Information Technology-

Telecommunications and Information Exchange Between Systems –

LAN/MAN Specific Requirements –

Air Interface for Fixed Broadband Wireless Access Systems Part A: Systems between 2 and 11 GHz

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~~**LAN MAN Standards Committee**~~

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Abstract: This document is 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: wireless metropolitan area network (WirelessMAN[TM]) standards, fixed broadband wireless access networks

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Introduction

(This introduction is not part of IEEE Std 802.16, IEEE Standard for Broadband Wireless Access.)

This document defines services and protocol elements that permit the exchange of management information between stations attached to IEEE 802 local and metropolitan area networks. The standard includes the specification of managed objects that permit the operation of the protocol elements to be remotely managed.

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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 in ***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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802.16a/b Amendment to the 802.16 Standard Air Interface for Fixed Broadband Wireless Access Systems

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

802.16ab MAC and PHY have to support point-to-multipoint applications in the range 2 to 11 GHz. Radio communications in the above range may be possible in near- and non-line-of-sight situations between a base station and subscriber station. Operation 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 transmit power, channel characteristics, availability requirement, local regulations and atmospheric conditions (see IEEE 802.16.3-00/02r4 "Functional Requirements for the 802.16ab Interoperability Standard").

All the above features request implementation of such PHY functions as support of non-line-of-sight communication, advanced power management, smart antennae support.

For MAC it means that first of all it has to support the abovementioned PHY features and implement the proper interface to PHY. On the other hand, some of these problems may be completely or partially fixed in MAC sublayer using such tools as ARQ, advanced packing, additional scheduling flexibility.

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 802.16 TG4 system has an optional mesh topology. Unlike the basic point-to-multipoint 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.

The stations with which a station has direct links with are called neighbors and shall form a neighborhood. A two-hop neighborhood contains, additionally, all the neighbors of the neighborhood. All the stations shall coordinate their transmissions in their two-hop neighborhood. A station may select any of the links it does have to its neighbors to forward traffic originated in the node itself or in some other node in the network. Coordinated transmissions ensure collision-free scheduling.

For transmission coordination, there is a specific control period in the beginning of each MAC frame in which each station shall periodically transmit its own schedule on a point-to-multipoint basis to all its neighbors. Within a given frequency 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. A unique schedule transmission slot shall be determined with the aid of two-hop neighborhood addresses.

In normally scheduled transmissions, all stations act like either a BS or an SS does for uplink bandwidth requests in the point-to-multipoint mode. In other words, a station that wishes to transmit must be granted the bandwidth it had requested earlier from a neighbor. Thus the transmitting station acts like a SS in uplink direction. Thus a receiving station acts like a BS in the uplink direction.

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. ~~A t~~Two-way point-to-multipoint and mesh topology wireless networks ~~is a~~are good examples of ~~a~~ shared mediums: here the mediums ~~is~~are the space through which the radio waves propagate.

6.1 MAC Service Definitions

6.2 Data/Control Plane

6.2.1 Addressing and Connections

6.2.2 Message Formats

Please change the text in the following heading

6.2.2.4.3 10 to 66 Ghz Downlink Map (DL-MAP) Message

Please add the following new subclause

6.2.2.4.3.1 Sub-11 GHz Downlink Map (DL_MAP) Message

The Downlink MAP (DL-MAP) message defines the access to the downlink information.

6.2.2.4.3.1.1 Single Carrier PHY

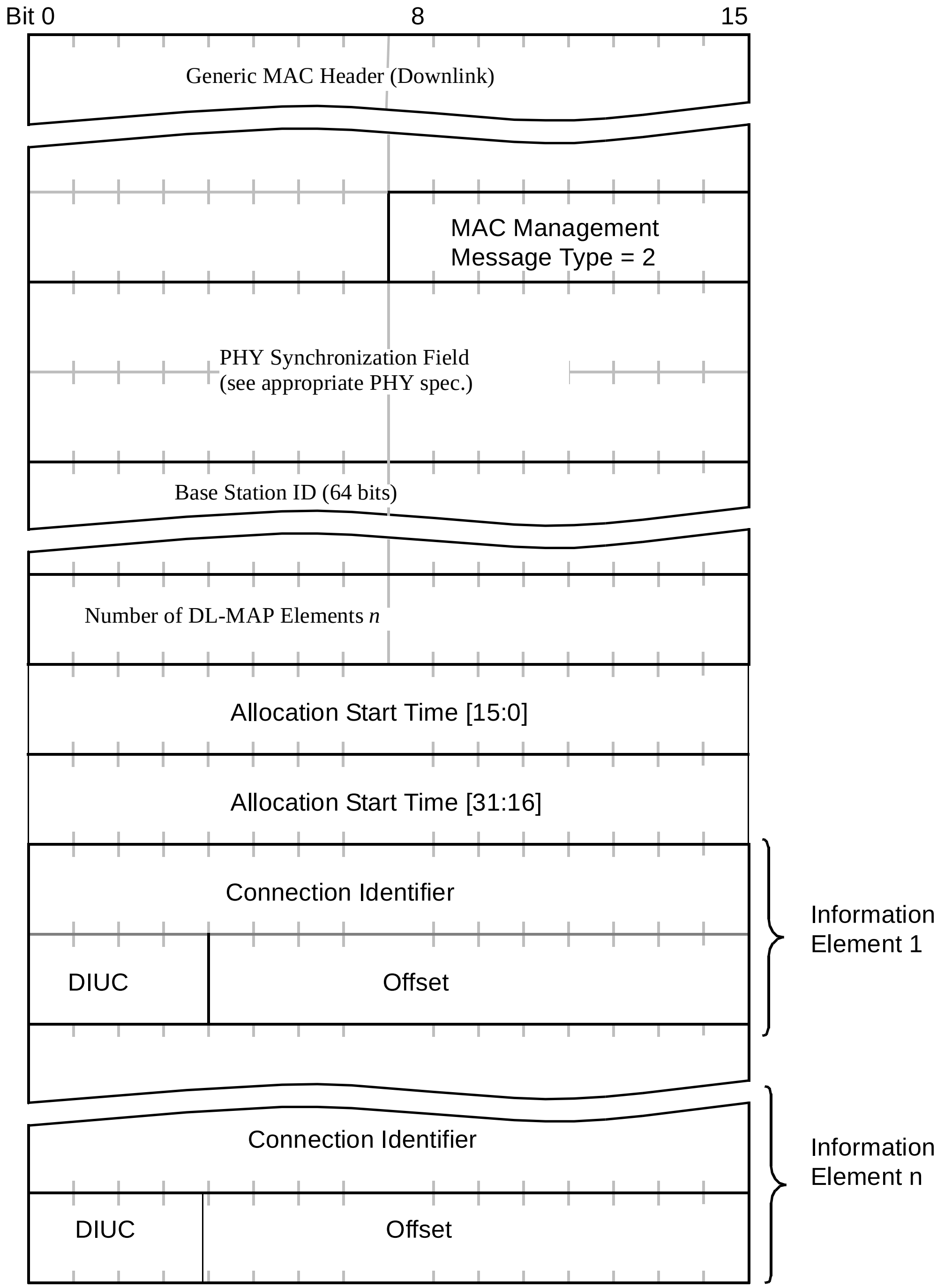


Figure 130—???

A BS shall generate DL-MAP messages in the format shown in Figure 1, 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:
  1) Connection Identifier
  2) Downlink Interval Usage Code
  3) Offset

The encoding of remaining portions of the DL-MAP message is PHY dependent and may not be present. Refer to the appropriate PHY specification.

6.2.2.4.3.1.2 OFDM PHY

6.2.2.4.3.1.3 OFDMA PHY

Please change the following heading name

6.2.2.4.4 <u>10 to 66 GHz</u> Uplink Map (UL-MAP) Message

Please insert the following new subclause

<u>6.2.2.4.4.1 Sub-10 GHz Uplink MAP (UL-MAP) Message</u>

The Uplink MAP (UL-MAP) message allocates access to the uplink channel. The UL-MAP message shall be as shown in Fig. ?.

6.2.2.4.4.1.1 Single Carrier PHY

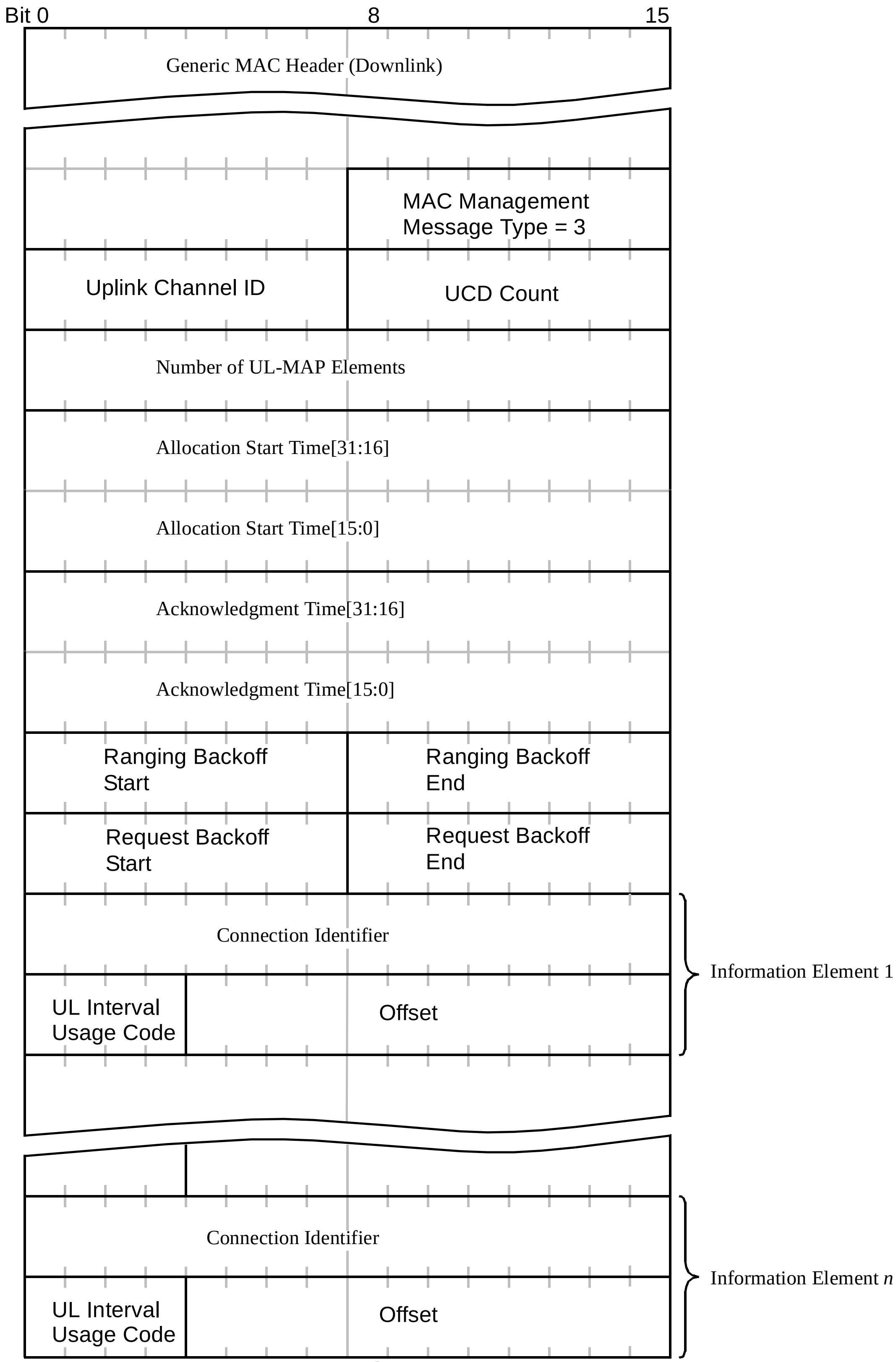

Bit 0
8
15
Generic MAC Header (Downlink)
MAC Management Message Type = 3
Uplink Channel ID
UCD Count
Number of UL-MAP Elements
Allocation Start Time[31:16]
Allocation Start Time[15:0]
Acknowledgment Time[31:16]
Acknowledgment Time[15:0]
Ranging Backoff Start
Ranging Backoff End
Request Backoff Start
Request Backoff End
Connection Identifier
UL Interval Usage Code
Offset
Information Element 1
Connection Identifier
UL Interval Usage Code
Offset
Information Element n

Figure 131—???

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:
  1) Connection Identifier
  2) Uplink Interval Usage Code
  3) 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. The Information Elements are strictly order within the UL-MAP, as shown in Figure 2.

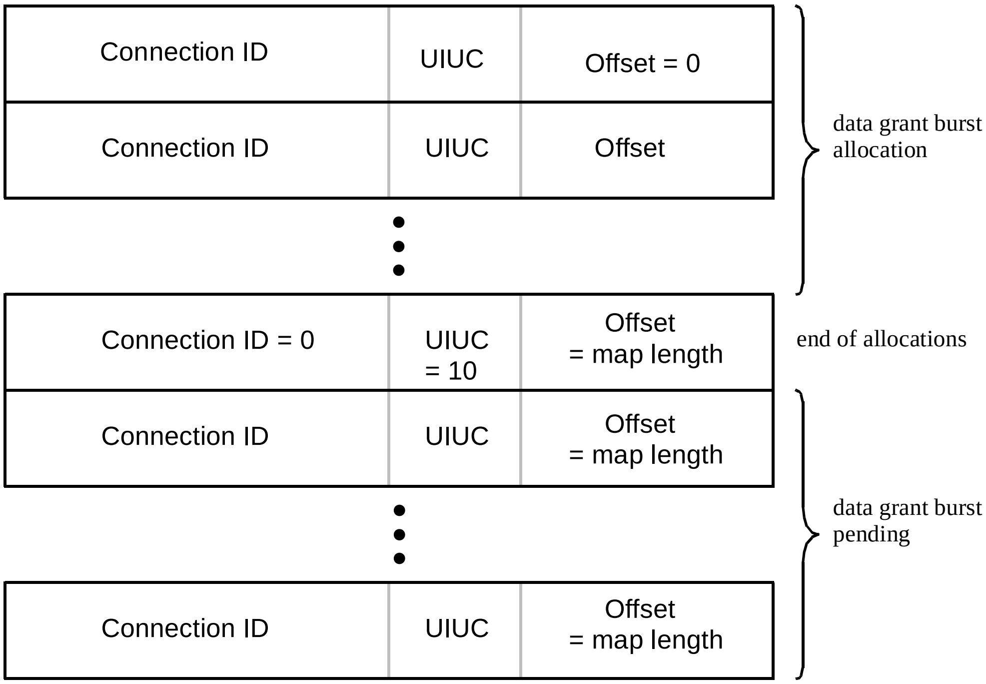


Figure 132—???

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 145—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 assignment If inferred length = 0, then it is a Data Grant Burst Type pending.
Data Grant Burst Type 2	5	unicast	Starting offset of Data Grant Burst Type assignment If inferred length = 0, then it is a Data Grant Burst Type Pending
Data Grant Burst Type 3	6	unicast	Starting offset of Data Grant Burst Type 2 assignment If inferred length = 0, then it is a Data Grant Burst Type pending.
Data Grant Burst Type 4	7	unicast	Starting offset of Data Grant Burst Type 2 assignment If inferred length = 0, then it is a Data Grant Burst Type pending.
Data Grant Burst Type 5	8	unicast	Starting offset of Data Grant Burst Type 3 assignment If inferred length = 0, then it is a Data Grant Burst Type pending.
Data Grant Burst Type 6	9	unicast	Starting offset of Data Grant Burst Type 3 assignment If inferred length = 0, then it is a Data Grant Burst Type pending.
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	11-14	any	Reserved
Expansion	15	expanded UIUC	# of additional 32-bit words in this IE

6.2.2.4.4.1.2 OFDM PHY

6.2.2.4.4.1.3 OFDMA PHY

Please insert the following new subclause:

6.2.2.4.5 Sub-10 GHz Uplink + Downlink MAP

6.2.2.4.5.0.1 Single Carrier PHY

6.2.2.4.5.0.2 OFDM PHY

6.2.2.4.5.0.3 OFDMA PHY

For TDD and Burst FDD systems, a single MAP message is defined, that covers both uplink and downlink directions.

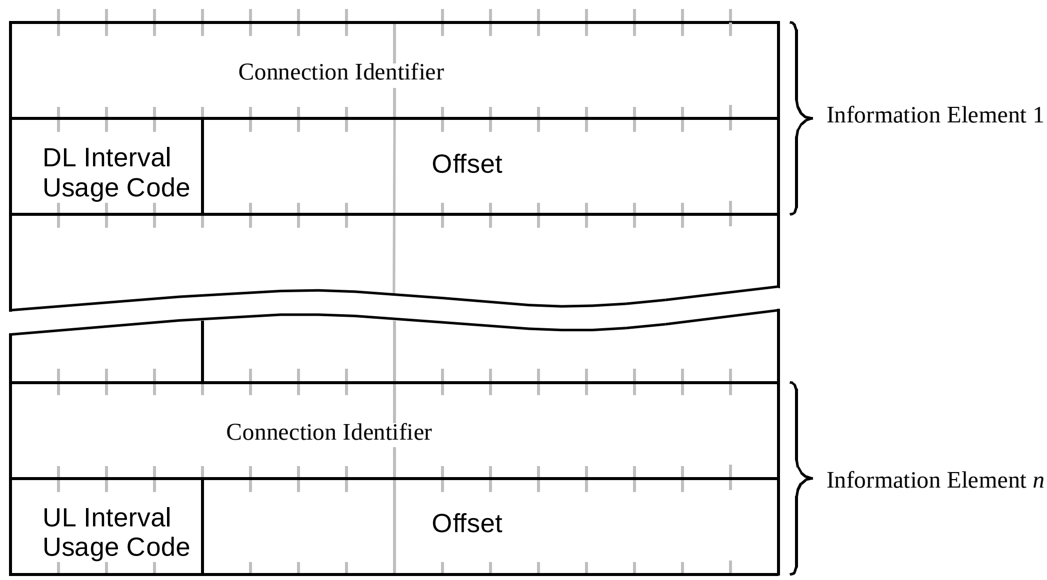


Figure 133—???

Please change the text in the following heading

6.2.7.6.1 <u>10 to 66 GHz </u>Map Relevance for Framed (Burst) PHY Systems

Please add the following new subclause

6.2.7.6.1.1 Sub-10 GHz MAP Relevance and Synchronization

6.2.7.6.1.1.1 Single Carrier PHY

6.2.7.6.1.1.2 OFDM PHY

6.2.7.6.1.1.3 OFDMA PHY

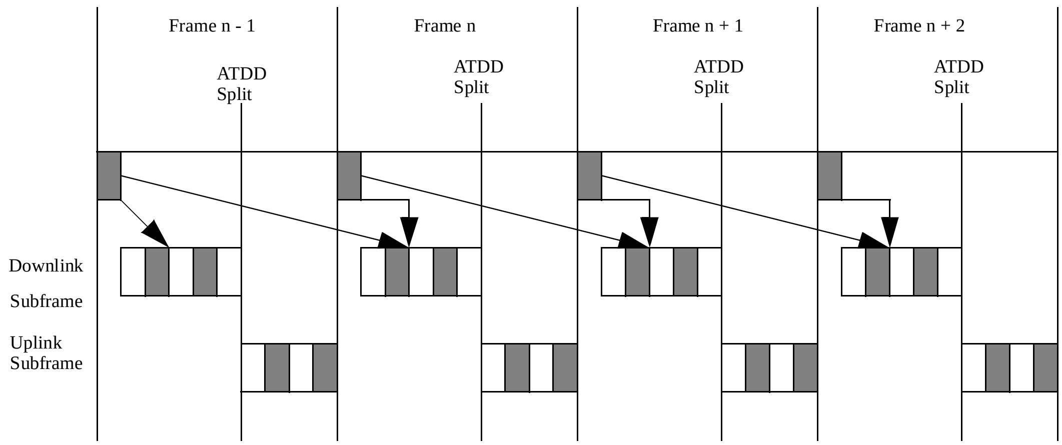


Figure 134—Maximum Time Relevance of PHY and MAC Control Information (TDD)

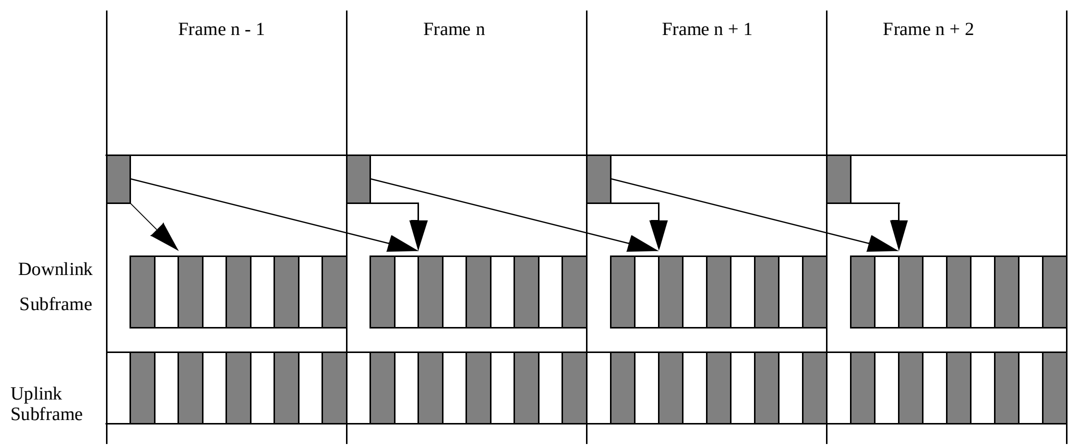


Figure 135—Maximum Time Relevance of PHY and MAC Control Information (FDD)

As shown in Figure 5 and 6, 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 5, 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.

Please change the following subclause

6.2.4 ARQ - 2-11 GHz Bands Only

6.2.4.1 Single Carrier PHY

6.2.4.2 OFDM PHY

6.2.4.3 OFDMA PHY

Session #14 Resolutions

4) The 802.16ab MAC document must specify an ARQ algorithm.
5) The 802.16ab MAC document must specify a single ARQ algorithm.
6) The 802.16ab MAC document must specify the ARQ algorithm is Select-Repeat.
7) The 802.16ab MAC document must specify the numbering scheme to be that shown in 802.16ab-01/01.
8) The 802.16ab MAC document must specify support for a piggybacked ACKnowledgement scheme.

Please insert the following new subclause

6.2.2.4.33 Mesh Schedule (MSH-SCH) message

This clause is applicable only to the licensed exempt mesh option.

A Mesh Schedule message shall be transmitted by all the stations in a mesh mode at a periodic interval to inform all the neighbors the schedule of the transmitting station. Each station shall determine its own unique Mesh Schedule message transmission time using the two-hop neighborhood information.

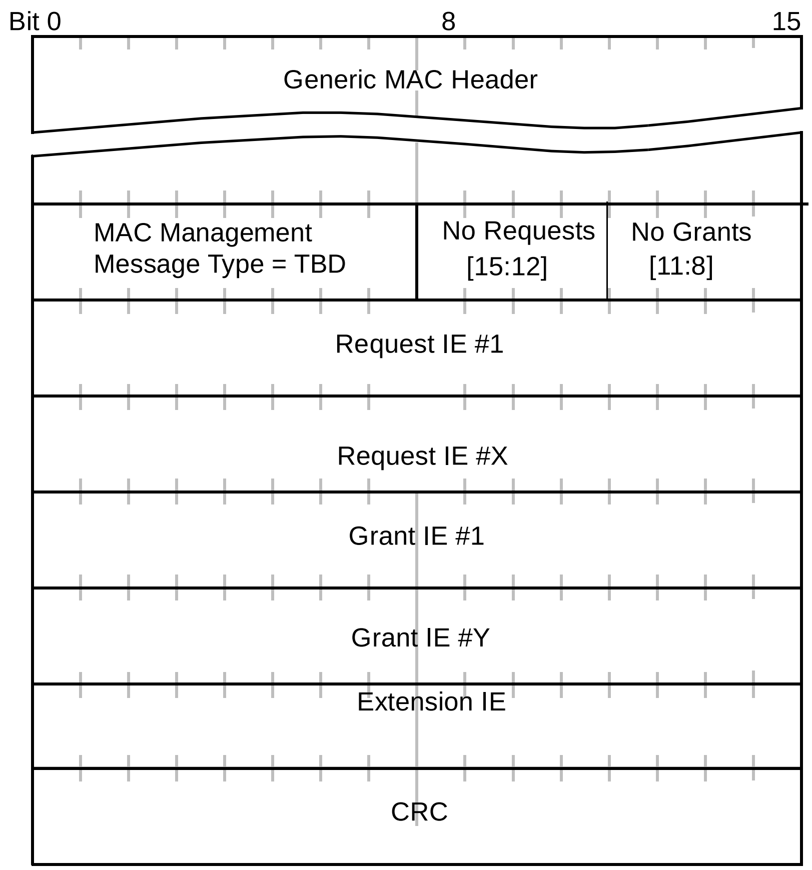


Figure 136—MSH-SCH Message Format (SS to SS)

The transfer syntax of each of the information elements of the MSH-SCH message is illustrated in Figure tbd through Figure tbd+3. Various fields are respectively described in Table n through Table n+3.

6.2.2.4.33.1 Mesh bandwidth request Information element (MSH-REQ)

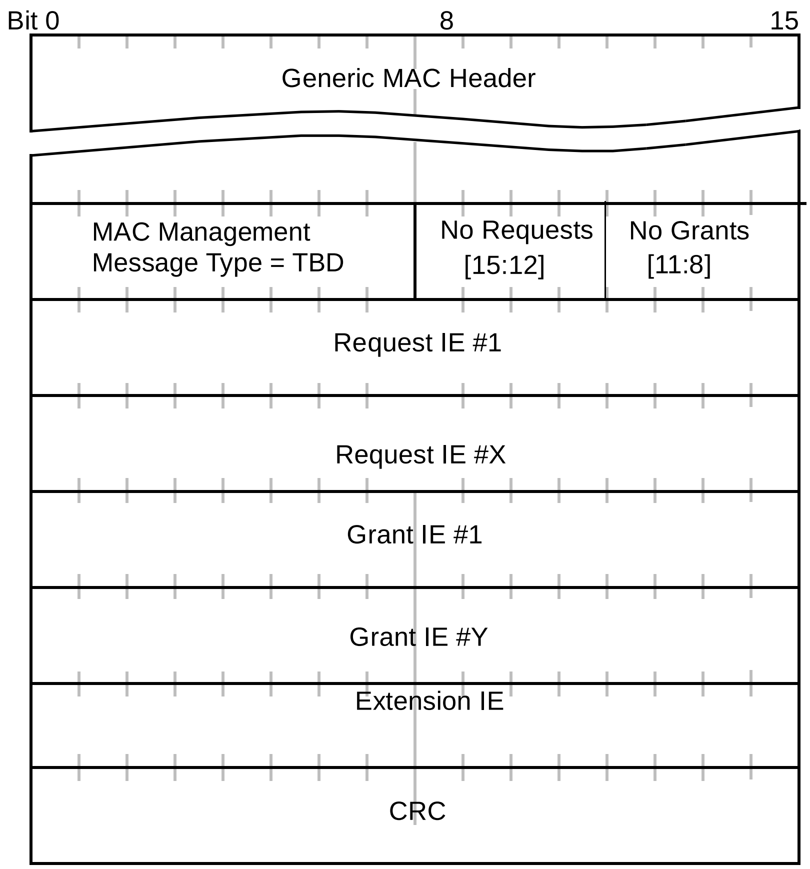


Figure 137—MSH-REQ Format (SS to SS)

Please insert the following new subclauses

6.2.7.7 License Exempt Dynamic Frequency Selection

6.2.7.7.1 OFDM PHY

6.2.7.7.2 OFDMA PHY

DFS is the process that is used primarily to assign one of several possible channels to the SS. Additionally, especially in a mesh mode, DFS may be also used to assign a most feasible 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 most feasible channels)

6.2.7.7.2.1 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, which will be determined by the PMD measurement of the preamble bits of the OFDM bursts (in a TBD manner), and a similar reading will be made of the Co-Channel Interference (CCI), also to be determined by the PMD measurement of a designated OFDM "quiet time" (TBD).

6.2.7.7.2.2 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

6.2.7.7.2.3 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 11.1.2.1, 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 most acceptable downlink channel to monitor. The higher processing layers will then tune the PMD to the most acceptable channel, and re-synchronize to this channel.

6.2.7.7.2.4 Registration Procedure

The SS will obtain all necessary downlink and uplink parameters as described in 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 802.16.4 MAC it is proposed that this step be delayed; and that a new message, a Dynamic Frequency Selection Request Message (DFS-REQ) be transmitted to the BS.

The DFS-REQ would be in the standard MAC Management Message Format (6.2.2). The DFS-REQ can be sent by the SS or the BS. Base Station originated DFS-REQ messages would be soliciting best-channel information from the particular SS (identified by the Vendor ID in the configuration file). SS originated DFS-REQ messages would be carrying candidate channel information to the BS.

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

The DFS-REQ would carry TLV encoded information. The TLV tuples will have configuration files having the settings described below.

6.2.7.7.2.5 TLV Configurations for SS Transmitted DFS-REQ Messages

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

1) Vendor ID of SS
2) Base Station ID (current)
3) Downlink Channel Configuration Setting (current)
4) Uplink Channel Configuration Setting (current)
5) Downlink ID
6) Channel EIRP
7) Mean RSSI
8) Mean CCI
9) CCI variance
10) RSSI variance
11) RSSI Fading rate (optional) (current channel)

Base Station ID, Downlink ID, Channel EIRP, mean RSSI, mean CCI,CCI variance, RSSI Variance, RSSI Fading rate (optional) (First Alternative channel)

Base Station ID, Downlink ID, Channel EIRP, mean RSSI, mean CCI,CCI variance, RSSI Variance, RSSI Fading rate (optional) (Last Alternative channel)

6.2.7.7.2.6 TLV Configurations 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 al, or a set of, the possible received channels. This message is generated by the upper processing layers 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 TLV for this message would contain:

1) Vendor ID of SS
2) Base Station ID
3) Downlink ID (1st channel to measure)
4) Base Station ID
5) Downlink ID (Nth channel to measure)
6) Measurement Bandwidth

6.2.7.7.2.7 TLV Configuration Settings for BS Transmitted DFS-RSP Messages

All downlink DFS-RSP messages sent by the BS to the SS shall contain the following TLV configuration settings:

1) Vendor ID of SS
2) Base Station ID (assigned)
3) Downlink ID (assigned)
4) Downlink Channel Configuration Setting (assigned)
5) Uplink Channel Configuration Setting (assigned)
6) Uplink EIRP setting (assigned)

6.2.7.8 License Exempt Interference Mitigation and Co-Existence

6.2.7.8.1 PFDM PHY

6.2.7.8.2 OFDMA PHY

The DRFM forms the basis of co-existence, it is needed so that other terminals, operating on different systems will at least be able to learn something about the potential interference.

6.2.7.8.2.1 Hierarchical Assumption: First Come/First Claim

In the License-Exempt environment, it is proposed that for fixed point to multipoint access systems complying to the specification, that 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 to 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.

6.2.7.8.2.2 Downlink Radio Frequency Management (DRFM) Message

This message is sent out on an occasional basis (once every 30 seconds to once every minute) on the downstream channel of a base station, which can have multiple antennas. Its purpose is to send its RF configuration information to adjacent Base Stations. This message will provide 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.

A Radio Frequency Management Message shall be transmitted by the BS at a periodic interval (30 sec. TBD) (Table XX TBD).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 Figure (XX TBD)

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 single base station. The purpose of this message is to inform nearby and potentially interfering BS and SS of the radiation of the originating BS

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

1) 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.

2) 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.
3) 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.
4) 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.
5) 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}.

Please insert the following new figure:

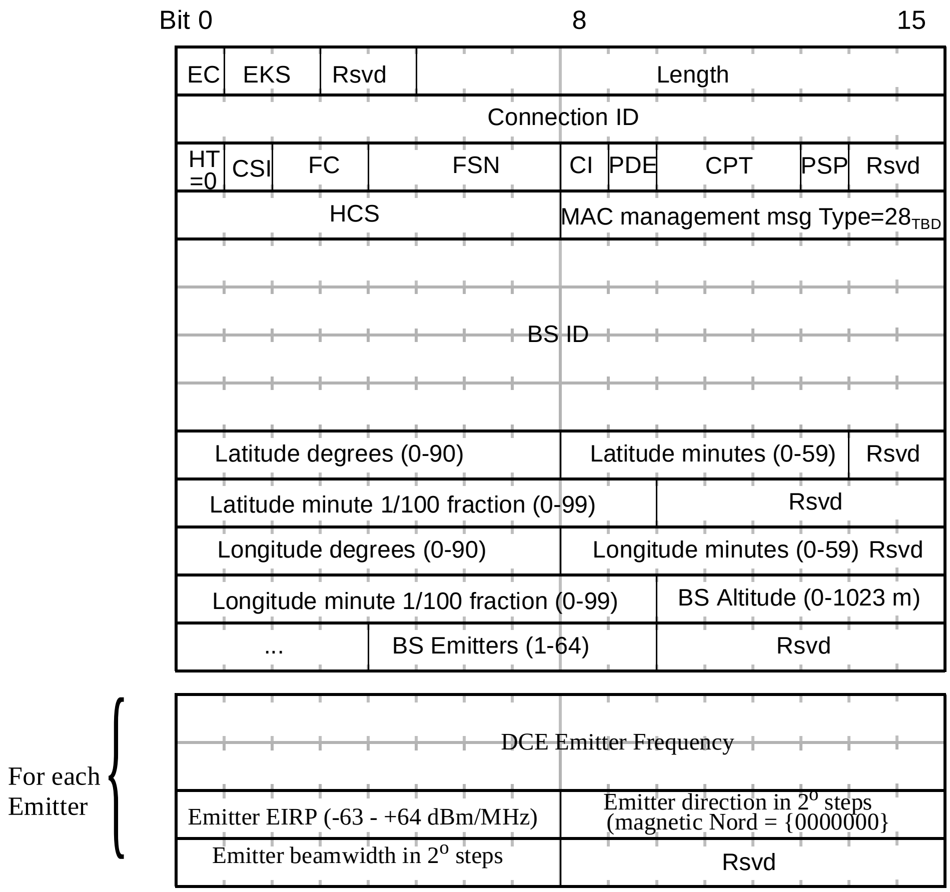


Figure 138—DL RF management message format

6.2.7.8.2.3 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.

6.2.7.9 License Exempt Mesh Mode Option

Only TDD is supported. On contrary to the basic point-to-multipoint mode, there are no clearly separate downlink and uplink subframes in the mesh mode. Otherwise the frame is similar:

1) It is divided into an integer number of physical slots.
2) TDD framing is adaptive (though a fixed framing is favored to ease MSCH scheduling).

Downlink-MAP and uplink-MAP messages are not used. Instead, mesh option specific MAC Management messages (MSCH) are used to define the usage of the rest of the TDD frame. First TBD Pass in the beginning of the frame shall be reserved solely for MSCH transmission.

6.2.7.10 Sub 11 Ghz Bandwidth Request Using CDMA Codes in OFDMA PHY

6.2.7.10.1 OFDM PHY

6.2.7.10.2 OFDMA PHY

6.2.7.10.2.1 Introduction

<<< This contribution is a complementary contribution to [6] and describes an option for fast bandwidth reservation mechanism.

The functional requirements [3] and several contributions about the expected nature of the traffic of TG3 and TG4 context, describe an IP centric environment, with dynamic and bursty traffic that requires option of fast bandwidth reservation mechanisms.

The two main access techniques in centralized systems that are most commonly used are: Contention Access (also Random Access) and Polling.

The Polling methods are best for systems with short propagation delays, small number of subscribers and small overhead for polling messages but usually are less efficient with bursty traffic.

The Contention methods usually well fit for bursty scenarios, increase the statistical multiplexing gain, supply short delay for the bursty packets but reduces the channel efficiency with high risk of collisions and potentially high jitter.>>>

The <<<proposed>>> described mechanism takes advantage of the OFDMA based PHY <<<as proposed in [1]>>> to provide a CDMA code based bandwidth reservation tool. <<< This mechanism has all the advantages of Contention scheme for bursty traffic but with much higher success percentage (90% Vs 10% for 20 simultaneous requests with window size of 10 slots, see Simulation Results) and better channel utilization >>>.

6.2.7.10.2.2 Description of the <<< proposed>>> Bandwidth Request mechanism

<<< As described in [6] and in [1],>>> several PHY configurations <<< are proposed, especially,>> exist.

The 1K and 2K modes define the concept of sub-channels as a subset of the frequencies transmitted in one OFDM symbol, those two modes define a unique ranging slots that co-exists with data slots for each OFDM symbol.

The SS may use the ranging slots to send CDMA codes from a three domains of codes: Initial Ranging, Maintenance Ranging and bandwidth requests. The CDMA codes used for bandwidth request are defined as Request Codes.

The <<< proposed >>> Bandwidth Request mechanism defines usage of the Request Code by the SS to request fast bandwidth allocation on a bursty basis.

Figure tbd below describes the messages sequence for CDMA bandwidth request:

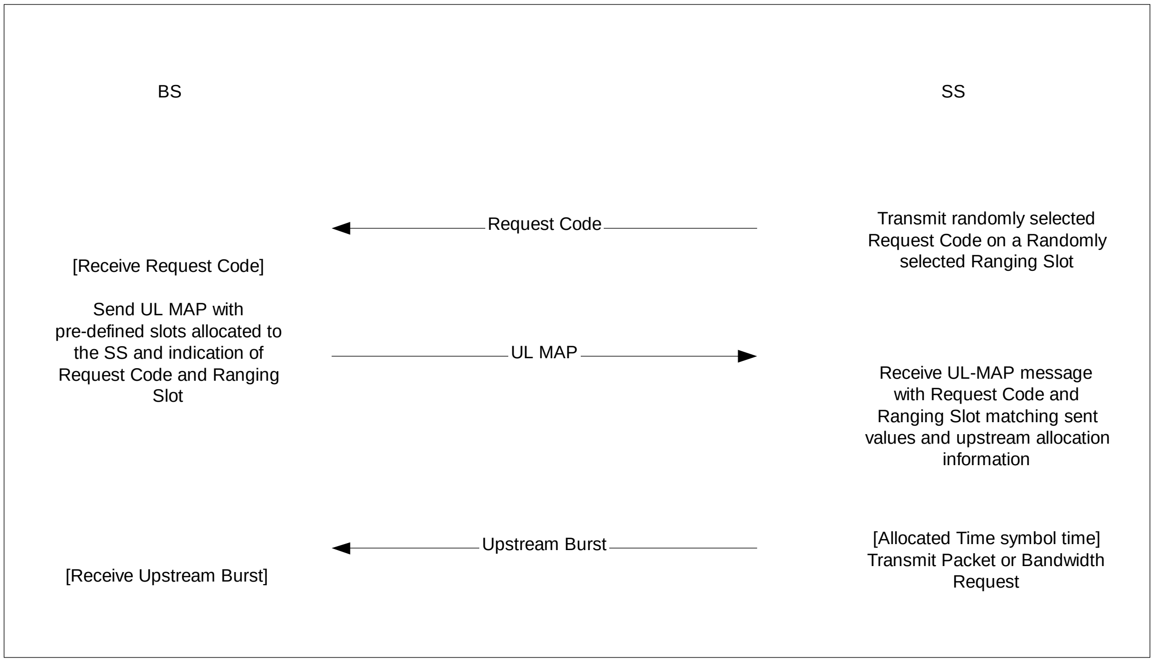


Figure 139—Bandwidth Request in high FFT modes

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 <<< actually there may be a collision but the data is believed to survive due to separation by CDMA codes >>> (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.

In the case of small FFT size (Access Scheme 1 in [6]), the UL MAP message shall have indication of the synchronization interval size and time (full OFDMA symbols carrying only CDMA codes with one or two sub-channels), the SS shall send the request codes in this interval.

Figure tbd below describes the messages sequence for this case:

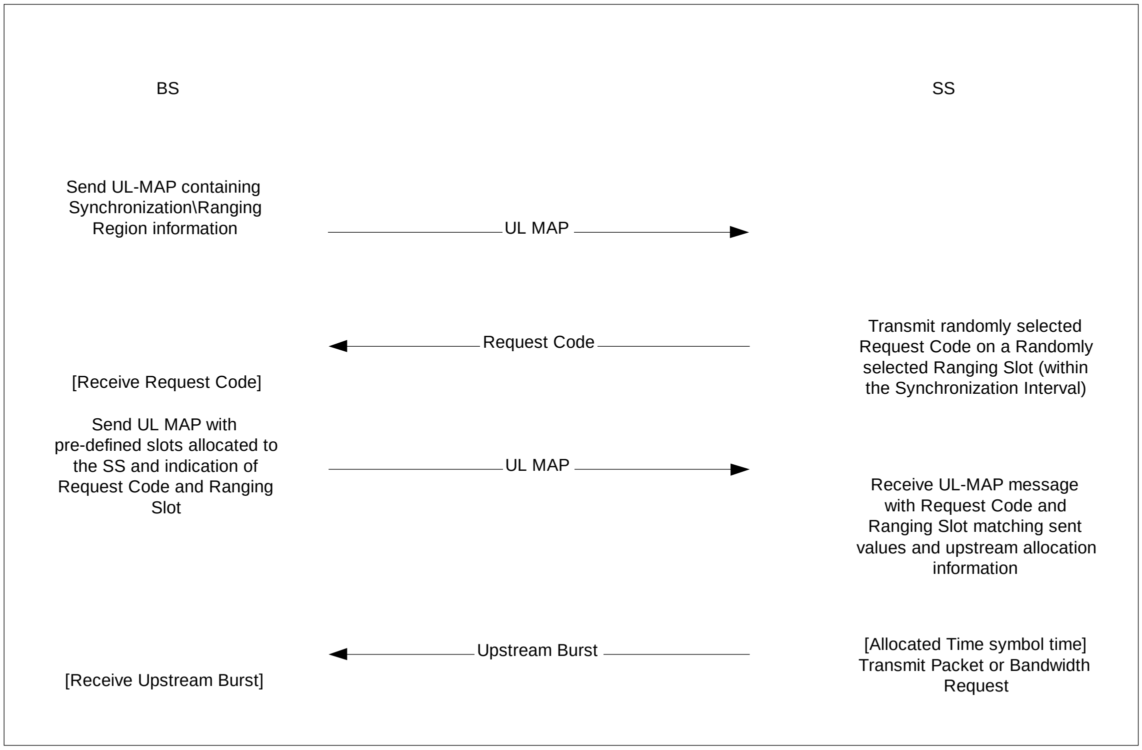


Figure 140—Bandwidth Request in high FFT modes

<<< The advantage of the proposed mechanism is the fairly safe request indication by the SS and transmitting bandwidth request in a unique allocated slot, or the option for fast requests for small allocation that can be used to send bursty based packets (like TCP Acks) in a highly dense cells. >>

6.2.7.10.2.3 Request Code Grant Interval

When using the Request Code, the BS allocates a pre-defined number of slots to the sending SS whose Request code and Ranging slots are provided in the upstream MAP IE. The value of such allocation is defined by the BS and can be optimizes according to the traffic behavior. The minimum value of the grant interval should be big enough to accommodate at least upstream bandwidth request message.

The Unsolicited Grant Size parameter (section 11.4.12.19 page 356) can be used for this purpose.

6.2.7.10.2.4 New UIUC Addition

New UIUC value should be added in order to identify allocation as reaction to Request Code.

The following UIUC value should be added to section 6.2.2.2.4 Table 5 page 67:

Table 146—Number of bits in OFDM symbol

IE Name	UIUC	Connecti on ID	Mini-slot Offset
Request code allocation	12	broadcast	TBD

In this proposal, we adopt the Upstream MAP IE structure presented in [4] to provide enhancements with full backward compatibility.

Figure 141 below shows the proposed Upstream MAP IE for the proposed new UIUC (as defined in Table 3)

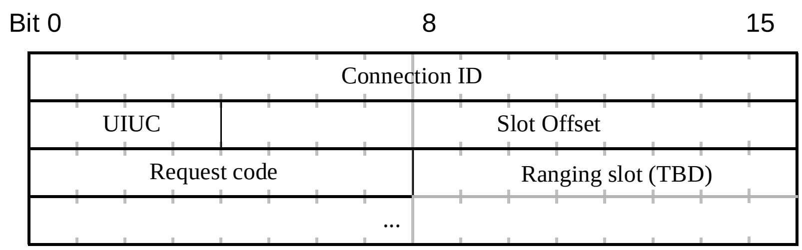


Figure 141—Upstream MAP IE structure for Request Code UIUC

Ranging Slot: A required parameter if the SS used CDMA Ranging Slot for bandwidth request, in this case the UL-MAP IE element will use broadcast CID, and the combination of Ranging Slot and Request Code shall be used to address the requesting SS.

The Ranging Slot value shall indicate a combination of OFDMA time symbol and Sub-Channel number

Request Code: A required parameter if the SS used CDMA Request Code for bandwidth request, in this case the UL-MAP IE element will use broadcast CID, and the combination of Ranging Slot and Request Code shall be used to address the requesting SS.

6.2.7.11 Sub 11 Ghz Ranging Enhancement

6.2.7.11.1 OFDM PHY

6.2.7.11.2 OFDMA PHY

6.2.7.11.2.1 Introduction

This section describes proposed enhancements to the TG1 MAC's ranging mechanism for the TG3 and TG4 MAC.

The goal of the enhancements is to use the advantages of the OFDM/OFDMA based PHY to facilitate simpler and safer synchronization of the user with the base station.

The physical part of the proposed enhancements are described in the PHY proposals [1] <<< submitted several times to the TG3 & TG4 groups.

The proposed mechanism is fully integrated in the approved (since April 2001) DVB-RCT standard (that is based on an OFDMA return channel) as a mature and well-defined improvement technique of the classical Ranging algorithms.>>>

The contribution describes full description of the Ranging enhancements, proposed changes to the TG1 MAC to accommodate the proposed mechanism.

6.2.7.11.2.2 Background

The OFDMA (OFDM) upstream physical layer access method is based on the use of a combination of time and frequency division access technique.

The <<< proposed >>> described synchronization technique is based on several sub-carriers that are spread on the entire bandwidth and are collected in CDMA form. This allows several users to perform synchronization simultaneously <<<; those special carriers within an OFDMA (OFDM) <<< time symbol are allocated for synchronization purpose and shall be referred as Ranging slots. – the definition is done below>>>

The basic allocation unit (e.g. slot) is a combination of a time symbol and a sub-channel. The <<< current >>> OFDMA (OFDM) based PHY <<< proposals >>> define several working modes, those modes define 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 142 illustrates the concept of access scheme 1

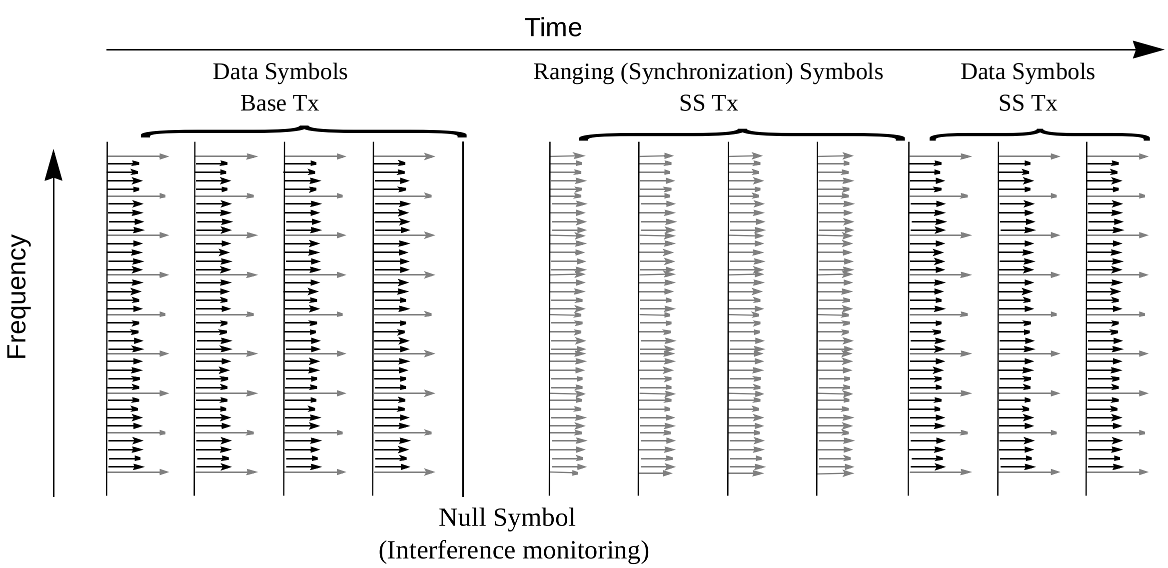


Figure 142—OFDMA Ranging symbol allocation

Figure 143and Figure 144 illustrate the concept of access scheme 2

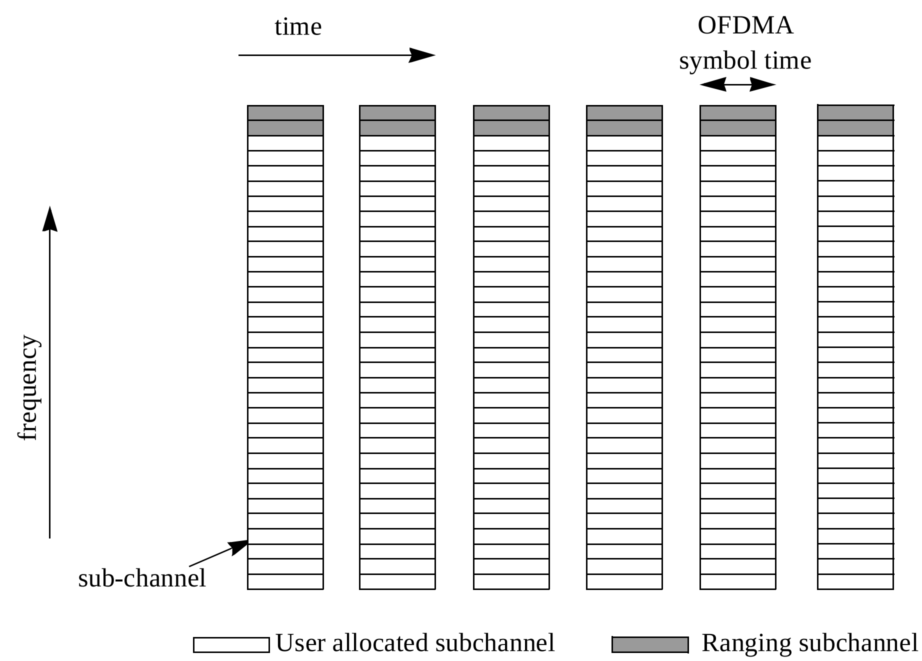


Figure 143—OFDMA ranging allocation concept

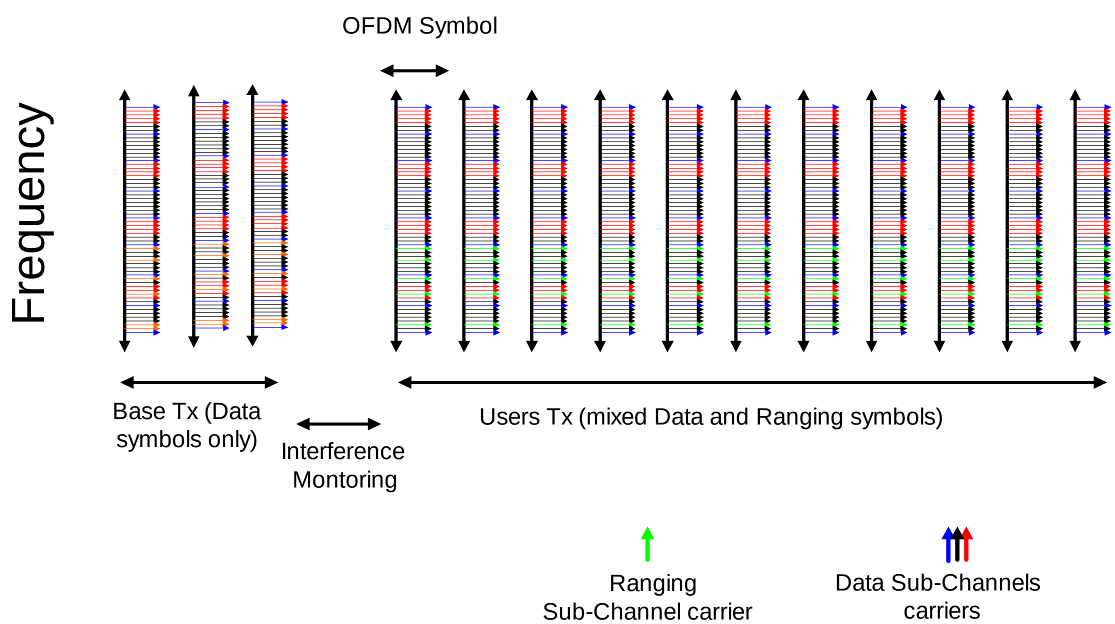


Figure 144—OFDMA Ranging - TDD mode

Each user that wants to perform ranging will choose randomly a PN sequence from a pre-defined set of PN sequences (16 different sequences) and will modulate (with a pre-defined robust modulation scheme, i.e. BPSK) it on a pre-defined set of carriers. The randomly chosen PN is referred as *Ranging Code.*

6.2.7.11.2.3 ▪<<< Proposed >>> Ranging Mechanism Overview

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 proposed ranging technique is mostly similar to the one presented in [2]:

a) The SS, after acquiring downstream synchronization and upstream transmission parameters, shall choose randomly a Ranging Slot (with 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).
b) 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.
c) Upon receiving Ranging Response message with continue status, the SS shall continue the ranging process as done on the first entry.

The main points of difference with the <<< classical >>> 802.16 MAC ranging process are:

In modes with number of carriers = 1K, a specific set of carriers shall be used for ranging, hence deduce that each OFDM symbol will always contain a pre-defined and fixed ranging slot.

In modes with number of carriers < 1K, a full symbol(s) shall be used for ranging, this means that the base station shall define an Initial Maintenance region in the same way it defined in [2].

The entry to the system is anonymous and remains so for the whole ranging process, the SS is identified by the indication of the sent ranging slot and sent ranging code.

In modes with number of carriers = 1K, the BS does not need to allocate a specific ranging region, this allow the SS to choose when to initiate the system entry.

Several SS can send ranging code simultaneously without colliding (due to the CDMA technique).

The following message flow charts (ýFigure 35 and Figure 36) describe the ranging adjustments process in the two access mode.

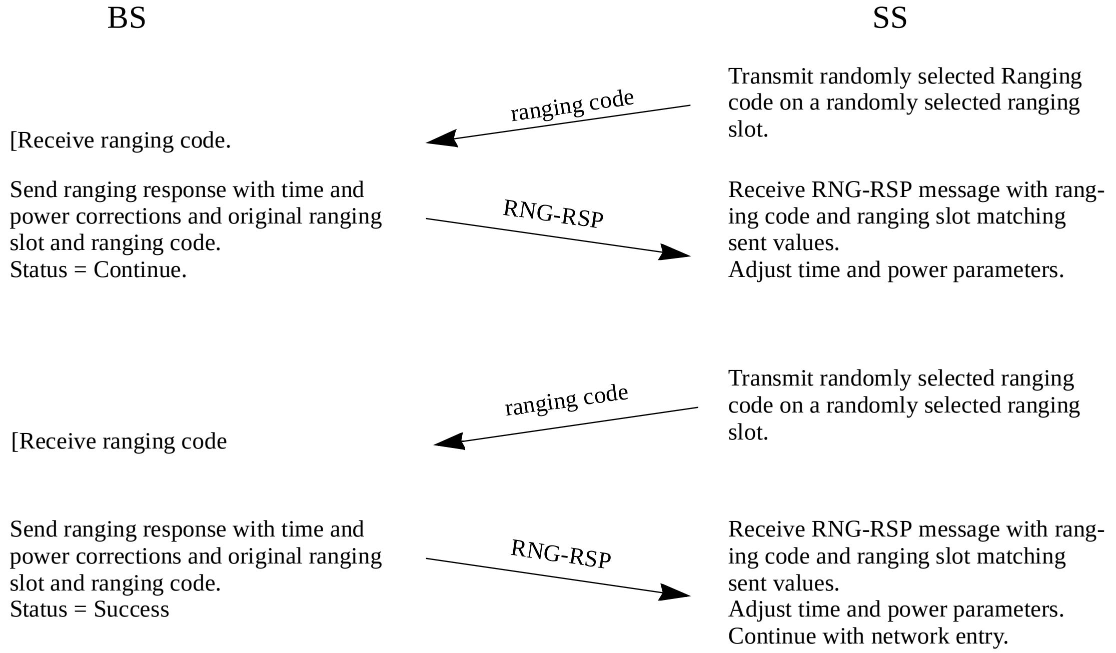


Figure 145—Ranging and automatic adjustments procedure for access scheme 2.

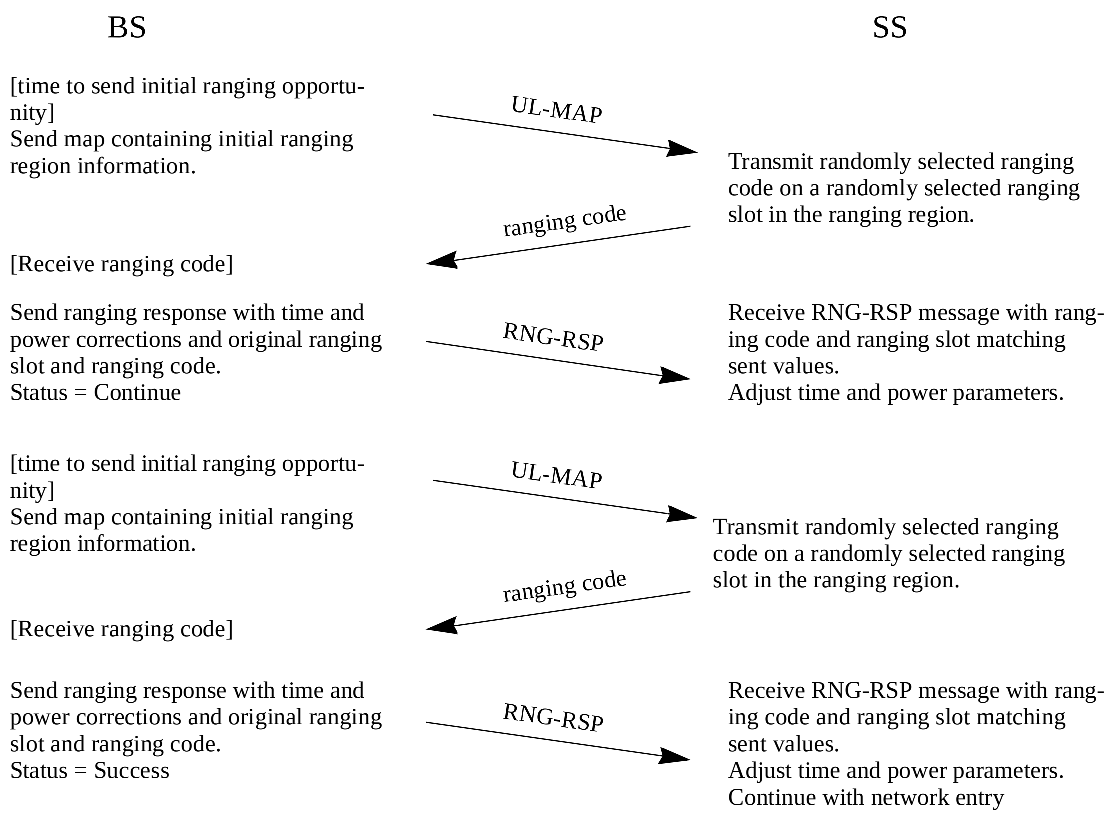


Figure 146—Ranging and automatic adjustments procedure for access scheme 1.

<<< Proposed Modifications to the 802.16.1 MAC >>>

The following sections define the detailed modifications need to done to the 802.16.1 MAC in order to accommodate the proposed CDMA ranging technique assuming that the PHY layer supports the required features (e.g. ranging slots, ranging codes etc.)

6.2.7.11.2.4 Ranging region <<< indication >> Definition

For the modes with number of carriers < 1K, the ranging slots shall use full OFDM symbols, therefore the initial ranging interval shall be allocated in the same way it is done in [2].

For the modes with number of carriers = 1K, the ranging slots shall use one (or more) sub-channels of an OFDMA symbol and will exists for each OFDMA symbol, therefore no indication about initial maintenance region is required.

6.2.7.11.2.5 Update to 6.2.2.2.6 Section

The following addition should be done to the RNG-RSP Message description in section 6.2.2.2.6 line 61 page 69:

Ranging Slot: 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 Slot and Ranging Code shall be used to address the sending SS.

The Ranging Slot value shall indicate a combination of OFDMA time symbol and Sub-Channel number

Ranging 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 Slot and Ranging Code shall be used to address the sending SS.

6.2.7.11.2.6 Change in the RNG-RSP Message

The following TLV values should be added to the RNG-RSP message encoding table, section 11.1.4 page 318:

Table 147—RNG-RSP TLV addition

Name	Type	Length (1 byte)	Value (variable length)
ranging slot	13	TBD	Used to indicate the OFDMA (OFDM) time symbol and Sub-Channel reference that was used to transmit the ranging code. This TLV is used in conjunction with the Ranging Code value to identify the sending SS.
Ranging code	14	1	Used to indicate the ranging code that was sent by the SS (unsigned 8-bit). This TLV is used in conjunction with the Ranging Slot value to identify the sending SS.

6.2.7.11.2.7 References

[1] Y.Segal, Z.Hadad, I.Kitroser. Initial OFDMA Proposal for the 802.16.3 PHY Layer. January 2001.

[2] IEEE 802.16.1/D2. Draft Standard for Air Interface for Fixed Broadband Wireless Access Systems. January 2001.

[3] IEEE 802.16.3-00/02r4. Functional Requirements for the 802.16.3 Interoperability Standard. September 2000.

[4] IEEE 802.16.4c-01/02. Modifications to the TG1 MAC for use in TG4 Systems. January 2001

[5] DVB-RCT v.116 standard approved draft, April 2001.

Please insert the following new subclause:

6.2.7.12 License Exempt Bands - Power Control Information Element

6.2.7.12.1 OFDM PHY

6.2.7.12.2 OFDMA PHY

When a power change for a connection (CID) is required, use the Expansion IE (UIUC Code=15) as follows:

1) Connection Identifier (16-bit)- This is the basic uplink connection ID.
2) Additional Set - (4-bits)
3) Power Control - (4-bits)

This IE shall be sent only when is needed.

For example, to adjust the power control for a specific CID, the BS must create a UL-MAP message with two different IEs applied to the same SS (in case of GPT mode), a standard IE providing the active Burst Type (Dynamic Set) with offset, and a second Expanded IE (UIUC=15). This IE contains both the Power Control adjustments and an additional set of parameters.

6.2.7.13 Sub 11 Ghz Support for Advanced Antenna Technology

6.2.7.13.1 Single Carrier PHY

6.2.7.13.2 OFDM PHY

6.2.7.13.3 OFDMA PHY

6.2.7.13.3.1 Architectural Overview

Adaptive Antenna Arrays are elements of the BWA system that are used in conjunction with the PHY, to enhance the performance of the system. Adaptive Arrays can improve range and system capacity. 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, adaptive array support in the MAC sub-layer is defined by a set of services supplied by the underlying PHY, and by MAC protocol functions controlled by the CS. The main functions affected by Adaptive Array Support are:

a) MAC control functions- Uplink/Downlink MAP distribution, Channel Description
b) MAC utility function- PHY related information provided by MAC
c) Registration functions- Initial Synchronization/Ranging

The main purpose of Adaptive Array Support is to enable the MAC to use any PHY that may have Adaptive Array capabilities, independent of the PHY type, or the type of Adaptive Array in use. Adaptive Array Support can be implemented in the SS MAC (which then will be able to interoperate with the MAC of any BS that have Adaptive Array Support at the MAC layer), or in the BS MAC (Which will be able to interoperate with any SS that have this capability, at the MAC layer).

6.2.7.13.3.2 Definitions

The following definitions apply to Adaptive Array support:

<<< It is a list of the terms, that still need definitions >>>

a) AAS- Adaptive Array Support
b) Broadcast Coverage
c) Unicast Coverage
d) Reciprocal Matrix Channel Estimation
e) Feedback Matrix Channel Estimation
f) AAS Ranging interval

6.2.7.13.3.3 Compatibility model

The Adaptive Array Support (AAS) is an optional component of the 802.16ab standard MAC.

6.2.7.13.3.4 MAC Control functions to support Adaptive Arrays

The main difference between a system with Adaptive Array Processing capabilities, and a system that do not have these, are related to differences in capacity and range than is offered to each of the individual SSs. One property, inherent to FBWA system with AAS is that the Broadcast Coverage is in general, smaller then the Unicast Coverage. The MAC control functions related to AAS are aimed to compensate for this property, as to enable the MAC to work seamlessly with respect to the Adaptive array.

The following messages are used to provide AAS MAC control functions

a) P-DUCD (Private Uplink/Downlink Channel Descriptor) used as an alternative to UCD and DCD
b) P-MAP (Private MAP) used as an alternative to UL-MAP and DL-MAP.

6.2.7.13.3.5 Private Uplink/Downlink Channel Descriptor (P-DUCD) message

A Private Uplink/Downlink Channel Descriptor message shall be transmitted by the BS to each SS that did not receive the last DCD or UCD. The P-DUCD message should contain all information contained in the DCD and UCD messages that is relevant to the addressed SS.

The MAC header and Downlink/Uplink channel ID are identical to the type-0 (UCD) packet format. The Type field value is TBD. The Configuration Change Count field is the sum of the values of Configuration Change Count fields in both corresponding UCD and DCD messages, to allow each SS to track changes and discard the P-DUCD message, in case no changes made since last update.

All TLV information that describe Uplink and Downlink channel and burst profiles are identical to their corresponding fields in the original DCD/UCD messages (the final TLV encodings should be updated after determination of the final channel encodings and DCD/UCD fields content for 802.16ab). A SS receiving a P-DUCD will ignore the message, if it had received the UCD and DCD containing the same information. This can be verified easily by comparing the Configuration Change Count field.

6.2.7.13.3.6 Private MAP (P-MAP) message

The BS shall generate a Private MAP (P-MAP) message for each SS that had not received the last UL-MAP or DL-MAP. The P-MAP message defines the access to Downlink and Uplink information and contains all information relevant to the addressed SS, contained in the UL-MAP and DL-MAP messages.

The MAC header and Downlink/Uplink channel ID are identical to the type-2 (DL-MAP) packet format. The Type field value is TBD. The P-MAP contains the same fields of UL-MAP and DL-MAP, in a single message. Unlike the typical UL-MAP, which has a large number of information elements (one for each connection for several SSs), the P-MAP shall have only few information elements, since only connections relevant to the addressed SS are informed. A SS receiving a P-MAP will ignore the message, if it had received the MAP of the current frame correctly.

6.2.7.13.3.7 MAC Utility functions to support Adaptive Arrays

Adaptive Arrays use channel state information that are measured by the receiver at one end of the link. When channel state of the downlink is required at the BS, there are two ways to obtain it:

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

While the first method seems to be more elegant, it will not fit FDD systems, where reciprocity does not apply (due to the large frequency separation between uplink and downlink channels).

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 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.

6.2.7.14 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.

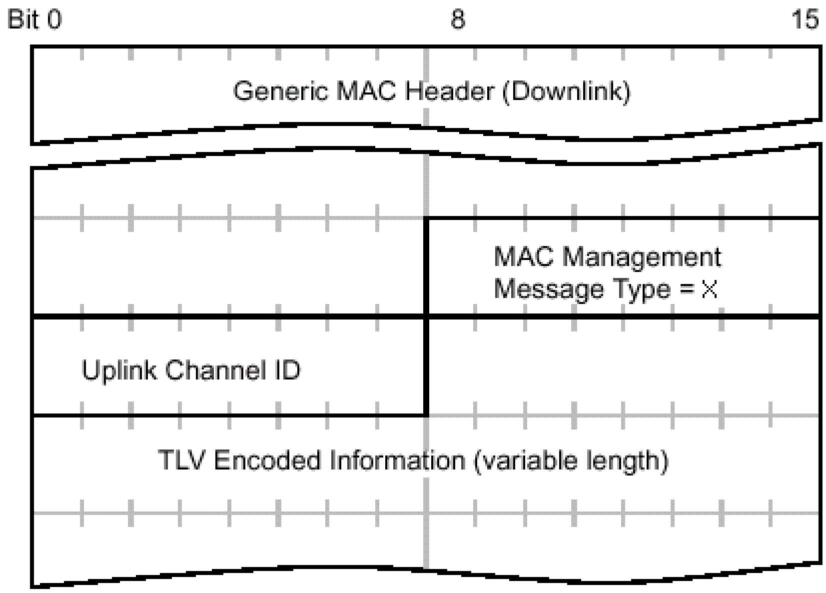


Figure 147—CSF-REQ message

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:

a) Frequency adjust information
b) Power adjust information
c) Timing adjust information

6.2.7.15 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. 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.

Note:

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.

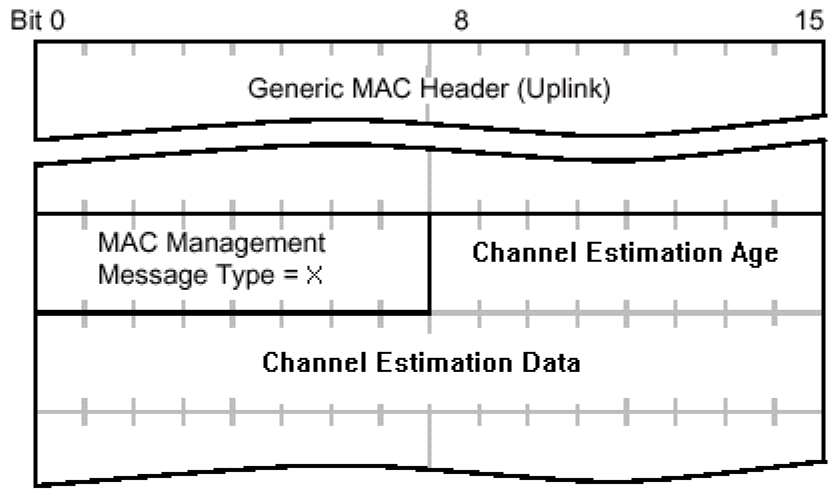


Figure 148—CSF-REP message

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.

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, the system SHALL comply with the Single Carrier (SC) Physical Layer (PHY) as described in clause 8.3.5 or the Orthogonal Frequency Division Multiplexing (OFDM) PHY as described in clause 8.3.6.2 and 8.3.6.3. The system MAY implement both PHYs. It SHALL further comply with all requirements set out in clause 8.3.1 through 8.3.4 that apply to the implemented PHY(s) and with the Medium Access Control Layer (MAC) as described in ???.

In order to claim compliance of a system with the IEEE 802.16 standard for license-exempt frequencies, the system SHALL comply with the OFDM Physical Layer (PHY) as described in clause 8.3.6.2 and 8.3.6.4. It SHALL further comply with all requirements set out in clause 8.3.1 through 8.3.4 that apply to the implemented mode and with the Medium Access Control Layer (MAC) as described in ????.

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 149. 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.

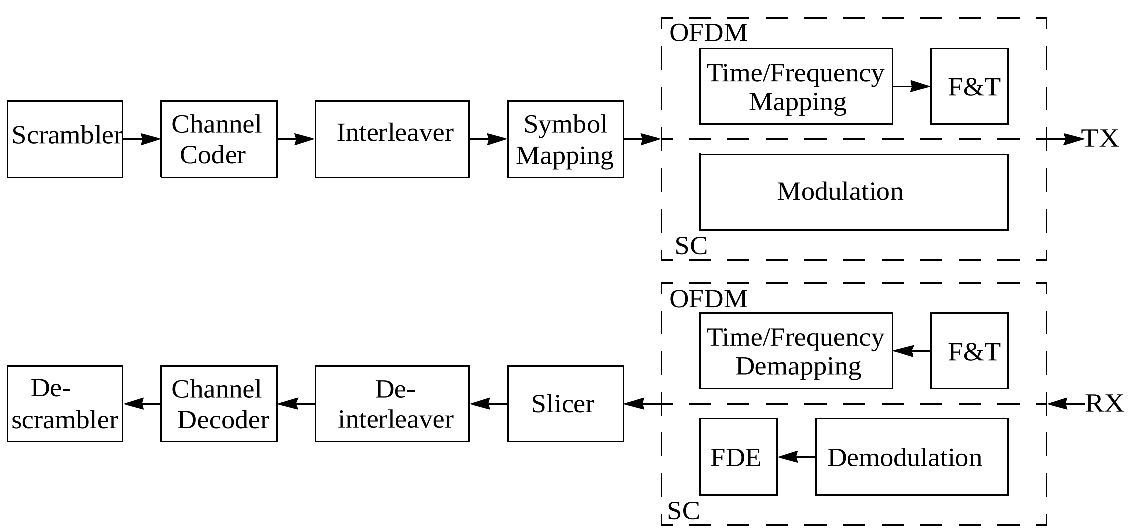


Figure 149—Generic OFDM PHY block diagram

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 single carrier 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 150. Additional details on a SC-FDE will be presented in clause 8.3.5.

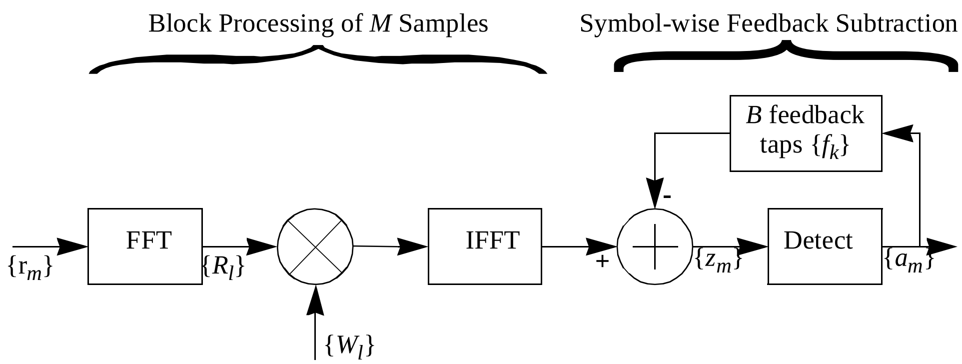


Figure 150—SC-FDE decision feedback equalization at the receiver

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 151, exists in the OFDM based PHYs only.

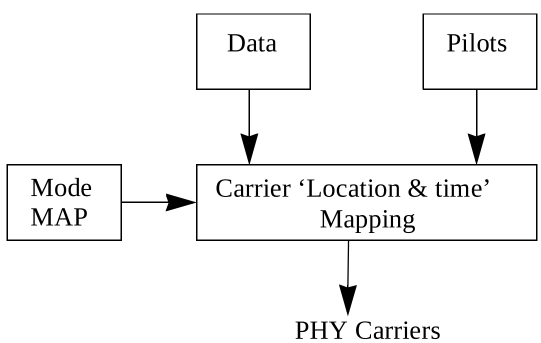


Figure 151—Time/frequency mapping function

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 bandwidth of the PHY system are given in Table 148.

Table 148—Frequency bands and channel bandwidth

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 152. [B18]. The spectral mask for the WCS band is shown in Figure 153 and the spectral mask for the MMDS band is shown in Figure 154.

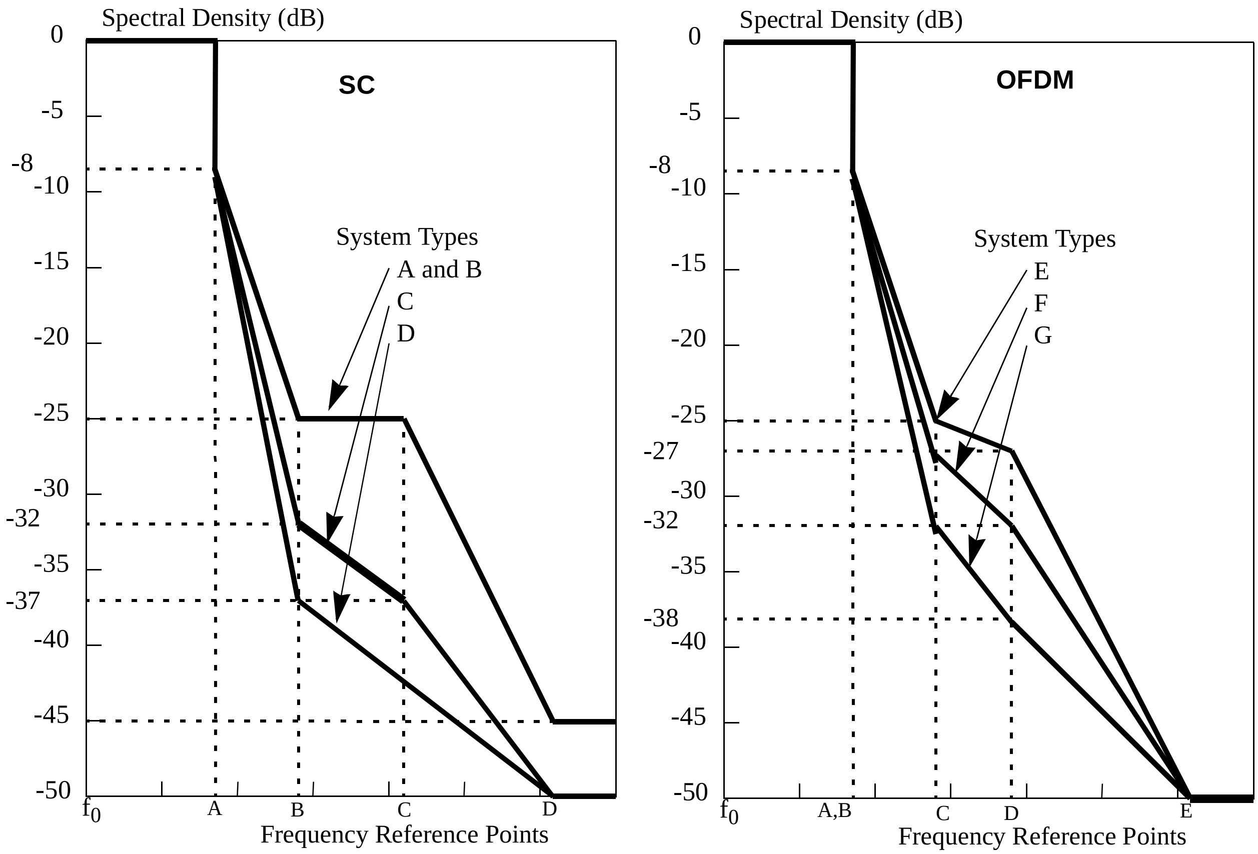


Figure 152—ETSI SC and OFDM spectral masks

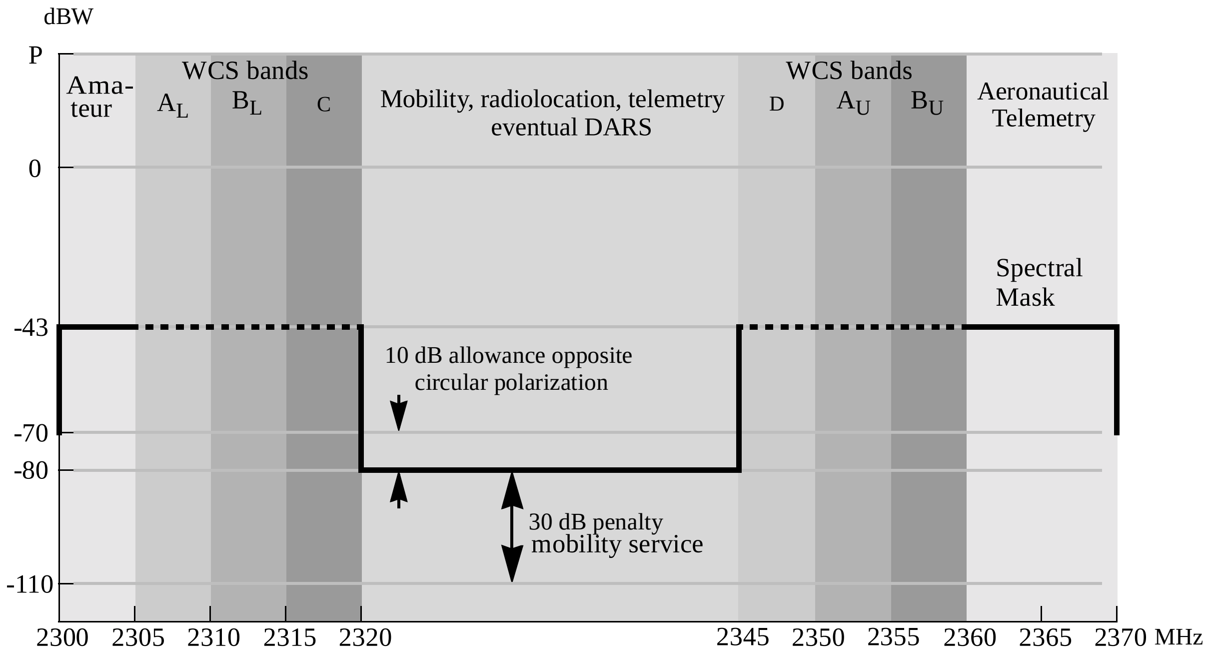


Figure 153—WCS spectral mask

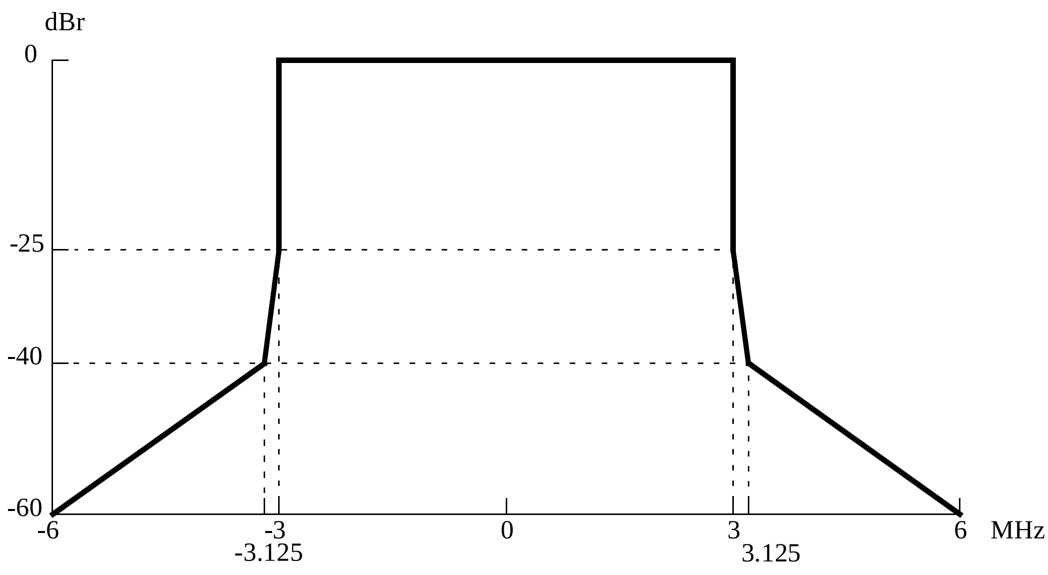


Figure 154—MMDS spectral mask

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 maybe 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 the USA, the FCC is the agency responsible for the allocation of the 5 GHz U-NII bands.

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+10log(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+10log(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 149.

Table 149—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 8.3.6.4.2.3.

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 155 illustrates the concatenated Reed Solomon/ Convolutional code FEC.

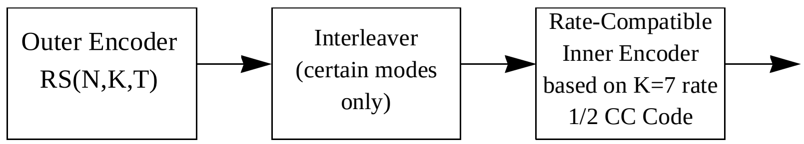


Figure 155—Concatenated Reed Solomon / Convolutional Code Encoder Block.

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:

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

The generator is depicted in Figure 156.

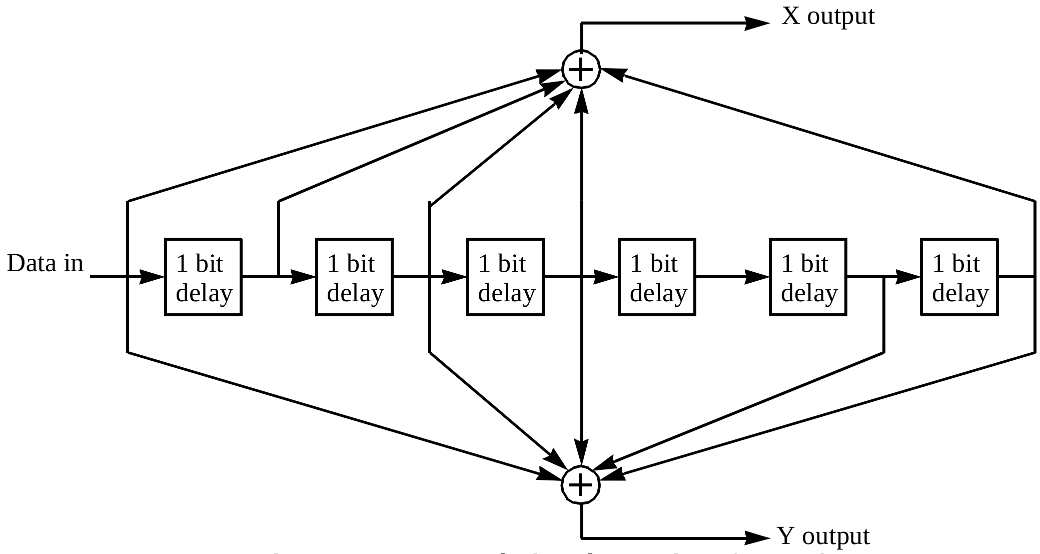


Figure 156—Convolutional encoder of rate 1/2

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 addition to these two, the table lists a third set of puncturing patterns that shall be used only with the OFDM PHY in the license-exempt bands for the optional convolutional-only mode. 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 150. They are defined seperately for the SC-mode, the OFDM modes, and the optional convolutional-only mode in the license-exempt bands (see 8.3.6.4.2.6.2.2). For the SC mode, the IQ mapping is also provided. In the notation used by Figure 156, (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 150—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	-
optional CC puncturing in license-exempt mode (see 8.3.6.4.2.6.2.2)		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 157. 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 $d = d_x \times d_y$.

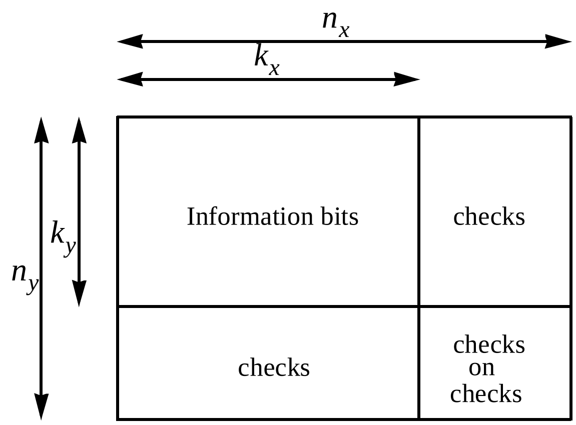


Figure 157—Two-dimensional TPC matrix

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 151 specifies the generator polynomials for the Hamming Codes.

Table 151—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 152 summarizes the component codes available for use in this specification:

Table 152—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 158 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 158—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

Bits derived from the Convolutional coder shall be mapped to a signal constellation as shown in Figure 159 and Figure 160.

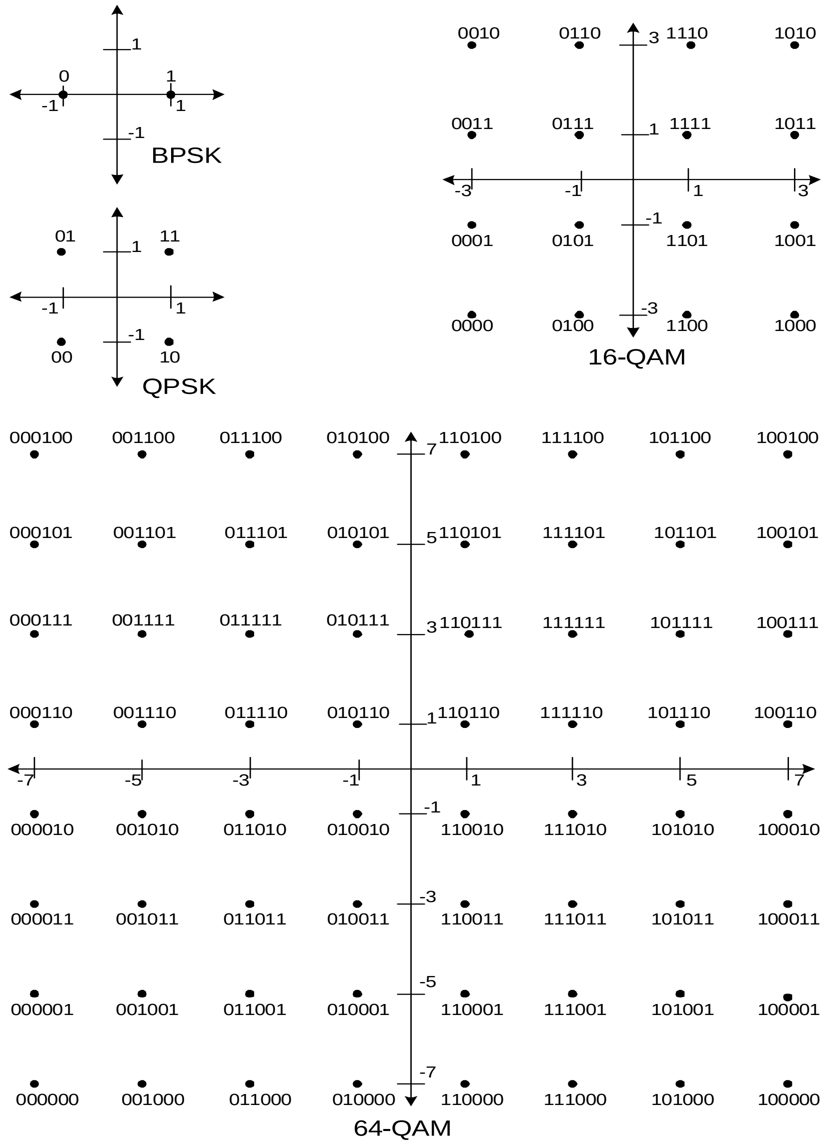


Figure 159—BPSK, QPSK, 16 QAM and 64 QAM constella-

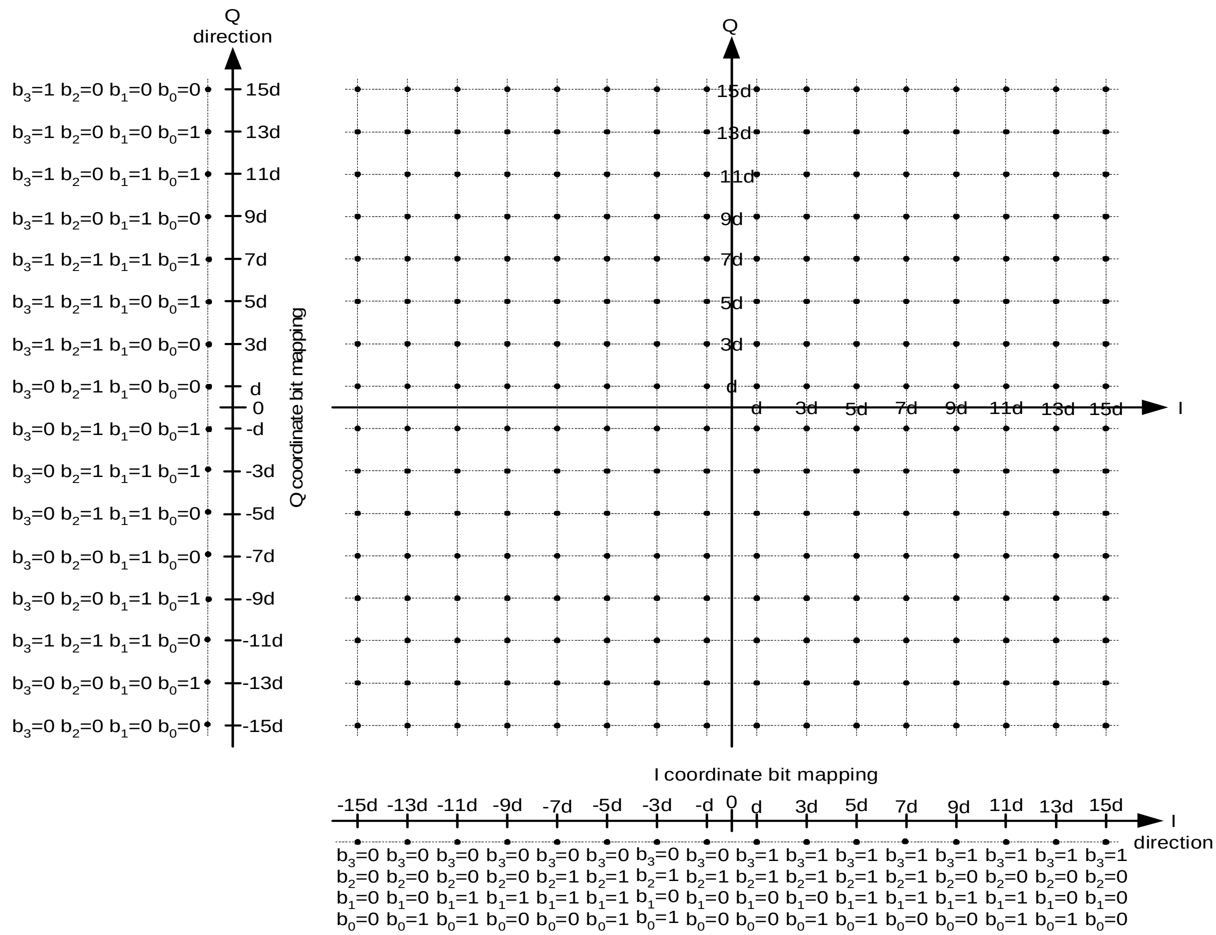


Figure 160—256 QAM constellation (SC mode only)

8.3.3.1.6 Adaptive modulations

Adaptive Modulation & 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 8.3.4.

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 153.

Table 153— 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 154.

Table 154—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 MAC and PHY Interface

8.3.4.1 Overview

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

- Mode A: supports a continuous transmission stream format, and
- Mode B: support a burst transmission stream format.

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.

In contrast, only one mode of operation is defined for the upstream channel:

- one targeted to support a burst transmission stream format

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).

8.3.4.2 Downlink and Uplink Operation

Two different downlink modes of operation are defined: Mode A and Mode B. Mode A supports a continuous transmission format, while Mode B supports a burst transmission format. The continuous transmission format of Mode A is intended for use in an FDD-only configuration. The burst transmission format of Mode B supports burst-FDD as well as TDD configurations. Devices operating in license-exempt bands shall employ only TDD.

The A and B options give service providers choice, so that they may tailor an installation to best meet a specific set of system requirements. Standards-compliant subscriber stations are required to support at least one (A or B) of the defined downlink modes of operation.

A single uplink mode of operation is also defined. This mode supports TDMA-based burst uplink transmissions. Standards-compliant subscriber stations are required to support this uplink mode of operation.

8.3.4.2.1 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.

8.3.4.2.2 Mode B - Burst Downlink

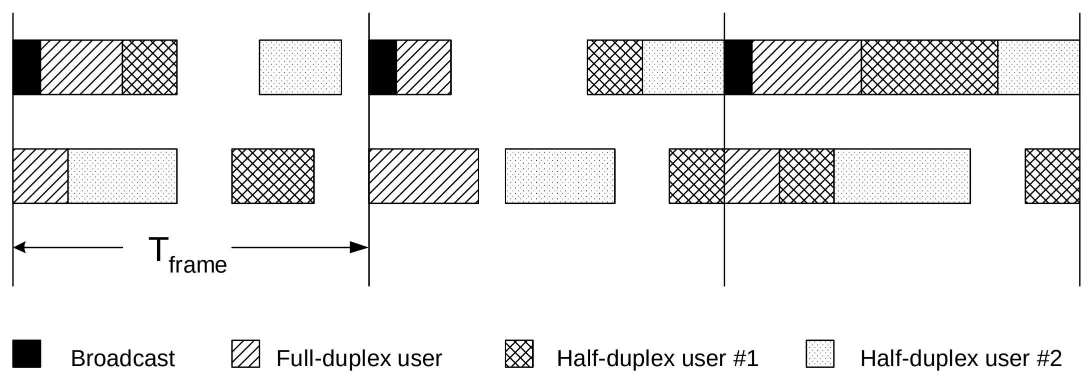


Figure 161—Example of burst FDD Bandwidth Allocation

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.

8.3.4.2.2.1 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.

8.3.4.3 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.

8.3.4.3.1 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.

8.3.4.3.1.1 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.

8.3.4.3.1.2 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.

Frequency separation is as defined in clause ???. Figure 162 describes the basics of the burst FDD mode of operation. 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.

8.3.4.3.1.3 Mode B: Burst Downstream for TDD Systems

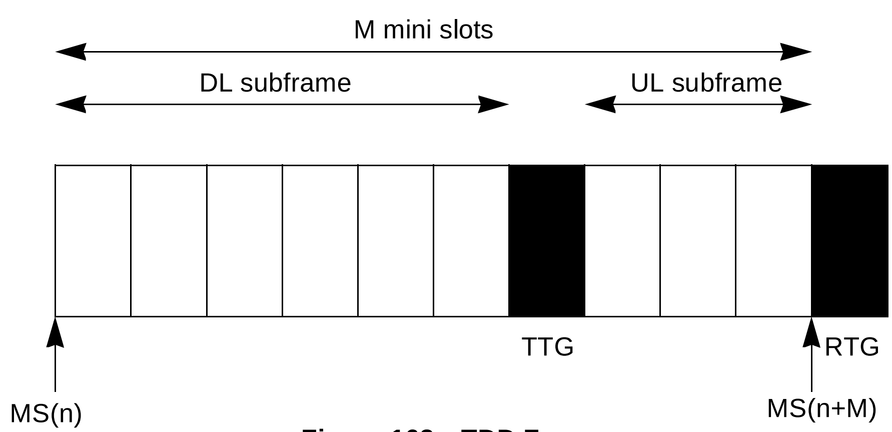


Figure 162—TDD Frame

In the case of TDD, the uplink and downlink transmissions share the same frequency, but are separated in time (Figure 1610). A TDD frame also has a fixed duration and contains one downlink and one uplink subframe. The frame is divided into an integer number of 'mini slots' (MS), which facilitate the partitioning of bandwidth. These mini slots are in turn made up of a finer unit of time called 'ticks', which are of duration 1 us each. TDD framing is adaptive in that the percentage of the bandwidth allocated to the downlink versus the uplink can vary. The split between uplink and downlink is a system parameter, and is controlled at higher layers within the system.

8.3.4.3.1.3.1 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.

8.3.4.3.1.3.2 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.

8.3.4.3.1.3.3 Mode B: Downlink Data

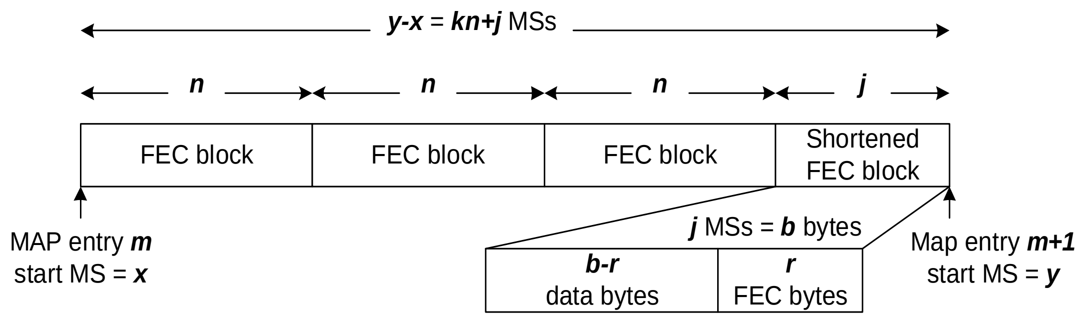


Figure 163—DL-MAP usage and shortened FEC blocks

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 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 163. 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.

8.3.4.3.2 Uplink Burst Subframe Structure

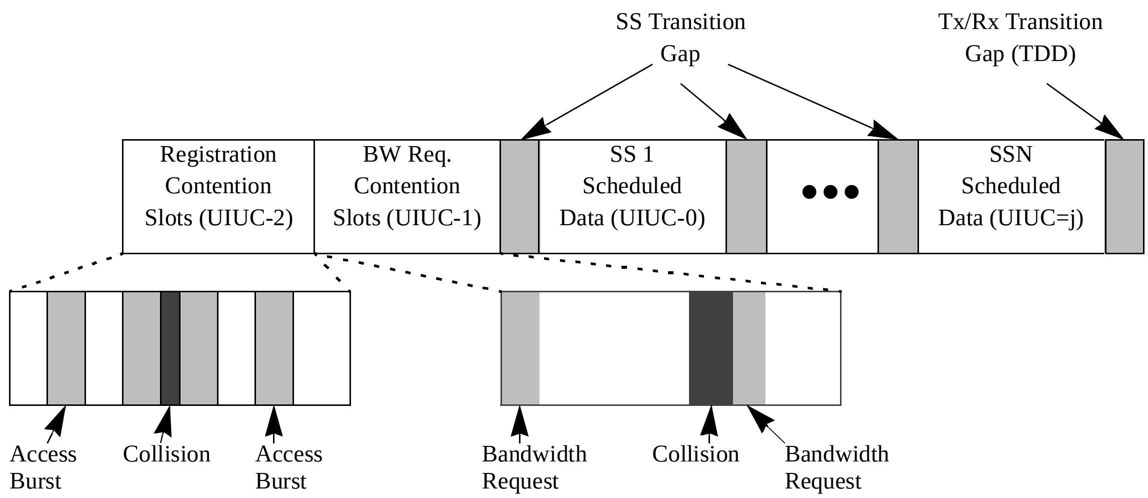


Figure 164—Uplink Subframe Structure

The structure of the uplink subframe used by the SSs to transmit to the BS is shown in Figure 164. 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.

8.3.4.3.2.1 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) (Remark: It is recommended that UIUC=1 will provide the most robust burst profile due to the extreme link budget and interference conditions of this case). 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????.

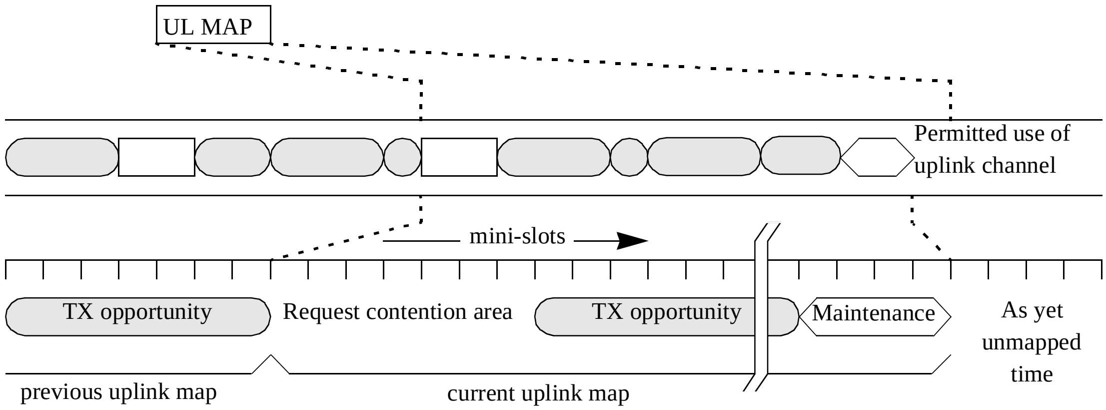


Figure 165—Uplink Mapping in the Continuous Downstream FDD Case

8.3.4.3.3 PHY SAP Parameter Definitions

TBD

8.3.4.3.4 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.

8.3.4.3.4.1 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 155.

Table 155—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

8.3.4.3.4.2 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.

8.3.4.3.4.3 Downlink Mode A: Message field definitions

8.3.4.3.4.3.1 Downlink Mode A: Required channel descriptor parameters

The following parameters shall be included in the UCD message:

TBD

8.3.4.3.4.3.2 Mode A: Required DCD parameters

The following parameters shall be included in the DCD message:

TBD

8.3.4.3.4.3.2.1 Downlink Mode A: DCD, Required burst decriptor parameters

TBD.

8.3.4.3.4.3.3 Mode A: DL-MAP

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

8.3.4.3.4.3.3.1Mode A: DL-MAP PHY Synchronization Field definition

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

Figure 166—PHY Synchronization Field (PHY Type = 2)

The format of the PHY Synchronization field is given in Figure 166. The Uplink Timestamp jitter must be less than 500 ns peak-to-peak at the output of the Downlink Transmission Convergence Sublayer. This jitter is relative to an ideal Downlink Transmission Convergence Sublayer that transfers the TC packet data to the Downlink Physical Media Dependent Sublayer with a perfectly continuous and smooth clock at symbol rate. Downlink Physical Media Dependent Sublayer processing shall not be considered in timestamp generation and transfer to the Downlink Physical Media Dependent Sub-layer. Thus, any two timestamps N1 and N2 (N2 > N1) which were transferred to the Downlink Physical Media Dependent Sublayer at times T1 and T2 respectively must satisfy the following relationship: (N2 - N1)/(4 x Symbol Rate) - (T2 - T1) < 500 ns.

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.

8.3.4.3.4.3.4 Mode A:UL-MAP Allocation Start Time definition

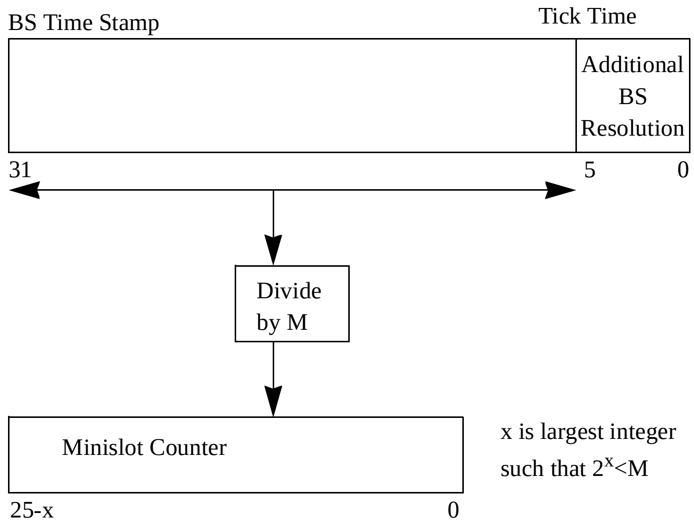


Figure 167—UL-MAP Alloc Start Time

The Alloc Start Time is the effective start time of the uplink allocation defined by the UL-MAP or DL_MAP in units of mini-slots. The start time is relative to the time of BS initialization (PHY Type = 2). The UL-MAP/DL_MAP Allocation Start Time is given as an offset to the Time Stamp defined in 8.3.4.3.4.3.3.1. Figure 167 illustrates the relation of the Time Stamp maintained in the BS to the BS Mini-slot Counter. The base time unit is called a tick and is of duration 1 us, independent of the symbol rate, and is counted using a 26 bit counter. The additional BS resolution is of duration (1 tick/ 64) = 15.625 ns. The Mini-Slot count is derived from the tick count by means of a divide by M operation. Note that the divisor M is not necessarily a power of 2.

For arbitrary symbol rates, the main constraint in the definition of a mini slot, is that the number of symbols per mini slot be an integer. For example given a symbol rate of R Symbols/tick, and M ticks/mini-slot, the number of symbols per mini-slot N, is given by N = MR. In this situation, M should be chosen such that N is an integer. In order to accommodate a wide range of symbol rates, it is important not to constrain M to be a power of 2. Since the additional BS resolution is independent of the symbol rate, the system can use an uniform time reference for distance ranging.

In order to show that the time base is applicable to single carrier and OFDM symbol rates, consider the following examples: (a) Single Carrier System - Given a symbol rate of 4.8 Msymbols/s (on a 6MHz channel), if the mini-slot duration is chosen to be 10 ticks (i.e., M = 10), then there are 48 symbols/mini-slot. Given 16QAM modulation this corresponds to a granularity of 24 bytes/mini-slot (b) OFDM System - Given an OFDM symbol time of 50 us, the mini-slot duration is also chosen to be 50 ticks (i.e., M = 50). In this case there is only a single symbol per mini-slot.

8.3.4.3.4.3.5 UL-MAP Ack Time definition

The Ack Time is the 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 given relative to the BS initialization time.

8.3.4.3.4.4 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????.

8.3.4.3.4.4.1 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 168. 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

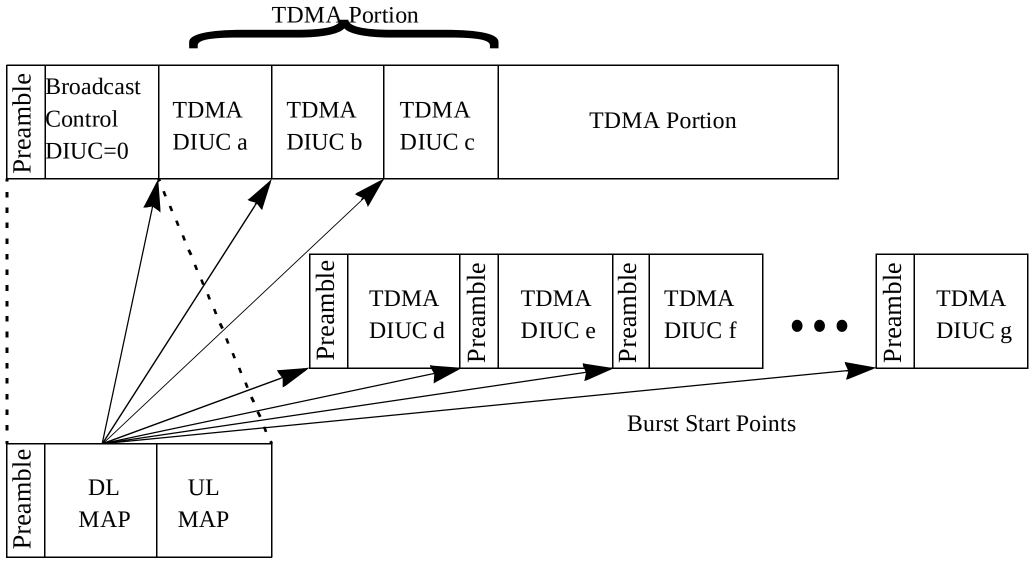


Figure 168—Mode B Downlink Subframe Structure

8.3.4.3.4.4.2 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.

8.3.4.3.4.4.3 Downlink Mode B: Required DCD parameters

The following parameters shall be included in the DCD message:

TBD

8.3.4.3.4.4.3.1Downlink Mode B: DCD, Required burst decriptor parameters

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

TBD

8.3.4.3.4.4.4 Downlink Mode B: Required UCD parameters

The following parameters shall be included in the UCD message:

TBD

8.3.4.3.4.4.5 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.

8.3.4.3.4.4.6 Allowable frame times

Table 156 indicates the various frame times that are allowed for the current downlink Mode B physical layer. The actual frame time used by the downlink channel can be determined by the periodicity of the frame start preambles

Table 156—Allowable Frame Times

Frame Length Code	Frame time (T_F) (ms)
0x01	0.5
0x02	1.0
0x03	1.5
0x04	2.0
0x05	2.5
0x06	3.0
0x07	3.5
0x08	4.0
0x09	4.5
0x0A	5.0

8.3.4.3.4.4.7 Mode B: DL-MAP PHY Syncronization Field definition

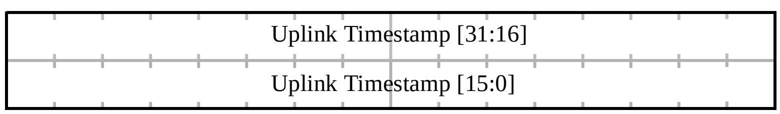


Figure 169—PHY Synchronization Field (PHY Type = {0,1})

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.

8.3.4.3.4.4.8 UL-MAP Allocation Start Time definition

The Alloc Start Time is the effective start time of the uplink allocation defined by the UL-MAP or DL_MAP in units of mini-slots. The start time is relative to the time of BS initialization (PHY Type = 2). The UL-MAP/DL_MAP Allocation Start Time is given as an offset to the Time Stamp defined in 8.3.4.3.4.3.3. Figure 145???? illustrates the relation of the Time Stamp maintained in the BS to the BS Mini-slot Counter. The base time unit is called a tick and is of duration 1 us, independent of the symbol rate, and is counted using a 26 bit counter. The additional BS resolution is of duration (1 tick/ 64) = 15.625 ns. The Mini-Slot count is derived from the tick count by means of a divide by M operation. Note that the divisor M is not necessarily a power of 2.

For arbitrary symbol rates, the main constraint in the definition of a mini-slot, is that the number of symbols per mini-slot be an integer. For example given a symbol rate of R Symbols/tick, and M ticks/mini-slot, the number of symbols per mini-slot N, is given by N = MR. In this situation, M should be chosen such that N is an integer. In order to accommodate a wide range of symbol rates, it is important not to constrain M to be a power of 2. Since the additional BS resolution is independent of the symbol rate, the system can use an uniform time reference for distance ranging.

In order to show that the time base is applicable to single carrier and OFDM symbol rates, consider the following examples: (a) Single Carrier System - Given a symbol rate of 4.8 Msymbols/s (on a 6MHz channel), if the mini-slot duration is chosen to be 10 ticks (i.e., M = 10), then there are 48 symbols/mini-slot. Given 16QAM modulation this corresponds to a granularity of 24 bytes/mini-slot (b) OFDM System - Given an OFDM symbol time of 50 us, the mini-slot duration is also chosen to be 50 ticks (i.e., M = 50). In this case there is only a single symbol per mini-slot.

8.3.4.3.4.4.9 UL-MAP Ack Time definition

The Ack Time is the 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 given relative to the BS initialization time

8.3.4.4 OFDM PHY Burst Definition and MAP Messages

8.3.4.5 OFDMA PHY Burst Definition and MAP Messages

8.3.4.5.1 Introduction

This clause describes the MAC-PHY considerations and MAC-PHY information exchange needed for support OFDMA/OFDM based PHY layer.

The OFDMA access scheme defines an access scheme of a two dimensional grid that combines time and frequency division access technique.

<<< The 802.16.1 MAC layer needs to be enhanced\updated to support OFDMA\OFDM access scheme while saving the main working principles of the MAC layer. >>>

In a MAC protocol that supports OFDMA PHY layer, sub-channelization should be supported, mini-slot duration should last for the time duration of a full OFDM symbol and should be used as a time symbol reference. In addition, for each time symbol reference, a sub-channel reference should be provided for an OFDMA access resolution.

Each of the Uplink and Downlink symbols are built from subcarriers, which are divided statically into sub-channels that are groups of 53 (48 useful) sub-carriers. A sub-channel does not necessarily contain consequent subcarriers.

The OFDMA defines a slot as a pair {N,m} that represents a combination of an OFDM time symbol (N) and number of a sub-channel (m).

In each cell a single FFT size is used

8.3.4.5.2 Basic Parameters

This clause defines OFDMA related basic terminology and relevant parameters.

8.3.4.5.2.1 Region and PHY Burst

For both Uplink and Downlink transmissions, several consequent sub-channels may be aggregated for several consequent symbol duration intervals (OFDM Symbols). Such an aggregation is figured by a rectangle Region at the Sub-carrier(frequency)-Time domain. Figure 170 illustrates an allocation pattern instance of a Region

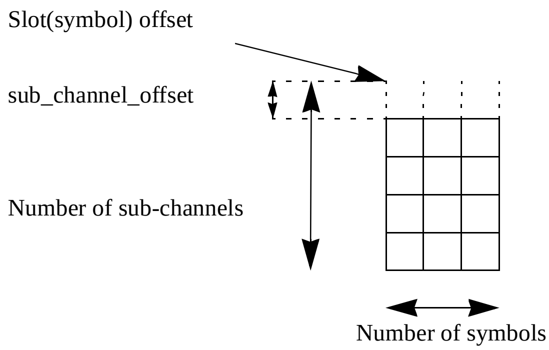


Figure 170—Example of a Two dimensional Pattern

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. The SS's transmission at the Region is called UL PHY Burst. The BS's transmission at the Region is called DL PHY Burst.

8.3.4.5.2.2 UL Transmission

The PHY Burst properties will be figured:

- In the MAC-PHY interface primitives.
- In UCD message within Burst Profile TLV encodings.
- In UL-MAP message, implicitly identified by UIUC.

The BS learns each of SS's specific working parameters (during the SS's UL maintenance Ranging and data transmission) and assigned internally UL PHY Burst profile for each SS.

<<<<<<<<<<<<<<The following paragraph is clearly a part of OFDM PHY

The parameters the BS uses are:

- *The CIR <<< SIR? >>> of the channel (which can be achieved when using the CDMA synchronization approach).*
- *The C/N of the user (by measurement from a user message).*

The basic suggested (partial) profiles for the uplink transmission can be summarized inTable 157:

Table 157—UL profiles

Profile	**0**	**1**	**2**	**3**	**4**	**5**
C/N (dB)	3-6	6-9	9-12	12-17	17-20	>20
Modulation	QPSK	QPSK	QAM16	QAM16	QAM64	QAM64
Code rate	1/2	3/4	1/2	3/4	2/3	3/4

The defined values are used for a reference, bad CIR can cause the BS to chose lower profile or allocation of fewer Sub-Channels enables the BS to choose higher profile.

>>>>>>>>>>>>>>>>>>>>>>

The UL MAP IEs shall have the UIUC that represent the relevant profile that determined by the BS.

Figure 171 describes the logical structure of UL PHY Burst.

<<< Note: for the next figures, the size (number of symbols) of the preamble is still under discussion of the PHY group. >>>

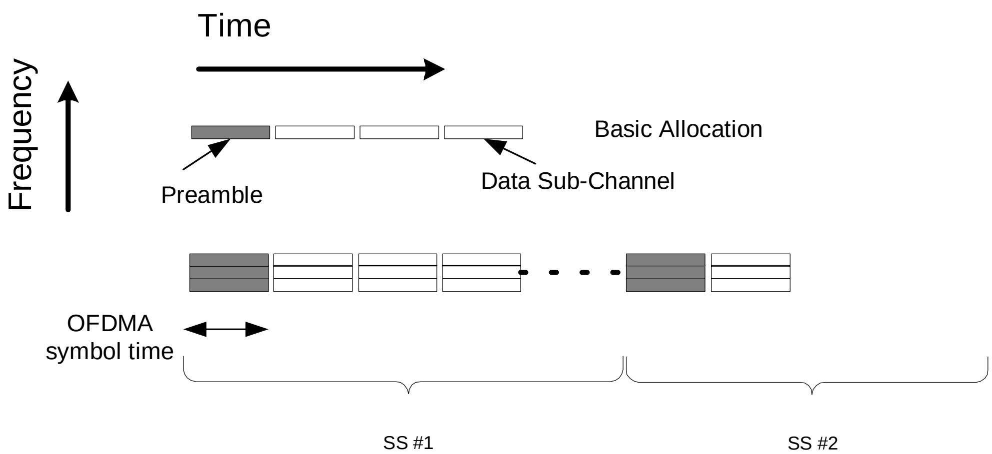


Figure 171—UL PHY Burst example

Figure 172 describes two different subscribers with different PHY Burst structures and profiles.

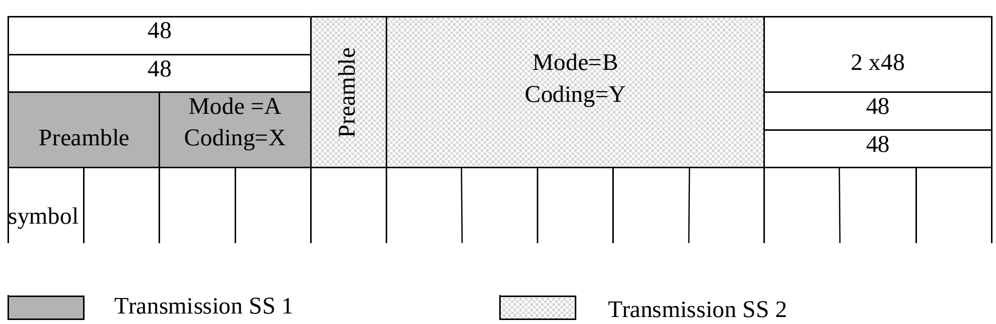


Figure 172—UL Burst definition Example #1

Figure 173 describes two different subscribers with similar PHY Burst structure and with different profiles

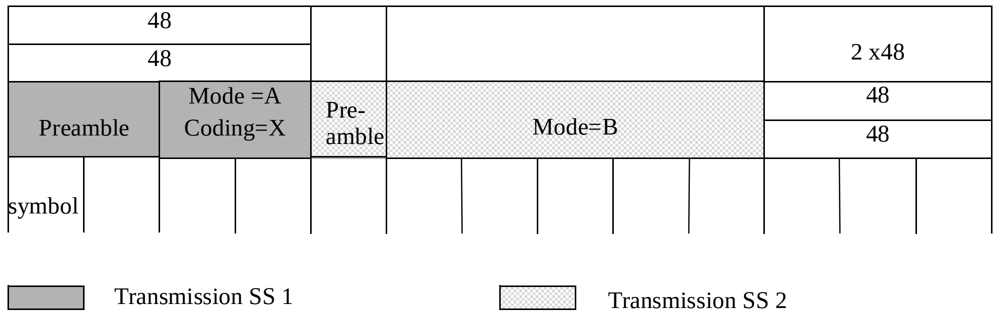


Figure 173—UL Burst Definition Example #2

8.3.4.5.2.3 DL Transmissions

The DL PHY Burst properties will be figured:

- In the MAC-PHY interface primitives
- In DCD message within Burst Profile TLV encodings
- In DL-MAP message, implicitly identified by DIUC.
- In the RNG-RSP or DBTC-RSP messages, implicitly identified by the Downlink Burst Type.

The set of DL PHY Burst parameters is specified in <Reference to OFDM PHY relevant clause> and includes at least:

- Modulation type
- FEC type
- Tx Power

The forward adaptive profiles are relevant in the Bursty working modes (FDD-B and TDD).

The SS requests from the BS a specific DL PHY Burst type (using the DBTC-REQ or RNG-REQ messages), the BS will acknowledge the user with a downstream working mode (using the DBTC-RSP or RNG-RSP messages).

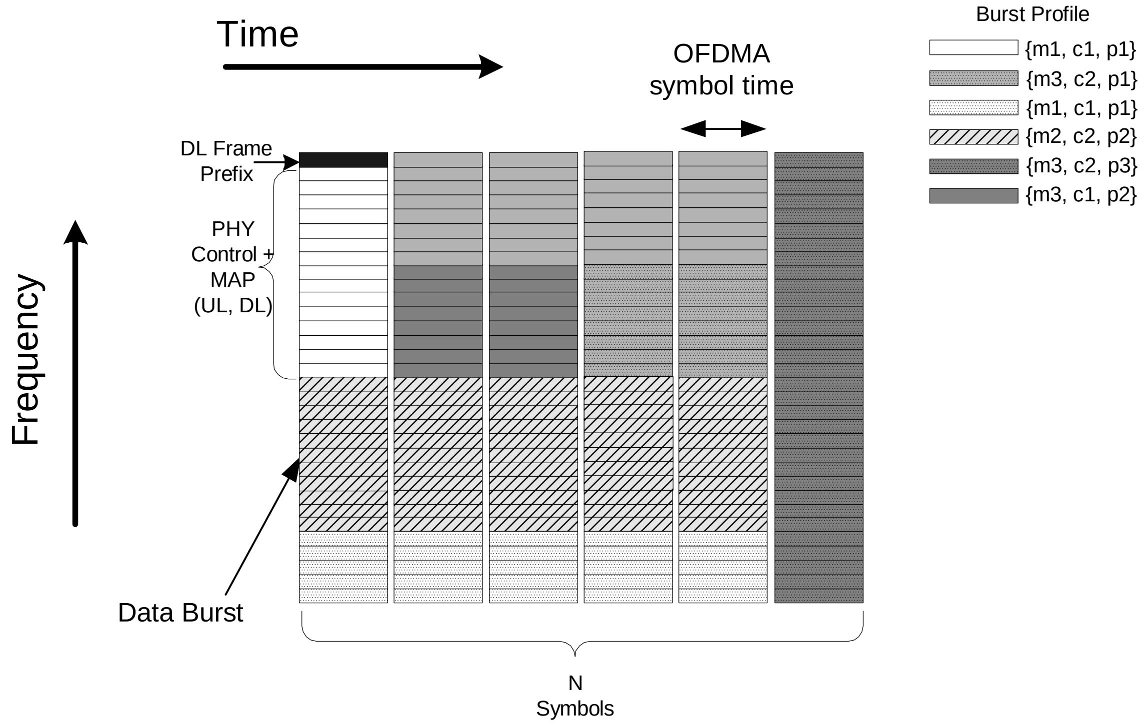


Figure 174—DL Period example #1

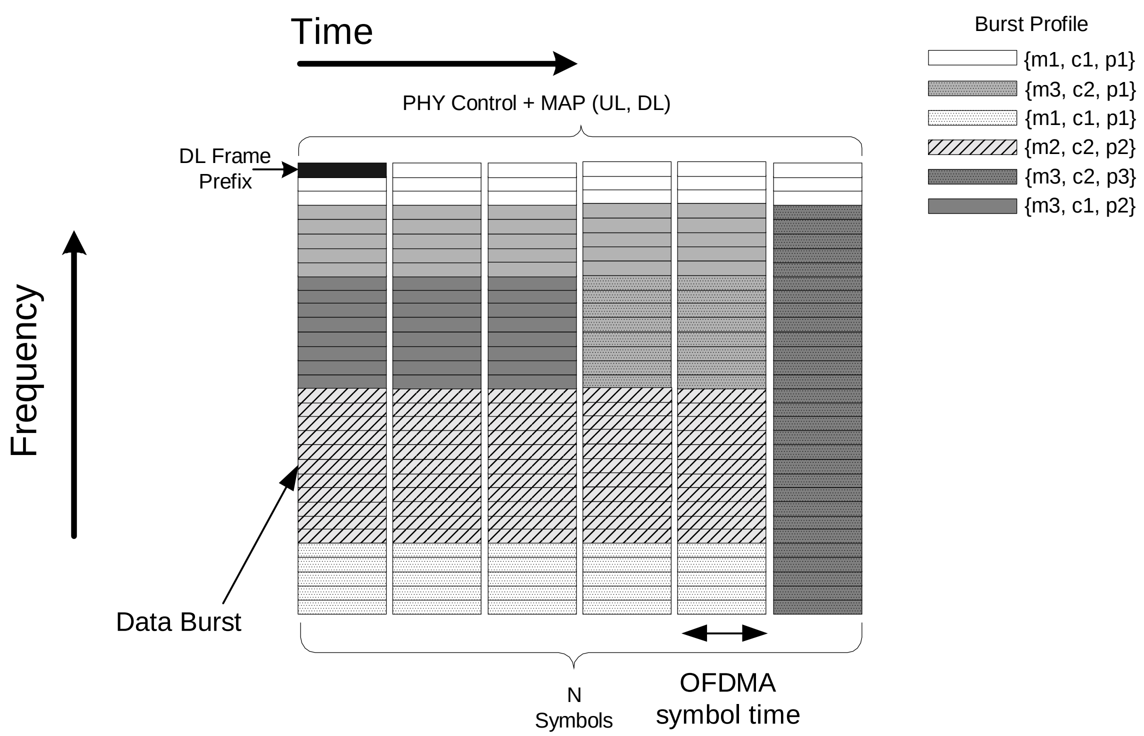


Figure 175—DL Period example #2

Figure 174 and Figure 175 describe two scenarios of DL OFDMA allocation with two options of sending DL MAP.

In the OFDM working modes (small FFT sizes), TDM\TDMA working model is used. This means that the unit of allocation is a full OFDM symbol. In those modes, the frame control information (DL/UL MAP) shall be sent on the first Symbol(s).

In the high FFT sizes modes, OFDMA working model is used. This means that the unit of allocation is a Burst (which is a combination of a sub-channels and time symbols). In those modes, there are two possibilities to transmit the DL\UL MAP:

- To take advantage of the option of forward power control, and robust transmission of frame control information, the transmission of the DL\UL MAP can be done by using 1-2 sub-channels for the duration of the whole frame while power boosting the used carriers.
- To use the basic method of the OFDM case, but with size optimization. This means that the DL\UL MAP shall be transmitted at the beginning of the frame, using all or part of the sub-channels.

The frame control information should be transmitted in a deterministic pre-defined (and robust) configuration, therefore indication about the frame control information should be defined. To be able to support a generic formation of frame control message in the downlink in the context of OFDMA\OFDM PHY modes, we propose the notion of DL Frame prefix.

DL Frame Prefix: One symbol long; it is transmitted at the well-known modulation/coding and occupies the well-known set of sub-carriers, e.g. the first N x 48 (for the FFT-64 always N = 1, for FFT-256 OFDM always N = 4 or For FFT-2048 OFDMA always N=1 etc.). It contains the information on the modulation/coding and formation of the DL frame control information (DL\UL MAP messages) relevant to the next frame or to the same frame. Figure 176 describes the structure of DL Frame Prefix:

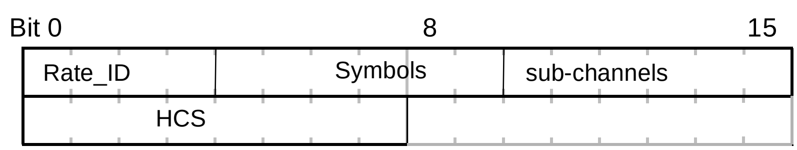


Figure 176—DL Frame Prefix Structure

Rate_ID: Enumerated field that describes the transmission parameters of the DL\UL MAP messages.

Symbols: Number of time symbols dedicated to the DL\UL MAP message.

Sub_Channels: Number of sub-channels dedicated to the DL\UL MAP message.

HCS: An 8-bit Header Check Sequence used to detect errors in the DL Frame Prefix. The generator polynomial is g(D)= D8 + D2 + D + 1

DL Frame Prefix can contain also MAP message(s) (for FFT-512 for example, the full first symbol will contain the DL Frame Prefix and beginning of the DL\UL MAP messages) and the "MAP" PHY burst may contain also the data. For the lowest modulation it is exactly 3 bytes.

The Combination of the fields Symbols and Sub_Channels defines the structure of the MAP message and position (relative to the top left entry of the DL frame). In the small FFT cases (OFDM modes) Sub_Channels field will always indicate full OFDM symbol.

8.3.5 Single Carrier PHY Layer

8.3.5.1 Introduction

Section 8.3.5 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 Section 8.3.5.2;
- an introduction to Frequency Domain Equalization (FDE), in Section 8.3.5.4; and
- a comparison drawing analogies between OFDM processing and SC processing with Frequency Domain Equalization, in Section 8.3.5.5.

The intended operating frequency bands for the SC Wireless MAN PHY will be from 2 to 11 GHz. Recent studies made within the 802.16a standard development process [B31], [B32] have indicated that the use of SC-FDE technology can offer as good or better performance than Orthogonal Frequency Division Modulation (OFDM) technology in addressing Non-Line of Sight (NLOS) channel conditions that may be seen in the 2 to 11 GHz frequency band applications. For this reason, equalization with a Frequency Domain Equalizer (FDE) (or SC-FDE) is recommended (but not required) when implementing a SC PHY compliant receiver.

The frame structure associated with the SC PHY fully supports adaptive modulation and coding. Both burst and continuos 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.

8.3.5.2 Single Carrier PHY Features

The Single Carrier PHY is a Broadband Wireless Access (BWA) Point-to-Multipoint communication system that can provide digital, two-way voice, data, Internet and video services. This PHY shall offer an effective alternative to traditional wire line (cable or DSL) services.

Employing the functions of the 802.16 MAC such as QoS, the BWA system using the PHY here will support services; such as packet data and Constant Bit Rate (CBR) as well as T1-E1, POTS, wide band audio and video services.

To maximize the utilization of limited spectrum resources in the low frequency bands (2 to 11 GHz), the air-interface supports uplink statistical multiplexing over the air-interface using Time Division Multiple Access (TDMA) technology.

The key features of the SC PHY are the following:

- Full compatibility with the 802.16 MAC.
- Uplink multiple access based on TDMA.
- Downlink multiple access based on broadcast Time Division Multiplexing (TDM).
- Options supporting both TDD and FDD duplexing.
- Block adaptive modulation and Forward Error Correction (FEC) coding for both Uplink and Downlink.
- Structured to facilitate use of high capacity single carrier modulation with frequency Domain Equalization (SC-FDE), in addition to temporal Decision Feedback Equalization.
- Economical single carrier demodulation techniques and equipment may be used to realize low cost Subscriber Stations (SSs) and Base Stations (BSs).
- Flexiblity in terms of geographic coverage, use of frequency bands, and capacity allocation.
- Multiple sector antennas may be used at the Base Station.
- Support for future use of smart antennas feasible and implicit in the PHY design.
- Easily accommodates multi-beam and antenna diversity options, such as Multiple-In Multiple-Out (MIMO) and Delay diversity.
- Wideband nature of modulation format provides robustness to frequency selective fading and other channel impairments.

- Potential re-configurability of SC-FDE PHY (via ‘hardware reuse’) receiver to support OFDM modulation.
- Downlink OFDM / uplink single carrier may yield potential complexity reduction and uplink power efficiency gains relative to downlink OFDM / uplink OFDM.
- A simple SC-FDE implementation performs at least as well as OFDM in severe multipath environments, with markedly better performance than OFDM when Forward Error Correction is not used.
- Unlike OFDM, does not require Forward Error Correction to provide good performance in multipath environments.
- Supports high throughput option based on uncoded transmission and ARQ error control.
- Frequency domain linear equalization has essentially the same overall system complexity as uncoded OFDM.

8.3.5.3 SC-FDE Wireless Access System Model

Figure 177 illustrates a Single carrier modulation (SCM) system and Figure 178 illustrates an OFDM-compatible single carrier modulation system.

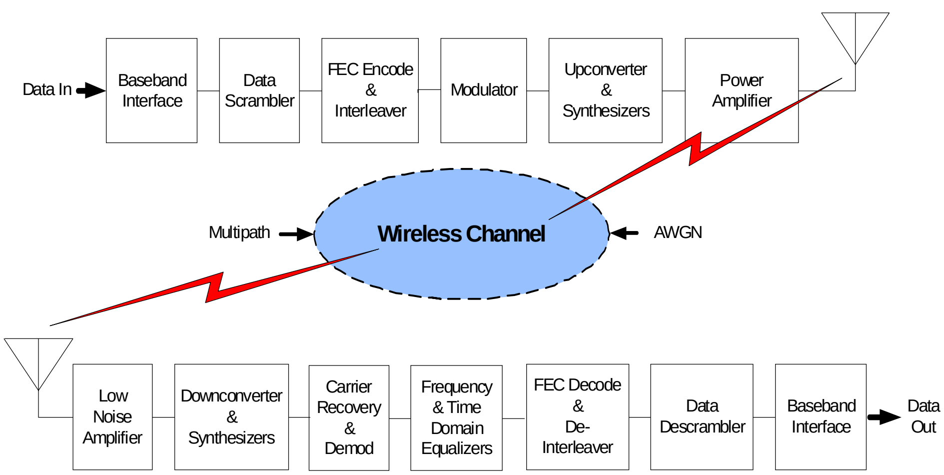


Figure 177—SCM system block diagram

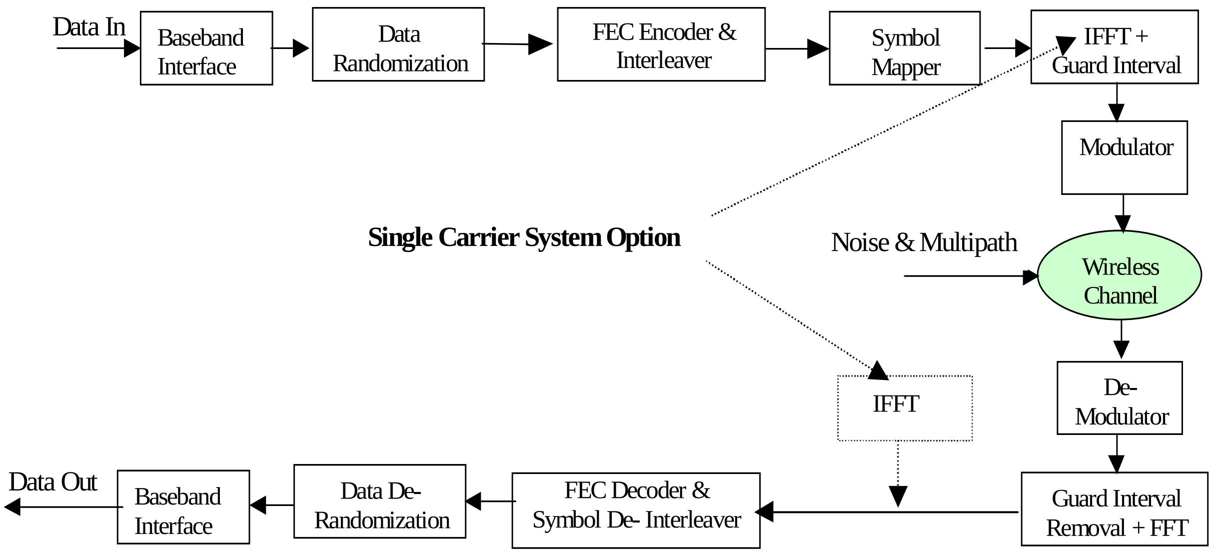


Figure 178—Block Diagram for an OFDM Compatible SCM System

8.3.5.4 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], [B32]).

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

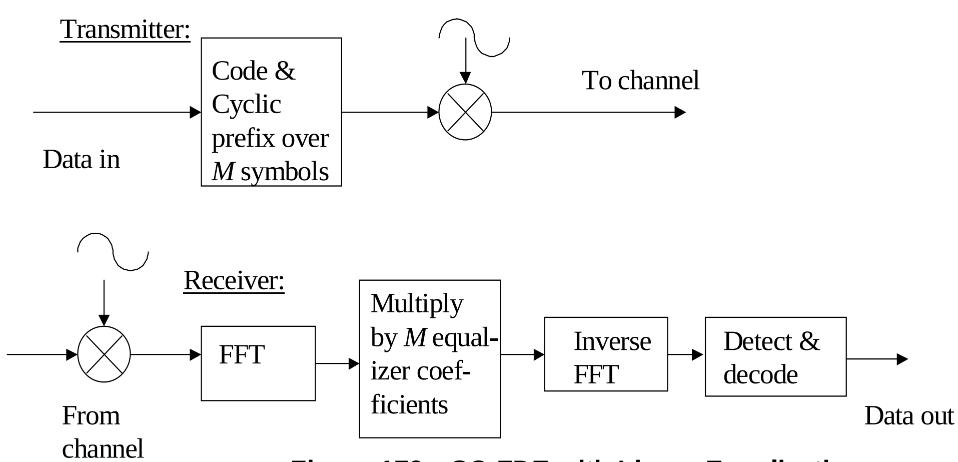
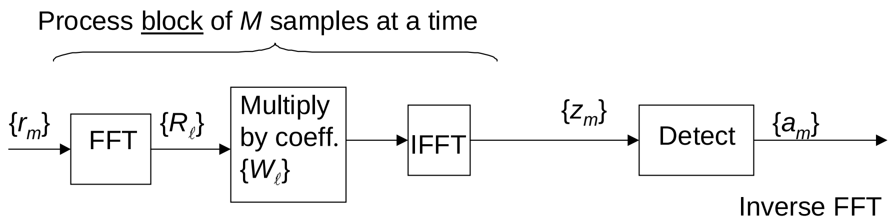


Figure 179—SC-FDE with Linear Equalization

The system of Figure 179 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.



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

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

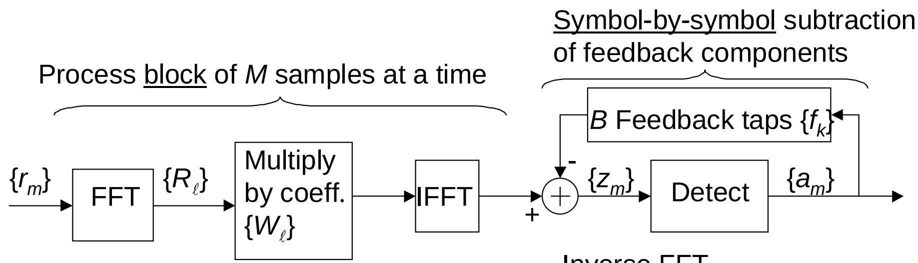
$$\text{Error } e_m = z_m - a_m. \quad (\text{Minimize } E(|e_m|^2).)$$

Figure 180—SC-FDE with Linear Equalization - Details

As shown in Figure 180, there are approximately log2 M multiplies per symbol for a SC - FDE with Linear Equalizer, which is similar to the case for OFDM. What's more, Figure 181 summarizes the implementation and complexity of a another single carrier equalizer using mixed-domain techniques, the SC - FDE with decision feedback (abbreviated 'SC-DFE'), and arrives at a similar complexity conclusion.

Since the block length, M, and the number of symbols used as a cyclic prefix are similar to those for OFDM, the SC-FDE and SC-DFE both 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], [B27]. 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.

Along with other researchers in the 1970s and 1980s, Hikmet Sari made significant contributions to the technology development of Single Carrier modulation with Frequency Domain Equalization (SC-FDE) (cf. [B21], [B27], [B28], [B29], [B30]). In addition, Sari 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

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

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

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 MSE $= \mathrm{E}(|e_m|^2)$.)

Figure 181—SC-FDE with Decision Feedback Equalizer (FD-DFE)

8.3.5.5 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 simple 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 it is simpler than 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 complexities are the 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 182)

Both systems can be enhanced by coding (which is in fact required for OFDM systems), adaptive modulation and space 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.

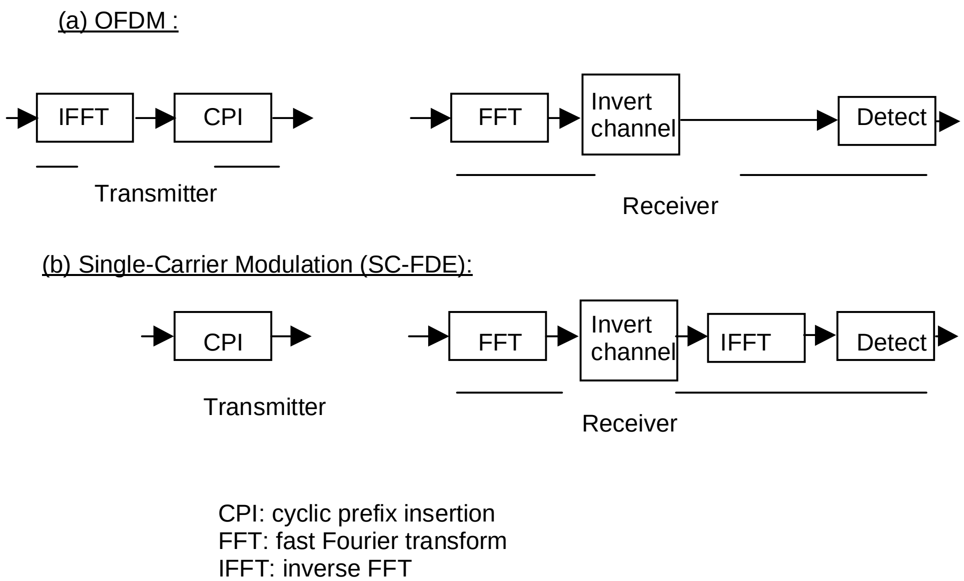


Figure 182—OFDM and SC-FDE relation

8.3.5.6 Downlink Channel

8.3.5.6.1 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 Section 8.3.5.9 uses TDM, while the burst mode of operation, described in Section 8.3.5.10 uses either TDM or TDMA.

8.3.5.6.2 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.

8.3.5.6.3 DL Transmit Processing

Figure 183 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.

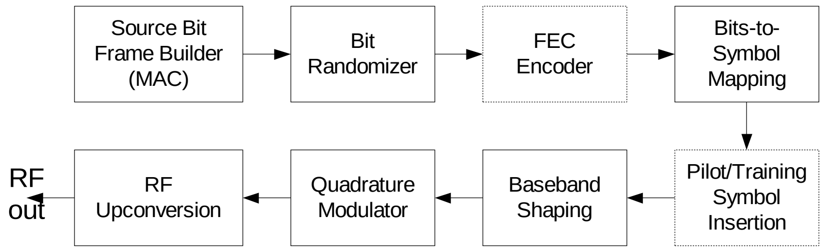


Figure 183—Functional Diagram of Downlink Transmit Processing

The FEC encoder block shown in Figure 183 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.

8.3.5.6.4 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.

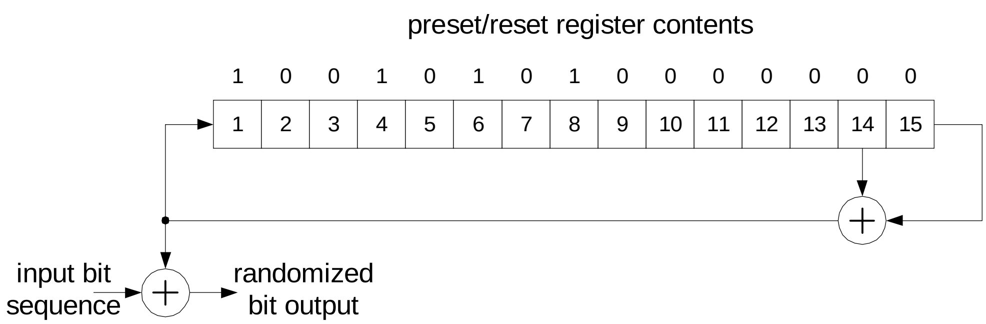


Figure 184—Randomizer for Energy Dispersal

As Figure 184 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.

8.3.5.6.5 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 Section 8.3.5.9.3

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 Section 8.3.5.6.5.1;
- An (Optional) Turbo Product Coding scheme, described in Section 8.3.5.6.5.4.

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.

8.3.5.6.5.1 Concatenated Reed-Solomon + Convolutional Code

As indicated in section 8.3.5.5.2, 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 185 illustrates the general topology for the concatenated FEC. As Figure 185 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 Section 8.3.5.6.5.1.1; the inner FEC, in Section 8.3.5.6.5.1.2; the optional interleaver in 8.3.5.5.2.1.3; and the bits-to-symbols maps (for BPSK, QPSK, 16-QAM, 64-QAM, and 256-QAM) in 8.3.5.5.2.1.4.

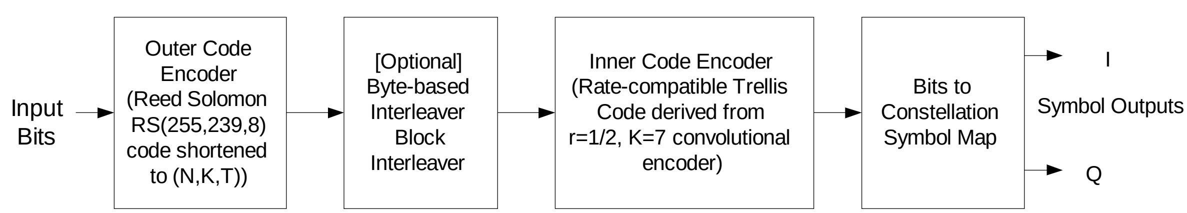


Figure 185—General topology for concatenated FEC used by single carrier mode

8.3.5.6.5.1.1 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:

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

8.3.5.6.5.1.2 Inner FEC

The inner FEC is a rate-compatible pragmatic TCM (Trellis Coded Modulation) code. References for pragmatic TCM codes include [B45] and [B46]. The modulation types and code rates supported by this inner FEC are listed in Table 158

The rate-compatible pragmatic TCM encoder is constructed from both systematic uncoded bits and nonsystematic coded bits as described in clause 8.3.3.1.5.2.2.

Table 158—Modulations and Code Rates for Single Carrier Inner FEC

Modulation	Code Rates	Bits/symbol
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
64-QAM	2/3, 5/6	4, 5
256-QAM [optional]	3/4, 7/8	6, 7

8.3.5.6.5.1.2.1 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 last row of Table 150. For QPSK, the multiplexed output sequence in Table 150 is alternately assigned to the I and Q coordinate QPSK mappers, with the I coordinate receiving the first assignment. Symbol mapping is discussed in Section 8.3.5.6.6.

8.3.5.6.5.1.2.2 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 186. Note that the baseline rate ½ binary convolutional encoder first generates a two-bit constellation index, b1b0, associated with the I symbol coordinate. Provided the next encoder input, it generates a two bit constellation index, b1b0, for the Q symbol coordinate. The I index generation should precede the Q index generation. Note that one might want to interpret this encoder as 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.

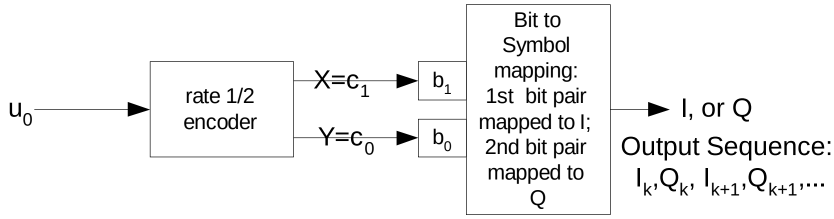


Figure 186—Pragmatic TCM encoder for rate ½ 16-QAM

8.3.5.6.5.1.2.3 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 187. 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 u2u1u0 input into the encoder is u2 arrives first, u1 second, u0 last. During the encoding process, the encoder generates a two bit constellation index, b1b0, for the I symbol coordinate, and simultaneously generates another two bit constellation index, also designated b1b0 (but valued independently), 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.

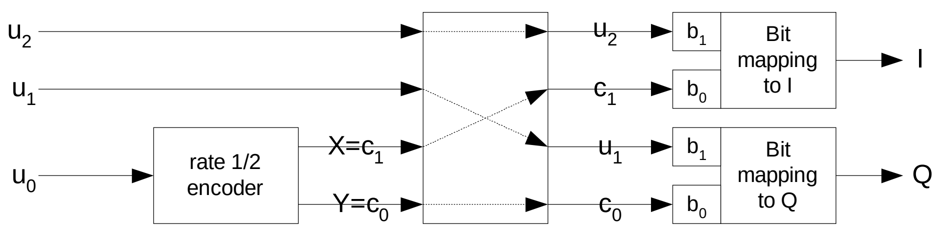


Figure 187—Pragmatic TCM encoder for rate 3/4 16-QAM

8.3.5.6.5.1.2.4 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 188. 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 u1u0 input into the encoder is u1 arrives first, u0 last. Note that the encoder (as a whole) first generates a three bit constellation index, b2b1b0, which is associated with the I symbol coordinate. Provided another two-bit encoder input, it generates a three bit constellation index, b2b1b0, 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 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.

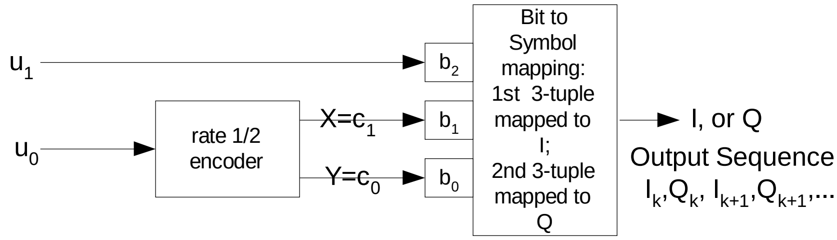


Figure 188—Pragmatic TCM encoder for rate 2/3 64-QAM

8.3.5.6.5.1.2.5 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 196. 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 using the appropriate puncture mask definition listed in Table 2. Puncture samples are sequenced c3 first, c2 second, c1 third, and c0 last. The sequence of arrival for the u4u3u2u1u0 input into the encoder is u4 arrives first, u3 arrives second, u2 arrives third, u1 arrives next to last, and u0 arrives last. During the encoding process, the encoder generates a three bit constellation index, b2b1b0, for the I symbol coordinate, and simultaneously generates another three bit constellation index, also designated b2b1b0 (but valued independently), 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.

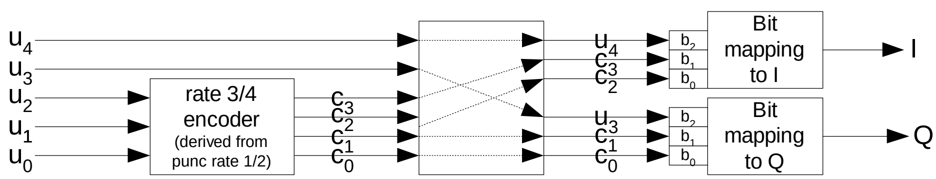


Figure 189—Pragmatic TCM encoder for rate 5/6 64-QAM

8.3.5.6.5.1.2.6 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 190. 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 u2u1u0 input into the encoder is u2 arrives first, u1 next, u0 last. Note that the encoder (as a whole) first generates a four bit constellation index, b3b2b1b0, which is associated with the I symbol coordinate. Provided another four bit encoder input, it generates a four bit constellation index, b3b2b1b0, 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.

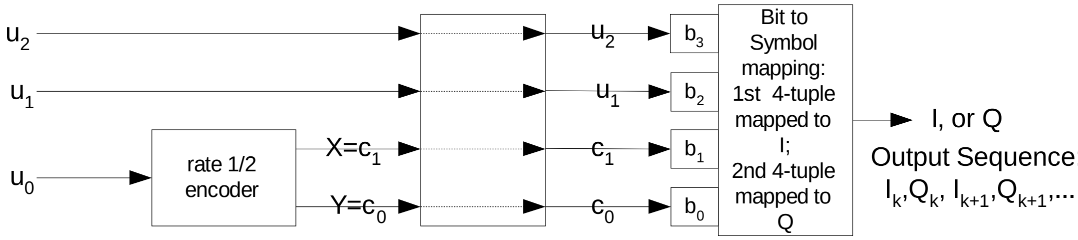


Figure 190—Optional pragmatic TCM encoder for rate ¾ 256-QAM

8.3.5.6.5.1.2.7 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 191. 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 using the appropriate puncture mask definition listed in Table 2. Puncture samples are sequenced c3 first, c2 second, c1 third, and c0 last. The sequence of arrival for the u6u5u4u3u2u1u0 input into the encoder (as a whole) is u6 arrives first, u5 arrives second, u4 arrives third, u3 arrives fourth, u2 arrives fifth, u1 arrives next to last, and u0 arrives last. During the encoding process, the encoder generates a four bit constellation index, b3b2b1b0, for the I symbol coordinate, and simultaneously generates another four bit constellation index, also designated b3b2b1b0 (but valued independently), 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.

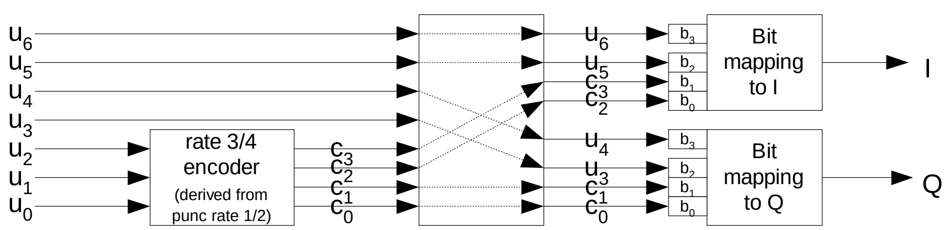


Figure 191—Optional pragmatic TCM encoder for rate 7/8 256-QAM

8.3.5.6.5.1.3 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 options are defined:

- Zero-state termination
- Tail biting

Zero-state termination shall be supported, with tail biting being an optional mode.

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 TC encoder.

When using tail biting, no extra termination bits are required. The initial state of the 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. Since the baseline rate ½ binary convolutional encoder is a shift register, this initial shift registers are loaded with the last 6 binary inputs in the 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, as well.

8.3.5.6.5.2 [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.

8.3.5.6.5.3 Symbol Mapping

For the concatenated Reed Solomon/trellis code, code bits will be mapped onto the I and Q axes using a pragmatic trellis code map. For BPSK and QPSK, the pragmatic trellis code maps are equivalent to the Gray code maps, and are illustrated in Figure 192, respectively. The pragmatic trellis code maps for 16-QAM, 64-QAM, and 256-QAM are illustrated in Figure 193, Figure 194, and Figure 195, respectively. In each of these figures, a value for the normalization factor d may be chosen such that the average signal energy of the constellation is constrained to be 1.

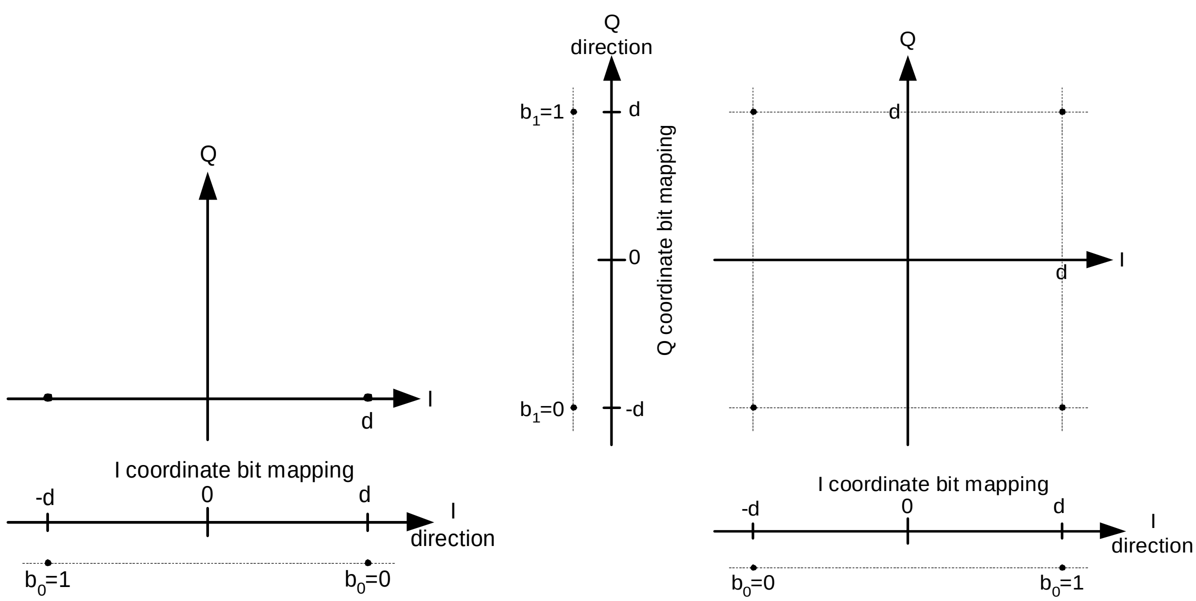


Figure 192—Pragmatic trellis (and Gray) code map for BPSK and QPSK

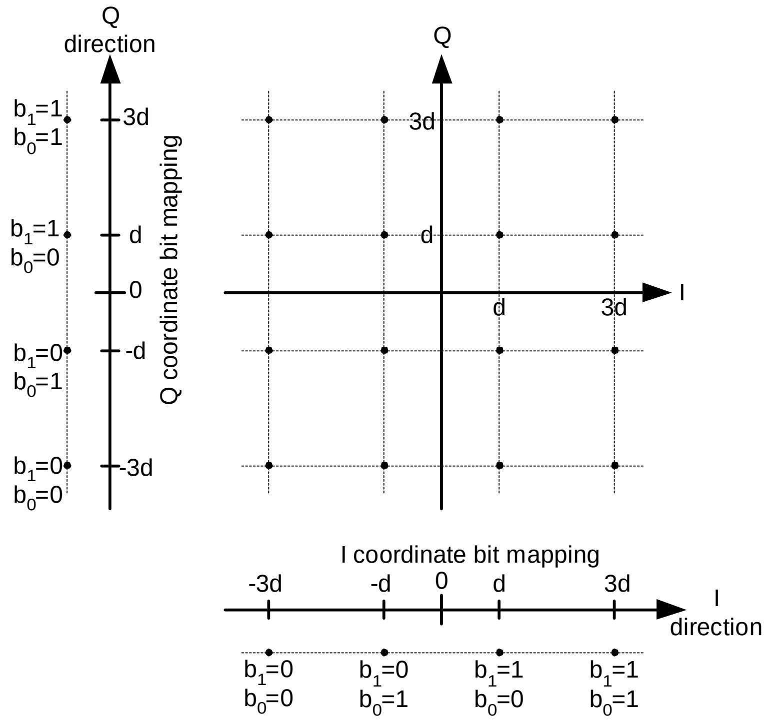


Figure 193—Pragmatic trellis code map for 16-QAM

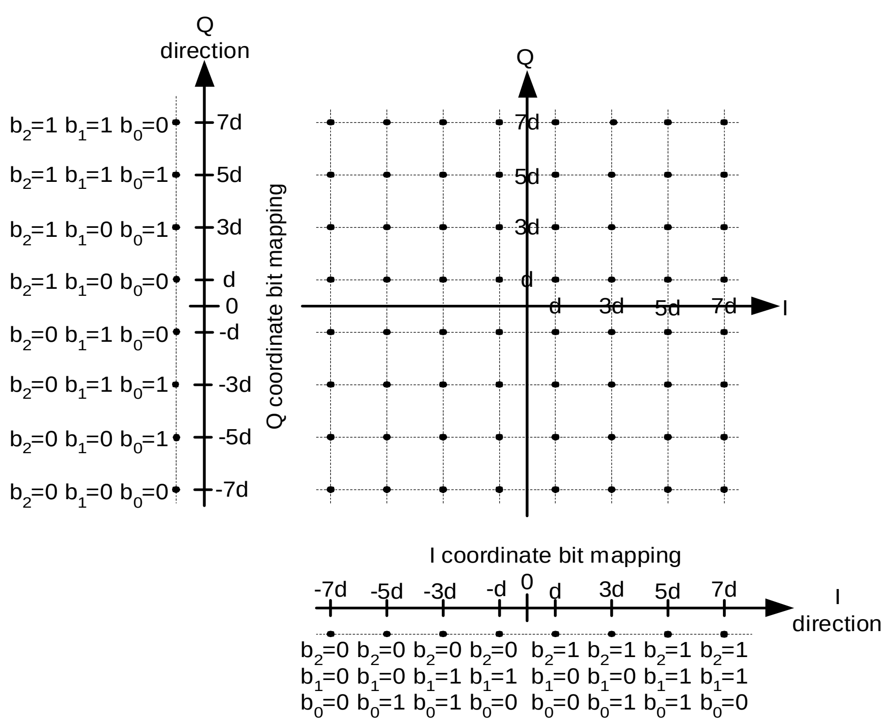


Figure 194—Pragmatic trellis code map for 64-QAM

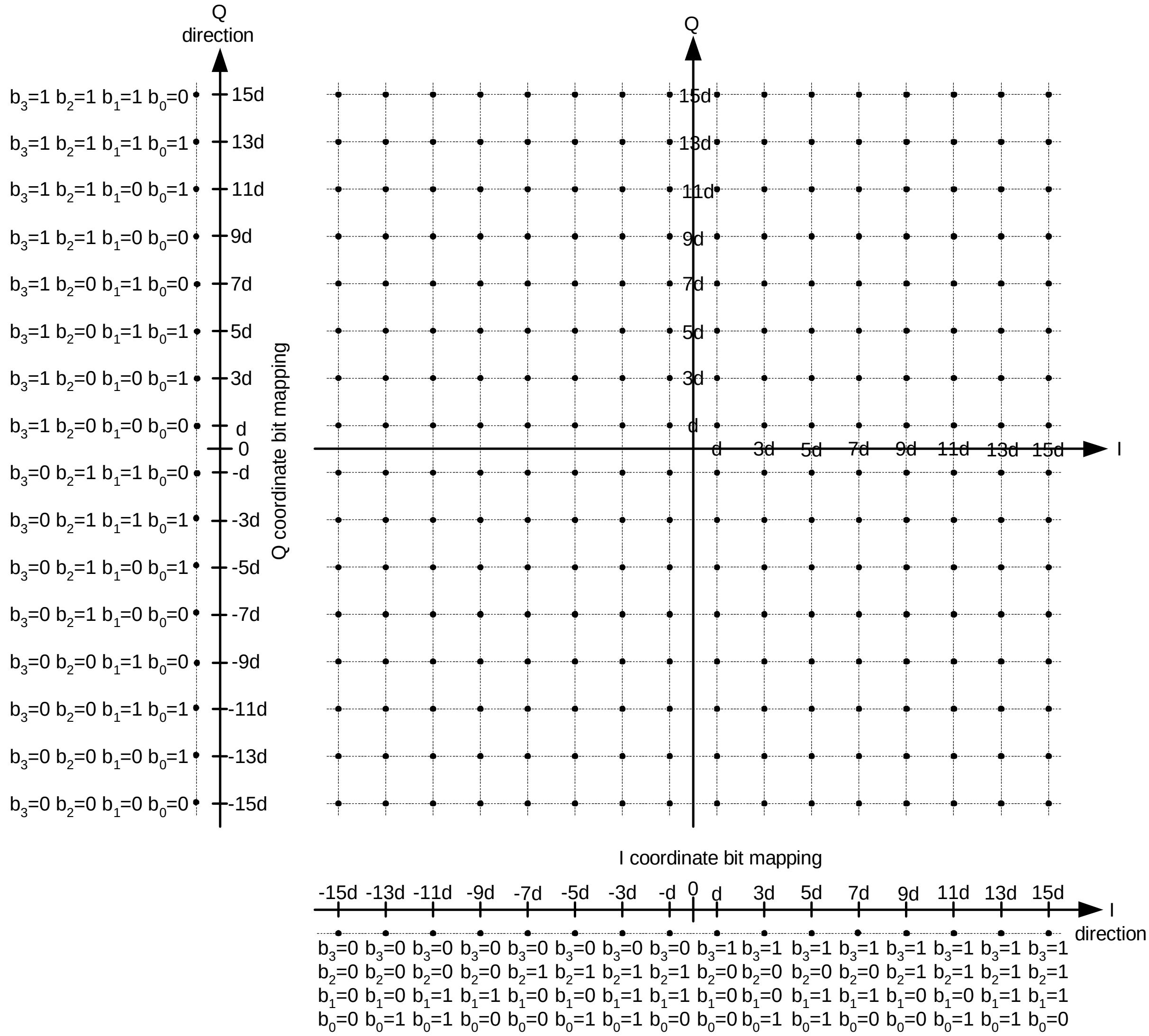


Figure 195—Pragmatic trellis code map for 256-QAM

8.3.5.6.5.4 Turbo Product Code

Turbo Product Codes are defined as an optional FEC; in addition to the sections on their bit Interleaving (Section 8.3.5.6.5.4.1) and Symbol Mapping (Section 8.3.5.6.5.4.2), which follow, more general specification details may be found in clause 8.3.3.1.5.4. The codes and related parameters in Table 159 are recommended; however, any code meeting the requirements of clause 8.3.3.1.5.4 may be utilized.

Table 159— 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

8.3.5.6.5.4.1 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.

8.3.5.6.5.4.2 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 196.

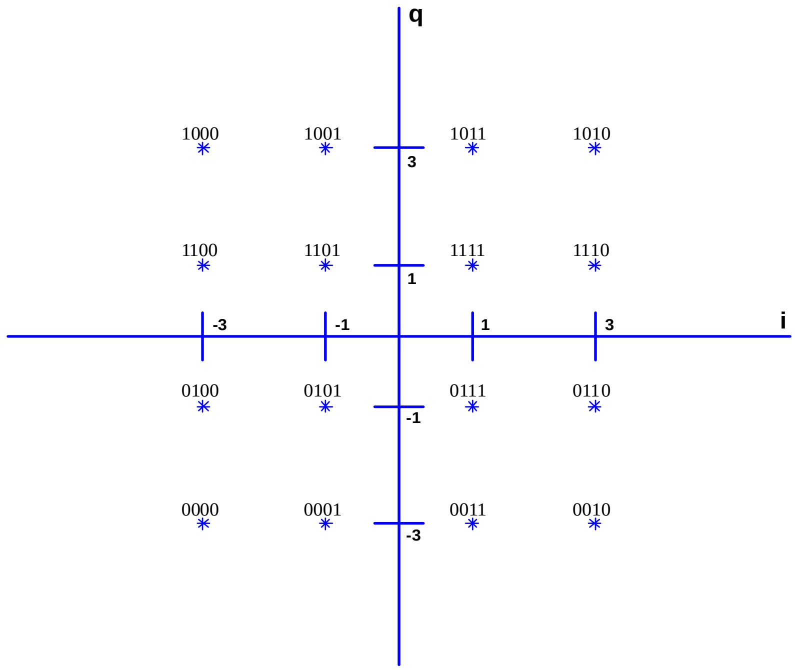


Figure 196—16 QAM Signal Mapping

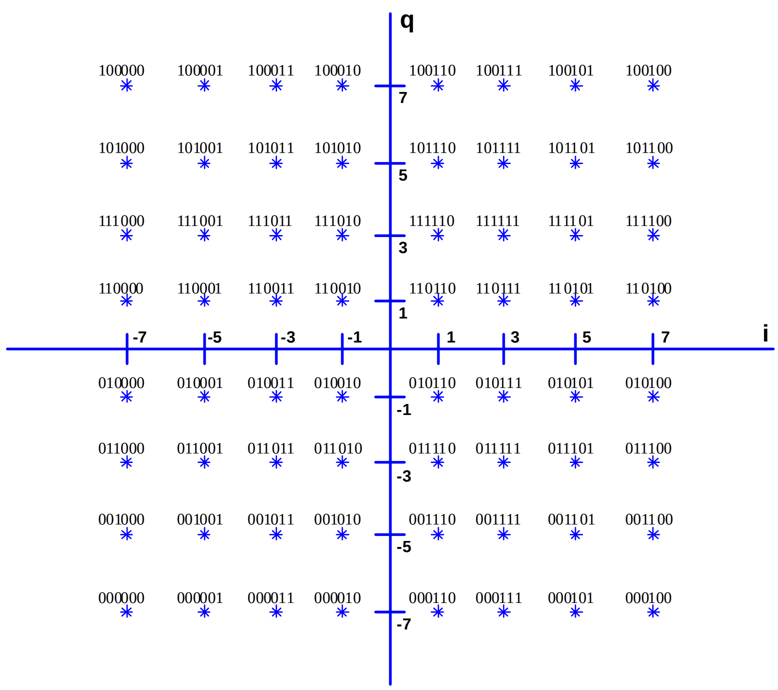


Figure 197—64 QAM Signal Mapping

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 159. 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 159. 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 198 describes the basic scheme for the TPC in a TCM scheme.

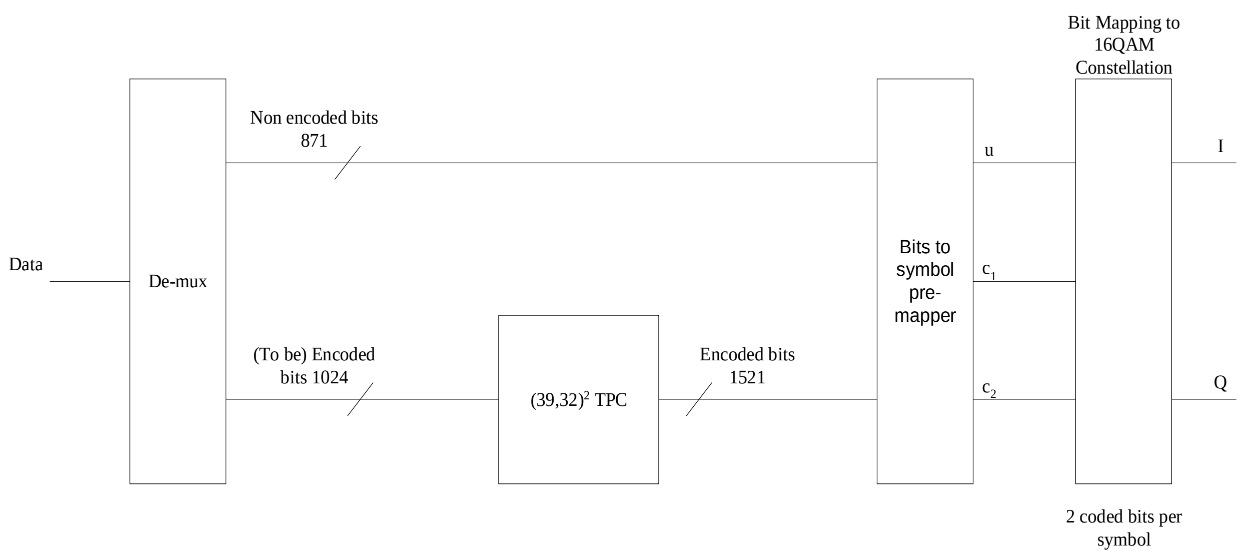


Figure 198—(39,32)2 TPC TCM Encoder

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.

8.3.5.6.6 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 modulation symbol duration.

8.3.5.7 Uplink Channel

8.3.5.7.1 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.

8.3.5.7.2 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.

8.3.5.7.3 UL Transmit Processing

The uplink transmit processing is identical in concept to that described for the downlink in Section 8.3.5.6.3. 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.

8.3.5.7.4 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 Section 8.3.5.6.4. The LFSR shall be preset at the beginning of each upstream burst to the value 100101010000000.

8.3.5.7.5 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 Section 8.3.5.6.5.1;
An (Optional) Turbo Product Coding scheme, described in Section 8.3.5.6.5.4.

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 Section 8.3.5.6.5.

8.3.5.7.6 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 Section 8.3.5.6.6.

8.3.5.8 Framing, Multiple Access, and Duplexing

Section 8.3.5.8 and its descending subsections describe framing elements used to realize the multiple access and duplexing formats supported by the single carrier PHY.

8.3.5.8.1 Overview of Frame Formats and Their Application

Two fundamental PHY block format options are available:

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

As demonstrated in Section 8.3.5.11.1.1, 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 Section 8.3.5.11.1);
- the downlink of a burst-FDD system (see Section 8.3.5.11.1.2); and
- the uplink and downlink of a TDD system (see Section 8.3.5.11.2).

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.

8.3.5.9 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 Section 8.3.5.11.1.1, 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.

8.3.5.9.1 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.

8.3.5.9.1.1 Frame Preamble Requirements

As illustrated in Figure 199, 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.

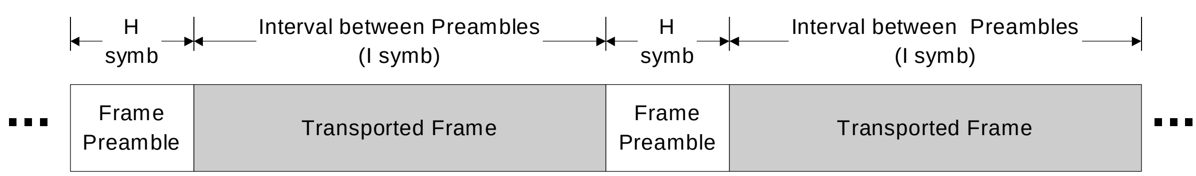


Figure 199—Frame Preamble

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 200, 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 Section 8.3.5.12.

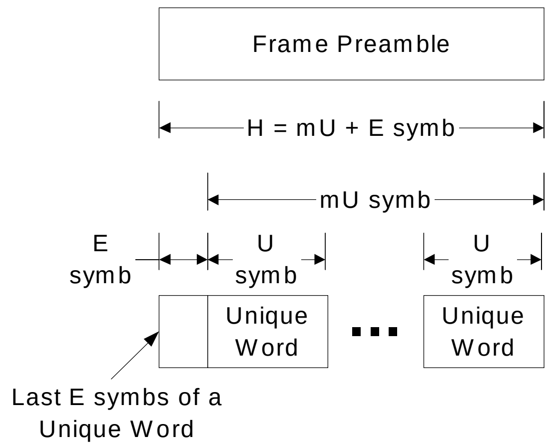


Figure 200— Unique Word Content within the Frame Preamble

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 [Section 8.3.5.10]).

8.3.5.9.1.2 Frame Preamble Usage

As Section 8.3.5.9.1 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 SINR 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 Section 8.3.5.9.3, user data is sequenced in terms of modulation robustness. Therefore, receivers experiencing low SINRs 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 SINR to successfully decode.

8.3.5.9.2 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.

8.3.5.9.2.1 Pilot Word Requirements

The use of Pilot Words is optional. When used, they must follow the guidelines hereforth described. Figure 201 illustrates some of these guidelines. As Figure 201 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 201, 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.

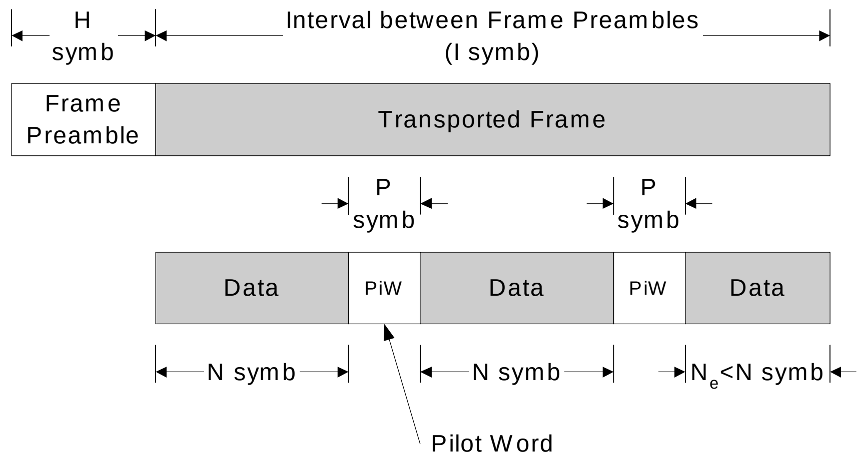


Figure 201—Pilot Words within a Frame

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.

8.3.5.9.2.1.1 Non-conflict of Pilot Words with Frame Preambles

Note that, as prescribed in Section 8.3.5.9.1.1, 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 maintaining 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.

8.3.5.9.2.2 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 SINR 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 Section 8.3.5.12.

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 have to equal pilot word intervals, since, for example, frequency domain equalizers can also be implemented using overlap save techniques.

8.3.5.9.3 Adaptive Modulation

8.3.5.9.3.1 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 SINRs. 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, SINR-disadvantaged SSs may require more powerful and redundant FEC schemes. On the other hand, SINR-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.

8.3.5.9.3.2 Frame Control Header Information and Adaptive Modulation

As Figure 202 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.

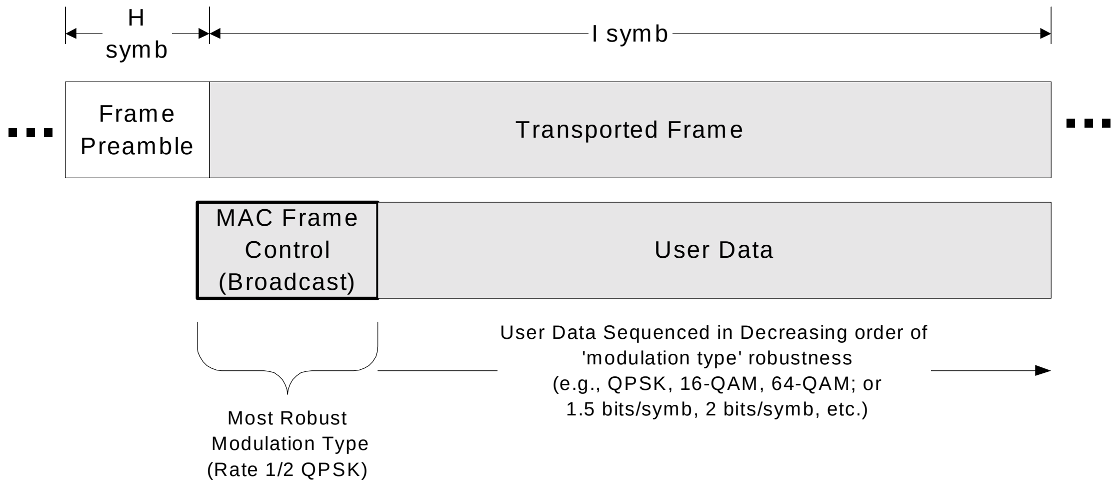


Figure 202—Adaptive Modulation Sequencing within a Continuous Frame

8.3.5.9.3.3 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 202 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 SINRs 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.

8.3.5.9.3.4 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.

8.3.5.9.3.5 Per-Adaptive-Modulation-Type FEC Encapsulation

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.

8.3.5.9.3.6 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.

8.3.5.9.4 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.

8.3.5.10 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 (Section 8.3.5.11.1), a TDD uplink and downlink (Section 8.3.5.11.2), or a burst-FDD downlink (Section 8.3.5.11.1.2).

The burst transmission format accommodates both TDMA and TDM bursts. Figure 203 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.

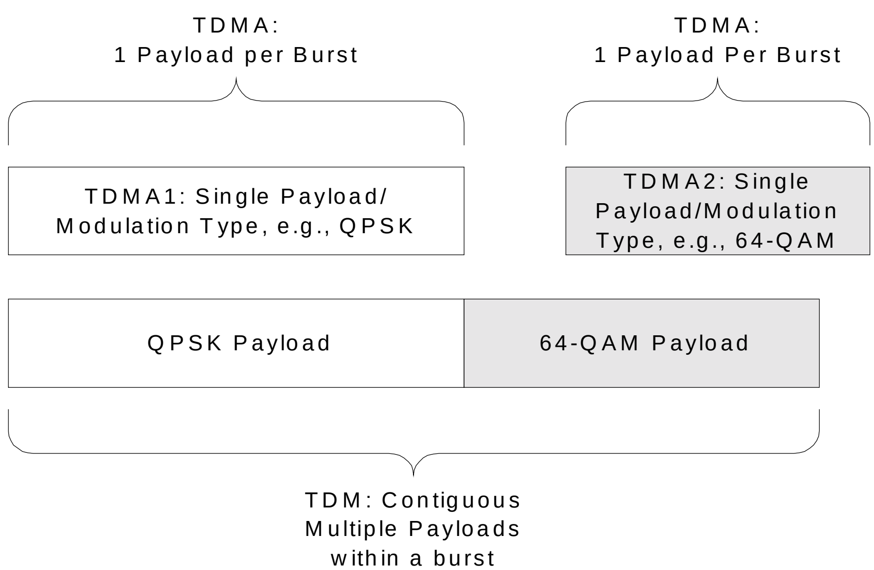


Figure 203—Comparison of TDMA and TDM bursts

8.3.5.10.1 Fundamental Burst Frame Elements

This section describes fundamental elements found in a burst. These fundamental elements are illustrated in Figure 204.

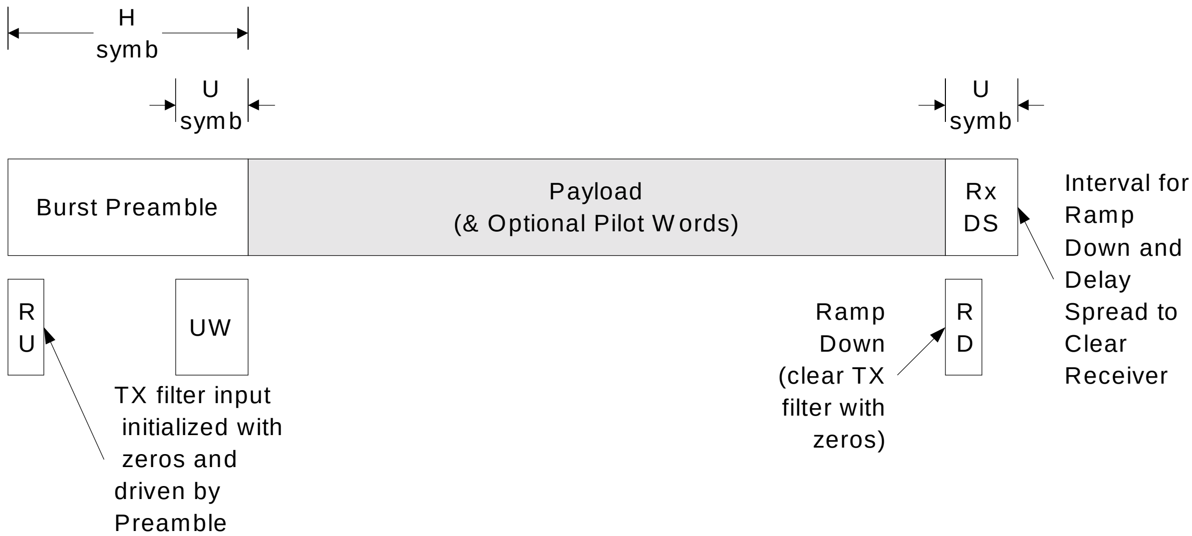


Figure 204—: Fundamental Burst Frame Elements

As illustrated in Figure 204, a burst consists of three fundamental elements: a Burst Preamble, a Payload, and null transmit (quiet) region (RxDS) following the end of a burst.

8.3.5.10.1.1 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.

8.3.5.10.1.1.1 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 205.

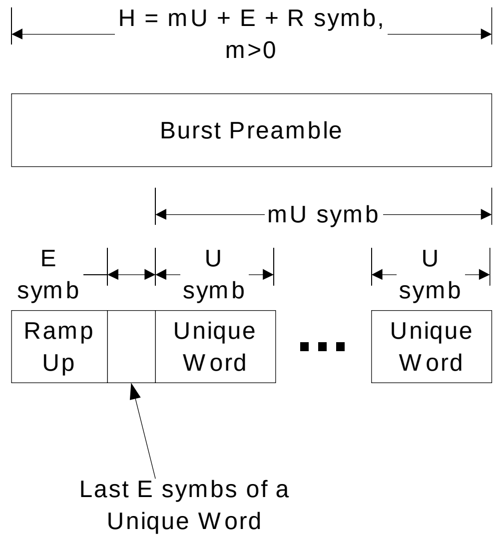


Figure 205—Contents of a Burst Preamble

8.3.5.10.1.1.2 Ramp Up

As both Figure 204 and Figure 205 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.

8.3.5.10.1.2 Burst Payload

The Payload block illustrated in Figure 204 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

8.3.5.10.1.3 Null Transmit Tail Region (RxDS)

The null transmit tail region (RxDS) illustrated in Figure 204 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, i.e., it must be as long as the maximum expected delay spread for the channel in use.

8.3.5.10.1.3.1 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 output power to zero. This ramp down approach is mandatory.

8.3.5.10.1.4 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 211 of Section 8.3.5.11.2 is specified and used to enable this switchover. The length of the Guard Interval, G, is TBD.

8.3.5.10.2 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 sequences of symbols that may be used to assist channel estimation and demodulation at the receiver.

8.3.5.10.2.1 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 Section 8.3.5.9.2.1, with the ‘burst frame payload’ being analogous to the ‘transported payload’ used in continuous mode. Note however, that the restriction of Section 8.3.5.9.2.1.1 on the distinctness of Pilot Words from Frame Preambles is not applicable.

8.3.5.10.2.2 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).

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 Section 8.3.5.12.

Burst profiles with particular Pilot Word length, P, and Pilot Word interval, N, 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 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.

8.3.5.10.3 Burst Profile and Frequency Domain Equalization Processing Examples

Figure 206 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 206, 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.

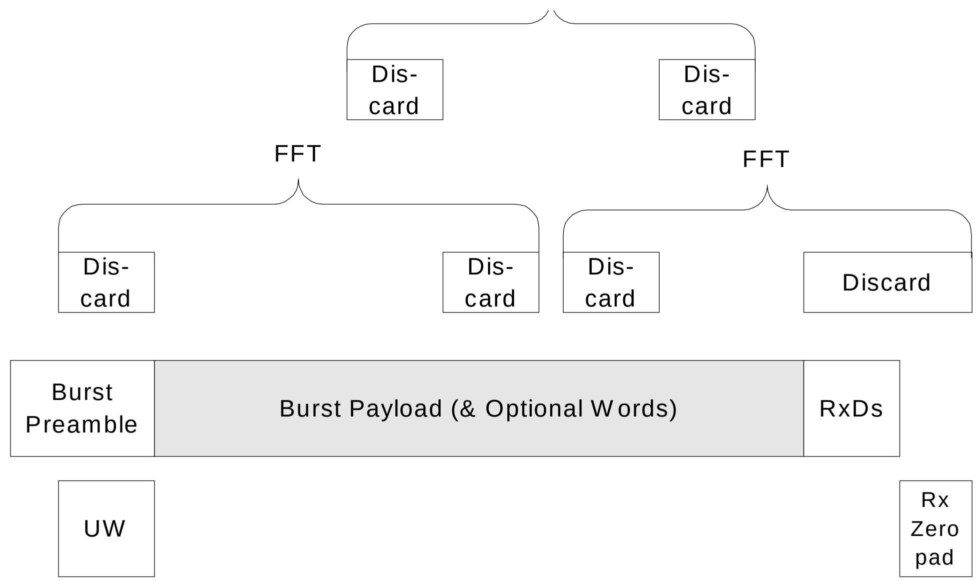


Figure 206—Using overlapping FFTs and receiver-injected zero-pad data

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 207. 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 206 is not necessary. Each FFT shown in Figure 207 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

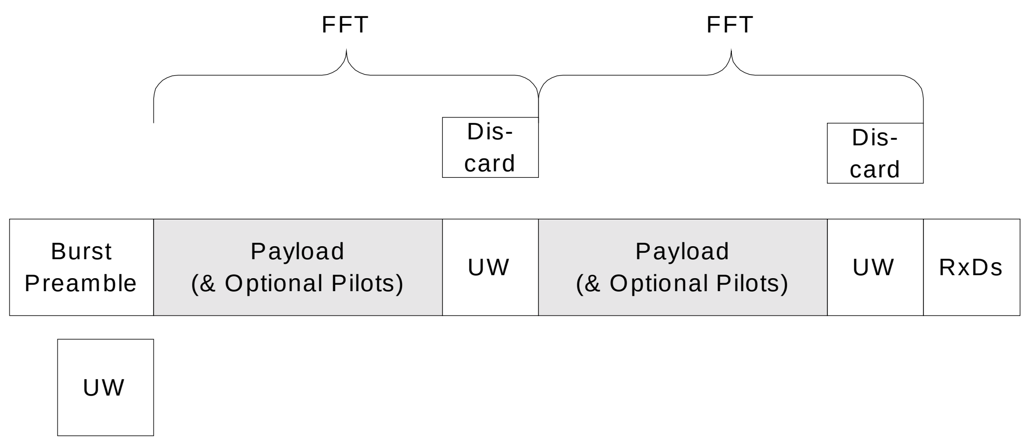


Figure 207—: Burst with UWs spaced to facilitate hardware-efficient FDE

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 206 is mandatory; the optional burst profile of Figure 207 may enable pipelined, faster processing in some high symbol rate, hardware-constrained applications.

8.3.5.10.4 Adaptive Modulation

Many Subscriper 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 SINRs. 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 SINR-disadvantaged transactions may require more powerful and redundant FEC schemes. On the other hand, SINR-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 SINR 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 203 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 203 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.

8.3.5.10.4.1 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.

8.3.5.10.4.2 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.

8.3.5.10.4.3 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.

8.3.5.11 Duplexing: FDD and TDD Operation

In the sections that follow, the framing and MAC messaging mechanisms developed in Section 8.3.5.9 (for the continuous transmission format) and Section 8.3.5.10 (for the burst transmission format) are used to generate duplexed communication schemes. Section 8.3.5.11.1 describes several types of FDD operation, and Section 8.3.5.11.2 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.

8.3.5.11.1 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.

8.3.5.11.1.1 FDD with Continuous Downlink

The downlink of an FDD system with a continuously transmitted downlink is illustrated in Figure 208. 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 208 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 to NACK/ACK messages previously received on the upstream.

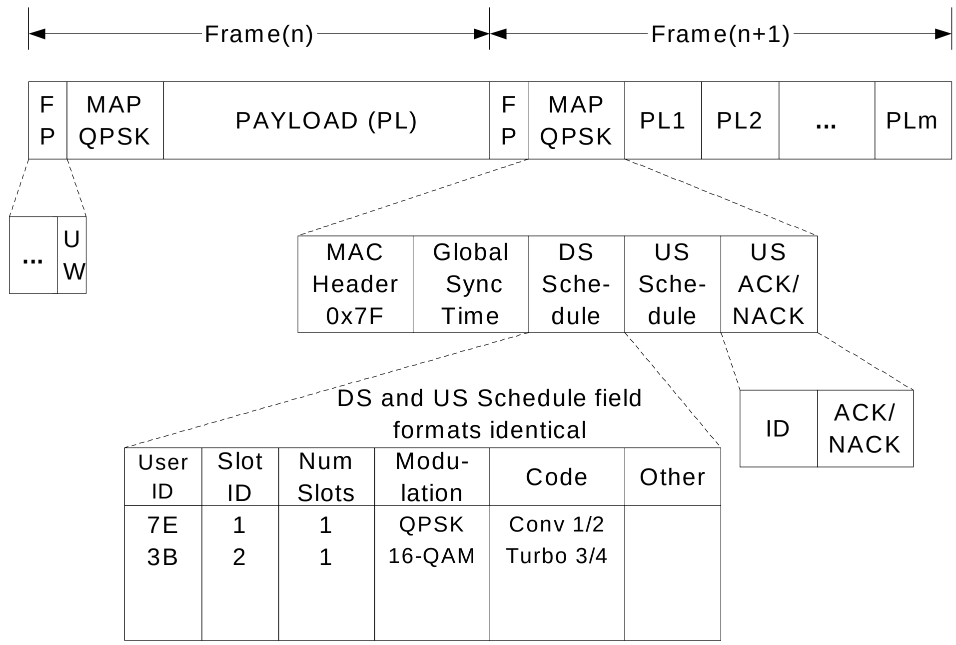


Figure 208—Downstream Duplex of FDD with a Continuous Downstream

Figure 209 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 209) 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.

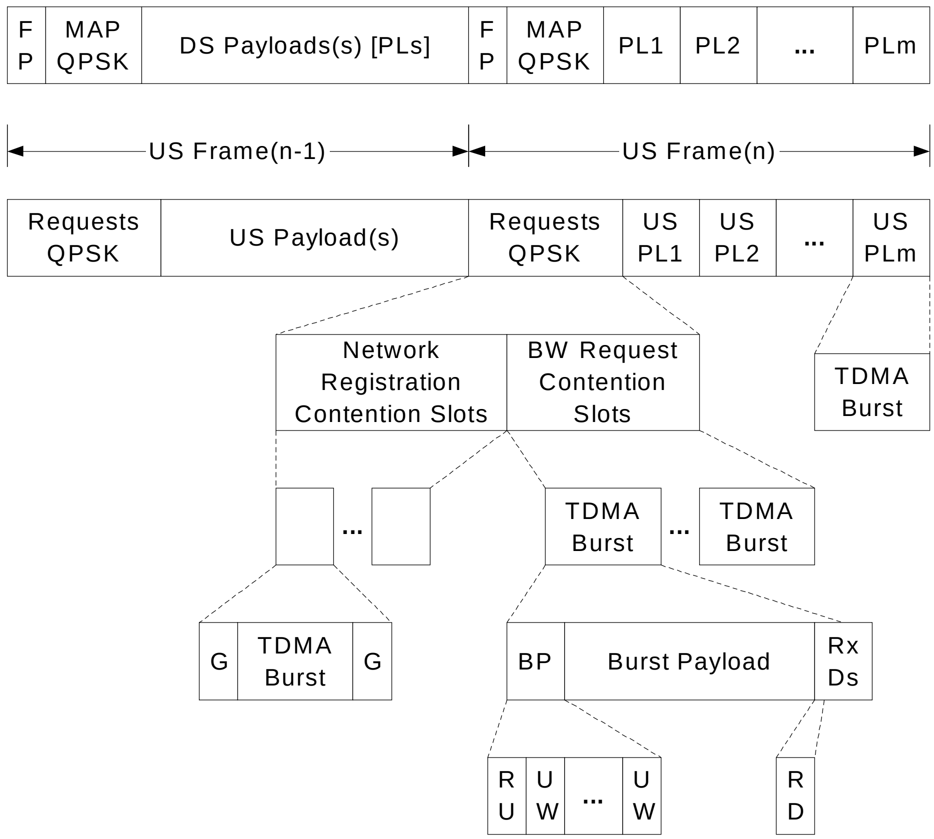


Figure 209— FDD Burst TDMA Upstream Juxtaposed with Continuous Downstream

8.3.5.11.1.2 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 210 illustrates the burst FDD downstream case.

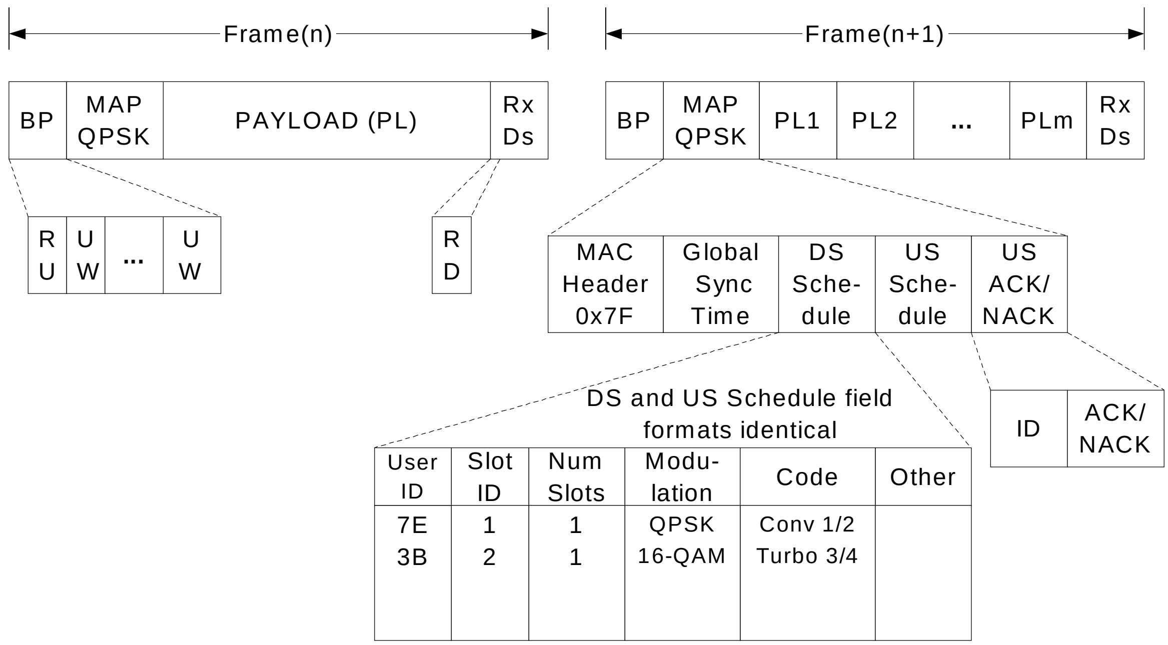


Figure 210—Burst FDD Downstream Frame

8.3.5.11.1.3 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 Section 8.3.5.11.2.

8.3.5.11.2 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 211 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 211 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.

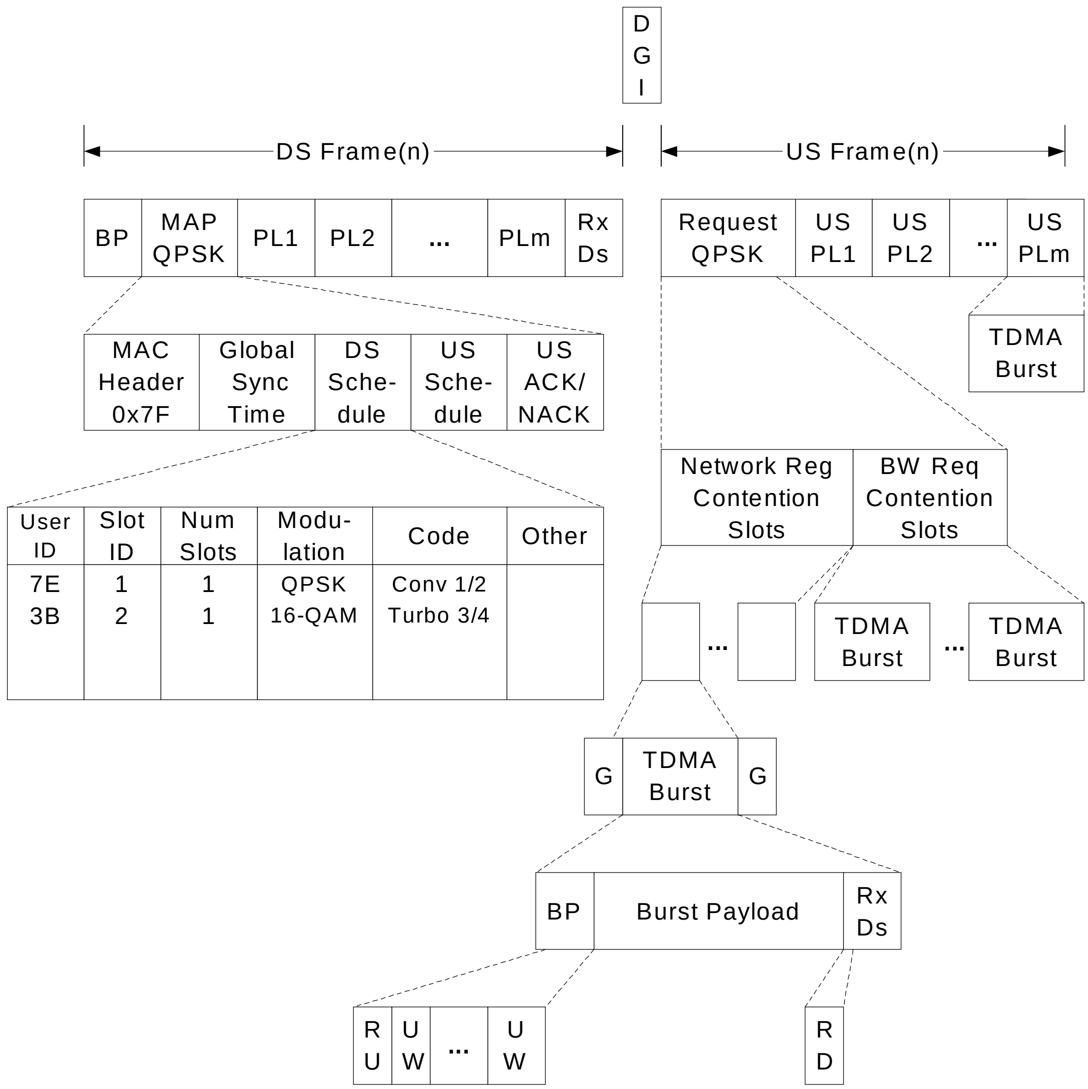


Figure 211—Ilustration of TDD messaging and operation (with TDM downlink)

8.3.5.12 Unique Word

8.3.5.12.1 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 another constraint: the Unique Word should have good correlation properties, and a broadband, un-notched frequency response. 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 required.

8.3.5.12.2 Unique Word Sequence Specification

One sequence class that seems to possess all of the desired properties is the 'modified PN' sequence, as described by Milewski in [B26]. As its title suggests, this sequence class has 'optimal properties for channel estimation and fast start-up equalization.' What's more, constructions for various sequence lengths are simple, due to their derivation from PN sequences.

The 'modified PN sequence' is a complex-valued (I + jQ) sequence that might be described as 'quasi-BPSK.' It possesses the following structure:

- The 'I' channel component is derived from a PN-generator (linear feedback shift register), initialized with all registers equal 1, of period $U=2^n-1$ (where n is an integer), and
- The 'Q' channel component is a small, but non-zero constant sequence, with value $1/(\sqrt{2^n-1})$.

In order to reference the constellation to the unit circle, the I and Q components described above each should be scaled by $\sqrt{(1-2^{-n})}$.

Table 160 lists the generator polynomials that must be used in generating the 'I' component of the Unique Word, over a useful and practical range of sequence lengths, U. Support for the lengths U= 63, and 127 is mandatory. Support of all other U lengths is optional.

Table 160—UW lengths and Generator Polynomials for I Channel PN Sequences

Length, U (symbols)	PN Generator Polynomial (Binary, with 100101 <-> x5 + x2 + 1)	Status
0	---	Optional
7	1011	Optional
15	10011	Optional
31	100101	Optional
63	1000011	Mandatory
127	10000011	Mandatory
255	100011101	Optional
511	1000010001	Optional

8.3.5.13 Framing Recommendations for Transmit Diversity

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 2-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. 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, the framing requires some thought when the Alamouti transmit diversity scheme [B31], which achieves 2-way maximal ratio transmit diversity combining, is used.

8.3.5.14 The Alamouti Algorithm:

Alamouti diversity combining may be applied to either the continuous or burst formats, if two consecutive Unique Word Intervals (which we will denote here as "blocks") are logically coupled, and are jointly processed at both the transmitter and receiver. Here we shall illustrate a technique which is particularly amenable to frequency domain equalization.

Figure 212 illustrates the aforesaid concept of block pairing, and also illustrates the necessity of separating the consecutively paired blocks with 'delay spread guard bands', so that no block leaks delayed information onto the other.

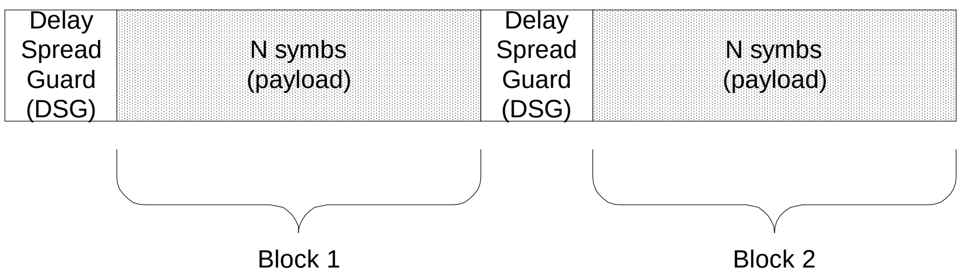


Figure 212—Two Blocks (Unique Word Intervals) for Alamouti transmit diversity combining

Table 161 indicates the block signaling structure that must be used at the transmitter.

Note that Transmit Antenna 0 would transmit data according to burst or continuous format specifications, with no modifications. However, Transmit Antenna 1 must not only reverse the block order, and conjugate the transmitted complex symbols, but must also reverse the time sequence of data within each block before sending data over the air.

Table 161—Multiplexing arrangement for block Alamouti-like processing

TX Antenna	Block 0	Block 1
0	$s_0(t)$	$s_1(t)$
1	$-s_1^*(-t)$	$s_0^*(-t)$

Let $S_0(e^{j\omega})$,$S_1(e^{j\omega})$ $H_0(e^{j\omega})$, $H_1(e^{j\omega})$,$N_0(e^{j\omega})$, and $N_1(e^{j\omega})$, be the Discrete-time Fourier transforms of symbol sequences $s_0(t)$ and $s_1(t)$, channel responses $h_0(t)$ and $h_1(t)$, and additive noise sequences $n_0(t)$ and $n_1(t)$.

The received signals associated with each block, interpreted in the frequency domain, are:

$$R_0(e^{j\omega}) = H_0(e^{j\omega})S_0(e^{j\omega}) - H_1(e^{j\omega})S_1(e^{j\omega}) + N_0(e^{j\omega}) \quad (2)$$

$$R_1(e^{j\omega}) = H_0(e^{j\omega})S_1{}^*(e^{j\omega}) - H_1(e^{j\omega})S_0{}^*(e^{j\omega}) + N_1(e^{j\omega}) \quad (3)$$

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

$$C_0(e^{j\omega}) = H_0^*(e^{j\omega})R_0(e^{j\omega}) + H_1(e^{j\omega})R_1^*(e^{j\omega}) \quad (4)$$

$$C_1(e^{j\omega}) = -H_1(e^{j\omega})R_0^*(e^{j\omega}) + H_0^*(e^{j\omega})R_1^*(e^{j\omega}) \quad (5)$$

to obtain the combiner outputs

$$C_0(e^{j\omega}) = (|H_0(e^{j\omega})|^2 + |H_1(e^{j\omega})|^2)S_0(e^{j\omega}) + H_0^*(e^{j\omega})N_0(e^{j\omega}) + H_1(e^{j\omega})N_1^*(e^{j\omega}) \quad (6)$$

$$C_1(e^{j\omega}) = (|H_0(e^{j\omega})|^2 + |H_1(e^{j\omega})|^2)S_1(e^{j\omega}) - H_1(e^{j\omega})N_0^*(e^{j\omega}) + H_0^*(e^{j\omega})N_1(e^{j\omega}) \quad (7)$$

These combiner outputs can be equalized using a frequency domain equalizer (see [B25], for example) to (eventually) obtain estimates for $s_0(t)$ and $s_1(t)$.

The channel responses can also be estimated using pilot symbols. Assume that corresponding pilot symbols are the same in the 0 and 1 blocks, i.e., $S_0(e^{j\omega_{pilot}}) = S_1(e^{j\omega_{pilot}}) = S(e^{j\omega_{pilot}})$, and that $S(e^{j\omega_{pilot}})$ is known.

Using the expression from Eq. 2 and Eq. 3, one can easily show that

$$S^*(e^{j\omega_{pilot}})R_0(e^{j\omega_{pilot}}) + S(e^{j\omega_{pilot}})R_1(e^{j\omega_{pilot}}) = 2|S(e^{j\omega_{pilot}})|^2 H_0(e^{j\omega_{pilot}}) \quad (8)$$

$$S^*(e^{j\omega_{pilot}})R_0(e^{j\omega_{pilot}}) + S(e^{j\omega_{pilot}})R_1(e^{j\omega_{pilot}}) = 2|S(e^{j\omega_{pilot}})|^2 (H_1(e^{j\omega_{pilot}})) \quad (9)$$

This suggests that one can estimate the channels $H_0(e^{j\omega})$ and $H_1(e^{j\omega})$ at the pilot locations, and thus identify the channels themselves (if the pilot sampling locations are selected properly) using the expressions

$$\hat{H}_0(e^{j\omega_{pilot}}) = \frac{S^*(e^{j\omega_{pilot}})R_0(e^{j\omega_{pilot}}) + S(e^{j\omega_{pilot}})R_1(e^{j\omega_{pilot}})}{2|S(e^{j\omega_{pilot}})|^2} \quad (10)$$

$$\hat{\cdot}_0(e^{j\omega_{pilot}}) = \frac{-S^*(e^{j\omega_{pilot}})R_0(e^{j\omega_{pilot}}) + S(e^{j\omega_{pilot}})R_1(e^{j\omega_{pilot}})}{2|S(e^{j\omega_{pilot}})|^2} \quad (11)$$

Figure 213 illustrates a frame structure, with pilot symbols (Unique Word repetitions) which enables implementation of the aforesaid techniques, including simultaneous estimation (or channel updates) of the two channels arising from the use of two transmit antennas. Note that although the although the spacing between basic Unique Words is the same as previously, the intervals over which FFTs (for a frequency domain equalizer) are computed are reduced.

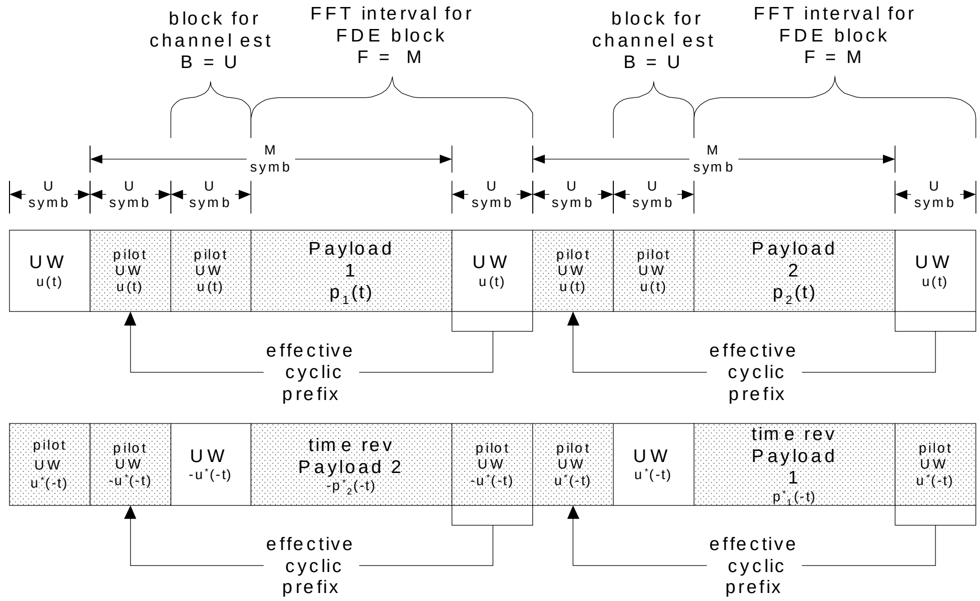


Figure 213—Frame structure for Alamouti TX diversity signaling with channel estimation

Figure 214 illustrates a similar case as Figure 213, but 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.

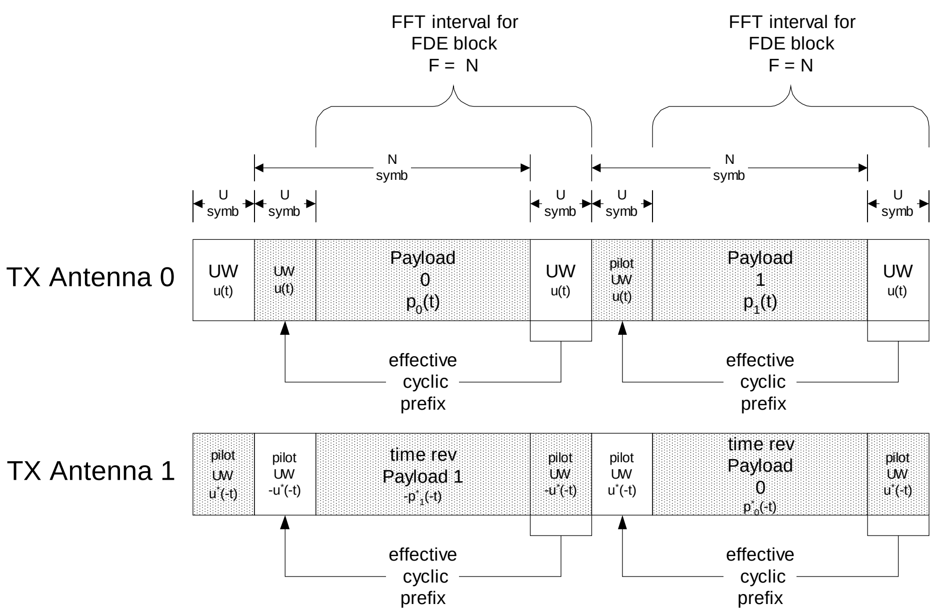


Figure 214—Frame structure for Alamouti TX diversity signaling without channel estimation

8.3.5.15 Antenna Systems

8.3.5.15.1 Application of Smart Antenna

The PHY layer shall support future application of smart antenna for primary feature of providing the ability to track the line of sight target within a predetermined angle of uncertainty. Typically, one would expect 3 or more degrees of tracking. This active tracking capability of smart antenna will potentially provide better coexistence and will optimize the antenna pattern (transmit where the subscriber is located)

8.3.5.15.2 Antenna Diversity

Multiple antennas can be used at the transmitter and/or receiver to provide added dimension to the model.

When multiple antenna diversity (so called Multiple-Input/Multiple-Output; MIMO) is compared with a Single-Input/ Single-Output (called SISO) technique, it is shown in performance that it can improve the capacity of the fading wireless channel regardless of the modulation techniques utilized, including Single Carrier (SC) modulation. Figure 215 illustrates the application of antenna array for Single Carrier systems with three receive antennas.

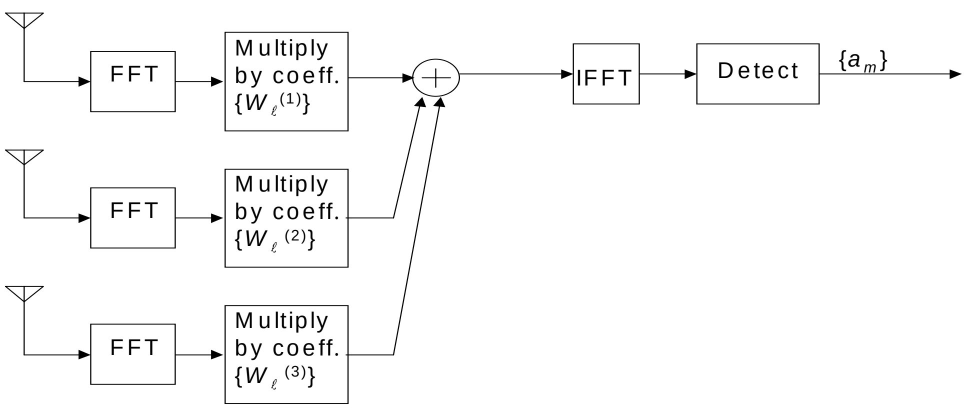


Figure 215—SC-FDE with Smart Antenna Array

8.3.5.16 SC-FDE System Capacity and Modulation Efficiency

8.3.5.16.0.1 System Capacity:

Table 162 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 162 is the overhead associated with the use of FEC and a Frequency Domain Equalizer with periodic Unique Word patterning.

Table 162—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

8.3.5.16.1 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:

$$T = R\frac{N-U}{N}r\frac{\log M}{\log 2} \qquad (12)$$

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:

$$T = R\frac{N-\lceil (R \cdot d) \rceil_2}{N}r\frac{\log M}{\log 2} \qquad (13)$$

where $\lceil x \rceil_2$ denotes rounding x up to the nearest power of 2.

Table 163 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 163—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

8.3.5.17 Minimum Performance Requirements

8.3.5.17.1 System Requirements

8.3.5.17.1.1 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.

8.3.5.17.1.2 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).

8.3.5.17.1.3 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 164—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

8.3.5.17.1.4 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.

8.3.5.17.1.5 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)%.

8.3.5.17.1.6 Transmitter Maximum EIRP

8.3.5.17.1.6.1 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 165—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)

8.3.5.17.1.7 Transmitter Power Level Control

The transmitter shall provide up to (TBD (~50dB)) of power level control with a tolerance of +/-3 dB.

8.3.5.17.1.8 Receiver Sensitivity

The maximum sensitivity value for the receiver, referenced to the receiver input, is identified in the following table.

Table 166—Receiver Sensitivity Values

Channel Bandwidth	Data Rate (Mbits/s)	Receiver Sensitivity (dBm)
7 MHz	(TBD)	(TBD)
7 MHz	(TBD)	(TBD)
7 MHz	(TBD)	(TBD)

Table 166—Receiver Sensitivity Values

Channel Bandwidth	Data Rate (Mbits/s)	Receiver Sensitivity (dBm)
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)

8.3.5.17.1.9 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.

8.3.5.17.1.10 Receiver Linearity

The receiver at the basestation and subscriber shall have a minimum input intercept point (IIP3) of (TBD (~0)) dBm.

8.3.5.17.1.11 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.

8.3.5.17.2 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.

8.3.5.17.2.1 Frequency Reuse

Frequency reuse shall be (TBD) for 3 sector cells, (TBD) for 4 sector cells, and (TBD) for 6 sector cells.

8.3.5.17.2.2 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 167—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
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

8.3.5.17.2.3 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 168—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
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

8.3.6 OFDM PHY Layers

8.3.6.1 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 8.3.6.3 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 8.3.6.4 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) [B38], [B39]. 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.

8.3.6.1.1 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 8.3.6.1.2).

The number of carriers utilized, N_{used}, is usually only about 83% of the FFT bins (see 8.3.6.1.3). 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:

$$BW_{Efficiency} = \frac{F_s}{BW} \cdot \frac{(N_{used}+1)}{N_{FFT}} = \frac{\Delta f \cdot (N_{used}+1)}{BW} \quad (14)$$

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:

$$F_s = BW_{Efficiency} \cdot BW \cdot \frac{N_{FFT}}{(N_{used}+1)} \quad (15)$$

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,

$$\Delta f = \frac{F_s}{N_{FFT}} \quad (16)$$

The FFT interval duration is related to carrier spacing by

$$T_b = \frac{1}{\Delta f} = \frac{N_{FFT}}{F_s} \quad (17)$$

8.3.6.1.2 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 216 illustrates this structure:

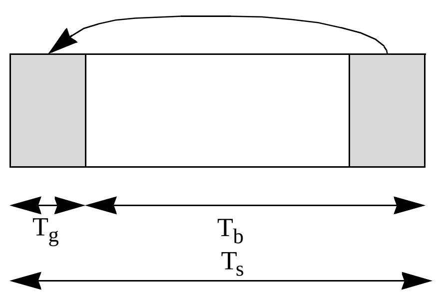


Figure 216—OFDM Symbol time structure

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.

8.3.6.1.3 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 217 illustrates such a scheme:

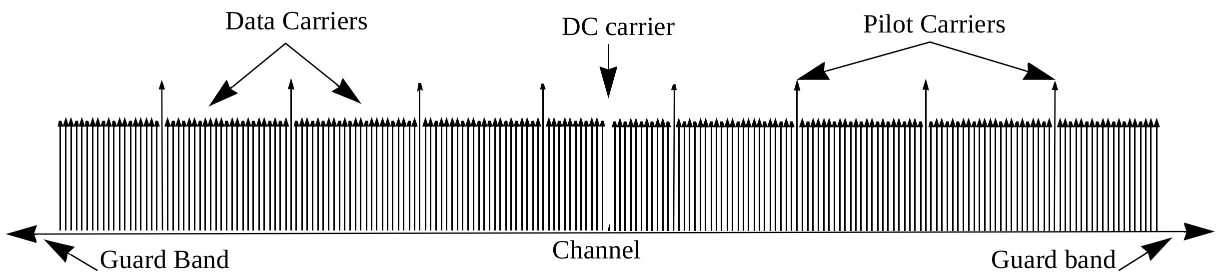


Figure 217—OFDM frequency description (256-FFT example)

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 218.

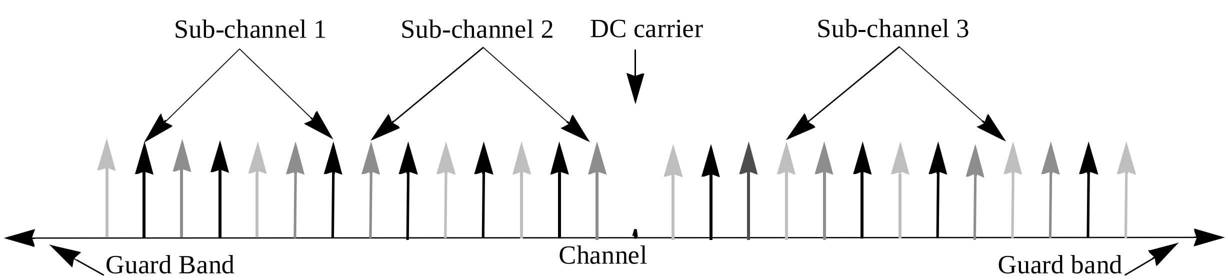


Figure 218—OFDMA frequency description (3 channel schematic example)

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.

8.3.6.1.4 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 8.3.6.3.4.1 and 8.3.6.4.4) with the following exceptions. When using 64-FFT in the U-NII band the sampling rate is $F_s = BW$ (see clause 8.3.6.3.3.1, 8.3.6.4.3.1). When using 256 or 512 FFT in a licensed band, $F_s = BW \cdot 7/6$ (see clause 8.3.6.3.3.1)..

Table 169—MMDS Channelization Parameters

			OFDM		**OFDMA**	
	$F_s/(BW)$		**7/6**		**8/7**	
BW(MHz)	N_{FFT}		**256**	512	**2048**	4096
1.5	$\Delta fkHz)$		**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 169—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 170—ETSI Channelization Parameters

			OFDM		**OFDMA**	
	F_s / BW		**7/6**		**8/7**	
BW(MHz)	N_{FFT}		**256**	512	**2048**	4096
1.75	$\Delta fkHz)$		**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 170—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 171—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 172—U-NII Channelization Parameters

			OFDM		OFDMA
	$F_s/(BW$		**1**	**8/7**	8/7
BW(MHz)	N_{FFT}		**64**	**256**	2048
5 (Optional)	$\Delta f kHz)$		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**	

8.3.6.2 Common elements

8.3.6.2.1 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 219). 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).

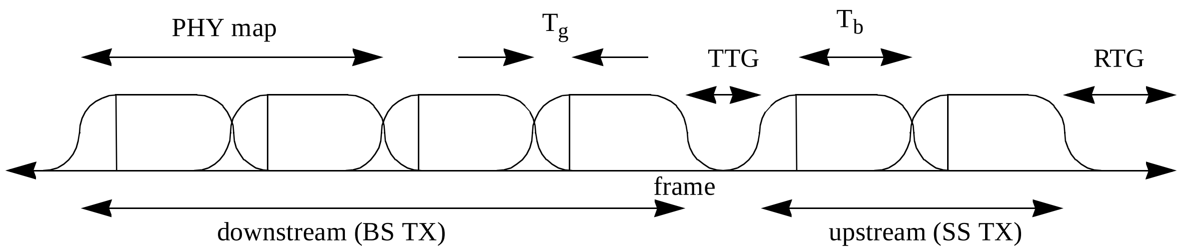


Figure 219—Time Plan - One TDD time frame

8.3.6.2.2 Ranging

8.3.6.2.3 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 [B40], 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).

8.3.6.2.3.1 Transmit diversity Alamouti's Space-Time Coding

Alamouti's scheme [B41] 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 220 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.

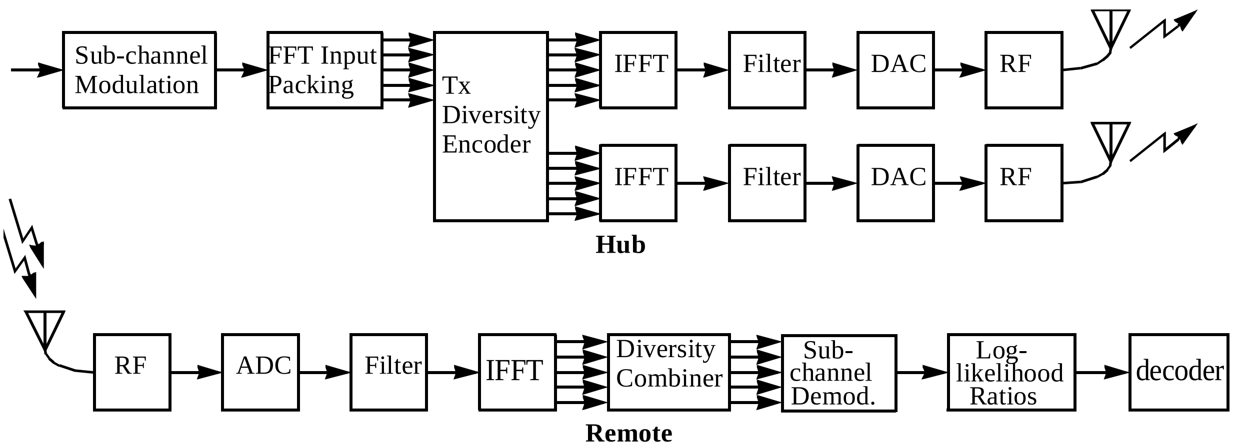


Figure 220—Illustration of the Alamouti STC

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.

8.3.6.2.3.2 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.

8.3.6.2.3.3 Alamouti STC Encoding

(Scheme explanation) The basic scheme [B41] 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:

$$s_0 = h_0* \cdot r_0 + h_1 \cdot r_1 \tag{18}$$

$$s_1 = h_1* \cdot r_0 - h_0 \cdot r_1* \tag{19}$$

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 221 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)

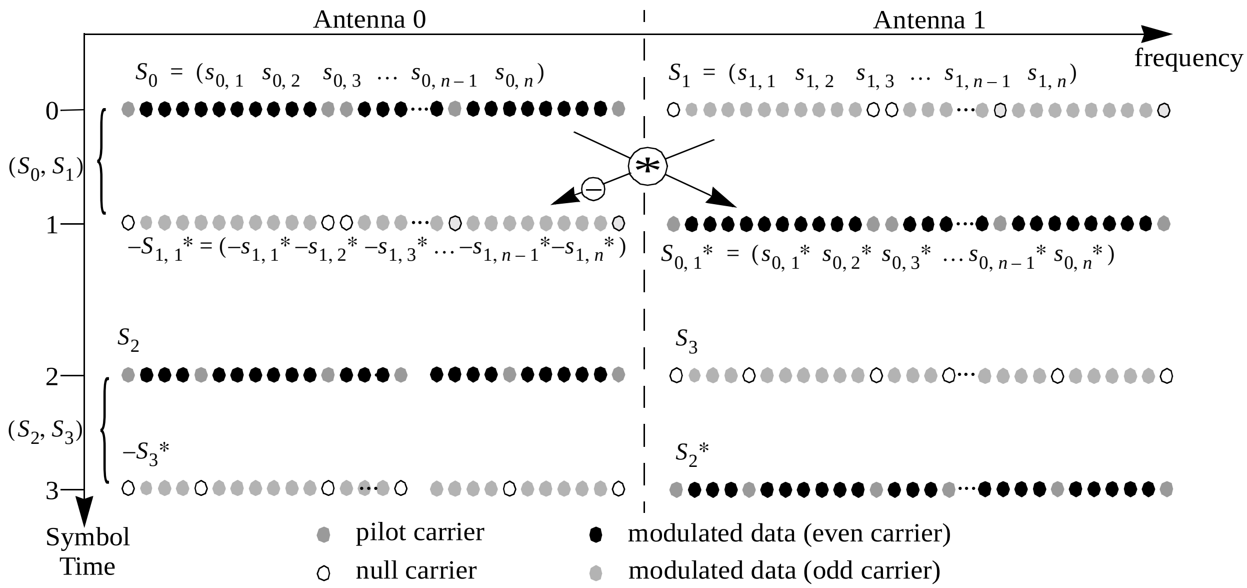


Figure 221—Alamouti Scheme Usage with OFDM/OFDMA

8.3.6.2.3.4 Alamouti STC Decoding

The receiver waits for 2 symbols, and combines them on a carrier basis according to the formula in clause 8.3.6.2.3.3.

8.3.6.3 OFDM PHY Layer for licensed bands

8.3.6.3.1 Introduction

This specification allows for FFT sizes 256, 512, 2048 and 4096. A compliant device shall implement either Mode A (256 FFT with TDMA), or alternatively Mode B (2048 FFT with OFDMA) for any bandwidth. The 512 FFT with TDMA and 4096 FFT with OFDMA modes are optional.

8.3.6.3.2 Common elements

8.3.6.3.2.1 Channel Coding

8.3.6.3.2.1.1 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 222. Each data byte to be transmitted shall enter sequentially into the randomizer, MSB first.

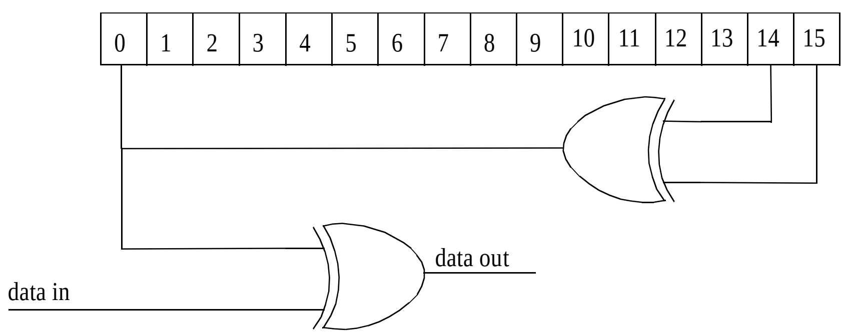


Figure 222—PRBS for Data Randomization

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 8.3.6.3.3.2.1. and for OFDMA in clause 8.3.6.3.3.2.1.

8.3.6.3.2.1.2 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 8.3.6.3.2.1.3.

The Reed-Solomon-Convolutional coding rate 1/2 shall be used as the coding mode when requesting access to the network.

8.3.6.3.2.1.2.1Tail 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 b0..bn).

8.3.6.3.2.1.3 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 8.3.6.3.3.2.2.2 and 8.3.6.3.4.2.2.2.

8.3.6.3.2.1.4 Interleaving

The PRBS generator depicted in Figure 223 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 8.3.6.3.3.2.3 and 8.3.6.3.4.2.3).
- 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

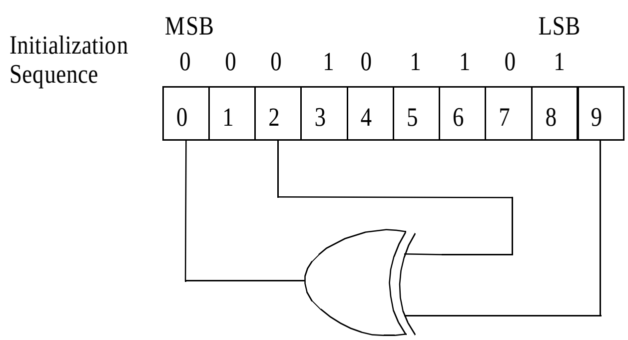


Figure 223—PRBS for Bit-Interleaver Array

8.3.6.3.2.2 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.

8.3.6.3.2.2.1 Data Modulation

After bit interleaving, the data bits are entered serially to the mapper, which is shown in Figure 159. The most significant bits are the first to arrive at the mapper and the ordering of bits in Figure 159 is MS bit to the left.

Note that 64-QAM is optional in all modes, whereas BPSK modulation is only implemented for license-exempt operation.

The complex number z in Figure 159, before mapping onto the carriers, shall be normalized to the value c as defined in Table 173:

Table 173—Normalization factors

Modulation scheme	Normalization Factor 6 dB attenuation	Normalization Factor Reference 0dB	Normalization Factor 6 dB busting
BPSK	$c = z/2$	$c = z$	$c = 2z$
QPSK	$c = c/\sqrt{2}$	$c = z/\sqrt{2}$	$c = z\sqrt{2}$
16 QAM	$c = z/\sqrt{40}$	$c = z/\sqrt{10}$	$c = z/\sqrt{5}$
64 QAM	$c = z/\sqrt{164}$	$c = z/\sqrt{42}$	$c = z/\sqrt{21}$

The complex number c, resulting from the normalization process, shall be 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.

8.3.6.3.2.2.2 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 $X_{11} + X_2 + 1$.

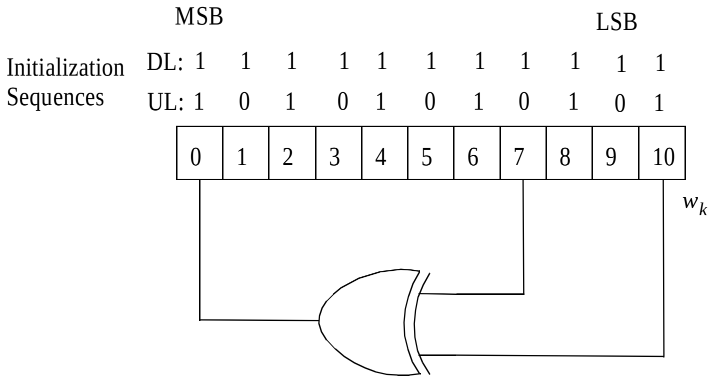


Figure 224—PRBS for pilot modulation

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 will be: [11111111111]. 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:

$$\Re\{C_k\} = \frac{8}{3}\left(\frac{1}{2} - w_k\right) \qquad \Im\{C_k\} = 0 \tag{20}$$

For preambles or midambles, the pilots shall not be boosted an shall be modulated according to the following formula:

$$\Re\{C_k\} = 2\left(\frac{1}{2} - w_k\right) \qquad \Im\{C_k\} = 0 \tag{21}$$

For Mode B, a ranging pilot modulation exception is defined in 8.3.6.3.4.3.1.3.

8.3.6.3.2.3 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 225 illustrates the DL framing:

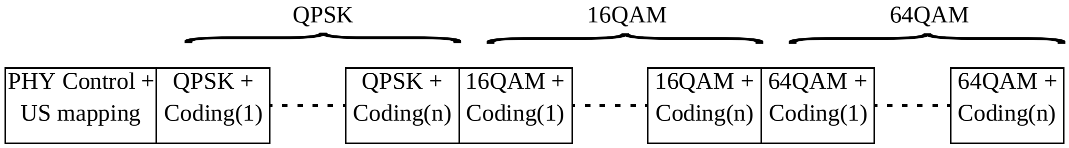


Figure 225—DL Frame Structure

In mode A, the transitions between modulations and coding takes place only on OFDM symbol boundaries, in mode B and C, the transition may take place on carriers within an OFDM symbol.

8.3.6.3.2.4 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.

8.3.6.3.2.4.1 Synchronization

8.3.6.3.2.4.1.1Network 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. 8.3.6.3.2.4.1.4. This applies during normal operation and during loss of timing reference.

8.3.6.3.2.4.1.2 Time Stamp, Frame Timing Reference

Each Base-Station and SS shall maintain a 32 bit system clock which is incremented as described in clause ???????.

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.

8.3.6.3.2.4.1.3 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.

8.3.6.3.2.4.1.4Subscriber 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.

8.3.6.3.2.4.2 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.

8.3.6.3.3 Mode A - OFDM

8.3.6.3.3.1 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 174, the DC carrier is numbered 0, whereas carrier numbers increase from the lowest to the highest frequency.

Table 174—Symbol Parameters

N_{FFT}	Parameter	Value	
256	N_{used}	200	
	Guard Carriers: Left, Right	28	27
	BasicConstantLocationPilots	{-84,-60,-36,-12,12,35,60,84}	
512	N_{used}	394	
	Guard Carriers: Left, Right	59	58
	BasicConstantLocationPilots	{-171,-133,-95,-57,-19,19,57,95,133,171}	

8.3.6.3.3.2 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.

8.3.6.3.3.2.1 Uplink Scrambling (Randomization) Initialization

The scrambler (see clause 8.3.6.3.2.1.1) is initialized with the following vector.

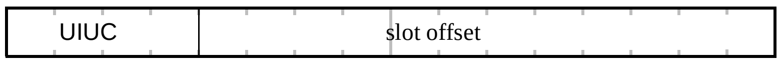


Figure 226—OFDM Randomizer Initialization vector

8.3.6.3.3.2.2 FEC

8.3.6.3.3.2.2.1Concatenated 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 175 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 175—Mandatory Channel Coding per Modulation

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

8.3.6.3.3.2.2.2Turbo Product Codes (Optional)

Table 176 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 176—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

8.3.6.3.3.2.3 Interleaving

A combination of a bit interleaver and a symbol interleaver is used to interleave the data over the frequency domain.

8.3.6.3.3.2.3.1Bit Interleaving

Table 177 summarises the bit interleaver sizes as a function of modulation and coding.

Table 177—Number of bits in OFDM symbol

96 Symbol Interleaver		N_{FFT}	
		256	**512**
Modulation	Bits/Block	Blocks/OFDM Symbol	
QPSK	192	2	4
16 QAM	384	2	4
64 QAM	576	2	4

8.3.6.3.3.2.3.2Symbol (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 227.

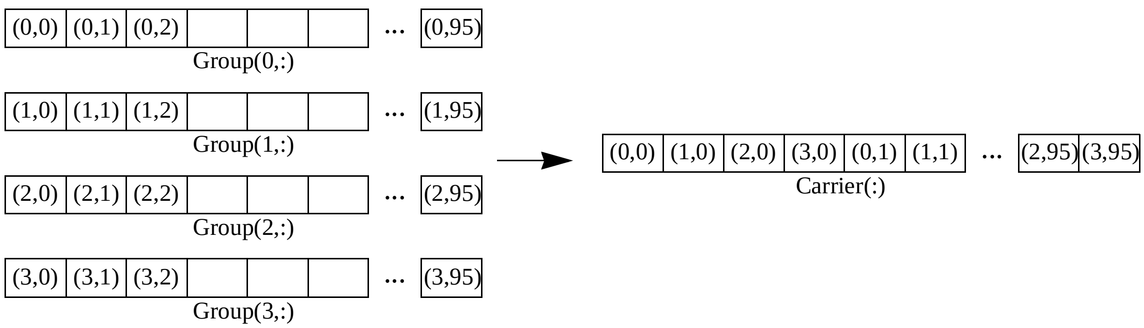


Figure 227—Symbol Interleaver for 512 FFT

8.3.6.3.3.3 Control Mechanisms

8.3.6.3.3.3.1 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.

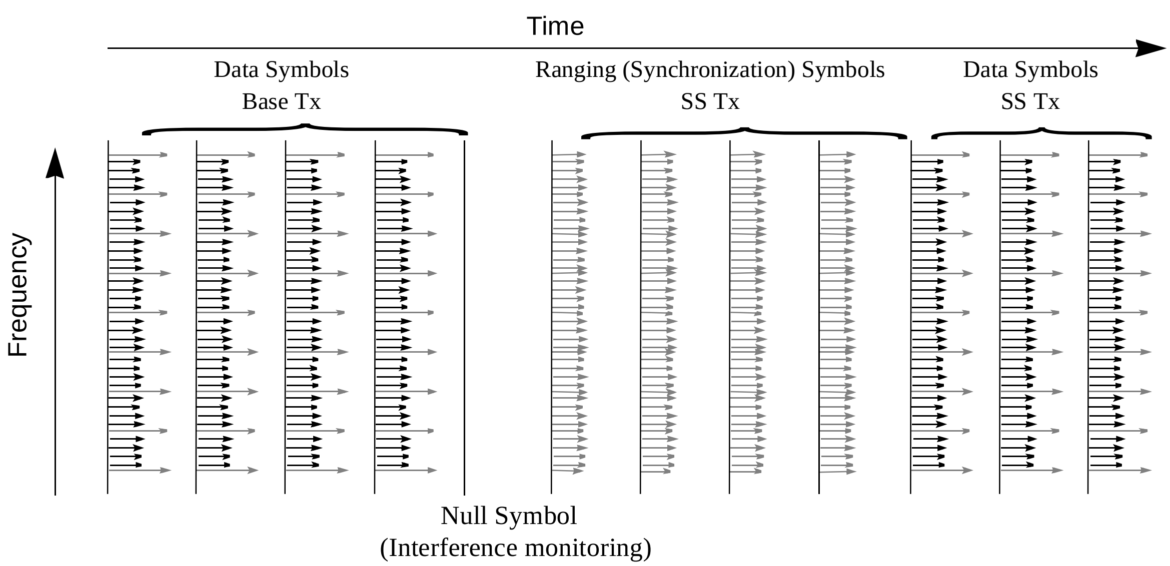


Figure 228—Ranging Symbol Allocation

8.3.6.3.3.3.2 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.

8.3.6.3.3.3.3 Power Control

8.3.6.3.3.4 Frame structure

8.3.6.3.3.4.1 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 229 (each block represents a symbol as depicted in Figure 228):

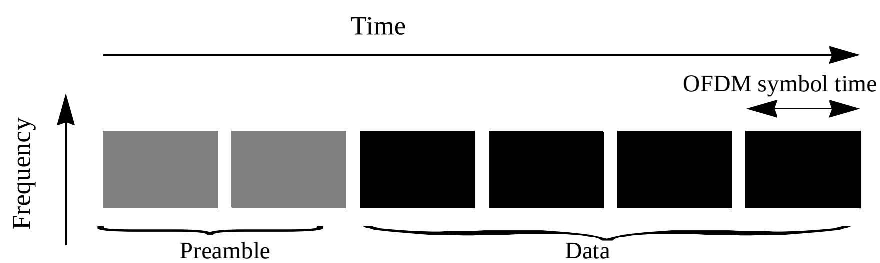


Figure 229—Mode A UL Framing

8.3.6.3.3.4.2 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 230 illustrates a possible two-dimensional transmission mapping (every color represents a different Modulation and coding scheme, see also Figure 225).

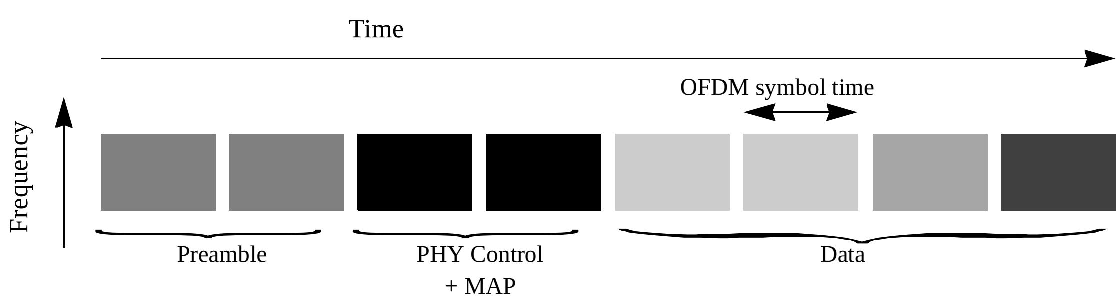


Figure 230—Mode A DL Framing

As shown in Figure 230, the DL frame starts with a preamble consisting of one or more pilot symbols.

8.3.6.3.3.5 Preamble structure

8.3.6.3.3.6 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.

8.3.6.3.4 Mode B - OFDMA

8.3.6.3.4.1 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.

8.3.6.3.4.1.1 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 231:

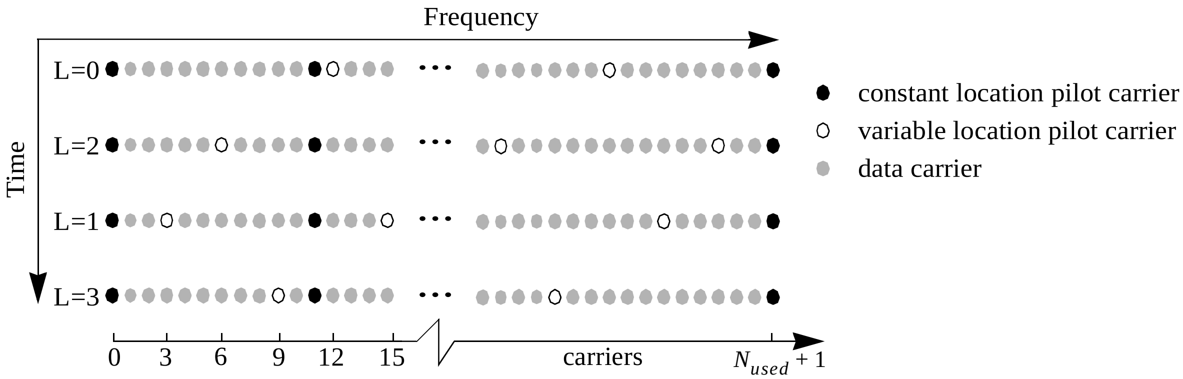


Figure 231—Pilot and data carrier location in DL OFDMA symbol

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 MAC defined parameter, defining the current cell identification numbers, to support different cells.

1 The usable carrier space is divided into N_{groups} basic groups. N_{groups} is equal to the number of data 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:

$$c_s[k] = \{p_s[k_{mod(N_{elements})}] + ceil[(k+1)/N_{elements}] \cdot ID_{Cell}\}_{mod(N_{elements})} \quad (22)$$

5 The last step achieves the carrier numbers allocated for the specific Sub-Channel with the current CellId. Using the next formula we achieve the $N_{subchannel}$ carriers (48 in DL, 53 in UL) of the current permutation in the cell:

$$carrier(n, s) = N_{elements} \cdot n + c_s[n] \quad (23)$$

Here carrier(n, s) is the n-th carrier of subchannel number s; n = 0,1..., .

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 178—Downlink Symbol Parameters

N_{FFT}	Parameter	Value	
2048 (2K)	N_{used}	1703	
	Guard Carriers: Left, Right	172	172
	Subchannels, data carriers/subchannel	32	48
	BasicConstantLocationPilots	{0,39, 261, 330, 342, 351, 522, 642, 645, 651, 708, 726, 756, 792, 849, 855, 918, 1017, 1143, 1155, 1158, 1185, 1206, 1260, 1407, 1419,1428, 1461, 1530,1545, 1572, 1701, 1702}	
	$\{PermutationBase_0\}$	{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}	TBD	
	Guard Carriers: Left, Right	TBD	TBD
	Subchannels, data carriers/subchannel	64	48
	BasicConstantLocationPilots	TBD	
	$\{PermutationBase_0\}$	TBD	

8.3.6.3.4.1.2 Uplink

A subchannel is made up of 48 usable carriers and 5 pilot carriers. The UL subchannel structure is shown in Figure 232.

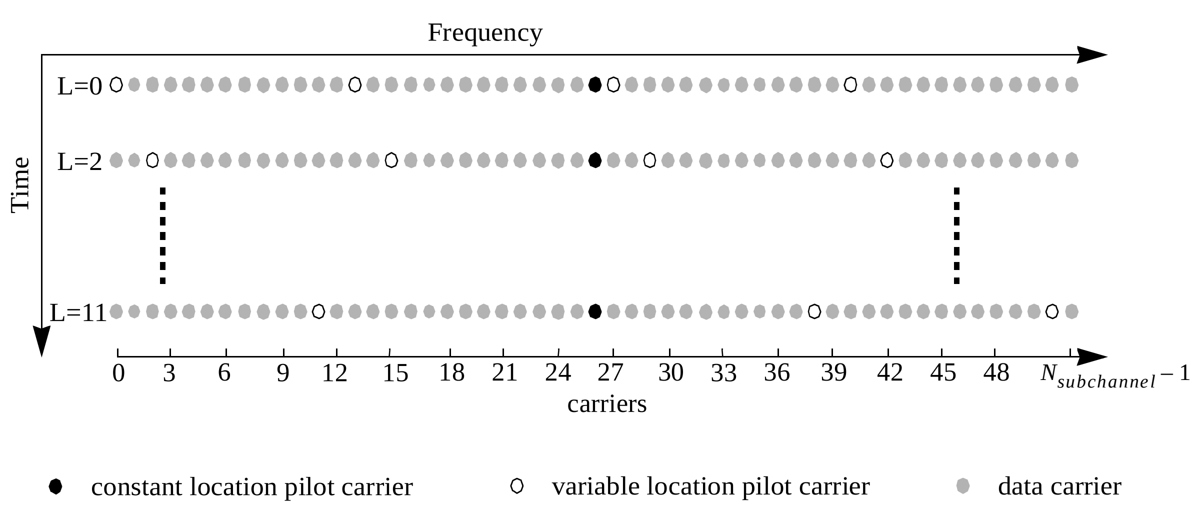


Figure 232—Pilot and data carrier Allocation of UL Sub-channel

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 8.3.6.3.2.2.2. 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 8.3.6.3.4.1.1, $N_{subchannel}$=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 179 provides the applicable uplink symbol parameters:

Table 179—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}	

8.3.6.3.4.1.3 Permutation Example

[would be better to replace this with a 2k example]

This clause is informative only.

For clarity, an example for using the permutation procedure with the UL 1024 mode is given.

The parameters characterizing the UL 1K mode are as follow:

- Number of FFT points: 1024 (1K)
- Overall Usable Carriers: 849
- Guard Bands: 88, 87 carriers on right an left side of the spectrum
- Number of Sub-Channels: 16

The parameters characterizing the Sub-Channels allocation:

- Number of carriers in each basic group: 16
- The basic series of 16 elements: {6, 14, 2, 3, 10, 8, 11, 15, 9, 1, 13, 12, 5, 7, 4, 0}

Using the defined procedure does the allocating:

1 The basic series of 16 numbers is {6, 14, 2, 3, 10, 8, 11, 15, 9, 1, 13, 12, 5, 7, 4, 0}

2 Given $CELL_{ID} = 2$, in order to get 16 different permutation the series is rotated to the left (from no rotation at all up to 15 rotations), for the first permutation we get the following series: 14, 2, 3, 10, 8, 11, 15, 9, 1, 13, 12, 5, 7, 4, 0, 6

3 To get a 53 length series we concatenate the permutated series 5 times (to get a 64 length series) and take the first 53 numbers only, the concatenation depends on the cell Id (which characterizes the working cell and can range from 0 to 15), the concatenated series is achieved using:

$$c_s[k] = \{p_s[k_{mod(16)}] + ceil[(k+1)/N_{elements}] - ID_{Cell}\}_{mod(16)}$$ with k=0,1,...,63

For example when using permutation s=1 with ID_{cell} we get the next concatenated series:

0 ,4 ,5 , 12, 10, 13, 1, 11, 3, 15, 14, 7, 9, 6, 2, 8, 2, 6, 7, 14, 12, 15, 3, 13, 5, 1, 0, 9, 11, 8, 4, 10, 4, 8, 9, 0, 14, 1, 5, 15, 7, 3, 2, 11, 13, 10, 6, 12, 6, 10, 11, 2, 0, 3, 7, 1, 9, 5, 4, 13, 15, 12, 8, 14

Therefore the 53 length series is:

0 ,4 ,5 , 12, 10, 13, 1, 11, 3, 15, 14, 7, 9, 6, 2, 8, 2, 6, 7, 14, 12, 15, 3, 13, 5, 1, 0, 9, 11, 8, 4, 12, 4, 8, 9, 0, 14, 1, 5, 15, 7, 3, 2, 11, 13, 10, 6, 14, 6, 10, 11, 2, 0

4 The last step achieves the carrier indices allocated for the specific Sub-Channel with the current Cell Id. Using the next formula we achieve the 53 carriers of the current permutation in the cell: $carrier(n, 1)) = 16n + p_1[n]$ Where carrier(n, 1) is the n-th carrier of subchannel number 1; $p_1[n]$ is the n-th element of and n = 0, 1, ..., 52.

8.3.6.3.4.2 Channel Coding

8.3.6.3.4.2.1 Uplink Scrambling (Randomization) Initialization

The scrambler (see clause 8.3.6.3.2.1.1) is initialized with the following vector

8LSB of the Slot Offset	Sub-channel Offset

Figure 233—OFDMA Randomizer Initialization Vector

8.3.6.3.4.2.2 FEC

8.3.6.3.4.2.2.1Concatenated 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 180 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 180—Mandatory Channel Coding per Modulation

Modulation	Block Size (Bytes)	Overall Coding Rate	RS Code	CC Code Rate
QPSK	18	1/2	(24,18,3)	2/3
QPSK	26	~3/4	(30,26,2)	5/6
16 QAM	36	1/2	(48,36,6)	2/3
16 QAM	54	3/4	(60,54,3)	5/6
64 QAM	72	2/3	(81,72,4)	3/4
64 QAM	82	~3/4	(90,82,4)	5/6

8.3.6.3.4.2.2.2Turbo Product Codes (Optional)

Table 181 gives the block sizes, code rates, channel efficiency, and code parameters for the different modulation and coding schemes.

Table 181—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

8.3.6.3.4.2.3 Interleaving

Table 182 summarises the bit interleaver sizes as a function of modulation and coding.

Table 182—Bit Interleaver Sizes

Modulation	144 Symbol Interleave
QPSK	288
16 QAM	576
64 QAM	864

8.3.6.3.4.3 Control Mechanisms

8.3.6.3.4.3.1 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 234 (the PRBS polynomial generator shall be):

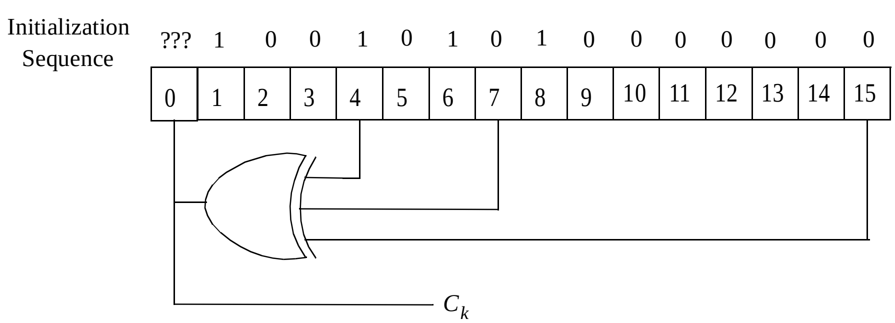


Figure 234—PRBS for Ranging Code Generation

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 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.

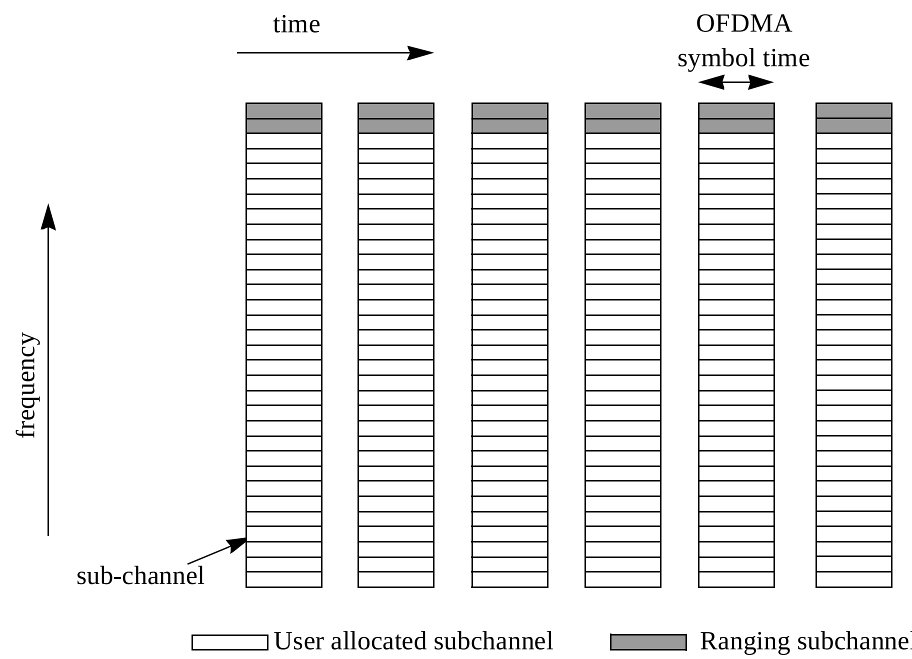


Figure 235—Ranging subchannel allocation (2K mode default configuration)

8.3.6.3.4.3.1.1Long 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.

8.3.6.3.4.3.1.2Short 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 one 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.

8.3.6.3.4.3.1.3Ranging Pilot Modulation

When using the ranging Sub-Channels the user shall modulate the pilots according to the following formula:

$$\Re\{Carrier_k\} = (1/2 - C_k)/6$$
$$\Im\{Carrier_k\} = 0 \tag{24}$$

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 8.3.6.3.4.3.1.1

8.3.6.3.4.3.2 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 8.3.6.3.4.3.1). Bandwidth requests are further provisioned by a piggy-back mechanism provided by the MAC.

8.3.6.3.4.3.3 Power Control

8.3.6.3.4.4 Frame structure

8.3.6.3.4.4.1 Downlink

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. Figure 236 illustrates a possible two-dimensional transmission mapping (every color represents a different Modulation and coding scheme). This example disregards the fact that the carriers composing a subchannel may be scattered within the OFDM symbol in non-consecutive locations.

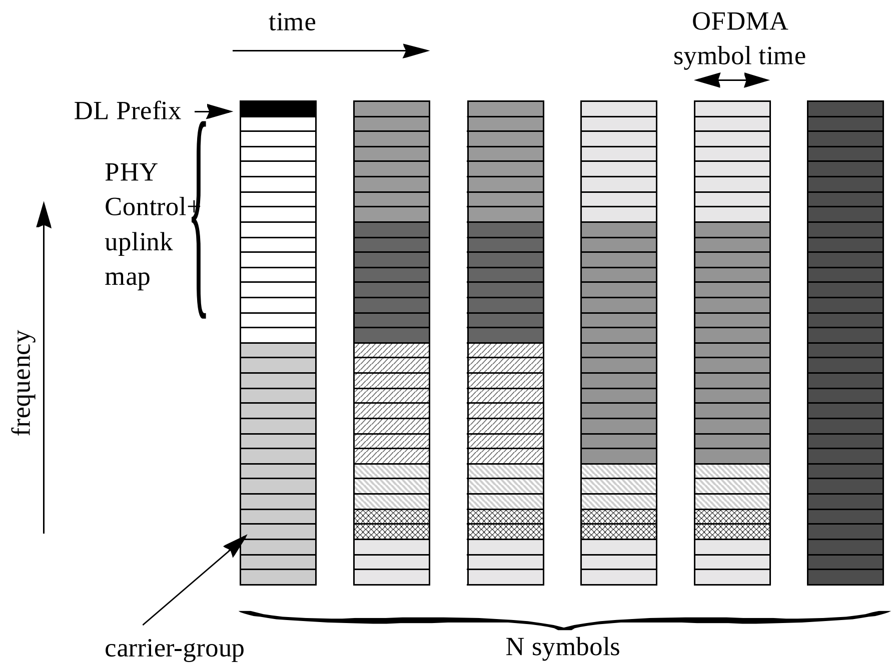


Figure 236—DL Framing

8.3.6.3.4.4.2 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 237:

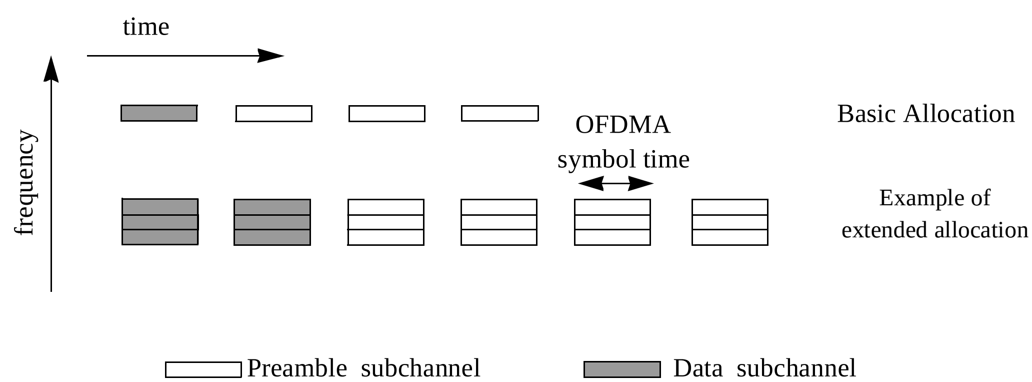


Figure 237—UL bandwidth Allocation

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 235. An optional Null symbol may be inserted to facilitate Jamming monitoring.

8.3.6.3.4.5 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).

8.3.6.3.5 Mode C (optional)

This mode specifies a mapping for advanced antenna array processing. Unless specified differently, clause 8.3.6.3.4 applies.

Mode C is based on a subchannel structure with 48 data carriers.

This mapping has the same fundamental subchannel tone utilization as Mode B. The main distinction between Mode B and Mode C is that the symbol data is assigned to adjacent carriers as indicated in the framing figures shown below. With Mode B, 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, 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.

8.3.6.3.5.1 Symbol Structure

Relative to Mode B, in this mapping the pilot and data carriers are assigned fixed positions in the frequency domain within an OFDM symbol.

8.3.6.3.5.2 Frame Format

8.3.6.3.5.2.1 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 238 illustrates a generic two-dimensional downlink transmission mapping where the different colors and shading reflect different modulation and coding schemes. Figure 239 shows a specific example as an overlay to a Mode B mapping.

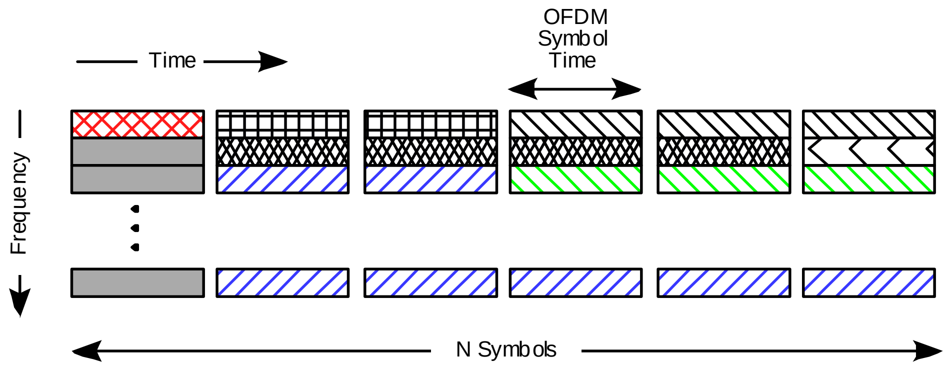


Figure 238—Downlink Framing

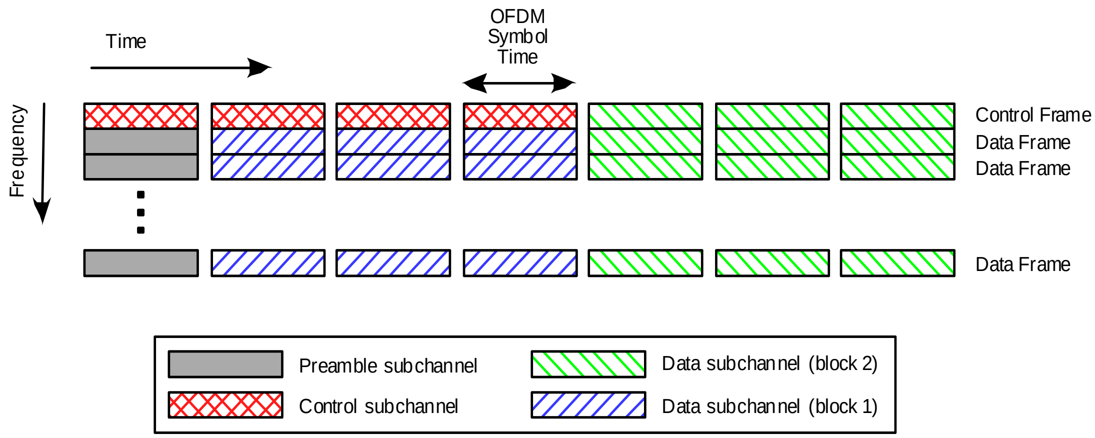


Figure 239—Downlink Framing, using Mode B Framing

8.3.6.3.5.2.2 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 240 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 241 with four OFDM symbols is one example, where the data frame is identical to the basic allocation in Mode B.

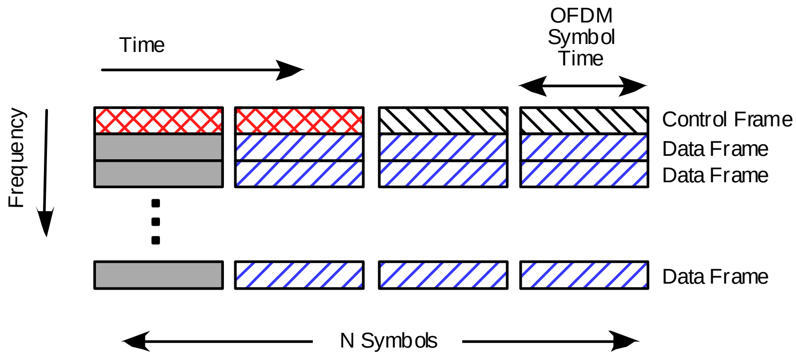


Figure 240—UL Framing

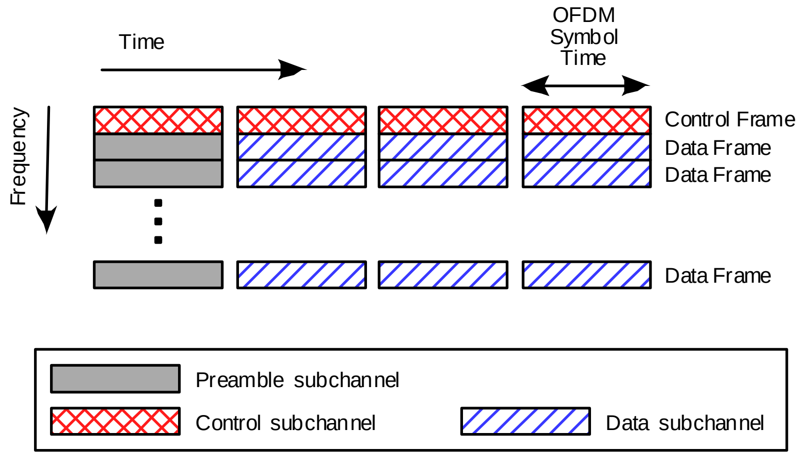


Figure 241—UL Framing Example

8.3.6.3.5.3 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 242, a superframe is defined as a control frame followed by one or more data frames.

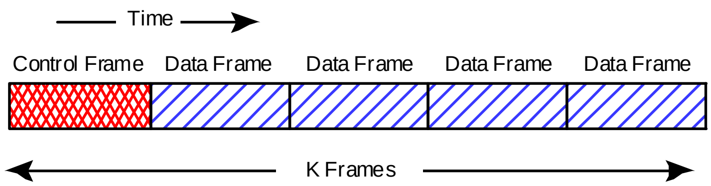


Figure 242—Superframe Structure

This superframe structure can be applied as shown in Figure 243. As with Mode B, the first two subchannels can be reserved for control functions such as ranging and contention based access. For the remaining subchannels, the superframe structure is offset so that the control frames are distributed throughout time and frequency.

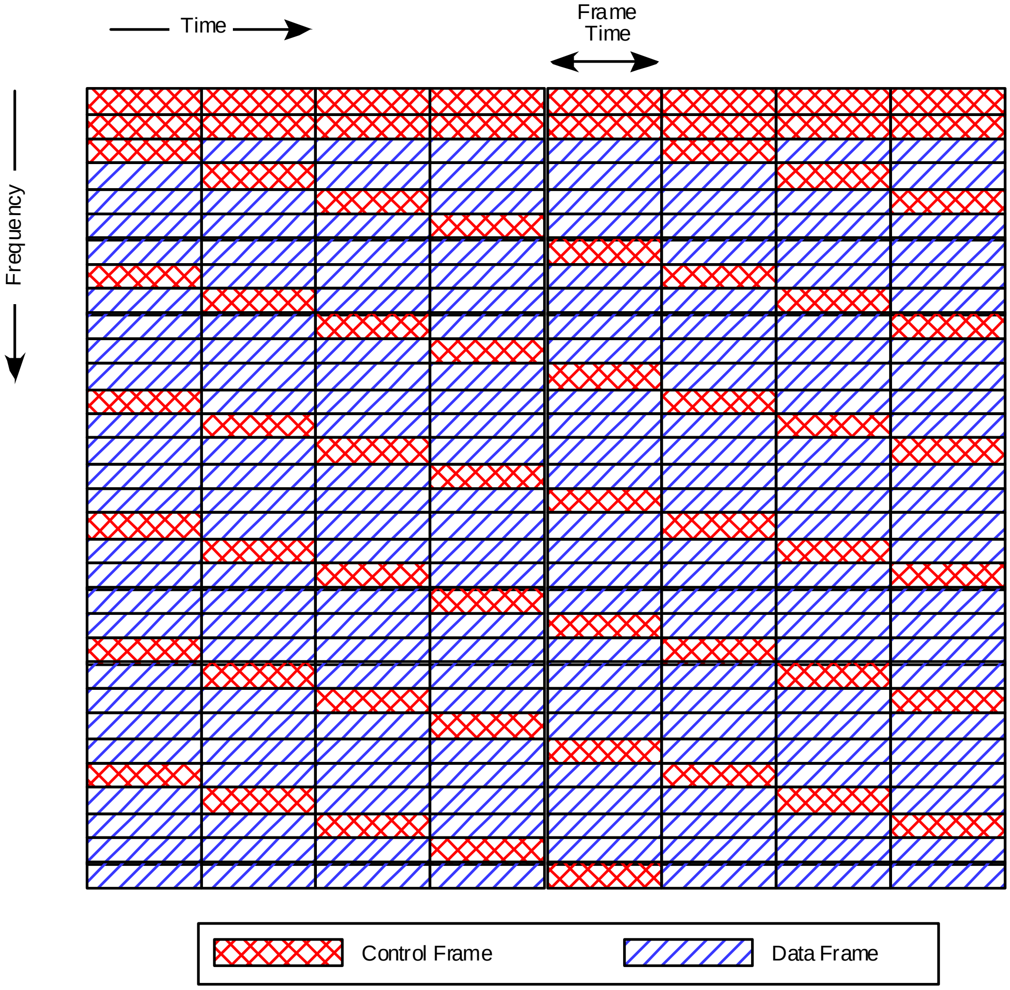


Figure 243—Superframe Layout

8.3.6.4 OFDM PHY Layer for license-exempt bands

8.3.6.4.1 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 8.3.6.4.2.3.1).

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 183.

Table 183—Mandatory and optional modes

Mode	Access method	FFT size	Status
A	TDMA	64	Mandatory
B	TDMA	256	Mandatory
C	OFDMA	2048	Optional

In order for a system to comply with this standard, it shall implement both mode A and mode B and may implement mode C. A compliant device shall be capable of facilitating devices using either mode A or mode B, but need not be capable of facilitating both modes in the same configuration.

8.3.6.4.2 Common elements

8.3.6.4.2.1 Symbol Description

The cyclic prefixes T_g (see Figure 216) 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 μs. If a fraction provides a time-duration below 750ns or above 6 μs for a given FFT size and channelization, this fraction does not have to be implemented (see Table 172).

In addition to the PMP frame structure in clause 8.3.6.2.1, an optional frame structure (see Figure 244) is defined to facilitate mesh networks.

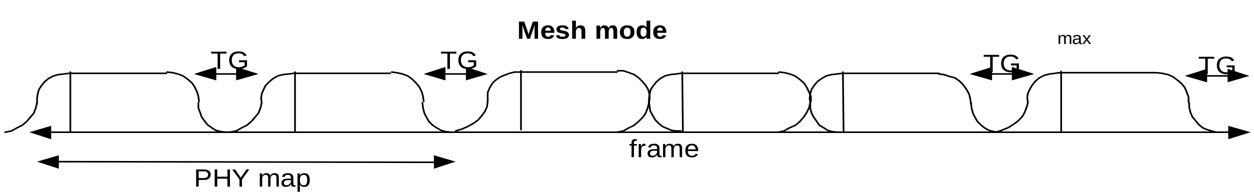


Figure 244—Mesh Frame Structure (optional)

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.

8.3.6.4.2.2 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 245 and consists of multiple short training symbols and 1 long training symbol.

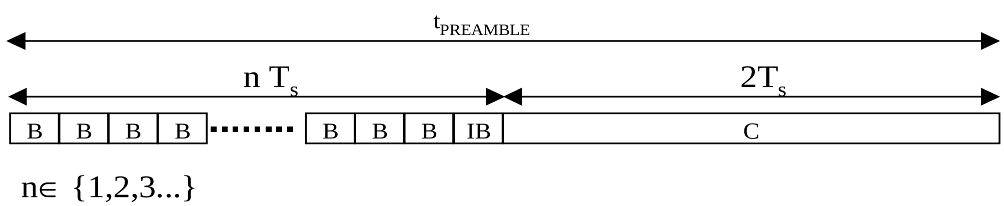


Figure 245—Complete Preamble Structure

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):

$$S16_{-7,7} = \{0, 1+j, -1-j, 1+j, -1-j, -1-j, 1+j, 0, -1-j, -1-j, 1+j, 1+j, 1+j, 1+j, 0\} \tag{25}$$

Equivalently, the same 12 carriers are spaced at 4 times the inter-carrier spacing with an FFT size of 64:

$$S16_{-31,31} = \begin{array}{l} \{0, 0, 0, 0, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0\ldots \\ 0, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 0, 0, 0, 0\} \end{array} \tag{26}$$

$$S16_{-127,127} = \begin{array}{l} \{ \quad 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1+j, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, \ldots \\ -1-j, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1+j, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, \ldots \\ -1-j, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1-j, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0\ldots \\ 1+j, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, \ldots \\ -1-j, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1-j, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, \ldots \\ 1+j, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1+j, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, \ldots \\ 1+j, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1+j, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, \ldots \\ \quad 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0\} \end{array} \tag{27}$$

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 184 summarizes the offset recovery capabilities for different channel bandwidths.

Table 184—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):

$$S64_{-31,31} = \begin{array}{l}\{0, 0, 0, 0, 0, 1, 1, -1, -1, 1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, 1, 1, 1, 1, 0, \ldots \\ \;1, -1, -1, 1, 1, -1, 1, -1, 1, -1, -1, -1, -1, -1, 1, 1, -1, -1, 1, -1, 1, -1, 1, 1, 1, 1, 0, 0, 0, 0, 0\}\end{array}$$

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 246.

I

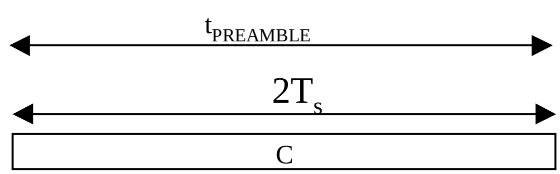


Figure 246—Shortened preamble: Long traing symbol with large GI

8.3.6.4.2.3 Transmitter Requirements

8.3.6.4.2.3.1 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 ETSI is actively investigating this posibility for the upper HIPERLAN/2 band. The set of valid operating channel numbers by regulatory domain is defined in Table 185. The channels in parenthesis are optional, the others are mandatory.

Table 185—Channelization

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)
USA	U-NII upper 5.725-5.825	298, 306, 314, 322	(292), 296, 300, 304, 308, 312, 316, 320, 324,(328)	(293), (295), (297), (299), (301), (303), (305), (307), (309), (311), (313), (315), (317), (319), (321), (323), (325), (327)
Europe	ETSI upper 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)

Figure 247 shows the channelization scheme which shal be used with this standard in the FCC U-NII bands. 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.

Figure (*to be added later*) shows the channelization scheme which should be used in the ETSI HIPERLAN/2 upper band. This band may accomodate up to 9 channels of 20MHz or 22 channels of 10MHz plus two optional 10MHz channels at the band edge. With the optional 5MHz channelization, 42 channels may be used.

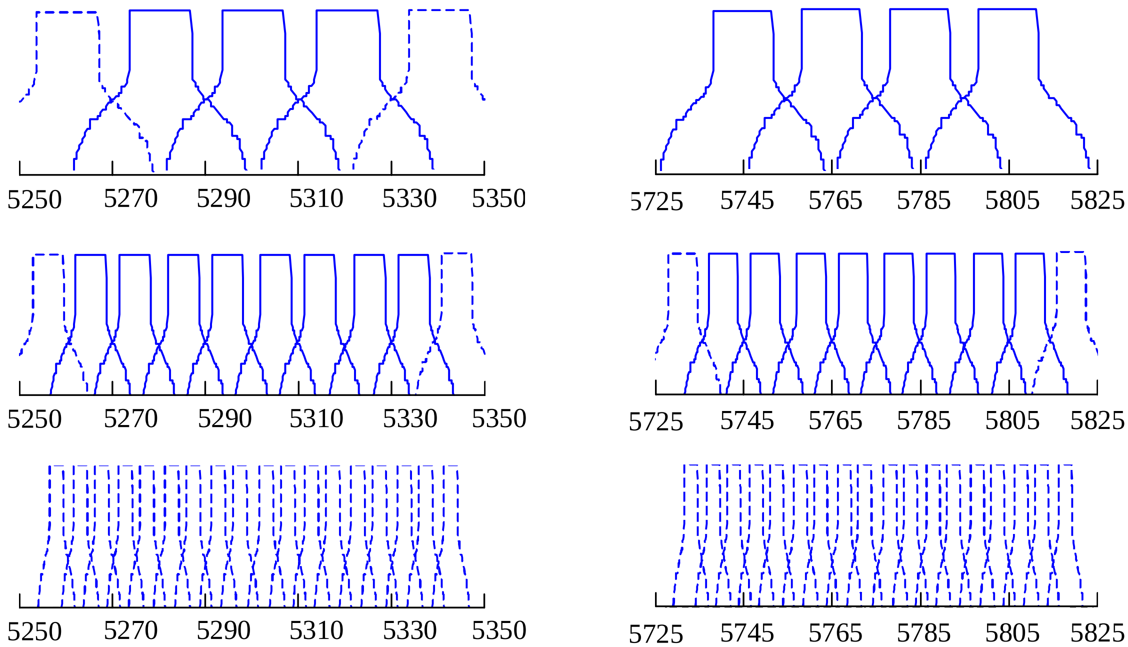


Figure 247—U-NII Frequency plan

8.3.6.4.2.3.2 Transmit spectral mask

The transmitted spectral density of the transmitted signal shall fall within the spectral mask as shown Figure 248 and Table 186. 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.

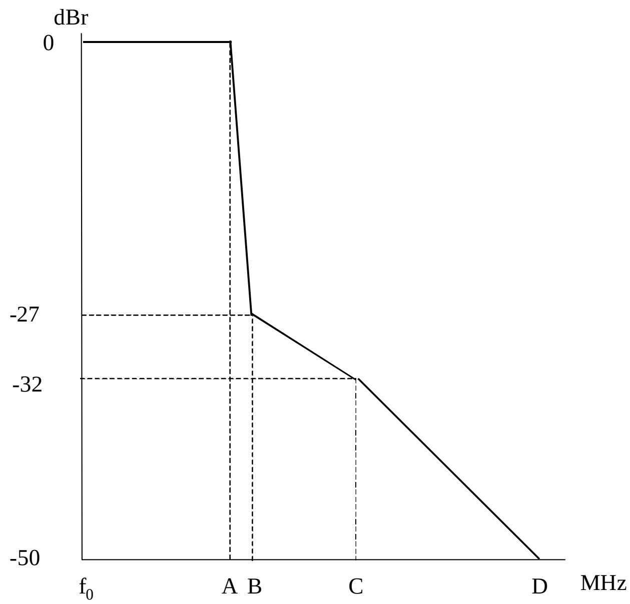


Figure 248—Transmit Spectral Mask (see Table 186)

Table 186—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

8.3.6.4.2.3.3 Transmit Power Level Control

The transmitter shall support monotonic power level control of 45dB minimum with resolution of 3dB.

8.3.6.4.2.3.4 Transmitter Linearity

Review alternate approaches and how transmitter quality handled in 802.11a/b and similar standards. One suggested option is:

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.

8.3.6.4.2.3.5 Transmitter Spectral Flatness

The average energy of the constellations in each of the n spectral lines shall deviate no more than the following:

Table 187—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.

8.3.6.4.2.3.6 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 802.11a clause 17.3.9.6.3. If this test is desired for 802.16.4, the definition can be copied straight from the 802.11a spec with the following addition:

For OFDMA modes, measurements will be taken with all subchannels active.

To separate EVM measurements for the BS and SS.

8.3.6.4.2.4 Receiver Requirements

8.3.6.4.2.4.1 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 188—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

8.3.6.4.2.4.2 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 188) 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 189—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?

8.3.6.4.2.4.3 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 190—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.

8.3.6.4.2.4.4 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.

8.3.6.4.2.4.5 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.

8.3.6.4.2.4.6 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)

8.3.6.4.2.5 Frequency Control Requirements

8.3.6.4.2.5.1 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.

8.3.6.4.2.5.2 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.

8.3.6.4.2.5.3 Phase Noise

Recommended phase noise mask for the SS and BS.

8.3.6.4.2.5.4 General Requirements

8.3.6.4.2.5.5 Temperature Range

To use BellCore temperature ranges:

Table 191—Operational Temperature Classes

Class	Range (^{o}C)	Environment
1	[0,40]	
2	[-20,50]	
3	[-30,70]	
4	[-40,85]	

8.3.6.4.2.5.6 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.

8.3.6.4.2.5.7 Diagnosis Features

??

8.3.6.4.2.6 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. Table 192 describes the mandatory and optional coding schemes:

Table 192—Channel Coding Schemes

FEC	Interleaving	Mode		
		A	B	C
Concatenated RS and CC with zero tailing	8.3.6.4.2.6.5.1	Mandatory 8.3.6.4.2.6.2.1	Mandatory 8.3.6.4.2.6.2.1	-
Concatenated RS and CC with tail biting	8.3.6.4.2.6.5.1	Optional 8.3.6.4.2.6.2.1	Optional 8.3.6.4.2.6.2.1	-
Convolutional with zero tailing	8.3.6.4.2.6.5.1	Optional 8.3.6.4.2.6.2.2	Optional 8.3.6.4.2.6.2.2	-
Convolutional with tail biting	8.3.6.4.2.6.5.1	Optional 8.3.6.4.2.6.2.2	Optional 8.3.6.4.2.6.2.2	-
Concatenated RS and CC with tail biting	8.3.6.4.2.6.5.2	-	-	Mandatory 8.3.6.4.2.6.2.1
Turbo Product Codes	8.3.6.4.2.6.5.2	Optional 8.3.6.4.2.6.3	Optional 8.3.6.4.2.6.3	Optional 8.3.6.4.2.6.3
Turbo Convolutional Codes	8.3.6.4.2.6.5.2	Optional 8.3.6.4.2.6.4	Optional 8.3.6.4.2.6.4	Optional 8.3.6.4.2.6.4

8.3.6.4.2.6.1 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 249. 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.

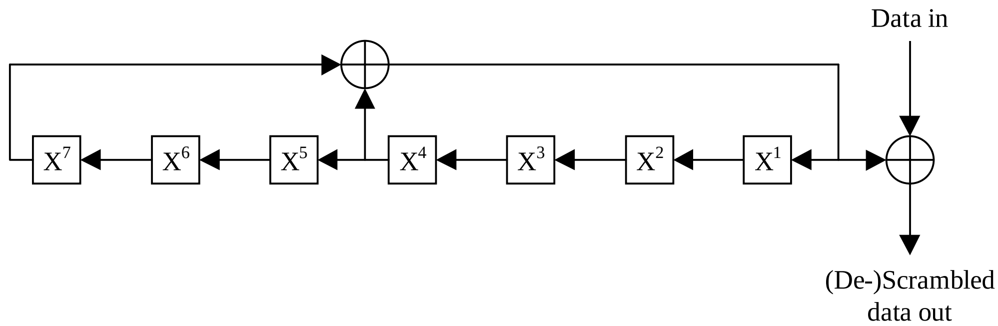


Figure 249—Data Randomizer

8.3.6.4.2.6.2 FEC

8.3.6.4.2.6.2.1Concatenated Reed-Solomon - Convolutional Coding

See clause 8.3.6.3.2.1.2.

The following amendments apply:

Code rates of 1/2 and 3/4 apply to BPSK. The coding rates for BPSK are described in Table 195 and Table 196.

8.3.6.4.2.6.2.2Convolutional encoder (Optional)

For 64-FFT and 256-FFT a convolutional encoder as descibed in clause 8.3.3.1.5.2.2 can be used instead of the concatenated RS and convolutional coding.

8.3.6.4.2.6.3 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 8.3.6.3.3.2.2.2 and 8.3.6.3.4.2.2.2.

8.3.6.4.2.6.4 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 250 illustrates the overall encoding process.

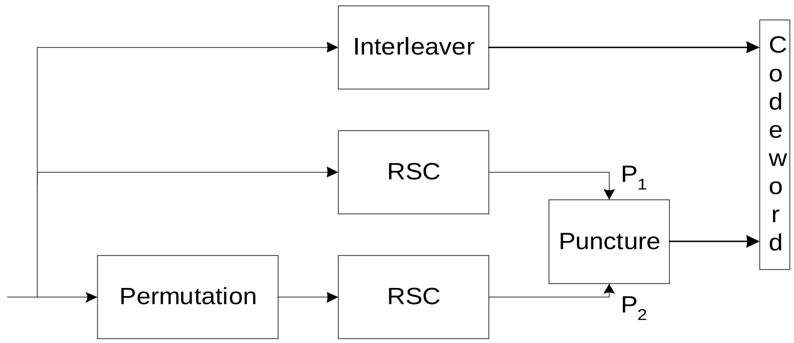


Figure 250—Turbo Encoder

The RSC coder is shown in Figure 251.

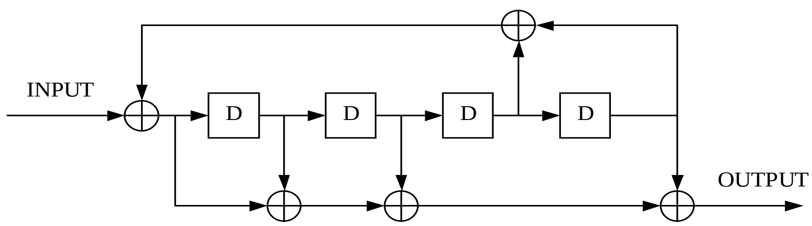


Figure 251—RSC Encoder

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 193 lists the puncture patterns used to implement these rates.

Table 193—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.

8.3.6.4.2.6.5 Interleaving

8.3.6.4.2.6.5.1Mode A and Mode B

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:

$$m = (N_{CBPS}/16) \cdot k_{mod\ 16} + floor(k/16) \qquad k = 0, 1, \ldots, N_{CBPS} \tag{28}$$

The second permutation is defined by the rule:

$$j = s \cdot floor(m/s) + (m + N_{CBPS} - floor(16 \cdot m/N_{CBPS}))_{mod\ s} \qquad k = 0, 1, \ldots, N_{CBPS} \tag{29}$$

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:

$$m = s \cdot floor(j/s) + (m + floor(16 \cdot j/N_{CBPS}))_{mod\ s} \qquad j = 0, 1, \ldots, N_{CBPS} \tag{30}$$

The second permutation is defined by the rule:

$$k = 16 \cdot m - (N_{CBPS} - 1) \cdot floor(16 \cdot m/N_{CBPS}) \qquad k = 0, 1, \ldots, N_{CBPS} \tag{31}$$

The first permutation in the deinterleaver is the inverse of the second permutation in the interleaver, and conversely.

8.3.6.4.2.6.5.2Mode C

See clause 8.3.6.3.2.1.4 and 8.3.6.3.4.2.3.

8.3.6.4.2.6.5.3Turbo Convolutional Coding specific Interleaver

The size of the code permuter is equal to the information bits in a block (see ???, ??? and ???). 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:

$$I(0) = C$$
$$I(x) = [I(x-1) + p]_{mod\ N} \tag{32}$$

8.3.6.4.2.7 Control mechanisms

8.3.6.4.2.7.1 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.

8.3.6.4.2.7.2 Ranging

See clause 8.3.6.3.2.4.2.

8.3.6.4.3 Mode A - OFDM, 64 FFT

8.3.6.4.3.1 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 194, the DC carrier is numbered 0, whereas carrier numbers increase from the lowest to the highest frequency.

Table 194—Symbol Parameters

N_{FFT}	Parameter	Value	
64	N_{used}	52	
	Guard Carriers: Left, Right	6	5
	BasicConstantLocationPilots	{-21,-7,7,21}	

8.3.6.4.3.2 Channel Coding

8.3.6.4.3.2.1 FEC

8.3.6.4.3.2.1.1Concatenated Reed-Solomon - Convolutional Coding

See clause 8.3.6.4.4.2.1.1.

8.3.6.4.3.3 Control Mechanisms

8.3.6.4.3.3.1 Ranging

See clause 8.3.6.4.4.3.1.

8.3.6.4.3.3.2 Bandwidth Requests

See clause 8.3.6.4.4.3.2.

8.3.6.4.4 Mode B - OFDM, 256 FFT

8.3.6.4.4.1 OFDM Symbol Parameters

See 8.3.6.3.3.1 where applicable for 256-FFT. .

8.3.6.4.4.2 Channel Coding

8.3.6.4.4.2.1 FEC

8.3.6.4.4.2.1.1Concatenated Reed-Solomon - Convolutional Coding

In addition to Table 175, the following code rates are defined for BPSK in Table 195.

Table 195—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

8.3.6.4.4.3 Control Mechanisms

8.3.6.4.4.3.1 Ranging

See clause 8.3.6.3.3.3.1.

In the optional Mesh mode, the ranging and network entry shall be done in the control-slots.

8.3.6.4.4.3.2 Bandwidth requests

See clause 8.3.6.3.3.3.2.

8.3.6.4.5 Mode C - OFDMA (optional)

See 8.3.6.3.4.1 where applicable for 2048-FFT. 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 8.3.6.3.4.1.2.

8.3.6.4.5.1 Channel Coding

8.3.6.4.5.1.1 FEC

8.3.6.4.5.1.1.1Concatenated Reed-Solomon - Convolutional Coding

In addition to Table 180, the following code rates are defined for BPSK in Table 195.

Table 196—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

8.3.6.4.5.2 Control Mechanisms

8.3.6.4.5.2.1 Ranging

See clause 8.3.6.3.4.3.1.

8.3.6.4.5.2.2 Bandwidth requests

See clause 8.3.6.3.4.3.2.

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A. Annex to systems between 2 and 11 GHz

A.1 Turbo product codes

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 252 shows the structure of the resultant block.

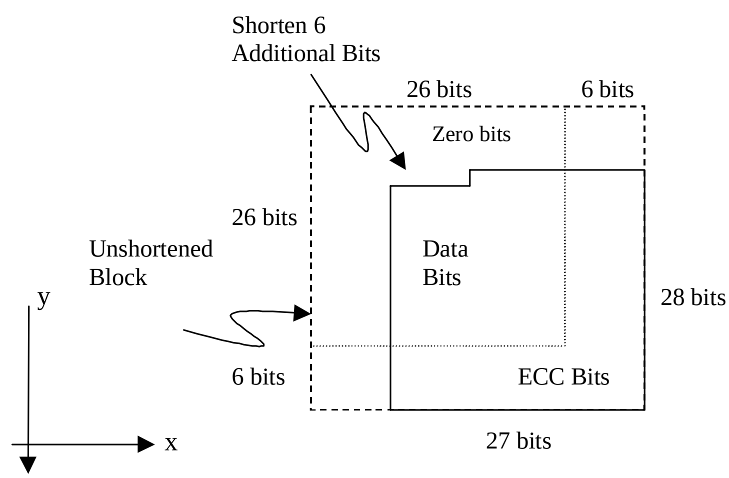

Figure 252—Structure of Shortened 2d Block

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) [B37]
The modified Chase algorithm [B35]
The BCJR algorithm [B36],

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 253 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).

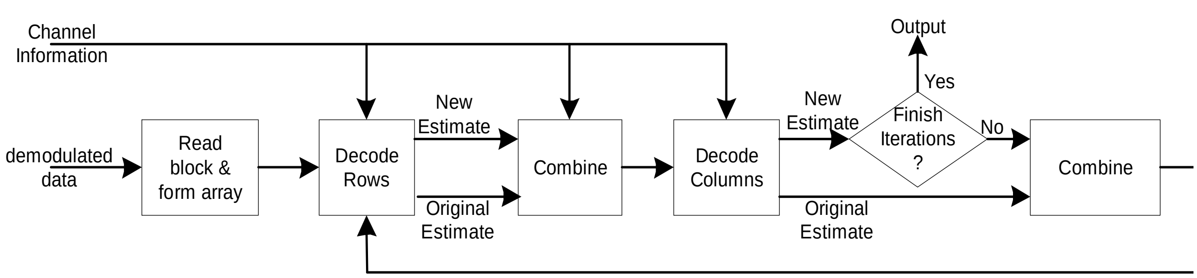

Figure 253—2-D TPC Decoding Procedure

It can easily be seen from Figure 253 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

A.2.1 Coexistence in middle UNII: Interference and Sharing Mechanisms

A.2.1.1 General

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).

The goal of this Section is to identify (and where possible quantify) the interference requirements and identify mechanism that can be used by the Wireless HUMAN Standard-based systems to successfully share spectrum and geographical location with the likely to be encountered diverse systems.

A.2.1.2 EESS SAR interference requirement

This Wireless HUMAN interference requirement is considered first as it stems from the 1997 World Radiocommunications Conference (WRC '97) that allocated the 5250-5350MHz and 5350-5460 MHz bands on a world wide-primary basis to radiolocation services. These bands are currently also allocated on a world wide-primary basis to active space-borne sensors, including SARs (e.g., SAR 1-4). For the Characteristics of these SARs see Appendix 2 in ITU-R WP7C/126, "Analysis of Potential interference Between Spaceborne SARs and Wireless High speed Local Area Networks Around 5.3.GHz.". The "primary basis" classification means that it is a requirement that must be met by Wireless HUMAN Standard-based systems. The clauses that follow identify mechanisms that can be used to enable the Wireless HUMAN Standard-based systems to meet the interference requirements of EESS SAR sensors.

A.2.1.3 Antenna directivity to mitigate interference to EESS

What follows gives an indication of the interference that Wireless HUMAN based BFWA systems can cause to SARs operating in Middle U-NII band, and identify means for minimization of this interference. 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 197 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 -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 spaceborne 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 197—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 197 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.

It should also be noted that antenna characteristics vary from antenna to antenna and from manufacturer to manufacturer. Also, the physical environment at the antenna mounting site can degrade the off-beam lobes of many antennas, especially omni-directional and directional antennas with no/small backplanes. Therefore, designers/installers should not assume published patterns and antenna range measurements are totally reliable.

A.2.1.4 DFS to mitigate interference

As frequency planning is not practical in licensed-exempt bands, Dynamic Frequency Selection (DFS) can be used to avoid assigning a channel to a channel occupied by another system. DFS action will be based on Subscriber Unit (SS) and/or Access Point (AP) received signal measurements (during idle channel conditions) and comparing the measurements to a threshold based on the required C/I parameter.

Considering that a Wireless HUMAN-based devices will cohabit the licensed exempt bands with other Wireless HUMAN-based devices and non-Wireless HUMAN-based devices, detailed DFS parameter description is needed for intra- and inter-system interference estimations. This inter-system interference includes coexistence considerations for such WRC 1997 globally primary assignments as Earth Exploratory Satellite Service SARs, and military radars. Wireless HUMAN-based intra-system interference estimates are also needed to assure that the desired level of performance is also possible.

A.2.1.5 Transmitted power control to mitigate interference

With power control, the EIRP of some transmitters will be below the permissible level. Therefore, an estimate of total interference within the footprint could be as much as 'n' dB below the reference value. However, this assumption might well be negated as the subscriber population grows and interference between neighbors increase-in which case, the transmitted EIRP could remain near the legal limit.

A.2.1.6 Antenna polarization to mitigate interference

The margin calculation in Table 197 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.2.1.7 No-transmit mode when a Spaceborne SAR is in the area

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 stations, 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. The main concern with Ephemeris calculations is the ability to maintain a reliable muting process over time. To do so requires as a minimum: 1) monitoring individual stations to assure that muting is taking place at the correct time, 2) maintenances process that assure prompt repair of faulty stations, 3) capability to update Ephemeris algorithms should orbital/time corrections be required, 4) adding new satellites as they are launched.

A.2.1.8 Other ways to mitigate interference

A.2.2 Channel and Interference Model

A.2.2.1 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 254. The specific blocks are described in subsequent clauses.

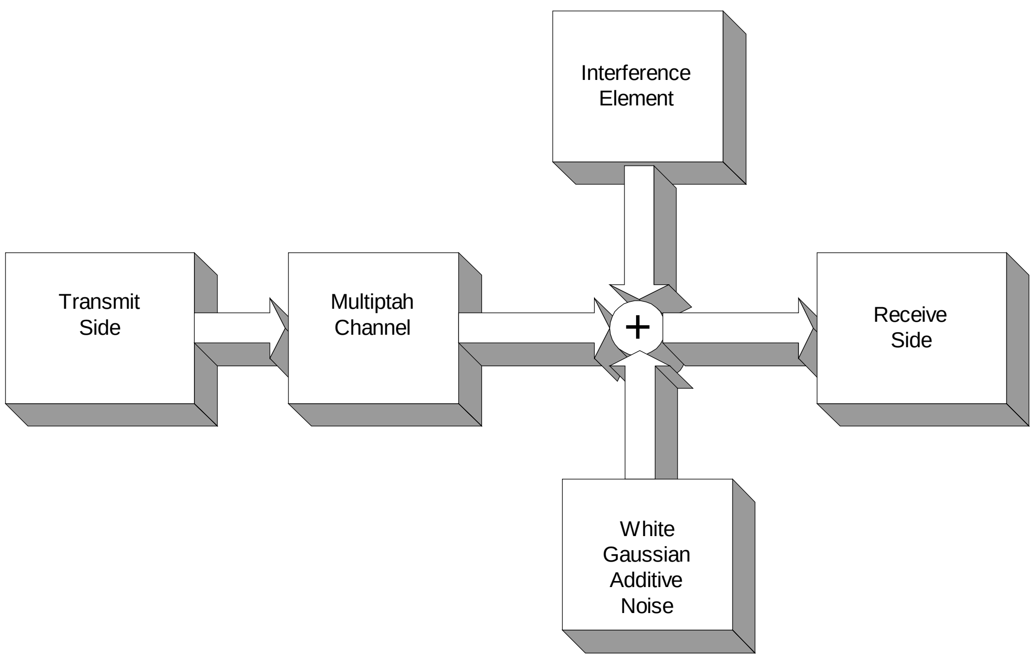

Figure 254—Basic Model

A.2.2.2 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 [B41] or [B42].

The following, taken from [B38], 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 255, the exponential power profile and a single realization of a channel are shown.

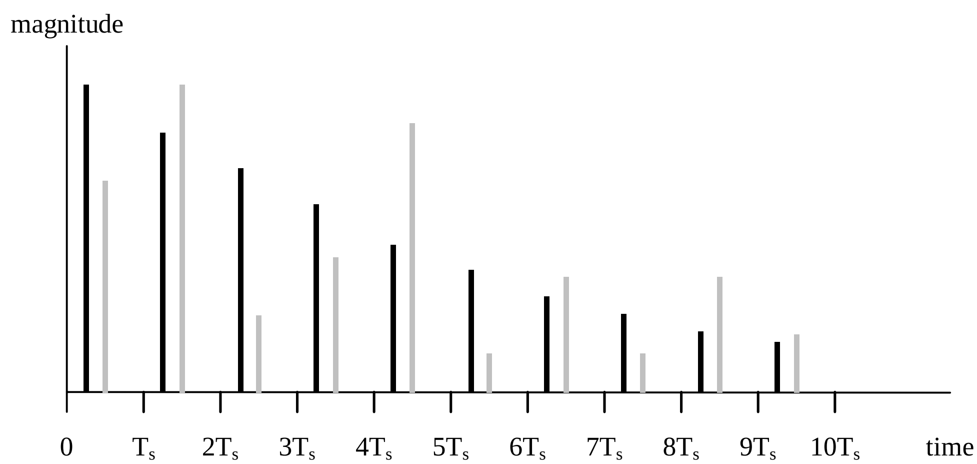

Figure 255—Power Profile (black) and realization (gray) (time staggered for clarity only)

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.2.2.3 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 256. Section A2.2.3.1 gives the underlying assumptions for the interference source. From those assumptions, the timing, power and signal descriptions are derived. They are described in clause A2.2.3.2. Section A2.2.3.3 describes the procedure of generating the interference signal.

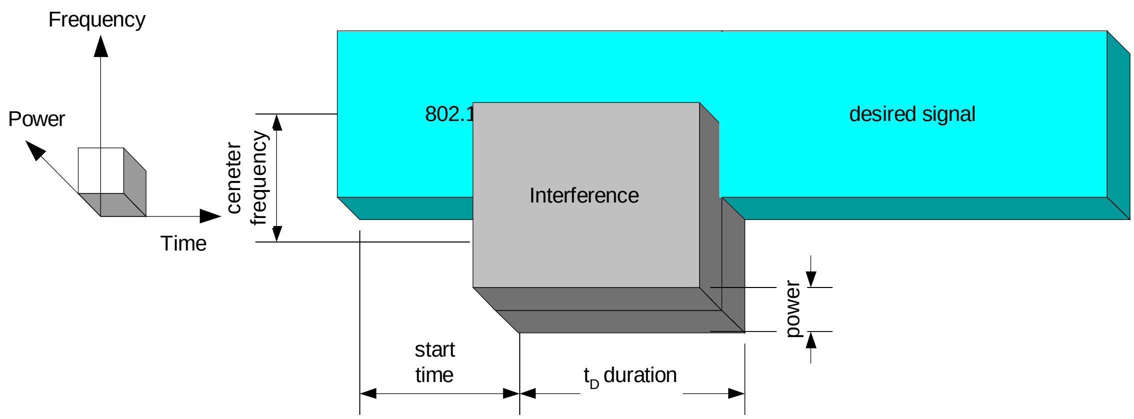

Figure 256—Interference Model

A2.2.3.1 Basic assumptions

Here we shall assume that the interferer is a 802.11a like signal (see [B43]). 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 [B44], 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.

A2.2.3.2 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:

$$H(f) = \begin{cases} 1 & |f| < (1-\beta) f_c \\ 1/2\left[1 - \sin\frac{\pi}{2}\left(\frac{f}{f_c} - 1\right)\Big/\beta\right] & (1-\beta) f_c \le |f| < (1+\beta) f_c \end{cases}$$

A2.2.3.3 Generating Procedure

The signal generation is depicted in Figure 257. The procedure for generating the interference is given below.

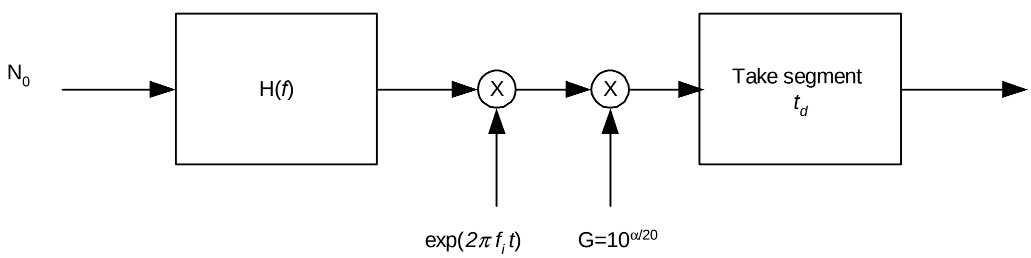

Figure 257—Interference Signal Generation

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.2.2.4 Radio Impairments

The radio impairments models consist of phase noise models and power amplifier non-linearties.

A2.2.4.1 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:

$$v_{OUT} = v_{IN} / (1 + (|v_{IN}| / v_{SAT})^{2P})^{1/(2P)} \qquad , P = 2$$

A2.2.4.2 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 258.

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.

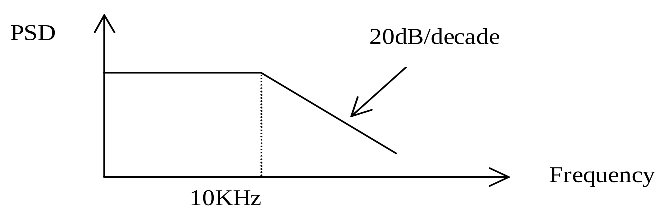

Figure 258—Phase Noise PSD

A.3 MIMO Systems and Beamforming Antenna Technology

In this clause, we will cover application of multiple input / multiple output (MIMO) and beamforming antenna technology.

A.3.1 Introduction

FWA system 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 will affect 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)
- Spatial diversity receivers (demodulation and coherent combining of one or more antenna/receiver sources)

In 1999 and 2000 two important paper 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 [B32]. 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 the 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 198.

Table 198—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 [B33]. As with the previously noted 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 [B34] that diversity improvement for 2 branches 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 of multiple diversity branches to reconstruct the receive signal.

In conjunction with Multiple Input technology, Multiple Output technology (e.g. Alamouti antenna diversity algorithm described in the previous clause) seeks to create additional "artificial" diversity branch energy in the received signal.

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. Beamforming antennas will provide spatial reuse factors will typically result in 2x to 4x increase in frequency efficiency.

- Compatibility with existing installed IEEE 802.16.3 subscribers meeting defined minimum requirements (MIMO/beamforming upgrade at a Base Station supports the current installed base)
- Consistent with industry requirements to reduce the cost of subscribers. Add complexity at the Base Station and reduce complexity at the subscriber
- Conform to all Regulatory requirements for EIRP, spurious emissions, and antenna beam restrictions (side lobe and front to back requirements)

The following clauses will discuss the application of MIMO and beamforming. Mutiple input processing will be covered seperatly from mutiple output.

Note: These techniques can be applied to both FDD and TDD system. When specific processing for a type of duplexing method is required, this will be noted in the 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 the previous clause, directional antennas at the subscriber greatly reduce multi-path and resulting delay spread. The 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:

- Increase transmission gain and reduce cost and complexity of transmit PA (subscriber and basestation)Reduce interIference from subscribers in adjacent cells. Increase 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 2 or more transmission paths 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 system Base Stations to enhance mobile subscriber reception. Time diversity (transmitting the same information at different times) has 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 have 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. The rate of scanning and selection must be performed at a rate much higher than the fade rate of the system. Selection diversity is shown Figure 259. 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.

Combining Diversity is shown in Figure 260. An active receiver is required for each antenna. The signals of each receiver are combined (co-phased and summed) using either a maximum ration criteria or by equal gain. 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.

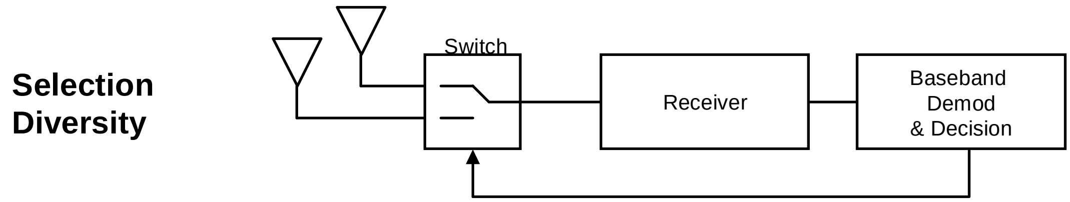

Figure 259—Selection Diversity Receiver

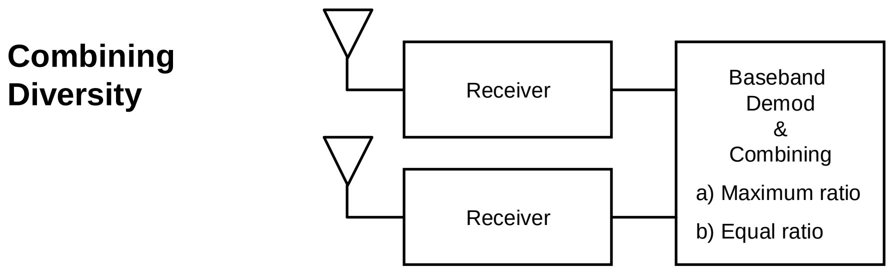

Figure 260—Combining Diversity Receiver

Selection diversity can readily be applied to both TDD and FDD systems. TDD systems have the added benefit that the selected diversity branch can also be used to improve transmission.

A.3.3 Multiple Output Systems

As previously discussed, the motivation for multiple output (MO) is to create and exploit a self-generated diversity branch in the processing of the system.

Given that the minimum requirements for Single Input Single Output (SISO) subscriber, the MO technique selected must be compatible with the minimum standards processing. It is anticipated that MO transmissions will 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 type of Multiple Output techniques are being investigated:

- The Alamouti antenna diversity algorithm
- Subscriber equalization delay diversity algorithm.

(Base Station would transmit the signal and a delayed replica at a delay that exceeds the channel delay spread ... Thus the equalizer would effectively act as a time domain combiner).

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 up/down link for FDD
- Modulation Complexity
- FEC Rate
- Beam/Combining parameters.

Figure 261 illustrates the concept of coordinating MAC/PHY with the beam forming antenna element. While this standard 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.

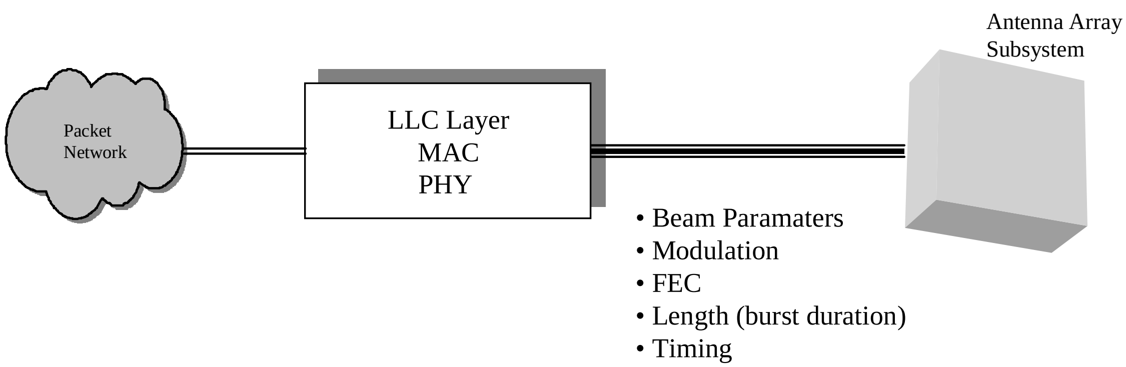

Figure 261—MAC/PHY Coordination concept with Beam Forming Antenna

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 262 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.

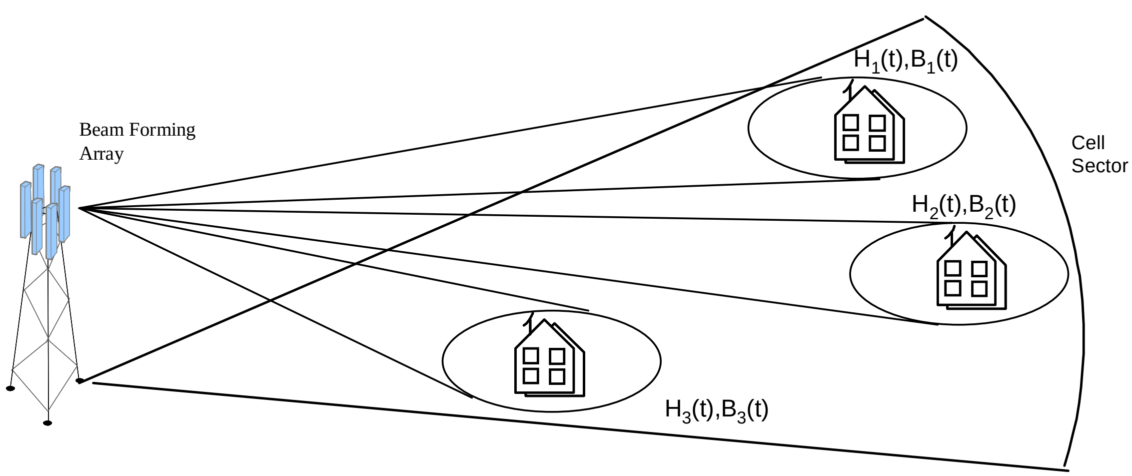

Figure 262—BS sector with 3 Subscribers

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.

The following diagram illustrates the beam forming burst concept for both FDD and TDD.

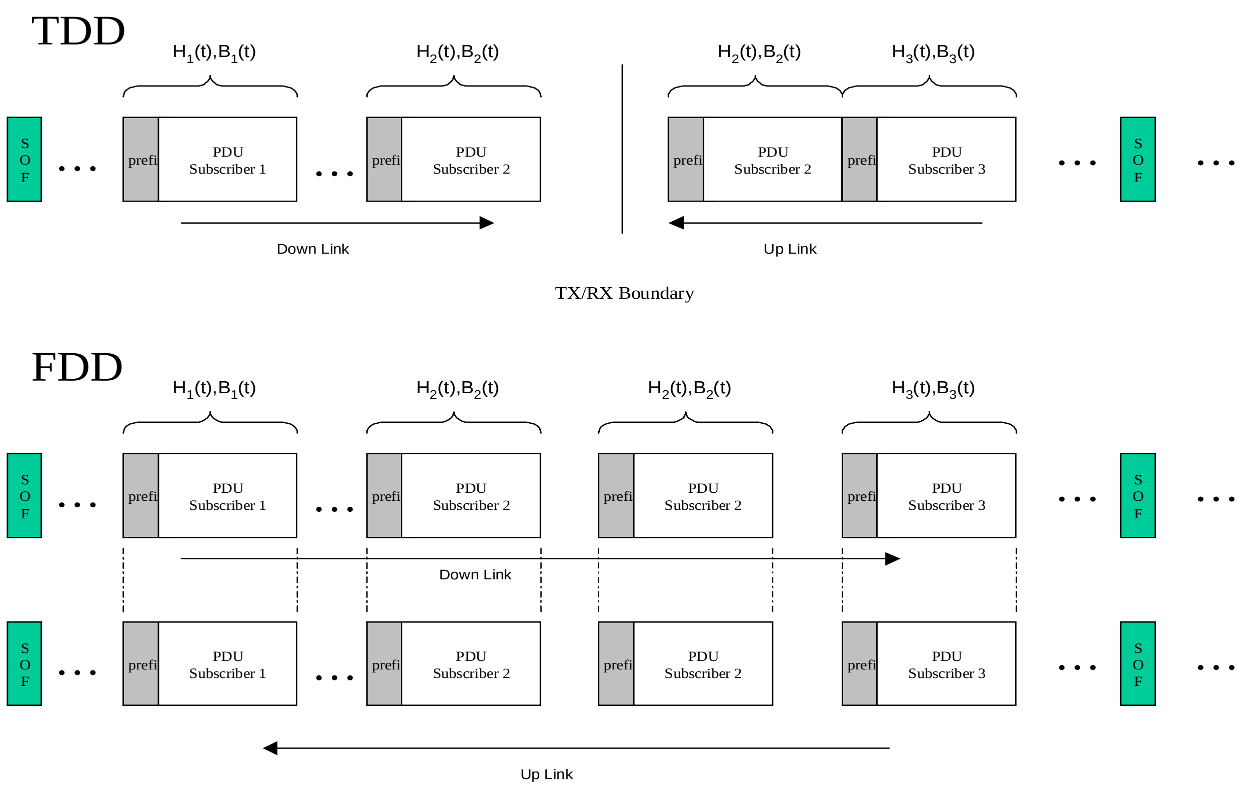

Figure 263—Beamforming Concept for TDD and FDD

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 Up/ Down Link
- Independent Up and Down Link beamforming. The system can support 2 independent formations of the beam on the up link frequency and the down link frequency (below)

FDD with Independent beam forming

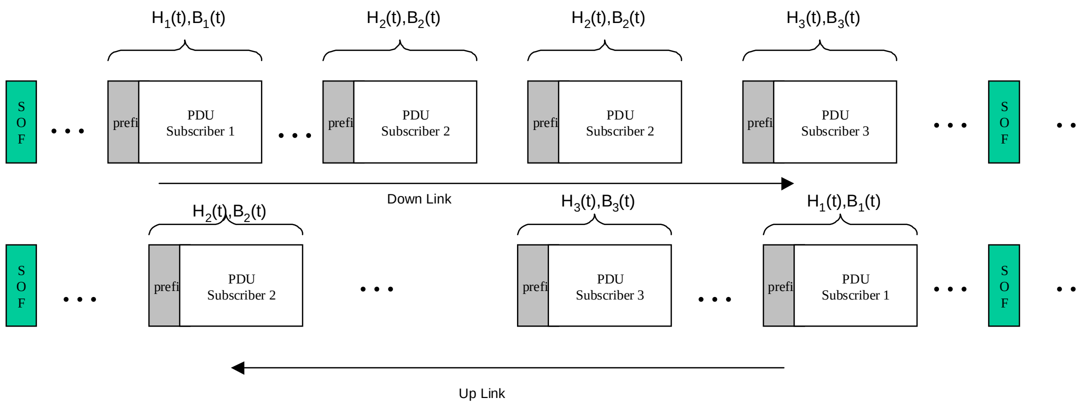

Figure 264—FDD with Independent UL/DL Beam Forming Example

These simple sequential cases can be expanded to advanced beam forming techniques to provide simultaneous multiple access to spatially independent users. A beam-forming 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 265. For this case, bursts to the subscribers that share the same beams.

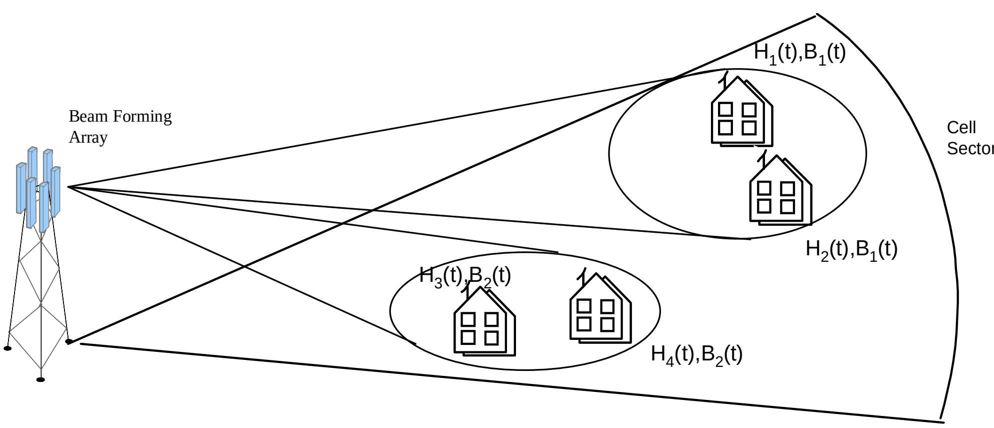

Figure 265—BS sector using Spacial Concatenated Communication

Figure 266 illustrates how packets are grouped (concatenated) and transmitted by based on physical proximity for a TDD Physical layer.

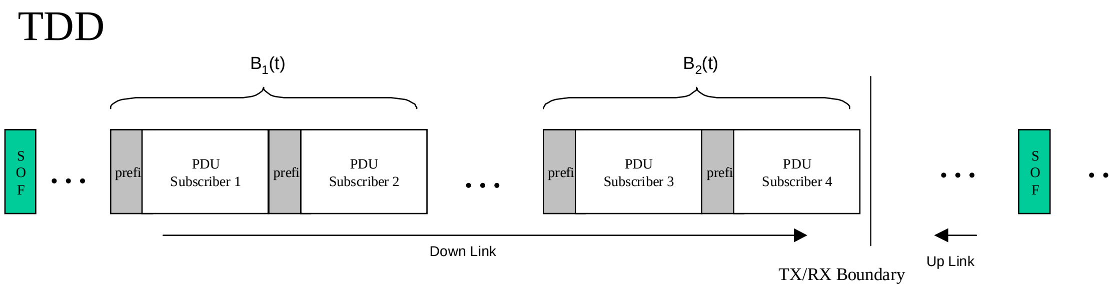

Figure 266—TDD with Concatenated Packet Transmission Example

The PHY based on block processing and burst packet formats meets all the requirements to support advanced antenna processing techniques. As the standard progresses we must address the following issues in greater detail:

- Beam forming Transition/ Set-up time definition in the MAC (passing parameters to 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

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 199.

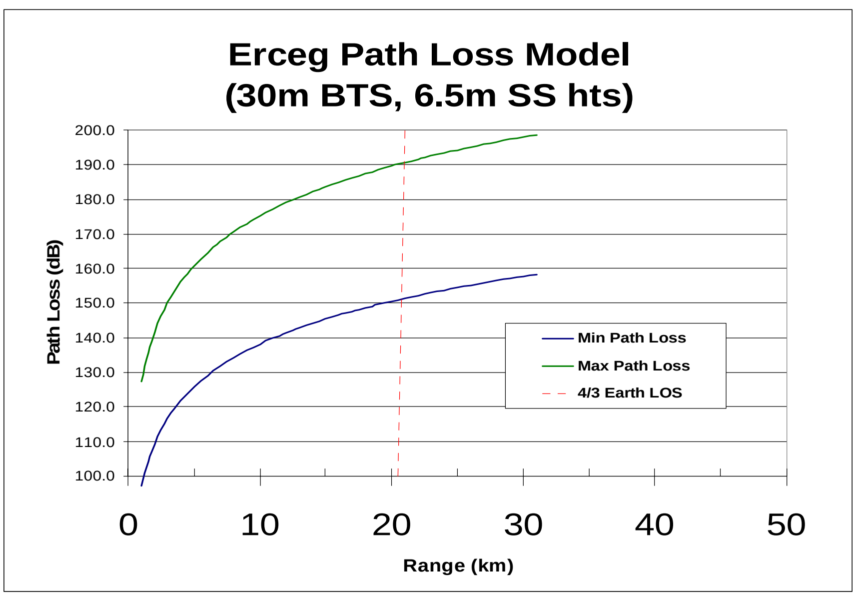

Figure 267—Path Loss Model

Table 199 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 199—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 199, we have generated link budget for various scenarios. Some typical results are for QPSK and 64 QAM that are presented in the following Table 200 and Table 201, respectively. These results assume very similar scenarios for SC-FDE and OFDM systems.

Table 200—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 201—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 OFDM/OFDMA - FDD/TDD Co-existence

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

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 268).

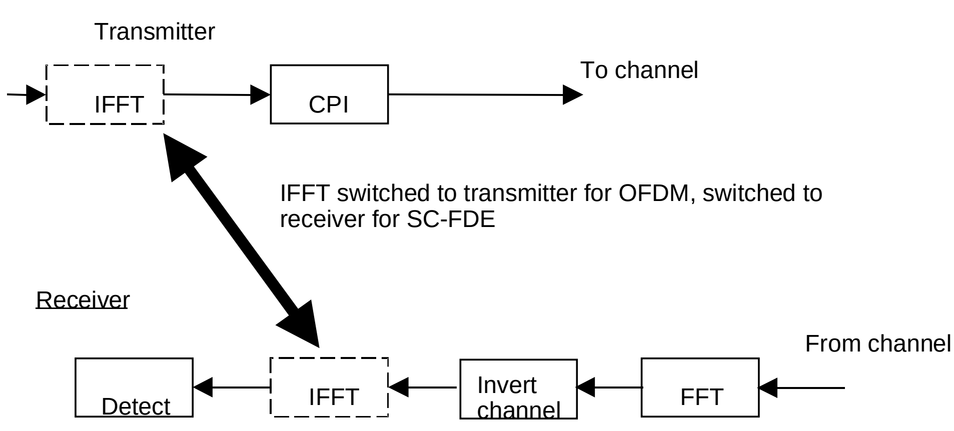

Figure 268—OFDM and SC-FDE ‘convertible’ Modem

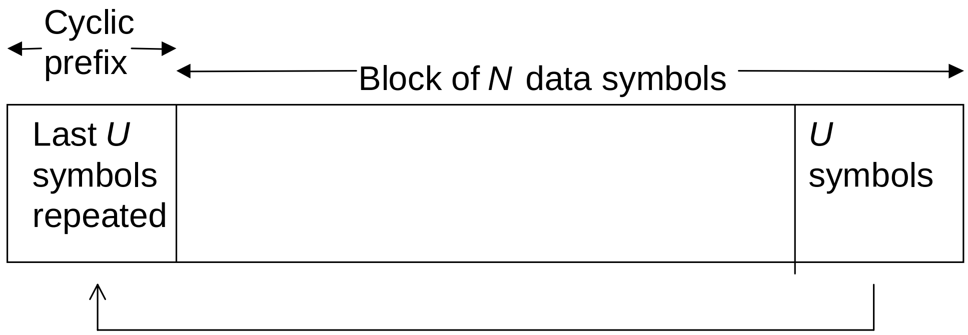

Figure 269—Block Processing in FDE

As shown in Figure 269, 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.