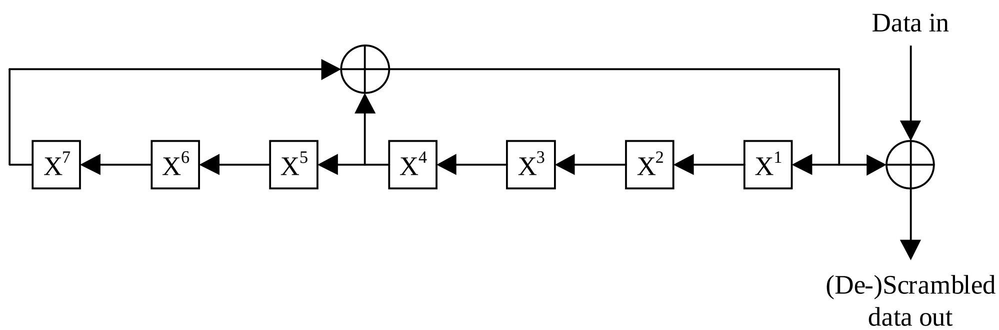

Figure 246—Data Randomizer

8.3.5.4.2.6.2 FEC

8.3.5.4.2.6.2.1Concatenated Reed-Solomon - Convolutional Coding

Concatenated RS-CC with tail-biting termination must be used as the mandatory FEC. See clause 8.3.5.3.2.1.2 for details.

The following amendments apply:

Code rates of 1/2 and 3/4 apply for BPSK. The coding rates for BPSK are described in Table 234 and Table 235.

8.3.5.4.2.6.3 Turbo Product Coding (Optional)

The Turbo Product Codes and shortening methods used for the OFDM PHY layer (licensed bands) are generically described in clause 8.3.3.1.5.3, with specific codes provided in clause 8.3.5.3.3.2.2.2 and 8.3.5.3.4.2.2.2.

8.3.5.4.2.6.4 Turbo Convolutional Coding (Optional)

Turbo Convolutional Coding is based on Recursive Systematic Convolutional (RSC) codes with a base rate of 1/2. The frames are encoded in blocks. Figure 247 illustrates the overall encoding process.

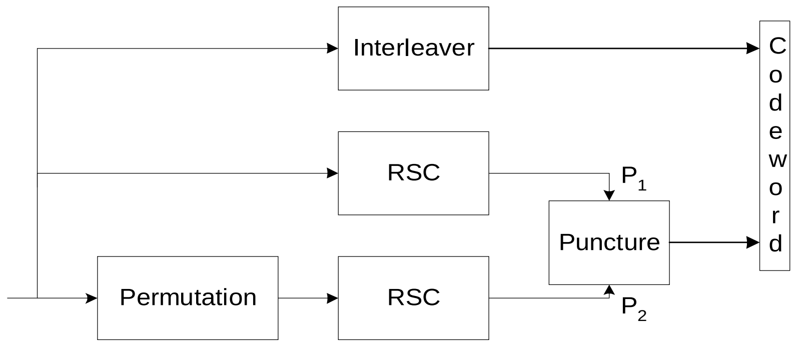

Figure 247—Turbo Encoder

The RSC coder is shown in Figure 248.

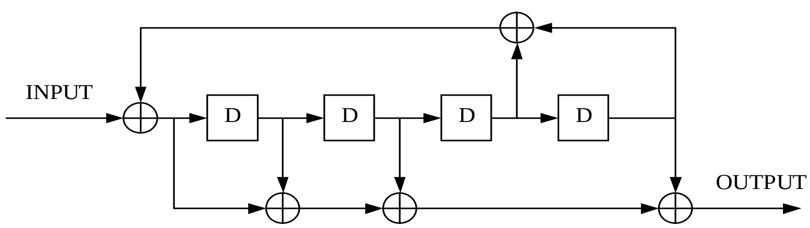

Figure 248—RSC Encoder

Each constituent code shall be terminated using a tail biting scheme.

Codes rates of 1/2, 2/3 and 3/4, are supported via puncturing. Table 232 lists the puncture patterns used to implement these rates.

Table 232—Puncturing patterns

Rate	Puncturing Pattern						
1/2	P_1	1	0				
	P_2	0	1				
2/3	P_1	1	0	0	0		
	P_2	0	0	1	0		
3/4	P_1	1	0	0	0	0	0
	P_2	0	0	0	1	0	0

All the systematic bits are transmitted for each rate.

8.3.5.4.2.6.5 Interleaving

8.3.5.4.2.6.5.1Mode A_E and Mode B_E

All encoded data bits shall be interleaved by block interleaver with a block size corresponding to the number of coded bits per OFDM symbol, N_{CBPS}. The interleaver is defined by a two step permutation. The first ensures that adjacent coded bits are mapped onto nonadjacent sub-carriers. The second permutation insures that adjacent coded bits are mapped alternately onto less or more significant bits of the constellation, thus avoiding long runs of lowly reliable bits (LSB).

Let N_{BPSC} be the number of bits per sub-carrier, i.e. 1, 2, 4 or 6 for BPSK, QPSK, 16QAM or 64QAM, respectively. Let s = max(N_{BPSC}/2,1). Let k be the index of the coded bit before the first permutation at transmission, *m* be the index after the first and before the second permutation and *j* be the index after the second permutation, just prior to modulation mapping.

The first permutation is defined by the rule:

$$m = (N_{CBPS}/16) \cdot k_{mod\,16} + floor(k/16) \qquad k = 0, 1, \ldots, N_{CBPS} \qquad (29)$$

The second permutation is defined by the rule:

$$j = s \cdot floor(m/s) + (m + N_{CBPS} - floor(16 \cdot m/N_{CBPS}))_{mod\ s} \qquad k = 0, 1, \ldots, N_{CBPS} \qquad (30)$$

The deinterleaver, which performs the inverse operation, is also defined by two permutations. Let *j* be the index of the received bit before the first permutation, *m* be the index after the first and before the second permutation and *k* be the index after the second permutation, just prior to delivering the coded bits to the convolutional decoder.

The first permutation is defined by the rule:

$$m = s \cdot floor(j/s) + (m + floor(16 \cdot j/N_{CBPS}))_{mod\ s} \qquad j = 0, 1, \ldots, N_{CBPS} \qquad (31)$$

The second permutation is defined by the rule:

$$k = 16 \cdot m - (N_{CBPS} - 1) \cdot floor(16 \cdot m/N_{CBPS}) \qquad k = 0, 1, \ldots, N_{CBPS} \qquad (32)$$

The first permutation in the deinterleaver is the inverse of the second permutation in the interleaver, and conversely.

8.3.5.4.2.6.5.2Mode C_E

See clause 8.3.5.3.2.1.4 and 8.3.5.3.4.2.3.

8.3.5.4.2.6.5.3Turbo Convolutional Coding specific Interleaver

The size of the code permuter is equal to the information bits in a block. To generate the interleaver of size *N*, two sets of values are stored in memory. The first set of values is size *n* and the second set of values is size *m*, where $n \cdot m = N$. The n stored values are labeled n[0..n-1] and the m stored values are labeled *m*[0..*m*-1]. The interleaved addresses *j*[0..*N*-1] are generated as follows:

For first n addresses: $j[0 \ldots n-1] = n[0 \ldots n-1]$

Subsequent sets of n addresses are generated using: $j[x]] = (j[x-n] + m[x])_{mod\ N}$

Tables for n and m will be provided once frame sizes have been agreed upon.

For each frame size a channel interleaver of size *N* is also defined. The channel interleaver is applied to the information bits after encoding by the first encoder. The interleaver *I*(*x*) is defined as follows:

$$I(0) = C$$
$$I(x) = [I(x-1) + p]_{mod\ N} \quad (33)$$

8.3.5.4.2.7 Control mechanisms

8.3.5.4.2.7.1 Network entry

The base station shall allocate a number of symbols every few frames for network entry. This number of symbols shall be large enough to contain the maximum Round Trip Duration (RTDmax) plus a long preamble uplink burst with one OFDM symbol in data. A SS attempting to enter the network shall listen to the base station until such a period is scheduled and send a network entry request using a long preamble uplink burst.

The PHY map must include the knowledge of the power used in the PHY map burst transmission (TxP_PHYmap). The power used for transmitting the network entry burst is thus TxP_NetworkEntry = TxP_PHYmap - RSSI_max + Rx_sensitivity + M, in which RSSI_max is the maximum signal level received from the basestation and Rx_sensitivity is the receiver sensitivity of the modulation to be used (BPSK, rate TBD) and M is a margin factor, or the maximum available which one is less. In the first attempt M is TBD dB (proposal 3dB) and if the attempt fails, the output power may be increased by 3dB per retry. For the mesh mode the procedure is similar with the exception that the used output power is chosen according to the furthest neighbor (from path loss perspective) to be reached.

8.3.5.4.2.7.2 Ranging

See clause 8.3.5.3.2.4.2.

8.3.5.4.3 Mode A_E - OFDM, 64 FFT

8.3.5.4.3.1 OFDM Symbol Parameters

For any channel bandwidth *BW*, $F_s = BW$ and the mandatory FFT size is 64.

The data symbol structure is made up of data carriers and constant location pilots. The number of data carriers and pilots depends on the FFT size being employed, but it is the same for up- and down-stream.

In Table 233, the DC carrier is numbered 0, whereas carrier numbers increase from the lowest to the highest frequency.

Table 233—Symbol Parameters

N_{FFT}	Parameter	Value	
64	N_{used}	52	
	Guard Carriers: Left, Right	6	5
	BasicConstantLocationPilots	{-21,-7,7,21}	

8.3.5.4.3.2 Channel Coding

8.3.5.4.3.2.1 FEC

8.3.5.4.3.2.1.1Concatenated Reed-Solomon - Convolutional Coding

See clause 8.3.5.4.4.2.1.1.

8.3.5.4.3.3 Control Mechanisms

See clause 8.3.5.4.4.3

8.3.5.4.4 Mode B_E- OFDM, 256 FFT

8.3.5.4.4.1 OFDM Symbol Parameters

See 8.3.5.3.3.1 where applicable for 256-FFT only

8.3.5.4.4.2 Channel Coding

8.3.5.4.4.2.1 FEC

8.3.5.4.4.2.1.1Concatenated Reed-Solomon - Convolutional Coding

In addition to Table 215, the following code rates are defined for BPSK in Table 234.

Table 234—BPSK Channel Coding

Modulation	Block Size (Bytes)	Overall Coding Rate	RS Code	CC Code rate
BPSK	12	1/2	(?,?,?)	2/3
BPSK	18	~3/4	(?,?,?)	5/6

8.3.5.4.4.3 Control Mechanisms

8.3.5.4.4.3.1 Ranging, network entry and bandwidth requests

In the optional Mesh mode, ranging, network entry and bandwidth requests shall be done in the control-slots

8.3.5.4.5 Mode C_E- OFDMA (optional)

See 8.3.5.3.4.1 where applicable for 2048-FFT only.

When using OFDMA for mesh topology, the format of all transmissions as well as the symbol structure shall comply to the PMP uplink format only (see clause 8.3.5.3.4.1.2.)

8.3.5.4.5.1 Channel Coding

8.3.5.4.5.1.1 FEC

8.3.5.4.5.1.1.1Concatenated Reed-Solomon - Convolutional Coding

In addition to Table 220, the following code rates are defined for BPSK in Table 234.

Table 235—BPSK Channel Coding

Modulation	Block Size (Bytes)	Overall Coding Rate	RS Code	CC Code Rate
BPSK	13	1/2	(?,?,?)	2/3
BPSK	26	~3/4	(?,?,?)	5/6

11. TLV-encodings

11.1 TLV-encoding for OFDM PHY

11.1.1 UCD message encodings

Table 122 —UCD Channel Encodings in the section 11.1.1 "UCD message encodings" is amended by replacing the “roll-off” factor parameter with Table 236.

Table 236—UCD Channel Encoding

Name	Type	Length	Value
FFT Size Code	8	1	0 = FFT-64 1 = FFT-256 2 = FFT-512 4 = FFT-2048 8 = FFT-4096 16,32,64,128 reserved

The FFT Size Code parameter is used in SS Capabilities Encodings only to indicate the set of FFT sizes supported by the given SS. The set is indicated by the addition of all applicable Codes.

11.1.1.2 UCD Burst Profile Encodings

Table 237 replaces Table 123 —UCD Burst Profile Encodings from 11.1.1.2 "UCD Burst Profile Encodings".

Table 237—UCD Burst Profile Encoding

Name	Type	Length	Value
FFT Size Code	2	1	0 = FFT-64 1 = FFT-256 2 = FFT-512 3 = FFT-2048 4 = FFT-4096 5-255 reserved
CC FEC type	3	1	TBD
RS FEC type	4	1	TBD

11.1.2.2 DCD burst profile encodings

Table 238 amends Table 125 —DCD Burst Profile Encodings from "11.1.2.2 DCD Burst Profile Encodings"

Table 238—DCD Burst Profile Encoding

Name	Type	Length	Value
FFT Size Code	2	1	0 = BPSK 1 = QPSK 2 = 16 QAM 3 = 64 QAM 4= 256 QAM 5-255 reserved
CC FEC type	3	1	TBD
RS FEC type	4	1	TBD
DIUC max. exit threshold	5	2	C/(N+I) at or below which this UIUC can no longer be used and at which a change to a more robust DIUC is required, in 0.25 dB units
DIUC min. entry threshold	6	2	The minimum C/(N+I) required to start using this UIUC when changing from a more robust UIUC is required, in 0.25 dB units

11.1.4 "RNG-RSP message encodings"

Table 239 amends Table 127—RNG-RSP Message Encodings from the section 11.1.4 "RNG-RSP message encodings"

Table 239—DCD Burst Profile Encoding

Name	Type	Length	Value
Timing Adjust	1	4	Tx timing offset adjustment (signed 32-bit, units of sample duration). The time by which to advance SS transmission so that frames arrive at the expected time instance at the BS

11.2 TLV encoding for OFDMA PHY

11.1.4 RNG-RSP Message Encodings

Add Table 240 to end of Table127-RNG-RSP Message Encodings

Table 240—RNG-RSP TLV Additions

Name	**Type (1 byte)**	**Length (1 byte)**	**Value (Variable Lenght)**
Ranging symbol	12	2	Used to indicate the OFDM time symbol reference that was used to transmit the ranging code (unsigned 12-bit). This TLV is used in conjunction with the Ranging Sub Channel and Ranging Code values to identify the sending SS.
Ranging sub-channel	13	1	Used to indicate the OFDM sub-channel reference that was used to transmit the ranging code (unsigned 6-bit). This TLV is used in conjunction with the Ranging Sub Channel and Ranging Code values to identify the sending SS.
Ranging Code	14	1	Used to indicate the ranging code that was sent by the SS (unsigned 6-bit). This TLV is used in conjunction with the Ranging Slot value to identify the sending SS.

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A. Annex to systems between 2 and 11 GHz

A.1 Turbo product codes

This annex is informative only.

A.1.1 Example of a shortened 2-dimensional TPC

For example, assume a 456-bit block size is required with a code rate of approximately 0.6. The base code chosen before shortening is the (32,26)*(32,26) code which has a data size of 676 bits. Shortening all rows by 5 bits and all columns by 4 bits results in a (27,21)*(28,22) code, with a data size of 462 bits. To get the exact block size, the first row of the product is shortened by an additional 6 bits. The final code is a (750,456) code, with a code rate of 0.608. Figure 249 shows the structure of the resultant block.

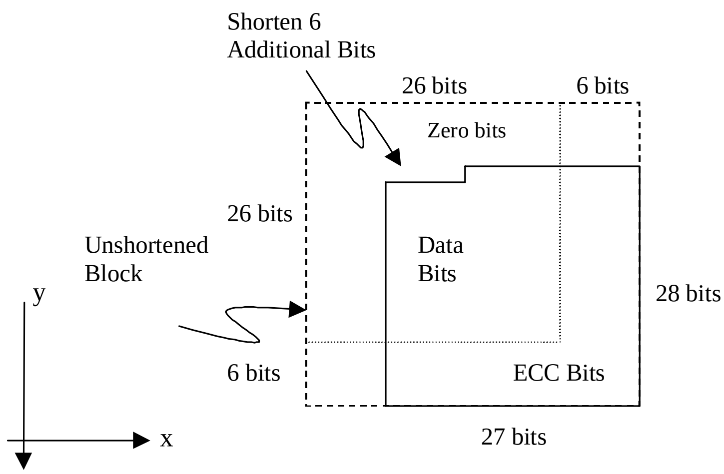


Figure 249—Structure of Shortened 2d Block

Modifications to the encoder to support shortening are minimal. The shortening procedure is trivial, and yet an extremely powerful tool that enables construction of a very versatile code set.

A.1.2 Iterative Decoding

Huge performance advantages may be directly associated with the decoding mechanism for product codes. There are many different ways to decode product codes and each has its merits, however, the goal is maximum performance for a manageable level of complexity.

It is known that if it is possible to use unquantized information (so called soft information) from the demodulator to decode an error correcting code, then an additional gain of up to 2 dB over fully quantized (hard decision) information is achievable. It is therefore desirable to have soft information decision available to the TPC decoder.

Of course, we could in theory consider the decoding of this code a single linear code of size (nx*ny*nz,kx*ky*kz), using a soft decision decoder, but this will in general (apart from the smallest, and of course worst performing) be prohibitively complex.

It makes sense therefore, since these codes are constructed from (simple) constituent code that these soft decoders are used to decode the overall code. However until recently there have only been hard decision decoders for these constituent decoders. In recent years the computational power of devices has made it possible to consider (sub optimal) soft decision decoders for all linear codes. This is only half the solution as the main difficulty is with passing the information from one decoder to the next (i.e. when switching from decoding the rows to decoding the columns). For this, accuracy will need to be kept to a maximum, and so using soft input soft output (SISO) decoders will need to be considered. This is such that an estimate of the transmitted code word may be found and also an indication of the reliability. This new estimate may then be passed onto the next decoding cycle. Inevitably, there will be some degradation from optimal if we are to achieve our decoding using this method, but it does enable the complexity to be reduced to a level that can be implemented. Also, studies have shown that this degradation is very small, so this decoding system is very powerful.

What follows now is an explanation regarding the iterative nature of the decoding procedure. If we consider that, given 2-D TPC block, we define the first round of row and column decoding as a single iteration. We may then perform further iterations, if required. Thus, the main areas of investigation are that of the SISOs, and that of using some previously decoded information in subsequent decoding operations. These are both separate and yet connected areas of interest, as shall be explained.

With regards to the SISOs, there are many different methods including the following which have been described in detail in published academic papers:

Soft-Output Viterbi Algorithm (SOVA) [B38]
The modified Chase algorithm [B36]
The BCJR algorithm [B37],

There have been many other papers explaining these algorithms both as independent algorithms for coding schemes and as part of turbo type decoding schemes. It must be noted that these are not the only algorithms that can achieve soft input soft output style decoding, but they are at present the most readily cited in academic literature.

Each block in a product code is decoded using the information from a previous block decoding. This is then repeated as many times as. In this way, each decoding iteration builds on the previous decoding performance.

Figure 250 illustrates the decoding of a 2-D TPC. Note here that prior to each decoding there needs to be a mathematical operation on all the data we have at that particular time, that is the current estimate of the decoded bits, the original estimate from the demodulator (this will not be used in the first decoding) and the channel information (where applicable).

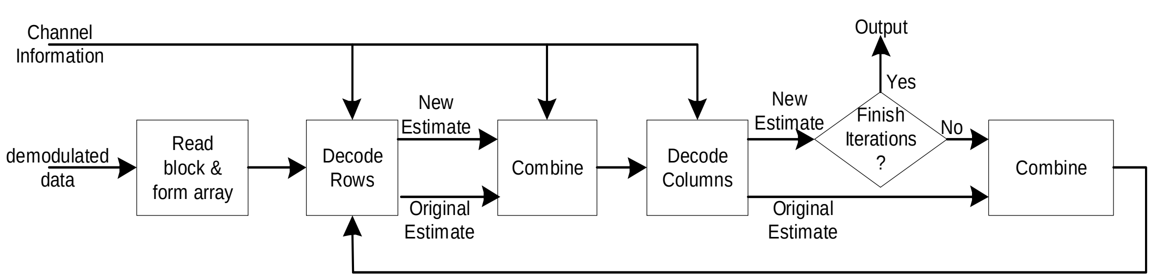


Figure 250—2-D TPC Decoding Procedure

It can easily be seen from Figure 250 that the iteration idea is applicable to one complete decoding of the rows and one complete decoding of the columns.

There is an obvious question as to how the iteration procedure is terminated. This is a question only answerable by the system provider and depends on performance and delay; more iterations imply better performance as the expense of a larger latency. Of course, over clocking the system in comparison can significantly reduce the latency. When considering hardware, the problem of varying delays may be encountered, thus it may be advantageous to fix the number of iterations performed.

A.2 License-exempt

This annex is informative only.

A.2.1 Interference mitigation and sharing mechanisms

In this clause a number of license exempt interference mitigation and sharing mechanisms is identified. Two categories are considered: mechanisms that fall within the scope of the IEEE 802.16b standard and methods that fall outside that scope.

Within the scope of the IEEE 802.16 standard, three methods are identified: dynamic frequency selection (DFS), which is not mandated by the standard, but mandated by some regulatory bodies such as ERC [B55]; transmit power control, which is mandated by the standard [REF????] and by some regulatory regions such as ERC [B55]; and ephemeris transmit interruption, which is mandated by neither.

Outside the scope of the IEEE 802.16 standard, two methods are identified: antenna directivity and antenna polarization.

A.2.1.1 Dynamic frequency selection

As frequency planning is not practical in licensed-exempt bands, DFS can be used to avoid assigning a channel to a channel occupied by another system. DFS is generally based on comparison of a C/I threshold against idle time RSSI measurements. DFS is predominantly effective to combat interference from and to ground based systems, such as WLANS, RTTT, radar and other IEEE 802.16b compliant systems. It is generally ineffective to combat interference from and to airborne systems, such as airborne radars and satellites.

A.2.1.2 Transmit power control

With power control, the transmitter EIRP is reduced according to the link margin. Shorter link ranges hence result in lower transmitted power levels. For PMP systems, the average EIRP will hence typically be several dB's below the legal limit assuming that SSs are spread throughout the coverage area. For mesh systems, this means that EIRP values decrease rapidly as customer deployment density increases. Therefore, an estimate of total interference within the footprint could be as much as 'n' dB below the reference value. As power control is also influenced by C/I levels, the use of TPC with DFS, where possible, tends to result in the most effective interference mitigation.

A.2.1.3 Ephemeris transmit interruption

Earth Resources Satellites operate at very precise orbits, therefore, the Ephemeris (orbital position correlated to time) of the satellites can be calculated with great accuracy. If an Ephemeris calculator is included in the basestations, and/or in the networks, the stations could be muted during the satellite pass. This would amount to a muting time of approximately 15 seconds per satellite pass-typically 5-10 days per pass. Coupled with antenna directivity, this feature would allow virtually any number of stations to operate within the satellite footprint.

A.2.1.4 Antenna directivity

Antenna directivity, in horizontal but especially in vertical direction can significantly reduce an FWA's interference potential and resilience. Vertical directivity especially reduces the interference caused to satellite systems, which are designated primary users of part of the addressed bands. It also can significantly help reduce interference to and from indoor WLAN systems. Horizontal directivity significantly reduces the probability of interference to other systems (assuming interference is mainly caused in the main lobe), but tends to increase the severity of the interference, as the energy in the main lobe is generally higher.

A.2.1.5 Antenna polarization

Antenna cross-polarization in the 5GHz band can achieve an isolation of up to 15 dB in LOS, but reduces significantly in near-LOS and NLOS environments. Most deployments use both horizontal and vertical polarization (circular polarization is not as common in currently known systems) to maximize spectral re-use. Polarization hence has the potential to provide some isolation between differently polarized systems, especially in LOS, but given the operational needs and implementation of most systems in the targeted spectrum, the effectiveness will be mostly marginal.

A.2.2 Services in the 5 GHz band

In this section a short description of the systems and services in the 5GHz bands is given together with the necessary parameters for the subsequent interference analysis. This includes assumptions on parameters of IEEE 802.16b compliant systems that are beyond the scope of this standard.

It is important to note that, throughout this study, the use of 6 dBW max. EIRP is assumed for all parts of the spectrum with a backoff of only 3 dB for WLAN type devices. In a practical OFDM system, the backoff is in the order of at least 6 dB minimum, whereas the rules commonly specify at most 0 dBW maximum mean EIRP [B56] or 6dBW maximum peak EIRP [B19] for fractions of the band. It should hence be understood that this study errs on the side of caution in how much interference can be tolerated.

A.2.2.1 IEEE 802.16b PMP system

TBD

A.2.2.2 IEEE 802.16b mesh system

The Mesh deployment scenario is abstracted into a regular hexagonal shape as shown in Figure 251. On each corner of each hexagon, one mesh node is located. By parameterizing the distance between a set of neighboring nodes, different mesh deployment density scenario's can relatively easily be analyzed.

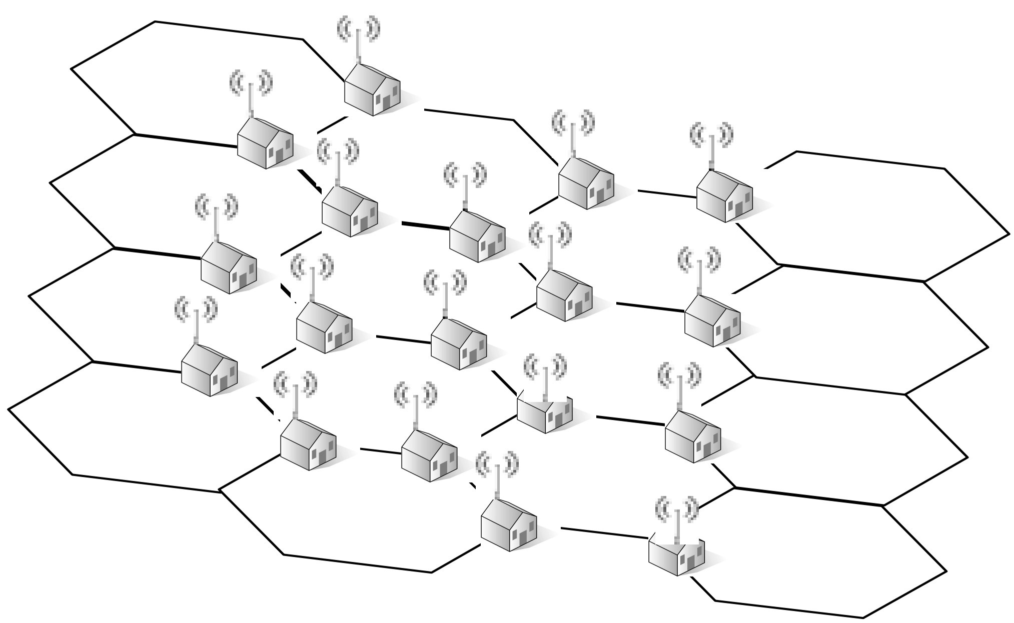


Figure 251—IEEE 802.16b mesh deployment model

If the distance between two nodes is denoted *r*, then from each node, we have 3 neighbors at distance *r*, 6 nodes at distance $2r\sqrt{3}/2$, 3 nodes at distance $2r$, 6 nodes at distance $3r\sqrt{3}/2$, 6 nodes at distance $3r$, 12 nodes at distance $\sim 4r\sqrt{3}/2$, 3 nodes at distance $4r$, 12 nodes at distance $\sim 5r\sqrt{3}/2$ etc.

Mesh devices that are close to each other cannot transmit at the same time on the same channel. This is normally defined in terms of extended neighborhoods, which comprises all nodes within two hops from the transmitting node. For modeling purposes, it is assumed that if a node is transmitting, all other nodes on the three hexagons that intersect on that node are silent. This translates into all nodes within a distance of $2r$ being silent.

In Table 241, the topology and traffic assumptions are shown. The Tx activity of a node depends heavily on its position in the network, i.e. on how much traffic must be forwarded from/to other nodes, and how active neighboring nodes are. To keep the analysis simple, an average of 5% is assumed (This based on the current average household internet usage of 30 minutes per day, as well as the activity probability during this on-time).

Table 241—Tx activity parameters

Parameter	Value
Typical hops/packet	2
Total Tx activity	5%

Based on this model, the background interference at any node can be computed, which can be added to the interference from the node in question, resulting in the overall system interference.

A.2.2.2.1 Antenna parameters

The mesh device is assumed to be using omni-directional antennas at all times, which is a worst-case assumption, as non-broadcast communications between nodes could be performed with smart antennas to reduce overall interference.

It is extremely important to notice that the mesh device is by necessity a roof-mounted device, as it must extend coverage in all directions. In contrast to PMP Subscriber System (SSs), which are typically installed under the eves, the amount of vertical scattering, which is harmful to both ground-based WLAN devices and satellites, is significantly less despite the lack of horizontal directivity. This is due to the relatively good probability of clear line-of-sight of the nodes to each other due to their individual mounting location as well as the significantly shorter distances to each other than a PMP SS typically enjoys to its BS. On top of this, the variation in heights of the nodes' antennas is negligible, whereas a PMP BS typically is installed at much greater height than its SUs, the result of which is that SSs are generally installed with some vertical tilt, which worsens their illumination of satellites.

For these reasons, no extra scattering in the vertical direction is assumed for this evaluation besides the antenna pattern.

Table 242—Antenna parameters

Parameter	Value
Mounting	Outdoors/rooftop
Gain (Horizontal omni-directional)	8 dBi @ 90° -22 dBi @ 0 - 30° -15 dBi @ 30 - 50°
Polarization	vertical

As shown in Table 242, the antenna is an 8dBi gain omni-directional antenna with a -22 dBi vertical gain and worst-case -15 dBi between 30 and 50° from vertical.

A.2.2.2.2 Mandatory mode Radio parameters

Although 5 and 10 MHz channelization are also defined, the focus here is on the mandatory 20 MHz channelization, which gives the worst case scenarios.

It is important to note that the use of 6 dBW max. EIRP is assumed for all parts of the spectrum with a backoff of only 3 dB. In a practical OFDM system, the backoff is in the order of at least 6 dB minimum, whereas the rules commonly specify at most 0 dBW maximum mean EIRP [B56] or 6dBW maximum peak EIRP [B19] for fractions of the band. It should hence be understood that the analyses err (by 3 to 10 dB) on the side of caution in how much interference can be tolerated.

Table 243—Relevant Radio parameters I

Parameter	Value
Transmit Power	28 dBm (i.e. 36 dBm max EIRP) with dynamic power control
20 dB bandwidth	21 MHz
Peak-to-Average Power ratio	3 dB

The Rx Sensitivity and C/I parameters for the code rates defined in Table 215 and Table 234 are temporarily, as they are currently not yet defined in the IEEE 802.16b standard.

They are estimated using the formula:

$$Rx_{sens}(dBm) = K \cdot T_0(dBm) + 10\log(BW_{-26dB}) + NF(dB) + SNR_{avg} + margin$$

The thermal noise is $K \cdot T_0 = -174dBm$ and the noise figure is chosen to be $NF = 7dB$. The margin is assumed to be 5dB, consistent with [B49]. This leaves us with $Rx_{sens}(dBm) = SNR_{avg} - 88.5$. SNR's are guesstimated from several preliminary studies

Table 244—Relevant Radio parameters II

Modulation	Coding Rate	SNR_{avg} (dB @ 0.1%PER)	Rx Sensitivity (dBm @ 0.1% PER)
BPSK	1/2	7	-82
	3/4	13	-76
QPSK	1/2	10	-79
	3/4	17	-72
16QAM	1/2	19	-70
	3/4	25	-64
64QAM	2/3	30	-59
	3/4	40	-49

For the purpose of analytical full network interference analysis, the receiver sensitivity of the mesh system is chosen to be -75 dBm, an average of the modulation and coding mode sensitivities up to rate 1/2, 16-QAM, which will be the most likely used in practical deployments.

A.2.2.3 EESS and FSS

Two types of satellite services are deployed in the 5 GHz; fixed satellite service (FSS) and earth exploratory satellite systems (EESS) services, EESS services are provided by two distinct types of satellite: Altimeter satellites and SAR satellites.

A.2.2.3.1 Altimeter satellites

The characteristics of altimeter satellites have been derived from [B48].

Table 245—Altimeter satellite characteristics

Parameter	Value
Bandwidth	320 MHz
Rx sensitivity	-88 dBm
On-axis Antenna gain	32.5 dBi
Off-axis Antenna gain	$10^{3.25}(\mathrm{Sin}(\varphi)/\varphi)^2$ [a]
Antenna size	1.2 m
height	1344 km
Input loss = Output loss	1 dB
coverage	$\varphi \in [-60°, 60°]$
Bandwidth	320 MHz

[a] φ is the angle between the vertical and the direction of the ground-based device

A.2.2.3.2 SAR satellites

The characteristics of SAR-1 through SAR-4 satellites have been derived from [B48].

Table 246—Typical Spaceborne Imaging Radar Characteristics

Parameter	Value			
	SAR1	**SAR2**	**SAR3**	**SAR4**
Orbital Altitude	426 km (circular)	600 km (circular)	400 km (circular)	400 km (circular)
Orbital Inclination	57 deg	57 deg	57 deg	57 deg
RF Centre Frequency	5305 MHz	5305 MHz	5305 MHz	5300 MHz
Peak Radiated power	4.8 Watts	4800 Watts	1700 Watts	1700 Watts
Polarization	Horizontal (HH)	Horizontal & Vertical (HH,HV,VH,VV)	Horizontal & Vertical (HH,HV,VH,VV)	Horizontal & Vertical (HH,HV,VH,VV)
Pulse Modulation	Linear FM chirp	Linear FM chirp	Linear FM chirp	Linear FM chirp
Pulse Bandwidth	8.5 MHz	310 MHz	310 MHz	40 MHz
Pulse Duration	100 µs	31 µs	33 µs	33 µs
Pulse Repetition Rate	650 pps	4492 pps	1395 pps	1395 pps
Duty Cycle	6.5%	13.9%	5.9%	5.9%
Range Compression Ratio	850	9610	10230	1320
Antenna Type	Planar phased array 0.5m x 16.0m	Planar phased array 1.8m x 3.8m	Planar phased array 0.7m x 12.0m	Planar phased array 0.7m x 12.0m
Antenna Peak Gain	42.2 dBi	42.9 dBi	42.7/38 dBi (full focus/beam-spoiling)	42.7/38 dBi (full focus/beam-spoiling)
Antenna Median Sidelobe Gain	-5 dBi	-5 dBi	-5 dBi	-5 dBi
Antenna Orientation	30 deg from nadir	20-38 deg from nadir	20-55 deg from nadir	20-55 deg from nadir
Antenna Half-power Beamwidth	8.5 deg (El), 0.25 deg (Az)	1.7 deg (El), 0.78 deg (Az)	4.9/18.0 deg (El), 0.25 deg (Az)	4.9/18.0 deg (El), 0.25 deg (Az)
Antenna Polarization	Linear horizontal/ vertical	Linear horizontal/ vertical	Linear horizontal/ vertical	Linear horizontal/ vertical
System Noise Temperature	550 K	550 K	550 K	550 K
Image swath width	50 km	20 km	16 km/ 320 km	16 km/ 320 km

For both the SAR imaging missions and the topographic missions, a minimum signal-to-noise ratio (SNR) is defined, below which the radar image pixels, and/or differential phase measurements are unacceptably degraded. The following interference criteria are from ITU-R JWP 7-8R:

- the degradation of the normalized standard deviation of power received from a pixel should be less than 10% in the presence of interference;
- the aggregate interference power-to-noise power ratio (corresponding to a pixel SNR of 0 dB) should be less than -6 dB;
- These levels may be exceeded upon consideration of the interference mitigation effect of SAR processing discrimination and the modulation characteristics of the radiolocation/ radio-navigation systems operating in the band;
- The maximum allowable interference level should not be exceeded for more than 1% of the images in the sensor service area for systematic occurrences of interference and should not be exceeded for more than 5% of the images in the sensor service area for random occurrences of interference.

The data loss criteria have been fully utilized to achieve sharing with the radio determination service. This study therefore uses the degradation interference criteria to derive the sharing constraints on FWA devices. Assuming that the interfering signal distribution is white Gaussian noise the maximum acceptable interference signal is indicated in the table below:

Table 247—Typical Spaceborne Imaging Radar Characteristics

Parameter	Value			
Noise (dBW)	-129.5	-113.8	-113.8	-122.7
Min. Desired Signal(dBW)	-189.7	-198.6	-187.1	-187.0
Max. Acceptable Interfering signal (dBW)	-135.5	-119.8	-119.8	-128.7
Receiver Bandwidth (MHz)	9.8	356.5	356.5	46
Max. Acceptable Interfering spectral power density (dBW/Hz)	-205.4	-205.4	-205.4	-205.4
Antenna Polarization	Linear horizontal/ vertical	Linear horizontal/ vertical	Linear horizontal/ vertical	Linear horizontal/ vertical
System Noise Temperature	550 K	550 K	550 K	550 K
Receiver front end 1 dB compression point ref to receiver input	-62 dBW input	-62 dBW input	-62 dBW input	-62 dBW input
Ground Illumination Area	93 km (elevation), 2.2 km (azimuth)	At 20° from nadir: 20 km (elevation), 8.7 km (azimuth)	At 20° from nadir: 40 km (elevation) 2 km (azimuth)	At 20° from nadir: 40 km (elevation) 2 km (azimuth)

A.2.2.3.3 FSS satellites

The characteristics of Fixed Satellite Service satellites have been derived from [B48].

The maximum allowable interference power spectral density tolerated by FSS satellites is given by

$$p = -42 + (G/T) - \gamma \qquad dBW/Hz$$

in which *G* is the gain of the satellite antenna, *T* the noise temperature (*G/T* is termed the merit factor), and γ the link gain. FSS satellites are geo-stationary and hence located at 36000 km, resulting in 199 dB path-loss. In the case of the Telecom 3 network [B48], which is used as example, γ is 0 dB, the total link equivalent noise temperature is 870 K, the gain for the 'Metropole' spot is 34 dBi and the coverage area of this spot is all of Europe. G/T then becomes 4.6 dB.

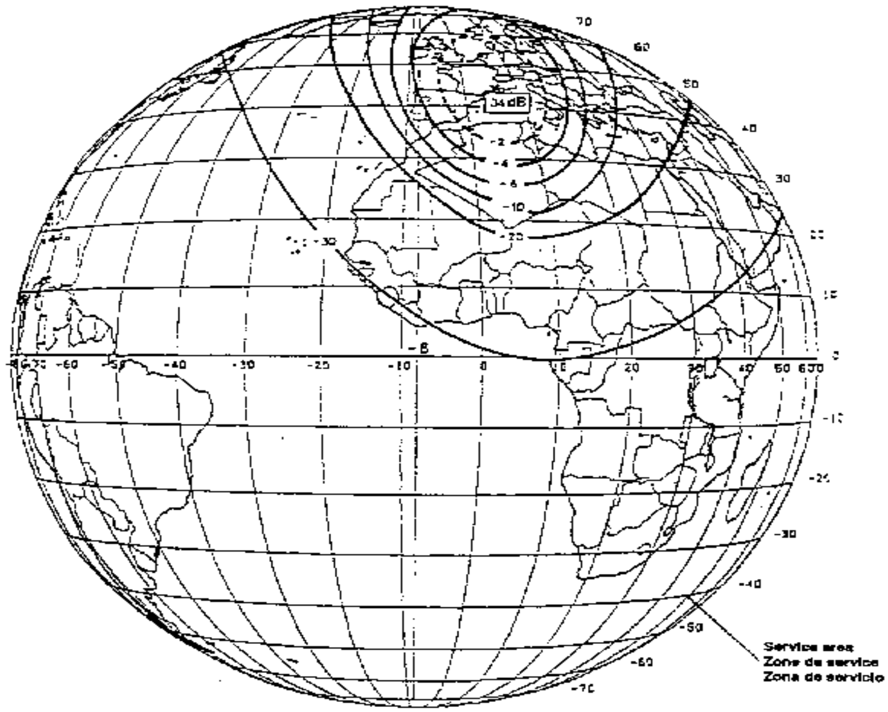


Figure 252—Telecom 3 FSS Satellite Service Region

A.2.2.4 WLANs

The WLAN deployments considered here are the ETSI BRAN HIPERLAN/2 [B50] and IEEE 802.11a devices. Only indoor deployments are considered in detail. It is clear that outdoor WLAN devices can generally not co-exist in the same channel with FWA devices in the same geographical area. However, the use of DFS, as well as the fact that the hotspot locations envisioned for outdoor WLAN deployments (such as airports and school campuses) do generally not coincide with the residential areas Mesh devices are targeted towards, easily resolve this type of WLAN deployments.

Table 248—WLAN Parameters I

Parameter	Value
Antenna type	Isotropical
Tx probability WLAN device	5%
Tx Power	30 dBm max EIRP with dynamic power control
Radio Access	TDD/TDMA

Table 249—WLAN parameters II[a]

Modulation	Coding Rate	Rx Sensitivity (dBm @ 10% PER)	C/I (dB @ 10% PER)
BPSK	1/2	-82	6
	3/4	-81	11
QPSK	1/2	-79	9
	3/4	-77	14
16QAM	1/2	-74	16
	3/4	-70	20
64QAM	1/2	-66	25
	3/4	-65	30

[a]Copied from [B49], Table 91

A.2.2.5 RTTT

Road transport & traffic telematics (RTTT) devices[B53] are allocated in the band 5795-5805 MHz (2×5 or 1×10), with an extension band 5805-5815 MHz (2×5 or 1×10), which may be used on a national basis at multi-lane road junctions. These devices are split into the Road Side Unit (RSU) and the onboard unit (OBU), the parameters for which are shown in Table 250 and Table 251.

Table 250—RTTT RSU Parameters

Parameter	Value
Tx Power (max EIRP)	3 dBW
Rx sensitivity	-105 to -130 dBW[a]
Antenna gain	20 dB
C/I: 2 / 4 / 8 - PSK	6 / 9 /12 dB
polarization	circular

[a] This range is merely informative. The device must merely meet the manufacturer's claim.

Table 251—RTTT OBU Parameters (-35° to +35°)

Parameter	Value	
Class	A,B,C,D	E
Re-radiated subcarrier power (max EIRP)	-54 dBW	-44 dBW
Antenna gain	1 dB	
Rx sensitivity	-73 dBW	-70 dBW
C/I: 2 / 4 / 8 - PSK	6 / 9 /12 dB	C/I: 2 / 4 / 8 - PSK
polarization	circular	polarization

In analyzing the compatibility between HIPERLANs and RTTT the basic approach taken is to use the Minimum Coupling Loss (MCL) technique to determine the necessary separation distances between the two systems.

Minimum coupling loss: $L = P_t - max\left\{10\log\left(\frac{B_i}{B_{Rx}}\right), 0\right\} - I_{Rx}$

Where P_t = transmitter power

B_{Rx} = receiver bandwidth (MHz)

B_i = interferer bandwidth (MHz)

I_{Rx} = tolerable interference at receiver (dBW)

Required separation distance: $d = \frac{\lambda}{4\pi}10^{pathloss/23}$ where *pathloss = L + Antenna and feeder gains and losses*

A.2.2.6 Radar

The radar parameters used in the radar analysis are taken from [B48],[B55]. In the analysis, the MCL technique described in clause A.2.2.5 will be used, with the exception that for the airborne radar (radar type B), a propagation exponent 2.0 instead of 2.3 is used.

Table 252—Relevant radar parameters

Parameter	Value				
Radar type	A	B	C	D	E
Peak EIRP (dBW)	98.6	26	60	93	97
BW_{radar} (MHz)	3	15	30	14	3
Antenna gain (dBi)	40	0	46	43	43
Tuning range (GHz)	5.30-5.60	5.70-5.80	5.40-5.82	5.25-5.85	5.60-5.65
Use	Transportable long range	Airborne	Fixed long range	Transportable multi-function	Fixed long range

A.2.3 IEEE 802.16b PMP interference analyses

A.2.3.1 Coexistence with SAR satellites in middle UNII

The Wireless HUMAN Standard-based systems that will operate in the middle U-NII band (5.25-5.35 GHz) will have to share this band with a number of other systems (e.g., Earth Exploratory Satellite (active) Service (EESS) Synthetic Aperture Radars (SARs), Wireless HUMAN Standard-based systems, non-standard point-to-multipoint Broadband Fixed Wireless Access (BFWA) systems, terrestrial Radars, and IEEE 802.11a, 802.15 and HIPERLAN/2 Wireless LANs). As this is a License-Exempt (LE) band these diverse systems will often be operated in the same geographical area by different operators. Moreover besides having to meet local Regulatory requirements (e.g., in the USA the FCC Subpart E Requirements) the Wireless HUMAN Standard-based systems will also be called to meet global agreements; e.g., from the World Radiocommunications Conference (WRC).

What follows gives an indication of the interference that Wireless HUMAN based BFWA systems can cause to SARs operating in Middle U-NII band. In particular it has been shown by published results of ITU-R studies that BFWA antenna directivity is effective in minimizing interference to SAR-4, (e.g., USA ITU-R WP7C/24 Contribution). Table 253 shows that use of 6dB antenna directivity can decrease the SAR-4 interference by 4dB.

Note: The value of antenna directivity that should be specified requires trade-off studies with the other mechanism. SAR-4 is used because the SAR-4 system is more interference sensitive than SAR-3 and SAR-4, and the SAR-4 center frequency is 5.3GHz.

The SAR-4 Synthetic Aperture Radar scans a path from 20^o to 55^o from Nadir. This corresponds to Earth incident angles of 21^o and 60^o-which can be translated to angles of 69^o and 30^o with respect to the horizon. That is, any radiation from U-NII devices within that angular range could cause/contribute to satellite interference.

An approach that can be used in analyzing the interference potential from Middle U-NII BFWA systems into space-borne SAR-4 receiver is to determine the worst case signal power received from a single BFWA transmitter at the spaceborne SAR. Then, the single interferer margin can be calculated by comparing the single

BFWA interferer level with the SAR-4 interference threshold. Knowing the SAR-4 footprint, the allowable density of active BFWA transmitters can then be calculated, if a positive margin results from a single BFWA interferer.

Table 253—Single U-NII BFWA to SAR-4 Interference

Parameter	System	Value	dB
Transmitted Power (W)	BFWA1	0.25	-6.02
	BFWA2	0.25	-6.05
Building Loss (dB)	-	0	0
Antenna High Elevation TX Gain (dB)	BFWA1	0	0
	BFWA2	-4	-4
Antenna Gain, RX (dB)	-	44.52	44.52
Polarization Loss (dB)	-	3	-3
Wavelength (m)		0.0565	24.96
$(4\pi)^2$		0.00633	-21.98
Distance (km)		425.67	-112.58
Power RX (dBW)	BFWA1	-	-124.03
	BFWA2	-	-128.03
Noise Figure (dB)	-	4.62	4.62
kT	-	$4 \cdot 10^{-21}$	-203.98
RX Bandwidth (MHz)	-	46	76.63
Noise Power (dBW)	-	-	-122.73
SAR-4 Interference Threshold (I/N=-6dB)	-	-	128.71
Margin (dB)	BFWA1	-	-4.71
	BFWA2	-	-0.71

Table 253 shows the signal power at the SAR-4 receiver from a transmitter with power output of -6 dBW (24 dBm) and an isotropic radiator with unity gain at all look angles. The space loss at angles of 21^o and 60^o, receive antenna gain, polarization loss, scattering gain and satellite interference threshold are derived from ITU-R reports. The reference margin is the difference between the Signal Power at the Satellite Receiver and the Satellite Interference Threshold. The negative margin numbers indicate that radiating an EIRP of 24 dBm toward the satellite will exceed the interference threshold. Fortunately, real-world antennas do not exhibit unity gain at high elevation look angles, and this feature can be used to mitigate interference

A conclusion that can be drawn is that antenna directivity, if properly utilized, will provide interference margin for multiple transmitters. However, it should be noted that the satellite footprint is large (53 sq. km at 20^o from Nadir and 208 sq. km at 55^o from Nadir). Therefore, given the potential variables associated with the design, installation and maintenance of the various unlicensed transmitters, antenna directivity alone may not be sufficient to assure non-interference.

The margin calculation in Table 253 includes 3 dB polarization loss. The fact that most P-MP systems rely on polarization for maximizing channelization, as many as half of the U-NII transmitters in a given area could be transmitting on each polarization. If so, the 3 dB polarization loss may not be fully realizable.

If the satellite were restricted to one linear polarization and the U-NII transmitters were restricted to the other linear polarization, greater polarization isolation could be achieved. Given the operational needs of both services, this is unlikely to happen.

A.2.4 IEEE 802.16b mesh interference analyses

A.2.4.1 Interference to EESS and FSS

A.2.4.1.1 Altimeter satellites

The interference from one mesh node into the boresight of the SAR can be described by (see [B48])

$$P_r = \frac{P_m G_m G_a \lambda^2}{(4\pi)^2 R^2} L$$

in which $P_m G_m = 6dBm$ (28 dBm Output power - 22 dBi top lobe) is the EIRP of the mesh antenna in the vertical direction, $G_a = 32.5dBi$ the gain of the altimeter antenna, $\lambda = 5.66cm$ the wavelength, $L = -1dB$ the input loss of the altimeter, and $R = 1344km$ the lowest orbit.

From this we obtain a value for $P_r = -132dBm$

The altimeter interference threshold is - 88 dBm; we can thus deduce that the altimeter can withstand the operation of huge numbers of mesh devices simultaneously, since we have a 44 dB margin. Furthermore, the altimeter is built to provide measurements mainly over oceans and is not able to provide accurate data when a significant amount of land is in view of its antenna beam. From this analysis, it is clear that the altimeter will not suffer from the operation of Mesh networks. However, for completeness, the number of mesh devices per square kilometer tolerable by the altimeter can be calculated.

The distance between the satellite and a mesh node under angle φ is R tan(φ) km. Only freespace attenuation, which ignores atmospheric properties (which further attenuate the signal, especially when φ>>0) has been considered.

For simplicity, the 3 mesh nodes that on average exist in one hexagon are assumed to all be in the centre point of the hexagon. The hexagon grid then reduces to a square grid with 3 nodes every 2 times the distance of a single set of nodes.

We then have:

$$P_r = \sum_{r_1}\sum_{r_2} \frac{3P_m G_m G_a \lambda^2}{(4\pi)^2 R^2} L\left(1 + 4A\sum_{r_1}\sum_{r_2} \mathrm{sin}c^2[2\varphi(r_1,r_2)]\right) \qquad \forall \sqrt{r_1^2 + r_2^2} < \frac{R\sqrt{3}}{2} \qquad \varphi = arc\tan\left[\frac{2\sqrt{r_1^2 + r_2^2}}{R}\right]$$

in which r_1 and r_2 enumerate over the square grid, and A is the activity factor. This derivation is easily computed numerically. According to [B52], significantly less than 15%[1] of land is used for residential areas and normally a significant fraction of the footprint covers water as well. Hence a Residential fraction of 0.05

[1] Figure includes land used for urban and other purposes, e.g. transport and recreation, and non-agricultural, semi-natural environments, e.g. sand dunes, grouse moors and non agricultural grasslands, and inland waters.

is introduced, to simulate clusters of nodes spread out over the whole satellite footprint. The receiver sensitivity is, as discussed in clause A.2.2.2.2, chosen to be -75 dBm.

```
%Satellite specifications
Ga = 32.5;              % dBi   Antenna gain
lambda = 0.0566;        % m     Wavelength
L = -1;                 % dB    Insertion Loss
R = 1344;               % km    Height
Int_limit = 88;         % dBm Interference limit
%Mesh specifications
Rbase = 0.5;            % km    Distance between two mesh nodes
AntGain  = 8            % dBi   Mesh antenna gain (max)
AntTop   = -22          % dBi   Mesh antenna gain (top-lobe)
RxSens      =-105       % dBW Rx sensitivity Mesh
Pout        = 28;       % dBm Max. output power Mesh
Backoff   = 3;          % dB   Average Backoff
Activity    = 0.05;
pi = 3.1415;
pathloss = -20*log10(3E8/(4*pi*5.3E9))+2.3*10*log10(Rbase*1000);
PmGm = (pathloss - AntGain + FadingMargin + RxSens) + (AntTop-AntGain) -Backoff+ 30; % dBm
Residential = 0.15;        % fraction residential landuse
Pr1 = 0;nodes =0;
for r1 = Rbase : Rbase/sqrt(Residential): R*sqrt(3)/2
   for r2 = Rbase : Rbase/sqrt(Residential): R*sqrt(3)/2
      if( sqrt(r1*r1+r2*r2) < R*sqrt(3)/2)
         nodes = nodes+3;
         phi = atan( 2*sqrt(r1*r1+r2*r2)/R );
         Pr1 = Pr1 + sinc(2*phi/pi)*sinc(2*phi/pi);
      end;
   end;
end;
Pr2=10*log10(3*lambda*lambda*(1+4*Pr1*Activity)*10^((Ga+PmGm+L)/10)/...
       ((4*pi)*(4*pi)*R*R*1E6) );
sprintf('Distance between nodes: %d m\n',Rbase*1E3)
sprintf('Interference margin to altimeter: %d dB\n',Int_limit + Pr2)
```

Figure 253—mesh interference code sample

The result of the simulation, as shown above, is that over 30 million nodes can be supported under the footprint, with 6 dB in interference margin. In many cases shorter distances between the nodes will result in lower used power due to power control. Hence in practice many more nodes could be supported without violating the interference limit.

A.2.4.1.2 SAR satellites

In analogy with [B48], only the case for SAR-1 satellites is examined, since this provides the worst case analysis. However, contrary to this report, it will show that using mesh technology, an increase in network density actually reduces the interference into the SAR satellite, since the dynamic power-control reduces the power for shorter links. The receiver sensitivity is, as discussed in clause A.2.2.2.2, chosen to be -75 dBm.

As can be seen from Table 254, a mesh networks has limitations both on the maximum distance and maximum density of the network. The maximum distance that can be achieved by the mesh network using 4 Watts EIRP is about 1 km, which retains a margin of 10 dB to the interference threshold.

Deployments with distances between nodes of one km are however exceedingly sparse and not practical except in the very early stages of service rollout (i.e. when seeding the service area).

Reducing the distance increases the number of nodes, but reduces the necessary power levels, hence reducing the overall interference into the satellite. Increasing the density, and hence the number of nodes to very high levels, up to about one device per 92 m would still obtain tolerable interference levels. Deployment densities of this nature, especially in the areas of major interest to the satellite community (which to our understanding are mostly oceanic and agrarian), are however extremely unlikely.

PMP systems do not enjoy the same advantage, as increased capacity needs are mostly met by increasing the number of sectors on the base-station, keeping the EIRP on each SU constant. Interference in that case increases linearly with the number of sectors deployed, and hence in practice linearly with the number of SUs installed on each basestation. The limitations on the SU density are hence much sooner violated.

To allow an easier comparison with the WLAN results in [B48], Table 254 computes the number of Mesh devices that can be situated in the SAR footprint without exceeding the interference limit.

Table 254—IEEE 802.16b mesh devices in the SAR footprint

Parameter	Value				
Node distance	1	0.5	0.25	0.1	km
Tx antenna gain	8				dBi
Rx sensitivity	-105				dBW
path loss	115.93	109.00	10.08	92.93	dB
P_{out} required (EIRP)	2.93	-4.00	-10.92	-20.07	dBW
P_{out} required (conducted)	-5.07	-12.00	-18.92	-28.07	dBW
freespace distance	-160.8				dB
building attenuation	0				dB
Tx antenna gain (top lobe)	-22				dBi
Polarization loss	-3				dB
Peak-to-Average ratio	-3				dB
Rx antenna gain (main lobe)	42.4				dBi
Rx Power	-224.90	-231.82	-238.74	-247.90	dBW/Hz
SAR threshold	-205				dBW/Hz
margin	19.54	26.46	33.38	42.54	dB/Hz
SAR footprint	22.59				dB
Tx activity	-13.01				dB
Permissible density/km^2/ch	9.91	498.78	240.22	1976.39	nodes
nodes within SAR footprint (CEPT region)	**26967**	**132804**	**654001**	**5380723**	**nodes**

In Table 254, it is assumed that all Mesh devices are located in the boresight of the SAR satellite, which provides the worst case scenario.

A.2.4.1.3 FSS satellites

The bandwidth of the Mesh device is 21 MHz (73.2 dBHz). The maximum allowable interference power spectral density tolerated by the Telecom 3 network (see clause A.2.2.3.3) then becomes 27 dBW/Hz.

Appendix S8 of the ITU Radio Regulations [B51] gives the method to calculate the maximum interference power produced by an earth station to a satellite receiver. When calculating the maximum interference power from Mesh devices into a satellite receiver, we have to consider all the mesh devices under the satellite footprint as a single source. This means that the source is not specifically located, and only the direct top lobe of the mesh antenna is taken into account.

Table 255—Tolerable mesh nodes for FSS operation

Parameter	Value				
Tx EIRP	-6	0	3	6	dBW
Tx antenna gain (main lobe)	8				dBi
Tx antenna gain (top lobe)	-22				dBi
Peak-to-Average Ratio	3				dB
Shielding effect	0				dB
Acceptable interference	27				dBW
Active users	1000	251	126	63	nodes (thousands)
Average Tx ratio	5				%
Tolerable nodes	300	75.4	37.8	18.9	nodes (millions)

From Table 255, it shows that even using 4 W (6 dBW) EIRP, an enormous amount of Mesh nodes can be in operation within the FSS footprint.

A.2.4.2 Interference to WLANs

A.2.4.2.1 Immediate neighborhood analysis

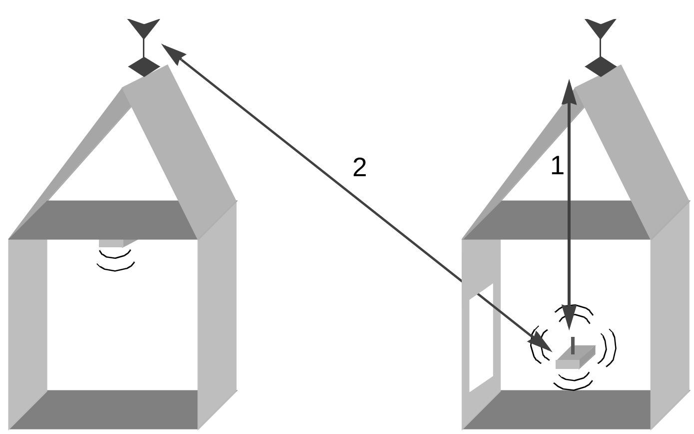


Figure 254—Immediate neighbourhood scenario

A.2.4.2.1.1 ‘Same building' analysis (1)

In the immediate neighborhood scenario, the interference from a Mesh node to a WLAN device in the same building is analyzed (link 1 in Figure 254).

It is assumed for this scenario, that the distance between the Mesh node and the WLAN device in the same building is 5 m. The structural isolation plus attenuation due to multipath/scattering is assumed to be 25 dB over that distance, based to Annex 2 of [B48]. Note that this is not the same as the average 13.4 dB assumed in [B48], since we consider only placement of Mesh devices on the roof, and not placement outside in general as in the outside WLAN case. This is likely to be a very modest value for a typical home with concrete ceiling and stone tile roofing. The total attenuation is then $25 + 20*\log10(4*\pi*d*f_0/c) = 86$ dB. Given the radiation pattern of a Mesh node transmitting at full 28 dBm (i.e. 36 dBm EIRP), the interference level at the WLAN = 28-22-86= -80 dBm. Taking into account the backoff, 3 dB, and the effect of the Mesh activity factor, an additional 13 dB, brings the average interference level, -97 dBm, far below receiver sensitivity values. Operation of a mesh device on the roof, while running an WLAN network inside is hence feasible, even in the same channel.

In this scenario, to operate the WLAN at its highest modulation and coding rate (64 QAM, 3/4 coding) while the Mesh device is transmitting, would require the separation to be at least 20 meters. (instead of the 5 meters used). For (16 QAM, 1/2 coding), the separation would be 10 meters.

A.2.4.2.1.2 'Across the street' analysis (2)

Another critical consideration is the analysis of illumination of indoor WLANs in adjacent buildings. This is due to the fact that despite the larger distance, normally only one isolating building layer (which may also be a window) is situated in-between, and the Mesh antenna gain increases with the angle from the vertical axis.

It is assumed for this scenario that the street is 10 m wide, which gives an antenna gain of -15dBi and an outdoor distance of $\sqrt{125}$=11.2m. The structural isolation plus attenuation due to multipath/scattering is assumed to be 10 dB (window plus some indoor scattering). The total attenuation is then $10+20*\log10(4*\pi*d*f_0/c) = 78$ dB. Taking into account the antenna gain, the backoff and the mesh activity factor of the mesh node reduces the average level at the WLAN to -78 dBm.

Of course, the numbers in the above analysis fluctuate by a number of dB's for individual deployments. The average structural attenuation was quoted to be 13.4 dB in [B48], but there may be variations in building height or terrain sloping which increase the antenna gain in the direction of the WLAN by a few dBs. Typically however, the above results are broadly applicable as conservative estimates to a wide range of deployment scenarios.

Power-control and DFS can assist in further reducing these interference levels. Note that the transmit probability of the WLAN device, (13 dB), has not been taken into consideration.

A.2.4.2.2 Outdoor WLAN analysis

An argument often used against the use of FWA devices in the 5GHz bands is that it will interfere with outdoor deployments of WLAN devices. It is quite obvious that co-location of these two types of devices on a roof (or neighboring roofs) will cause severe interference when operating in the same channel. However, it should be realized that exactly the same issue exists with two WLAN APs on a roof (or neighboring roofs) are competing for the same channel. (To be specific, this is mostly the case for HIPERLAN/2, which is schedule based. IEEE 802.11a uses CSMA/CD attempting to avoid this type of interference, which works well for low duty-cycles.) In both cases, the requirement for a DFS mechanism can gracefully resolves the problem.

In addition, outdoor WLAN deployments are predominantly used for hot-spot coverage and bridging, which implies the use of down-tilted antennas and oftentimes geographical isolation for hot-spot coverage and very directive antennas for bridging, each of which reduces the interference potential. In the cases where WLANs are currently used for access provisioning, IEEE 802.16 compliant systems will likely not be deployed or be used as more efficient substitutes.

FWA deployments require broad coverage and hence reasonable frequency re-use numbers to maintain sufficient Signal-to-Noise Ratio plus limited DFS flexibility to avoid local interference sources. The likelihood of roof-mounted WLAN devices not finding a sufficiently noise-free channel for proper operation are therefor rather small.

A.2.4.2.3 Network analysis

To illustrate the interference analysis further, an example typical scenario, consisting of a 4 node indoor WLAN network and a nearby 4 node Mesh network, is examined.

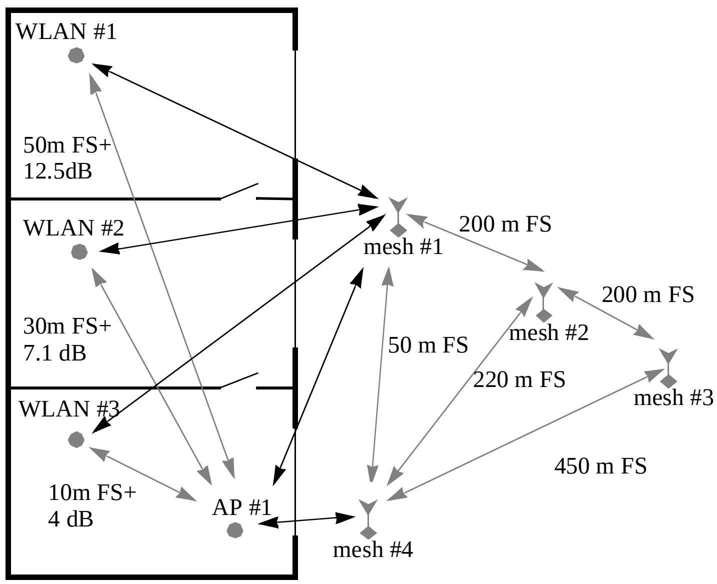
From Annex 2 of [B48], we extract that the typical indoor attenuation on top of free-space attenuation at 5 m is 4 dB for a mixture of line-of-sight through non-line-of-sight scenarios. The additional attenuation through 1 wall is 7.1 dB and the additional attenuation through 2 walls is 12.5 dB (the walls in these cases were breeze blocks and the rooms contained both wooden and metal furniture). The attenuation through a double-glazed window was found to be 7 dB.

In the case under study, a SU is assumed from each of these cases in a Small Office setting. The SU in the same room is assumed at 10 m, The SU in the adjacent room at 30 m and the SU behind two walls at 50 m.

The Small Office is assumed to be a single-floor building with a flat roof. The attenuation through the roof is 22 dB. 19 dB is a typical indoor cross-floor attenuation according to Annex two of [B48], so this is probably a fairly pessimistic value. The Mesh #4 node is situated on the roof directly atop AP #1 and provides the 'Internet access' for the WLAN service within the building. This makes sense, as the cabling distance between the data gathering point, the AP, and the access service, Mesh #4 node, is shortest. The distance between AP #1 and Mesh #4 is assumed to be 5m.

The nearest neighboring node, Mesh #1, is 50 m away on an adjacent building. The building attenuation is 10 dB (a window plus indoor scattering, as in clause A.2.4.2.1.2. It is assumed that this building is lower than the building with the WLANs, resulting in an antenna gain of -10 dBi in the direction of the WLANs, rather than the -15 dBi specified in Table 242). Two other nodes are each 200m away as shown in Figure 255. All mesh nodes are on the roof and hence only have free-space (FS) attenuation to each other. Mesh #3 is assumed to have an additional 15 dB obstruction to the WLANs in the form of a building (basically the building on which Mesh #2 is located).

Note that in the Path Losses in Figure 255, the antenna gain of the Mesh nodes (see Table 242) in the direction of the WLANs has been included.



Path	Path Loss
mesh#1 - AP#1	50m FS + 28dB
mesh#1 - WLAN#1	60m FS + 28dB
mesh#1 - WLAN#2	70m FS + 28dB
mesh#1 - WLAN#3	80m FS + 28dB
mesh#2 - AP#1	250m FS + 33dB
mesh#2 - WLAN#1	250m FS + 33dB
mesh#2 - WLAN#2	260m FS + 33dB
mesh#2 - WLAN#3	270m FS + 33dB
mesh#3 - AP#1	450m FS + 48dB
mesh#3 - WLAN#1	450m FS + 48dB
mesh#3 - WLAN#2	460m FS + 48dB
mesh#3 - WLAN#3	470m FS + 48dB
mesh#4 - AP#1	5m FS + 52dB
mesh#4 - WLAN#1	52m FS + 48dB
mesh#4 - WLAN#2	32m FS + 48dB
mesh#4 - WLAN#3	12m FS + 52dB

Figure 255—Example network scenario

In Table 256, the ranges and corresponding total link attenuations, which are assumed to be symmetrical, are gathered. In general, it can be observed that only nodes that are really close or in line of sight through little attenuation (particularly windows) result in significant interference.

Table 256—Link attenuations and ranges

	Link attenuation / Range							
	Mesh #1	Mesh #2	Mesh #3	Mesh #4	AP #1	WLAN #1	WLAN #2	WLAN #3
Mesh#1	-----------	200 m	400 m	50 m	50 m	60 m	60 m	60 m
Mesh#2	94 dB	-----------	200 m	220 m	220 m	230 m	230 m	230 m
Mesh#3	100 dB	94 dB	-----------	450 m	450 m	460 m	460 m	460 m
Mesh#4	82 dB	94 dB	101 dB	-----------	5 m	52 m	32 m	12 m
AP#1	110 dB	127 dB	149 dB	106 dB	------------	50 m	30 m	10 m
WLAN#1	111 dB	128 dB	149 dB	130 dB	94 dB	------------	50 m	20 m
WLAN#2	111 dB	128 dB	149 dB	126 dB	84 dB	132 dB	------------	30 m
WLAN#3	111 dB	128 dB	149 dB	121 dB	72 dB	94 dB	107 dB	------------

In Table 257, the maximum power and EIRP values for each of the devices is shown. For the WLAN devices and their AP, values are chosen which reflect implementations as are currently available in the market.

Table 257— Tx Power, conducted and EIRP (regulatory limited)

	AP	WLAN	mesh
Tx Power (mW)	200	200	500
Antenna (dBi)	2	0	8
EIRP (dBm)	25	23	35

In Table 258, the resulting received signal strengths are shown assuming transmission with EIRP values as shown in Table 257. Note that especially between the mesh nodes, the Rx values are extremely high, which would automatically be reduced by the AGC. For simplicity of computation, this is however ignored. This table is not symmetric since different antenna gains at each end can affect the perceived signal level.

Table 258—Received Signal Levels (dBm)

	Mesh #1	Mesh #2	Mesh #3	Mesh #4	AP #1	WLAN #1	WLAN #2	WLAN #3
Mesh #1	-----------	-54	-60	-42	-80	-83	-83	-83
Mesh #2	-54	-----------	-54	-54	-97	-100	-100	-100
Mesh #3	-60	-54	-----------	-61	-119	-121	-121	-121
Mesh #4	-42	-54	-61	-----------	-84	-102	-98	-93
AP #1	-76	-93	-115	-80	------------	-72	-62	-50
WLAN#1	-79	-96	-117	-98	-72	------------	-112	-74
WLAN#2	-79	-96	-117	-94	-62	-112	------------	-87
WLAN#3	-79	-96	-117	-89	-50	-74	-87	------------

Table 259 below shows the results. The top row in each box shows the actual communication direction, the used modulation and the Noise threshold. The four next rows illustrate the effect of interference from each source (using maximum allowed EIRP). If the modulation differs from the top box, then switch to a more robust modulation scheme was mandatory to maintain 3% PER. The last column defines the interference margin. A positive value means the threshold has been exceeded and is shown in bold.

Table 259—Sustainable modulation during interference

WLAN#1 =>AP#1	3/4 QPSK	-90
mesh #1	**PER>3%**	**4**
mesh #2	3/4 QPSK	-13
mesh #3	3/4 QPSK	-35
mesh #4	**PER>3%**	**0**

WLAN#2 =>AP#1	2/3 64QAM	-95
mesh #1	1/2 QPSK	-5
mesh #2	2/3 64QAM	-22
mesh #3	2/3 64QAM	-44
mesh #4	3/4 QPSK	-9

WLAN#3 =>AP#1	3/4 64QAM	-95
mesh #1	1/2 QPSK	-5
mesh #2	2/3 64QAM	-22
mesh #3	3/4 64QAM	-44
mesh #4	3/4 QPSK	-9

AP#1 => WLAN#1	3/4 QPSK	-90
mesh #1	**PER>3%**	**1**
mesh #2	3/4 QPSK	-16
mesh #3	3/4 QPSK	-37
mesh #4	3/4 QPSK	-18

AP#1 => WLAN#2	2/3 64QAM	-95
mesh #1	3/4 QPSK	-8
mesh #2	3/4 64QAM	-25
mesh #3	3/4 64QAM	-46
mesh #4	2/3 64QAM	-23

AP#1 => WLAN#3	3/4 64QAM	-95
mesh #1	3/4 QPSK	-8
mesh #2	3/4 64QAM	-25
mesh #3	3/4 64QAM	-46
mesh #4	3/4 16QAM	-18

From Table 259, two observations can be generalized. The first is that in certain scenarios interference in unavoidable if DFS is not used. The second is that interference only occurs when nodes are really close (such as mesh #4) or have relatively good line of sight properties (such as mesh #1, which only has a window in-between and a reduced height antenna) to the WLAN network. The later generalization means that very few nodes in a mesh network will cause degradation of a WLAN network. Realizing that the interference excess is relatively low, and the mesh network further uses power-control to reduce the EIRP where possible, interference from a transmitting mesh device will be very limited. Combined with the activity factors for both devices (on average 13 dB each) and DFS mechanisms, the likelihood of interference becomes so small that it is easily handled with Automatic Request (ARQ) causing minimal degradation of performance.

A.2.4.2.4 Adjacent channel issues

A nice feature of the OFDM technology used in both WLANs and Mesh technology at 5GHz, is that the adjacent channel rejection is very high, at least 35 dB (compare clause 8.3.5.4.2.4.2). Since the interference levels between WLANs and Mesh devices are relatively low compared to this (see previous sections), it is reasonable to assume that adjacent channels using WLAN and Mesh technology will not cause any noticeable interference to each other. Therefor, this is not further considered here.

A.2.4.3 Interference to RTTT

In accordance with [B48], [B54], the cross-polarization is assumed to be 10-15 dB to the RSU and 6-10 dB to the OBU (Table 260 uses the lower numbers).

Table 260—Needed separation distance mesh to RSU and OBU

Parameter	**RSU**		**OBU**
P_t	6		6
B_{Rx}	10	5	10
B_i	22		22
$I_{Rx}=Rx_{sens}-C/I_{8PSK}$	-117		-90
L	119.6	116.6	92.6
cross-polarization	10		6
Antenna & feeder gain	8		8
Separation distance	**553**	**394**	**53**

It should be noted that in the above calculations, the duty-cycle of the Mesh devices, which significantly reduces the interference scenario, has not been taken into consideration.

Especially for the RSU case, where the separation distance is fairly significant, it can be shown that the interference to the Mesh device is significantly larger than the other way around. Since RTTT devices normally have a fairly high duty-cycle, a close Mesh device would not be able to operate properly in this channel and would need to use the DFS mechanisms to switch to another channel. Therefor, for RSUs, proper operation is virtually guaranteed by virtue of its own interference potential.

A.2.4.4 Interference to Radar

For radars, a somewhat similar situation exists as with RTTT RSUs. To show this, the interference distance from radars into Mesh devices is derived, followed by the derivation of the interference distance from Mesh devices into radars. As is shown below, the first is much larger than the second, necessitating the use of the Mesh's DFS algorithm to switch to another channel to survive, eliminating the interference potential to the radar.

For analysis of the minimum distance at which an Mesh device still operates, shown in Table 261, the most robust modulation and coding mode is used.

Table 261—Minimum separation distance of radar to mesh

Radar type	A	B	C	D	E	
Peak EIRP	98.6	26	60	93	97	dBW
Antenna gain	40	0	46	43	43	dBi
P_t	58.6	26	14	50	54	dBW
BW_{radar}	3	15	30	14	3	MHz
I_{mesh}=Rx_{sens}-C/$I_{BPSK1/2}$	-116					dBW
L	174.6	142.0	131.3	166.0	170.0	dB
gain + feeder loss	48	8	54	51	51	dB
propagation loss	222.6	150	185.3	217	221	dB
distance @ 5.5GHz	20693	137	497	11813	17630	km
radio horizon	51.4	346.6	51.4	51.4	51.4	km (see [B55])
separation distance	**51.4**	**137**	**51.4**	**51.4**	**51.4**	**km**

In Table 262, the thermal noise level has been assumed -204 dB/Hz, whereas the Rx noise factor is assumed 5 dB. The maximum I/N is -6 dB as specified by NATO (see [B48], [B55]).

Table 262—Minimum separation distance of mesh to radar

Radar type	A	B	C	D	E	
P_t mesh	-2					dBW
BW_{radar}	3	15	30	14	3	MHz
Noise (dBW)	-134.2	-127.2	-124.2	-127.5	-134.2	dBW
On-tune rejection	-8.9	-1.9	0.0	-2.2	-8.9	dB (see [B48])
Max. Interference	-131.3	-131.3	-130.2	-131.3	-131.3	dBW
L	129.3					dB
gain + feeder loss	48	8	54	51	51	dB
propagation loss	177.3	145.3	191.6	188.3	188.3	dB
distance @ 5.5GHz	**220.1**	**79.4**	**916.3**	**662.7**	**662.0**	**km**

Comparing the result of Table 261 (line 10) and Table 262 (line 10), we see that in all cases, the separation distance is larger for the FWA system, forcing it effectively out of the channel used by the radar. In all cases, the separation distance is effectively limited by the radio horizon.

In the case of Radar type B, which is airborne, depending on the exact location of the radar, the gain+feeder loss will reduce from +8 to -22 dB, significantly reducing the necessary separation distance. Since the angle of detection (if any) is not known, this factor has not been used in the above tables. For the other types, the distance is limited by the radio horizon, but in practice likely much lower due to obstructions and clutter.

From the above tables, similar conclusions to the WLAN analysis in [B48] can be drawn. Sharing with maritime radars (which are not likely operating anywhere near residential areas) and S5.452 meteorological radars in band B and radiolocation radars in both band B and C is feasible when an effective DFS mechanism is employed by the Mesh system and the radar density isn't too high.

A.2.5 Channel and interference simulation model

A.2.5.1 Introduction

The purpose of this document is to present channel and interference models for 802.16.4 OFDM PHY. The models are targeted towards parameter optimization rather then for establishing the actual performance of the proposed system.

The models include the following elements:

- A channel model, which captures effects of multipath.
- A Radio impairments models.
- An interference model, capturing the effects of typical interference, which exists at unlicensed bands.

The underlying guidelines for this work, are to try to define a mathematical framework for the elements under consideration, rather then to try to match the models to specific scenarios. This approach will result in an set of flexible models, which can tailored to specific situations and scenarios by a simple change of parameters.

The models proposed here are straightforward, simple to simulate and yet gives a realistic description of the system and the related impairments. The models are also mathematically tractable, and support a single parameter characterization.

The basic model is depicted in Figure 256. The specific blocks are described in subsequent clauses.

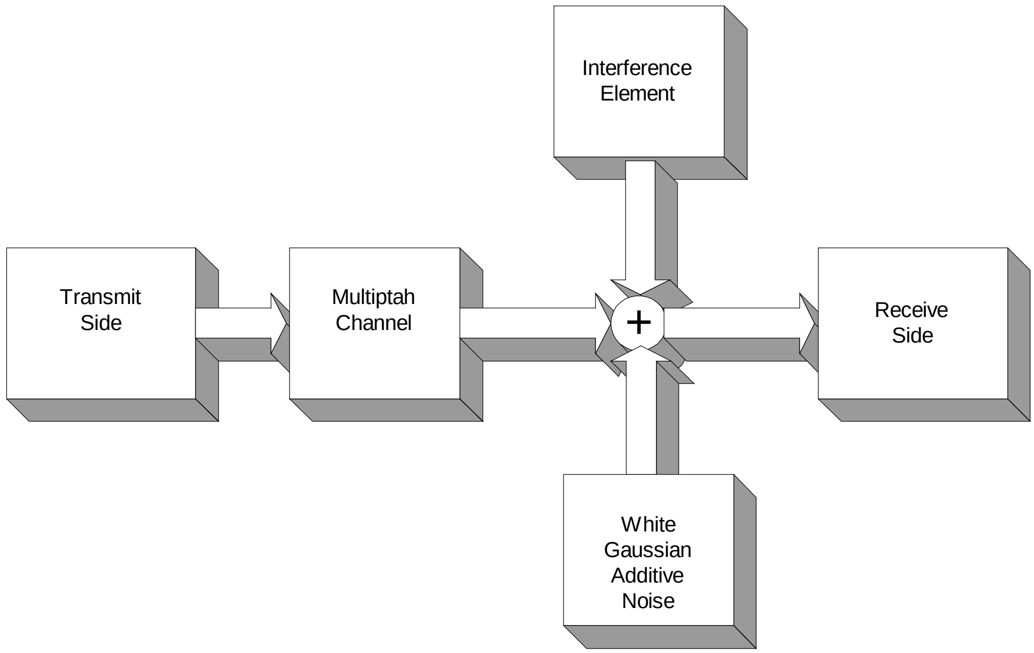


Figure 256—Basic Model

A.2.5.2 Multipath channel

The multipath model is selected to be a Rayleigh fading model with an exponentially decaying power profile. The channel is specified by the RMS of the tap weights. This model is simple to analyze and simulate. With a proper choice of delay spread values it represents realistic conditions. For further discussion see [B42] or [B43].

The following, taken from [B39], describes how to implement the multipath model in a discrete time simulation system.

Let $h_k = h(t)|_{t = kT_s}$ denote the sampled impulse response of the channel, where T_s is the sampling rate of the simulation system. The coefficients h_k are complex random numbers with random uniformly distributed phase and Rayleigh distributed magnitude. The average power decays exponentially. The RMS power average of the taps is given by the parameter T_{rms}. The coefficients are selected according to:

$$h_k = N\left(0, \frac{1}{2}\sigma_k^2\right) + jN\left(0, \frac{1}{2}\sigma_k^2\right)$$

$$\sigma_k^2 = \sigma_0^2 \exp(-kT_s/T_{RMS})$$

$$\sigma_0^2 = 1 - \exp(-kT_s/T_{RMS})$$

where $N(0, \sigma_k^2/2)$ is a zero mean Gaussian random variable with $\sigma_k^2/2$ variance, and σ_0^2 is chosen so that the condition $\sum \sigma_k^2 = 1$ is satisfied to ensure same average received power.

In Figure 257, the exponential power profile and a single realization of a channel are shown.

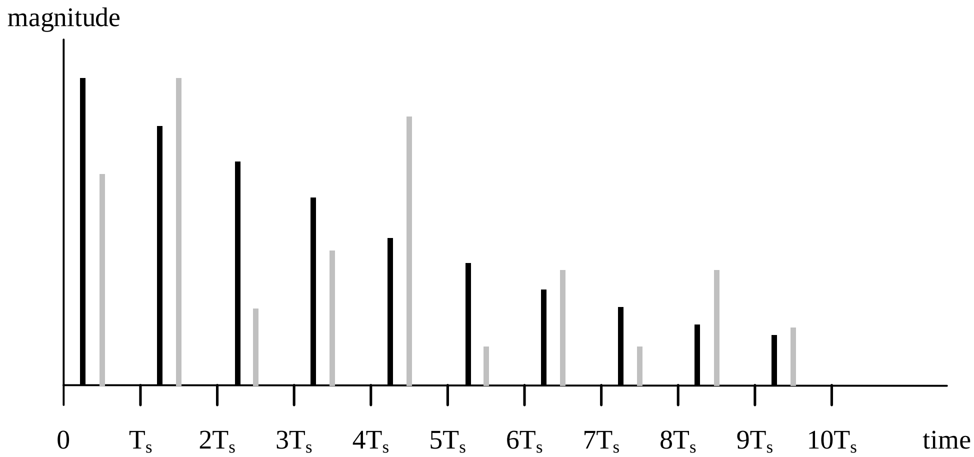


Figure 257—Power Profile (black) and realization (gray) (time staggered for clarity only)

The sampling time Ts in the simulation should not be longer than the smaller of 1/(signal bandwidth) or $T_{RMS}/2$. The number of samples to be taken in the impulse response should ensure sufficient decay of the impulse response tail, e.g. $_{kmax}=10T_{RMS}/T_{s}$.

For each packet, a new channel response is generated. The channel is assumed to be static during a packet.

A.2.5.3 Interference models

Here the interference is assumed to be stemming from wide-band packetized transmissions (e.g. 802.11a HiperLAN/2). The model generates random interference bursts. For each burst the following parameters are selected at random:

1. Arrival time of burst.
2. Length of burst.
3. Center frequency of burst.
4. Power of burst relative to noise floor.

The focus in this clause is to try to establish the mathematical framework for the interference model. Some crude assumptions are made with regard to the actual traffic parameters. These need to be refined.

The parameters are depicted schematically in Figure 258. Section A2.5.3.1 gives the underlying assumptions for the interference source. From those assumptions, the timing, power and signal descriptions are derived. They are described in clause A2.5.3.2. Section A2.5.3.3 describes the procedure of generating the interference signal.

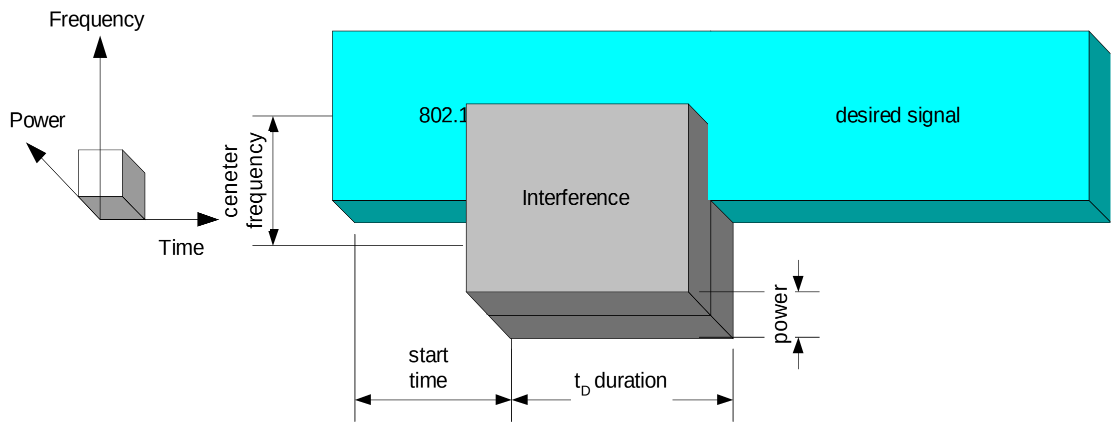


Figure 258—Interference Model

A2.5.3.1 Basic assumptions

Here we shall assume that the interferer is a 802.11a like signal (see [B44]). The instantaneous transmission rate is 24Mb/s. The occupied bandwidth is about 17MHz. The PHY layer overhead per packet is assumed to be 20uSec.

For the interferer traffic, we shall use the results published in [B45], where histograms of Ethernet packet sizes are shown. It is demonstrated that almost 75% of the packets are shorter than 522 bytes and nearly half the packets are 40-44bytes. In order to simplify and to reach round numbers, we shall assume that the packet size is uniformly distributed in the range 48 ...480bytes. This is equivalent to a packet duration in the range of 36...180 uSec.

The time between consecutive interference bursts is can be computed as follows. We can assume that most traffic, in bytes, is concentrated in long packets, say in 500bytes packets. Let us assume a channel utilization of 25%. Thus the average idle channel time is (1-0.25)/0.25*500*8/24Mb/s= 500uSec.

Here we shall assume that the average time from end of interference burst to beginning of next burst is Poisson distribution with a mean of 500uSec.

It is assumed that the power spectral density (PSD) of the interference is in the same order of magnitude as the thermal noise floor. More specifically, the PSD is in the range of N0 to N0+20dB, where N0 is the thermal noise floor.(-174dBm/Hz).

The frequency offset between the interferer and the desired signal is uniformly distributed in the range -10Mhz...+10MHz.

A2.5.3.2 Signal Wave shape

The interference signal is generated by passing a white complex Gaussian process, through a raised cosine filter and amplifying it to the desired level. Then it is shifted in frequency in to a randomly selected center frequency.

The motivation for using this wave shape is as follows:

- The proposed signal is easy to generate
- The spectral signature is similar to that of many communication systems.

- It has roughly the same peak to average power ratio as that of an OFDM signal.
- This signal, can be easily modified to represent other interfering signals.

The parameters of the raised cosine filter are rolloff factor of (=0.25 and 6dB corner of fc=10MHz. The filter is given by:

$$H(f) = \begin{cases} 1 & |f| < (1-\beta) f_c \\ 1/2\left[1 - \sin\frac{\pi}{2}\left(\frac{f}{f_c} - 1\right)\Big/\beta\right] & (1-\beta) f_c \le |f| < (1+\beta) f_c \end{cases}$$

A2.5.3.3 Generating Procedure

The signal generation is depicted in Figure 259. The procedure for generating the interference is given below.

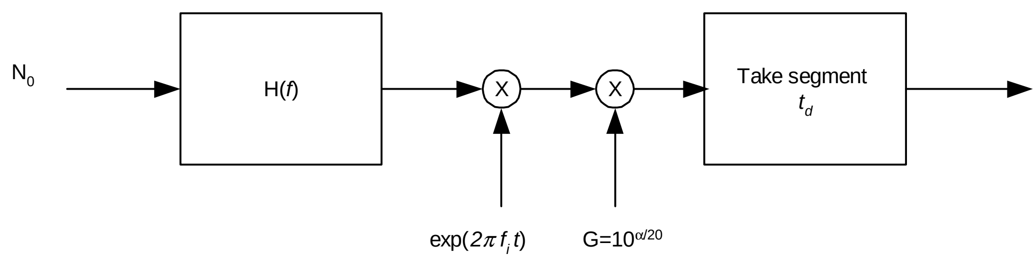


Figure 259—Interference Signal Generation

1. Select the start time. Generate a poisson random variable t_0 with a mean of $1/\lambda$ = 500uSec according to the probability distribution function given by : $f_t(t) = t\lambda\exp(-\lambda t)$
2. Add t_0 to the end of the last interference Burst. If this is the first interference burst, t_0 signifies start time from beginning of transmission burst.
3. Select the duration. Generate a uniformly distributed random t_D variable in the range 36uSec...180uSec.
4. Generate a white gaussian noise process with double sided PSD of N_0.
5. Filter the noise process with *H*(*f*) given above.
6. Select center frequency, f_i in the range -10MHz...10MHz.
7. Shift the signal in frequency by multiplying it by $\exp(j2\pi f_i t)$.
8. Select amplification. Generate a random variable (, uniformly distributed in the range 0...20. Set the amplification to $G = 10^{\alpha/20}$.
9. Take a segment of t_D of the generated signal. Add it to the desired signal at the start time selected in steps 1 and 2.
10. Repeat with step 1.

A.2.5.4 Radio Impairments

The radio impairments models consist of phase noise models and power amplifier non-linearties.

A2.5.4.1 Power amplifier non-linearity

The power amplifier model is based on the Rapp's model with knee parameter P=2. Besides its simplicity, the model well represents typical power amplifiers at the sub 10GHz range.

Consider using a complex baseband notation. Denote by v_{IN} and v_{OUT} the input and output complex signals, respectively. Let $P_{SAT} = |v_{SAT}|^2$ denote let the saturated power of the amplifier. Then the relation between v_{IN} and v_{OUT} is given by:

$$v_{OUT} = v_{IN} / (1 + (|v_{IN}| / v_{SAT})^{2P})^{1/(2P)} \qquad , P = 2$$

A2.5.4.2 Phase noise

For the phase noise simplified phase noise model is selected. While maintaining a simple description the model adequately represent the behavior of typical microwave phase-locked loop oscillator.

The phase noise is presented as white gaussian noise process for which is driven through a single pole low pass filter. The 3dB corner of the low-pass should be set at 10KHz, which is a typical value for large step oscillators. A typical PSD is shown in Figure 260.

The model ignores the contribution of the oscillator phase noise, which can be easily tracked and the effects of phase noise PSD flattening in high frequencies.

For simplicity it is recommended that the phase noise effects shall be simulated only on the transmitter side.

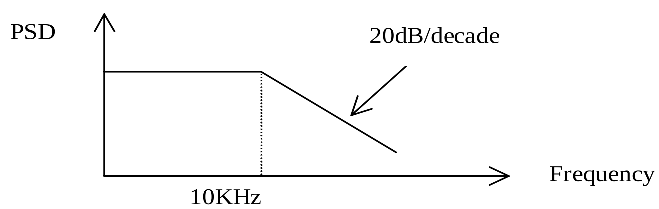


Figure 260—Phase Noise PSD

A.3 MIMO Systems and Beamforming Antenna Technology

This annex is informative only.

In this appendix we explore the application of multiple input/multiple output (MIMO) and beamforming antenna technology to Fixed Wireless Access (FWA).

A.3.1 Introduction

FWA systems have a key requirement to operate in channels with large delay spreads and to provide a means of operation in line of sight, near line of sight (edge diffraction), an non-line of sight RF propagation channels.

Propagation loss affects the energy level of the signal and, ultimately, the modulation complexity that can be supported. Multi-path and the resulting delay spread can result in distortions that make the signal impossible to demodulate regardless of received energy level---unless some method to combat the multi-path is implemented. These methods include:

- Signal processing to perform channel equalization
- Directional antennas (limit sources of multi-path and maximize gain in direction of receiver)
- Spatial diversity receivers (demodulation and coherent combining of one or more transmit and/or receiver sources).

In 1999 and 2000 two important papers provided detailed studies of the delay spread in 2 GHz and 2.5 GHz channels across a number of different line of sight (LOS) and non-line of sight (NLOS) channels.

Porter and Thweat provided a study of MMDS frequency propagation in a suburban environment [B33]. Their results noted that a combination of directional transmit and receive antennas provided for RMS Delay Spread of less that 1 usec in 90% of all link cases. Also lower antenna heights resulted in lower delay spread but also greater propagation loss due to non-line-of-sight conditions. A summary of the test results is provided in Table 263.

Table 263—Delay spread parameters

Visibility	Antenna Type	RMS Delay spread (μ s)		
		Min	**Max**	**Mean**
LOS	directional	0.02	0.04	0.02
LOS	omni	0.02	2.39	0.13
NLOS	directional	0.02	5.26	0.14
NLOS	omni	0.02	7.06	0.37

Erceg, Michelson, et. al. provided a similar study at 2 GHz [B34]. As with the Porter and Thweat study, delay spread (full time span, not RMS delay spread) of up to 1 usec was detected for both omni and directional antennas.

More importantly, the use of diversity (multiple input) based on one or a combination of spatially separated antennas, polarization, and frequency/coding is considered a standard method of improving link fading performance. Jakes noted in his 1971 IEEE paper [B35] that diversity improvement for 2 branches over a flat faded, frequency non-selective channel can provide nearly 20 dB of fade improvement while 3 branches can provide nearly 27 dB of improvement.

The use of diversity/MI (Multiple Input) techniques seek to improve signal performance in near/non-line of sight by combining the received energy from multiple diversity branches (i.e., multiple receiver antennas) to reconstruct the receive signal. In conjunction with Multiple Input technology, Multiple Output technology (e.g., Alamouti antenna diversity algorithm of 8.3.4.13.1) creates additional diversity by the use of multiple transmit antennas and special receiver combining and/or interference cancellation.

While MIMO technologies improve link performance they do not reduce the C/I levels between cells or increase the frequency reuse factor in a wide scale system deployment. As systems are rolled out and subscribers densities within deployed cells increases, it is expected that advanced beam forming will be applied at the cell Base Ststion. Expectations are that beamforming antennas will provide spatial reuse factors with typical increases of 2x to 4x increase in frequency efficiency.

Some of requirements of beamforming (adaptive antenna) and MIMO technologies are the following:

- Compatibility with an existing installed base of IEEE 802.16a subscribers, so that they continue to meet defined minimum requirements. A MIMO/beamforming upgrade at a Base Station must support the current installed base.
- Must be consistent with industry requirements to reduce the cost of subscribers. For example, complexity at the Base Station may be added if it reduces complexity at the Subscriber Station.
- Conform to all Regulatory requirements for EIRP, spurious emissions, and antenna beam restrictions (e.g., side lobe and front to back requirements).

The following sections will discuss the application of MIMO and beamforming. Mutiple input processing will be covered separately from mutiple output processing. Note that these advanced techniques can be applied to both FDD and TDD systems. When specific processing for a type of duplexing method is required, this will be explicitly stated in the associated text.

A.3.2 Multiple Input (MI) Systems

Diversity (MI) processing is the most powerful way to minimize multi-path and combat fading. Spatial techniques are applicable to any choice of modulation and represent a powerful enhancement that can improve the performance of any wireless access system. These techniques include:

- Directional antennas
- Multiple antennas with selection/scanning diversity
    - o Spatial separation
    - o Polarization separation
- Multiple antenna/receivers with signal combining.

As noted in A.3.1, directional antennas at the subscriber greatly reduce multi-path and resulting delay spread. The reason for this is that directional antenna acts as a spatial filter. Signals that are in the main beam (main-lobe) of the antenna are passed to the receiver while signals that reach the subscriber from the side-lobes are reduced by typically 25 to 40 dB. There are two other derivative benefits of directional antennas:

- They increase the transmission gain in the direction of receiver, and can therefore potential reduce cost and complexity of transmit PA (if not so much signal power is needed at the receiver. Therefore, both the Subscriber Station and Base Station may benefit from the directionality.
- They reduce interference from subscribers in adjacent cells. This increases the overall capacity of a multiple cell system deployment.

Diversity is the use of separate distinct signal sources to enhance the received error rate and/or throughput of the system. Frequency diversity (use of two or more transmission paths, or channels, to send the same data) has been used in microwave radio for decades. Likewise, polarization diversity (use of horizontal and vertical antenna patterns) has been used in microwave radio and in 2nd generation cellular systems. Time diversity (transmitting the same information at different times) has also been used to mitigate periodic burst interference in military systems. These techniques can enhance reception by as much as 20 to 30 dB at the expense of reducing system capacity.

It is possible to obtain significant gains at the receiver by processing two or more receive paths using spatial or polarization diversity receivers. The implementation cost clearly increases with the number of paths/receivers that are processed. As a practical matter the use of a second receive source can improve resistance to fade and multi-path by as much as 20 dB. The addition of a 3rd receive source provides only an additional 6 to 7 dB under optimal conditions.

The simplest form of diversity is to sample the received SNR (lowest error rate) of one or more antennas and select the best source. Obviously, the rate of scanning and selection must be performed at a rate much higher than the fading rate of the incoming signal. A system utilizing selection diversity is shown Figure 261. This requires only a single receiver and represents one of the most cost effective methods to implement receive diversity. This technique maps well to TDD duplexing where the start of frame header can be used to perform diversity selection. The performance of selection diversity is inferior (by 3 to 6 dB) to combining of multiple receivers, but is only 1 to 2 dB worse for the two-receiver case.

Selection diversity can readily be applied to both TDD and FDD systems. TDD systems have the added benefit that feedback from the selected receiver diversity branch can also be used to select the best antenna for a return transmission.

A system utilizing combining Diversity is depicted in Figure 262. An active receiver is required for each antenna. The signals of each receiver are combined (co-phased and summed) using either a maximum ratio criterion or by an equal gain criterion. The maximum ratio method weights signals based on their measured SNR (general S+N/N, i.e. signal & noise to noise ratio) and provides an output SNR that is the SUM of the input SNR (a gain in SNR). The benefit of maximum ratio combining is that the procedure it can result in producing an acceptable output SNR even when the individual channels have marginal SNR.

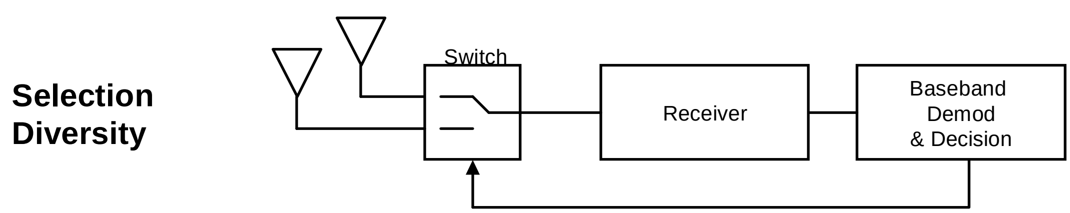


Figure 261—Selection Diversity Receiver

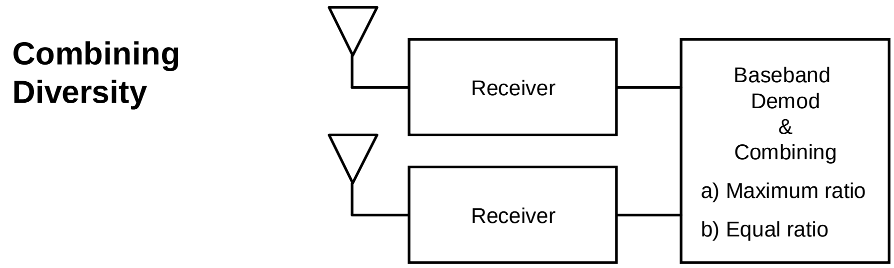


Figure 262—Combining Diversity Receiver

A.3.3 Multiple Output Systems

As briefly mentioned in A.3.1, the motivation for multiple output (MO) technology is to create and exploit a self-generated diversity branch in the processing of the system.

A MO technique selected for use in the future must be compatible with the minimum standards processing for a Single Input Single Output (SISO) subscriber with no special processing resources. It is anticipated that MO transmissions will originate at the Base Station and that the subscriber will, to minimize costs, be of either a SISO or MISO configuration.

At the current time two types of Multiple Output technology options are defined within the 802.16a standard:

- The Alamouti antenna diversity algorithm
- Transmit delay diversity, where multiple base station antennas transmit delayed versions of an original signal, and the receiver equalizer combines the resulting multipath signals to provide diversity gain.

A.3.4 Application of Beam Forming Antenna Technology

The use of advanced antenna technology introduces an additional level of Media Access Control (MAC) complexity. The MAC/PHY has an added spatial/beam component that must be factored into MAC coordination of the PHY. On a subscriber by subscriber (link by link) basis the MAC/PHY must coordinate the following parameters:

- Communications burst duration
    - o Individual uplink or downlink for TDD
    - o Joint uplink/downlink for FDD
- Modulation Complexity
- FEC Rate
- Beam/Combining parameters.

Figure 263 illustrates the concept of coordinating MAC/PHY with the beam forming antenna element. While this Appendix does not attempt to define the specific technology or implementation of the beam forming technology the design of the MAC and PHY must take into account that the beam forming subsystem places distinct restrictions on MAC/ PHY management and the coordination and passing of parameters necessary to support advanced beam forming.

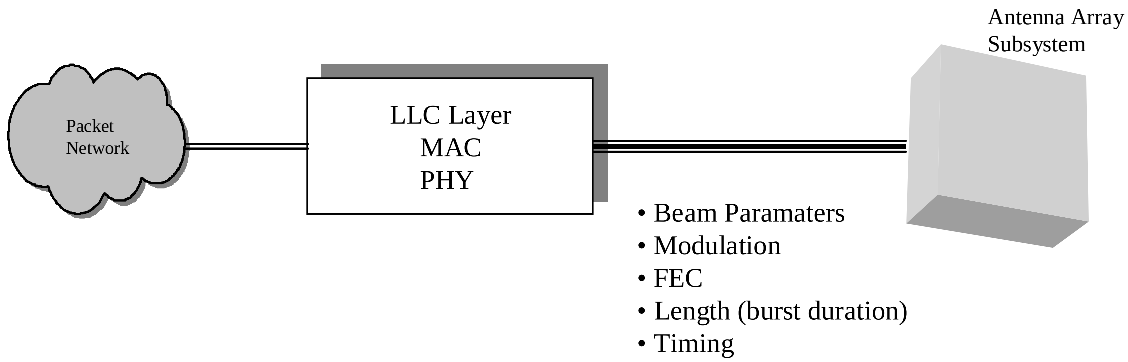


Figure 263—MAC/PHY Coordination concept with Beam Forming Antenna

Beam forming and advanced antennas remove the basic paradigm that all subscribers have the capability of simultaneously receiving broadcast information from the Base Station. Beams are formed to optimize communications to a given subscriber with a channel response $H_n(t)$ and beam parameters $B_n(t)$. Figure 264 illustrates a sector of a basestation that is communicating with 3 separate subscribers. Each subscriber is spatially distinct from the other subscribers. The transmission bursts sent to or from subscriber #1 would not be received by subscribers #2 or #3.

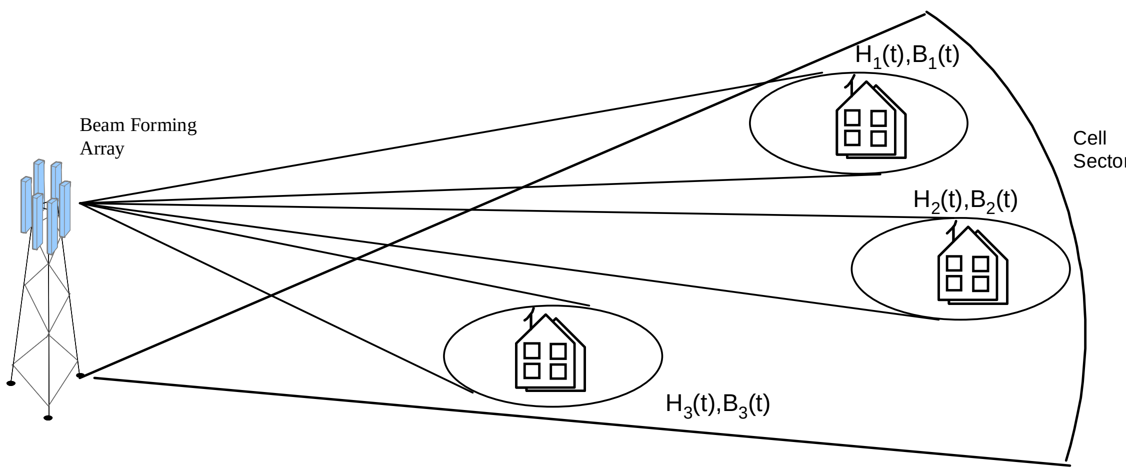


Figure 264—BS sector with 3 Subscribers

In the described scenario, the Base Station is sequentially forming the beam and either sending or receiving from the subscribers in an order determined by the MAC. To support advanced antenna systems both FDD and TDD links must be designed to provide transmissions based on self-contained bursts.

Figure 265 illustrates the beam forming burst concept for both FDD and TDD.

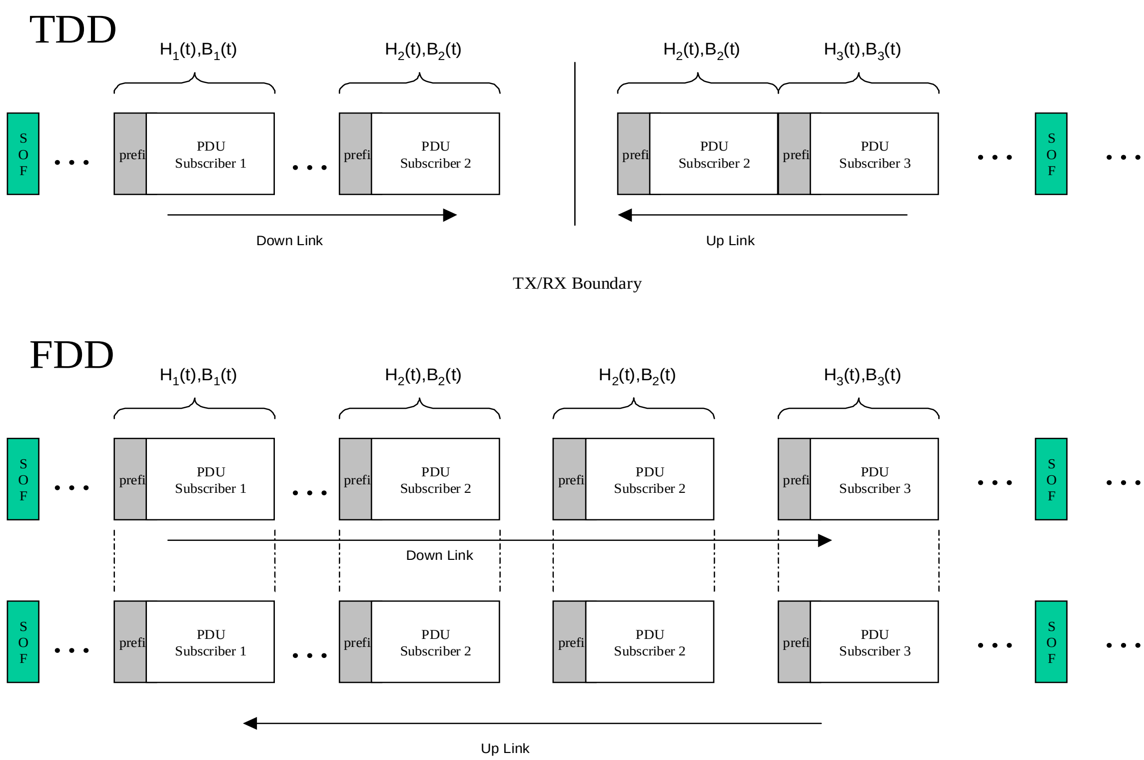


Figure 265—Beamforming Concept for TDD and FDD

Conceptually, TDD is easy to understand. A beam is formed for each transmitted burst in either the uplink or the down stream. The FDD solution can work one of two ways:

- Single beam forming for the uplink/downlink.
- Independent uplink and downlink beamforming. The system would support 2 independent formulations of the beam on the uplink frequency and the downlink frequency (see Figure 266).

FDD with Independent beam forming

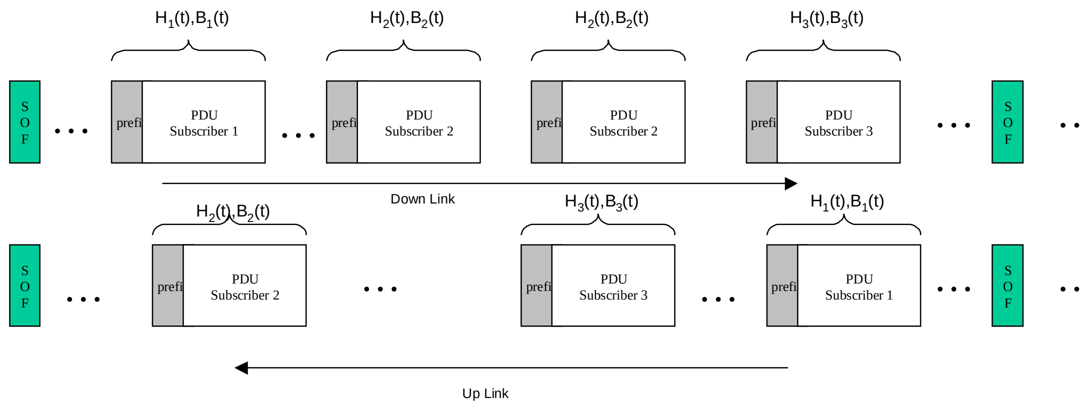


Figure 266—FDD with Independent UL/DL Beam Forming Example

The aforesaid simple sequential cases can be expanded to advanced beam forming techniques to provide simultaneous multiple access to spatially independent users. A beamforming network can create 2 or more independent beams with low self-interference that allow simultaneous communications using the same frequency. While beam-forming complexity is increased, spectral reuse is also increased. The complexity of PHY hardware and MAC scheduling software also increase proportionally with the number of beams created.

The MAC and PHY also need to perform burst scheduling and transmission based on "spatial concatenation". One or more subscribers can be supported by a single set of beam-forming parameters due to close physical proximity as shown in Figure 267. For this case, bursts to the subscribers that share the same beams.

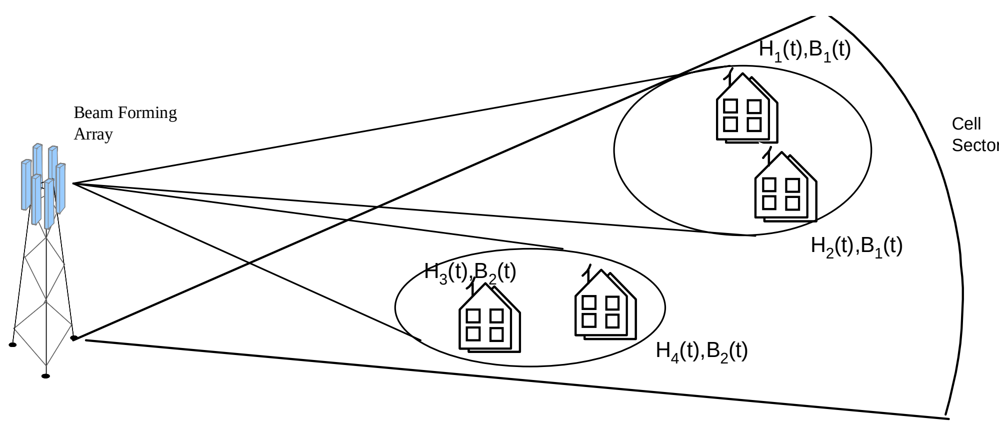


Figure 267—BS sector using Spacial Concatenated Communication

Figure 268 illustrates how packets are grouped (concatenated) and transmitted by based on physical proximity for a TDD Physical layer.

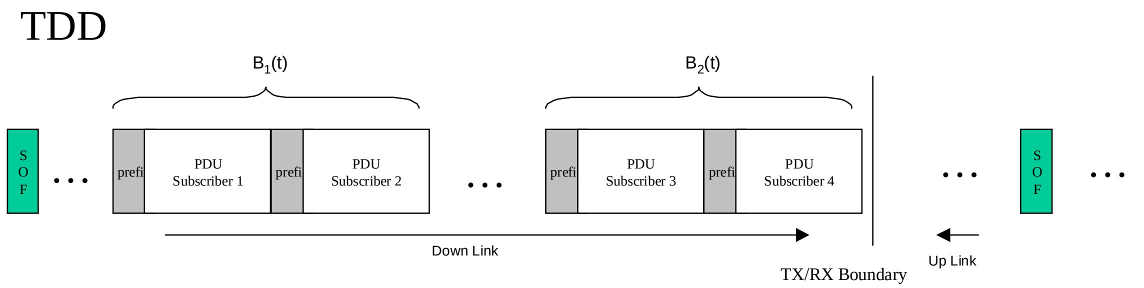


Figure 268—TDD with Concatenated Packet Transmission Example

The PHY based on block processing and burst packet formats meets all the requirements to support advanced antenna processing techniques. Extensions to the 802.16a standard to support such advanced techniques must address the following issues in greater detail:

- Beamforming transition/ set-up time definitions in the MAC (which passes parameters to the PHY);
- Method for broadcasting uplink and downlink MAP information;
- Acquisition methods and beam scanning;
- Cell-to-cell interference and C/I issues;
- Spatial multiplexing.

A.4 SC LINK Budget Analysis

This annex is informative only.

We have made a complete Link budget analysis for the various combinations of modulation format and channel bandwidth that were specified by Erceg's latest version of "channel model" for this proposal. The path loss given below was calculated using the median value for Condition C of the model in Erceg's latest version of the path model (802.16.3c-29r1). For each Downlink (D/S) and Uplink (U/S) pair we have calculated the maximum path length that could be supported given the 43 dBm EIRP at the BTS and a 40 dBm EIRP at the SS with "typical" values for SNR at the receiver for each modulation format. Some typical results are presented in Table 264.

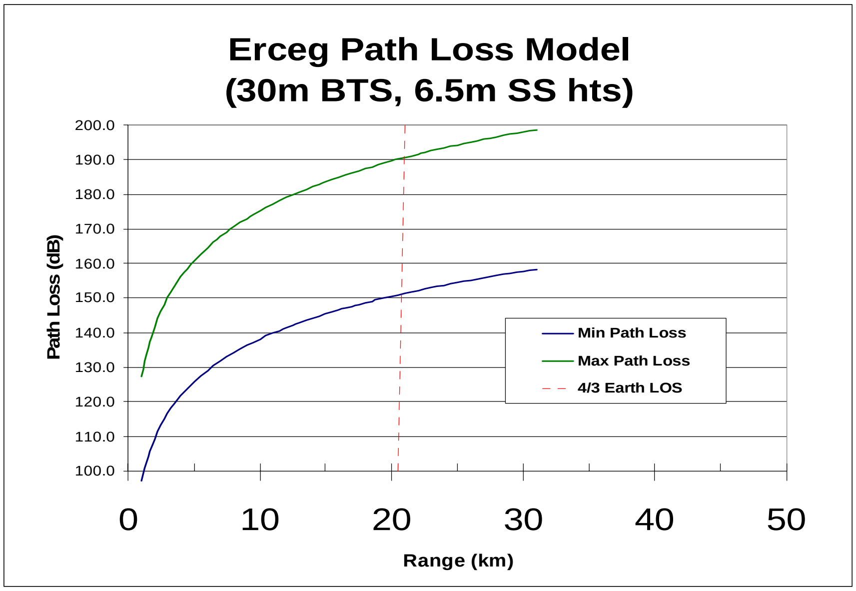


Figure 269—Path Loss Model

Table 264 present's channel model as per Erceg's contribution 802.16.3c-29r1. The selected channel is a typical MMDC channel at 2.5 GHz band.

Table 264—Channel Model

Parameter	**Category**		
	C	**B**	**A**
	Flat, few Trees	**Intermediate**	**Hilly, heavy trees**
a	3.6	4	4.6
b	0.005	0.0065	0.0075
c	20	17.1	12. 6
Channel Frequency (GHz)	2.5		
Wavelength (m)	0.12		
SS RX antenna height h (m)	6.5		
BS antenna height h_{bs} (m)	80		
y=(a-b h_b+c/h_b)	4.116667	4.375	4.795
$A = 20\log(4\pi d_0/\lambda)/\log(10)$	80.40057		
s	9.4		
$PL = A + 10\gamma\log(d/d_0)/\log(10) + DPI + DPh \pm s$			
4/3 Earth Line of Sight (km)	32.5		

Based on the parameter selection in Table 264, we have generated link budget for various scenarios. Some typical results are for QPSK and 64 QAM that are presented in the following Table 265 and Table 266, respectively. These results assume very similar scenarios for SC-FDE and OFDM systems.

Table 265—Typical Link Budgets for SC and OFDM for QPSK (1.5 and 6 MHz)

	Single Carrier		512 Carriers		Single Carrier		512 Carriers	
Bandwidth	**1.5** MHz		**1.5** MHz		**6.0** MHz		**6** MHz	
Modulation type/ Target SNR	**QPSK**	10 dB	**OFDM**	10 dB	**QPSK**	10 dB	**OFDM**	10 dB
Downstream								
EIRP (BTS)	43.0 dBm	20 w	43.0 dBm	20 w	43.0 dBm	20 w	43.0 dBm	20 w
Antenna Gain	3.0 dB		3.0 dB		3.0 dB		3.0 dB	
Back off	12.0 dB		14.0 dB		11.0 dB		14.0 dB	
Nominal 1 dB compression point	52.0 dBm	**158 w**	54.0 dBm	**251 w**	51.0 dBm	**126 w**	54.0 dBm	**251 w**
Normalized Price	**1.0**		**1.3**		**1.0**		**1.3**	
Path distance for targeted SNR	**8.0 km**		**8.0 km**		**8.0 km**		**8.0 km**	
Associated Path Loss (from 802.16.3c-29r1)	-153.8 dB		-153.8 dB		-153.8 dB		-153.8 dB	
Receive Antenna gain	14.0 dB		14.0 dB		14.0 dB		14.0 dB	
Power at Input to Receiver	-96.8 dBm		-96.8 dBm		-96.8 dBm		-96.8 dBm	
Receiver Noise Figure	5.0 dB		5.0 dB		5.0 dB		5.0 dB	
Equivalent Noise Power in channel BW	-107.2 dBm		-107.2 dBm		-101.2 dBm		-101.2 dBm	
SNR, Calculated	**10.4 dB**		**10.4 dB**		**4.4 dB**		**4.4 dB**	
Upstream								
EIRP (SS)	34.0 dBm	3 w	34.0 dBm	3 w	40.0 dBm	10 w	40.0 dBm	10 w
Antenna Gain	14.0 dB		14.0 dB		14.0 dB		14.0 dB	
Back off	6.0 dB		14.0 dB		11.0 dB		14.0 dB	
Nominal 1 dB compression point	26.0 dBm	**0.40 w**	34.0 dBm	**3 w**	37.0 dBm	**5 w**	40.0 dBm	**10 w**
Normalized Price	**1.0**		**4.0**		**1.0**		**4.0**	
Path distance for targeted SNR	**3.0 km**		**3.0 km**		**3.0 km**		**3.0 km**	
Associated Path Loss (from 802.16.3c-29)	-136.3 dB		-136.3 dB		-136.3 dB		-136.3 dB	
Receive Antenna gain	6.0 dB		6.0 dB		6.0 dB		6.0 dB	
Power at Input to Receiver	-96.3 dBm		-96.3 dBm		-90.3 dBm		-90.3 dBm	
Receiver Noise Figure	4.0 dB		4.0 dB		4.0 dB		4.0 dB	
Equivalent Noise Power in channel BW	-108.2 dBm		-108.2 dBm		-102.2 dBm		-102.2 dBm	
SNR, Calculated	**12.0 dB**		**12.0 dB**		**12.0 dB**		**12.0 dB**	

Table 266—Typical Link Budget for SC and OFDM for 64QAM (1.5 and 6 MHz)

	Single Carrier		512 Carriers		Single Carrier		512 Carriers	
Bandwidth	**1.5** MHz		**1.5** MHz		**6.0** MHz		**6** MHz	
Modulation type / Target SNR	**64 QAM**	25 dB	**OFDM**	25 dB	**64 QAM**	25 dB	**OFDM**	25 dB
Downstream								
EIRP (BTS)	43.0 dBm	20 w	43.0 dBm	20 w	43.0 dBm	20 w	43.0 dBm	20 w
Antenna Gain	3.0 dB		3.0 dB		3.0 dB		3.0 dB	
Back off	12.0 dB		14.0 dB		12.0 dB		14.0 dB	
Nominal 1 dB compression point	52.0 dBm	**158 w**	54.0 dBm	**251 w**	52.0 dBm	**158 w**	54.0 dBm	**251 w**
Normalized Price	**1.0**		**1.3**		**1.0**		**1.3**	
Path distance for targeted SNR	**6.5 km**		**6.5 km**		**4.5 km**		**4.5 km**	
Associated Path Loss (from 802.16.3c-29r1)	-150.1 dB		-150.1 dB		-143.5 dB		-143.5 dB	
Receive Antenna gain	14.0 dB		14.0 dB		14.0 dB		14.0 dB	
Power at Input to Receiver	-93.1 dBm		-93.1 dBm		-86.5 dBm		-86.5 dBm	
Receiver Noise Figure	5.0 dB		5.0 dB		5.0 dB		5.0 dB	
Equivalent Noise Power in channel BW	-107.2 dBm		-107.2 dBm		-101.2 dBm		-101.2 dBm	
SNR, Calculated	**14.2 dB**		**14.2 dB**		**14.7 dB**		**14.7 dB**	
Upstream								
EIRP (SS)	34.0 dBm	3 w	34.0 dBm	3 w	40.0 dBm	10 w	40.0 dBm	10 w
Antenna Gain	14.0 dB		14.0 dB		14.0 dB		14.0 dB	
Back off	6.0 dB		14.0 dB		6.0 dB		14.0 dB	
Nominal 1 dB compression point	26.0 dBm	**0.40 w**	34.0 dBm	**3 w**	32.0 dBm	**2 w**	40.0 dBm	**10 w**
Normalized Price	**1.0**		**4.0**		**1.0**		**4.0**	
Path distance for targeted SNR	**2.5 km**		**2.5 km**		**2.5 km**		**2.5 km**	
Associated Path Loss (from 802.16.3c-29)	-133.0 dB		-133.0 dB		-133.0 dB		-133.0 dB	
Receive Antenna gain	6.0 dB		6.0 dB		6.0 dB		6.0 dB	
Power at Input to Receiver	-93.0 dBm		-93.0 dBm		-87.0 dBm		-87.0 dBm	
Receiver Noise Figure	4.0 dB		4.0 dB		4.0 dB		4.0 dB	
Equivalent Noise Power in channel BW	-108.2 dBm		-108.2 dBm		-102.2 dBm		-102.2 dBm	
SNR, Calculated	**15.2 dB**		**15.2 dB**		**15.2 dB**		**15.2 dB**	

A.5 FDD/TDD Co-existence

This annex is informative only.

Coexistence requires additional consideration of adjacent channel interference, and has a significant impact on system design.

A number of engineering tradeoffs must be balanced in order to maximize system performance, maintain compatibility and enable RF coexistence. A number or facts are listed below which are significant factors within this trade space.

- We seek to fill the channel BW with active tones (the active tone bandwidth), thus minimizing the symbol duration and maximizing the link rate.
- We need to have adequate guard bands on each side of the active bandwidth so that energy generated by BSs and SSs decays to an acceptable level in the active tone region of the adjacent channel.
- Conditions will exist where an FDD system and a TDD system operating in adjacent channels will transmit while the other is receiving. Unfortunately, complying with the ETSI and North American emissions masks does not ensure RF coexistence between FDD and TDD systems in this case.
- RF emissions generated outside of the active tone bandwidth (ATB) arise from the spectral leakage of the rectangular windowed FFTs. For larger FFT sizes, this leakage decays more quickly for a fixed guard band.
- RF emissions generated outside of the active tone bandwidth arise from power amplifier intermodulation distortion (IMD) caused principally by 3rd order and 5th order non-linearities. The spectral bandwidth of the unwanted emissions is 3 and 5 times the ATB respectively for 3rd and 5th order IMD. In typical SS amplifiers, the 3rd order IMD dominates with the 5th order IMD 15 dB below the 3rd order. The 3rd order IMD is typically controlled by backing off output power to meet the emission mask limits
- Power amplifier IMD typically produces more unwanted IMD than spectral leakage from the FFT.
- High Q filtering technology is not available at SS price points that would significantly lower 3rd and 5th order IMD for the 2 - 3.5 MHz bands.
- High Q filtering technology is available at BS price points and can be used to reduce IMD. High Q filtering is usually needed at the BS since the active bandwidth occupies the majority of the channel bandwidth. Typical filter performance provides 20 dB rejection at 0.1% of the filter center frequency. Higher performance is achievable at 0.075% of the filter center frequency.
- Additional 3rd order IMD suppression can be obtained if the IMD falls in guard bands of the channel and adjacent channel. Only 5th order IMD will be present in the victim's band. In this case, the guard band should be specified as 1/2 of the active bandwidth.

A.6 Compatibility of SC-FD and OFDM

This annex is informative only.

Comparable SC-FDE and OFDM systems would have the same block length and cyclic prefix lengths. Since their main hardware difference is the location of the inverse FFT, a modem could be converted as required to handle both OFDM and single carrier signals by switching the location of the inverse FFT block between the transmitter and receiver. Therefore, the coexistence of OFDM and SC-FDE as a "convertible" modem can be feasible (see Figure 270).

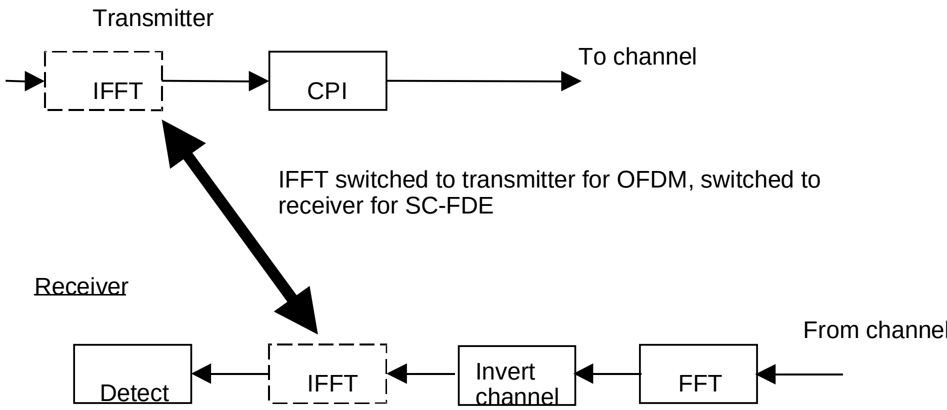


Figure 270—OFDM and SC-FDE ‘convertible’ Modem

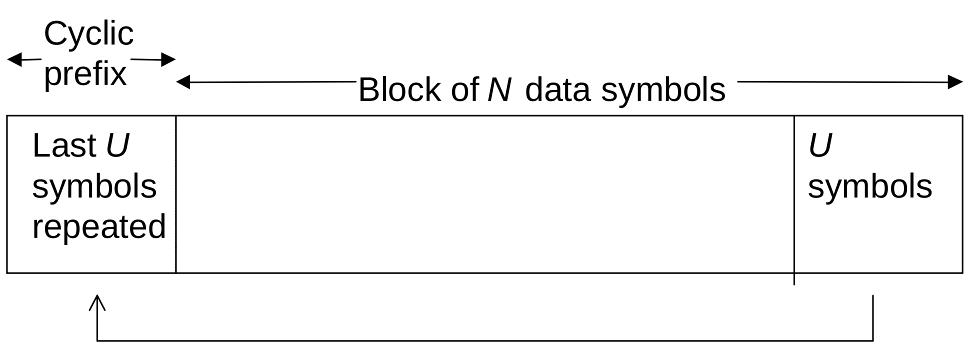


Figure 271—Block Processing in FDE

As shown in Figure 271, that the cyclic prefix used in both SC-FDE and OFDM systems at the beginning of each block has two main functions:

- It prevents contamination of a block by intersymbol interference from the previous block.
- It makes the received block appear to be periodic with period N which is essential to the proper functioning of the fast Fourier transform operation.

If the first U and last U symbols are identical unique word sequences of training symbols, the overhead fraction is 2U / (N+U). For either OFDM or SC-FDE MMDS systems, typical values of N could be 512 or 1024, and typical values of U could be 64 or 128.