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Re:	
Abstract	Baseline OFDM mode for PHY amendment to 802.16 standard for licensed frequencies between 2 and 11 GHz
Purpose	Addition to 802.16.3-01/13
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7 OFDM PHY Layer

7.1 Introduction

The following physical layer (PHY) specification is 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 frequency band. In addition, this physical layer was 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 PHY described in this clause is based on OFDM (Orthogonal Frequency Division Multiplex) modulation, and is described in terms of time/frequency mapping, which depending on the selected mapping parameters, can support Time Division Multiple Access (TDMA) as well as Orthogonal Frequency Division Multiple Access (OFDMA) [1], [2]. 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. An implementation in compliance with this standard shall implement at least one of the two mandatory time/frequency maps.

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. As the modulation is implemented using Discrete Fourier Transforms (FFT), the modes are designated by the FFT size, ranging from 64 for low bandwidth channels, up to 4096 where the FFT size is an artificial parameter equal to the smallest power of two above the number of carriers. The number of carriers used for conveying data typically amounts between 83% and 95% of the FFT bins. Another parameter controlling the multipath mitigation capability, at expense of overhead, is the time-domain “guard interval”. The size of the guard interval is programmable to 1/4, 1/8, 1/16, 1/32 of the FFT interval duration.

7.2 System Considerations

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.

7.2.1 Duplexing

Frequency division duplex (FDD), half-duplex frequency division (H-FDD) and time division duplex (TDD) modes provide for bi-directional operation.

7.2.2 Multiple Access

In a point to multipoint (P-MP) system, the downstream (DS) and upstream (US) access to shared resources can be handled differently. In the DS, a base station (BS) can manage (schedule) resources, while in the US 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.

7.2.3 Transmission Stream

Transmissions may be organized in either a burst or continuous mode. In a packet switched system, both DS and US links operate in a burst mode. Some designs use a continuous mode in the DS, although this approach is problematic when incorporating adaptive antenna arrays for spatial processing because of the limitations associated with a broadcast mechanism.

7.3 OFDM PHY Parameters

The carrier spacing, frequency extent, and guard time must be chosen to meet specific bit rate and delay spread requirements.

7.3.1 Enhanced Features

The use of antenna arrays and transmit diversity techniques can provide significant improvements in system performance or system capacity. These enhancements must be considered in the initial design so that their full potential can be realized.

7.4 OFDM PHY Concept

7.4.1 PHY Functionality

7.4.2 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 OFDM symbols.

This PHY specification addresses the definition of each of the blocks shown in Figure 1. This figure is not meant to imply a specific method or manner of implementation.

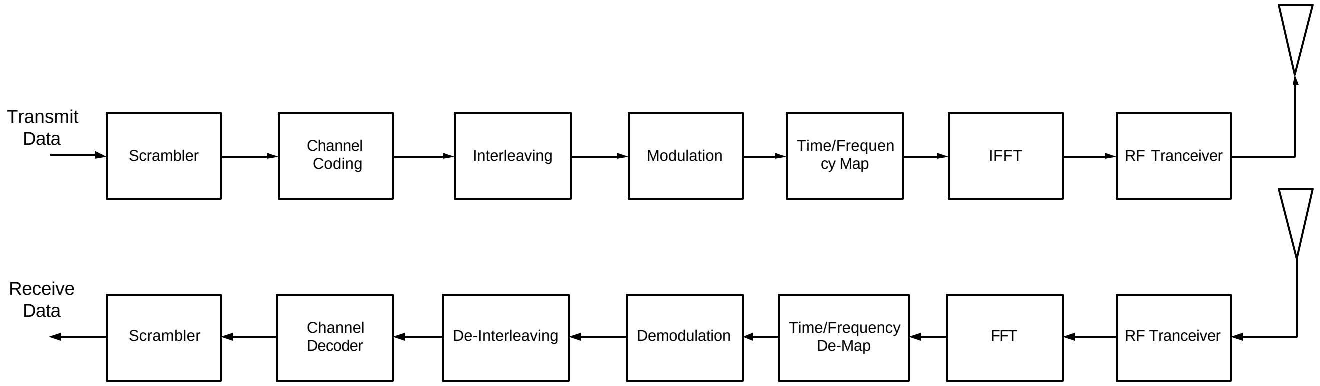

Figure 1: Generic OFDM PHY Block Diagram

7.4.3 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.

7.4.4 Channel Coding

The performance in different channel conditions (other than 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.

7.4.5 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 bits, which may occur on OFDMA/OFDM carriers due to channel conditions.

7.4.6 Modulation

Modulation is the means for mapping digital data to discrete or analog symbols to efficiently utilize the available channel bandwidth. The goal is to transfer data with a given reliability within transmit power and receiver complexity constraints. This can be done using a single carrier or multiple carriers. For single carrier systems, an equalizer is required to compensate for any distortion resulting from a non-ideal frequency response of a channel. Alternatively, the available channel bandwidth can be subdivided into a number of carriers such that the frequency response for each carrier is nearly ideal. Using OFDM, a channel is defined as consisting of all carriers. Using OFDMA, sub-channels are defined as a fraction of the available carriers.

When using a multi-carrier modulation, each carrier can be modulated by changing its amplitude and phase.

7.4.7 Time/ Frequency Map

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 it's specified sub-carriers.

7.4.8 Frequency and Time Domain Processing

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

7.4.9 RF Transceiver

The discrete-time signal is converted to an analog waveform and mixed to an 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.

7.5 OFDM Symbol Parameters

7.5.1 Introduction

The OFDM symbol duration, or the related carrier spacing in frequency, is the major design parameter of an OFDM system. The symbol duration is composed of the FFT interval and of the Guard Interval (GI) (see clause 7.5.2). The Guard Interval, which constitutes an overhead, is closely related to the multipath delay spread parameter. In order to keep the overhead of the GI low, there is an interest in increasing the FFT interval duration as much as possible. On the other hand, excessive duration of the FFT interval affects adversely the sensitivity of the system to phase noise of the oscillators. For these reasons, the OFDM PHY can be configured to FFT interval durations ranging from about ten microseconds to hundreds of microseconds. The carrier spacing ranges, correspondingly, from less than one kilohertz to tens of kilohertz.

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:

$$BWEfficiency = \frac{F_s}{BW} \cdot \frac{N_{used}}{N_{FFT}} = \frac{\Delta f \cdot N_{used}}{BW}$$

in which

BW	Channel bandwidth (Hz)
F_s	Sampling frequency (Hz)
Δf	Carrier spacing (Hz)
N_{used}	Number of carriers used in the FFT
N_{FFT}	FFT size

The Bandwidth efficiency is designed to be between 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:

$$F_s = BWEfficiency \cdot BW \cdot \frac{N_{FFT}}{N_{used}}$$

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 F_s. The carrier spacing is, therefore,

$$\Delta f = \frac{F_s}{N_{FFT}}$$

The number of carriers utilized is usually only about 83% of the FFT bins. 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 FFT interval duration is related to carrier spacing by

$$T_b = \frac{1}{\Delta f} = \frac{N_{FFT}}{F_s}$$

This specification allows for FFT sizes 64, 128, 256, 512, 1024, 2048, 4096. A compliant device shall implement either 256 FFT with TDMA, or alternatively 2048 FFT with OFDMA for any bandwidth.

The following tables give some calculation of the Carrier Spacing, Symbol Duration and Guard Interval duration for different masks. For FFT modes 256 and above, the sampling frequency is defined as $F_s = BW \cdot 8/7$. When using the 64, 128 FFT sizes, the sampling rate in the MMDS and WCS masks is $F_s = BW$.

		OFDM				**OFDMA**			
BW	N_{FFT}	64	128	**256**	512	512	1024	**2048**	4096
1.5	Δf (kHz)	23 7/16	11 23/32	**6 51/61**	3 28/67	3 8/23	1 60/89	**36/43**	18/43
	BW*efficiency*	82.81%	80.47%	**91.60%**	91.37%	94.64%	94.64%	**94.64%**	94.64%
	T_b (us)	42 2/3	85 1/3	**146 2/7**	292 4/7	298 2/3	597 1/3	**1194 2/3**	2389 1/3
	T_g/T_b =1/32	1 1/3	2 2/3	**4 4/7**	9 1/7	9 1/3	18 2/3	**37 1/3**	74 2/3
	1/16	2 2/3	5 1/3	**9 1/7**	18 2/7	18 2/3	37 1/3	**74 2/3**	149 1/3
	1/8	5 1/3	10 2/3	**18 2/7**	36 4/7	37 1/3	74 2/3	**149 1/3**	298 2/3
	1/4	10 2/3	21 1/3	**36 4/7**	73 1/7	74 2/3	149 1/3	**298 2/3**	597 1/3
3	Δf (kHz)	46 7/8	23 7/16	**13 43/64**	6 51/61	6 39/56	3 8/23	**1 60/89**	36/43
	BW*efficiency*	82.81%	80.47%	**91.60%**	91.37%	94.64%	94.64%	**94.64%**	94.64%
	T_b (us)	21 1/3	42 2/3	**73 1/7**	146 2/7	149 1/3	298 2/3	**597 1/3**	1194 2/3
	T_g/T_b =1/32	2/3	1 1/3	**2 2/7**	4 4/7	4 2/3	9 1/3	**18 2/3**	37 1/3
	1/16	1 1/3	2 2/3	**4 4/7**	9 1/7	9 1/3	18 2/3	**37 1/3**	74 2/3
	1/8	2 2/3	5 1/3	**9 1/7**	18 2/7	18 2/3	37 1/3	**74 2/3**	149 1/3
	1/4	5 1/3	10 2/3	**18 2/7**	36 4/7	37 1/3	74 2/3	**149 1/3**	298 2/3
6	Δf (kHz)	93 3/4	46 7/8	**27 11/32**	13 43/64	13 11/28	6 39/56	**3 8/23**	1 60/89
	BW*efficiency*	82.81%	80.47%	**91.60%**	91.37%	94.64%	94.64%	**94.64%**	94.64%
	T_b (us)	10 2/3	21 1/3	**36 4/7**	73 1/7	74 2/3	149 1/3	**298 2/3**	597 1/3
	T_g/T_b =1/32	1/3	2/3	**1 1/7**	2 2/7	2 1/3	4 2/3	**9 1/3**	18 2/3
	1/16	2/3	1 1/3	**2 2/7**	4 4/7	4 2/3	9 1/3	**18 2/3**	37 1/3
	1/8	1 1/3	2 2/3	**4 4/7**	9 1/7	9 1/3	18 2/3	**37 1/3**	74 2/3
	1/4	2 2/3	5 1/3	**9 1/7**	18 2/7	18 2/3	37 1/3	**74 2/3**	149 1/3
12	Δf (kHz)	187 1/2	93 3/4	**54 11/16**	27 11/32	26 11/14	13 11/28	**6 39/56**	3 8/23
	BW*efficiency*	82.81%	80.47%	**91.60%**	91.37%	94.64%	94.64%	**94.64%**	94.64%
	T_b (us)	5 1/3	10 2/3	**18 2/7**	36 4/7	37 1/3	74 2/3	**149 1/3**	298 2/3
	T_g/T_b =1/32	1/6	1/3	**4/7**	1 1/7	1 1/6	2 1/3	**4 2/3**	9 1/3
	1/16	1/3	2/3	**1 1/7**	2 2/7	2 1/3	4 2/3	**9 1/3**	18 2/3
	1/8	2/3	1 1/3	**2 2/7**	4 4/7	4 2/3	9 1/3	**18 2/3**	37 1/3
	1/4	1 1/3	2 2/3	**4 4/7**	9 1/7	9 1/3	18 2/3	**37 1/3**	74 2/3
24	Δf (kHz)	375	187 1/2	**109 3/8**	54 11/16	53 4/7	26 11/14	**13 11/28**	6 39/56
	BW*efficiency*	82.81%	80.47%	**91.60%**	91.60%	94.64%	94.64%	**94.64%**	94.64%
	T_b (us)	2 2/3	5 1/3	**9 1/7**	18 2/7	18 2/3	37 1/3	**74 2/3**	149 1/3
	T_g/T_b =1/32	1/12	1/6	**2/7**	4/7	7/12	1 1/6	**2 1/3**	4 2/3
	1/16	1/6	1/3	**4/7**	1 1/7	1 1/6	2 1/3	**4 2/3**	9 1/3
	1/8	1/3	2/3	**1 1/7**	2 2/7	2 1/3	4 2/3	**9 1/3**	18 2/3
	1/4	2/3	1 1/3	**2 2/7**	4 4/7	4 2/3	9 1/3	**18 2/3**	37 1/3

Table 1: MMDS channelization parameters

		OFDM				OFDMA			
BW	N_{FFT}	64	128	**256**	512	512	1024	**2048**	4096
1.75	Δf (kHz)	31 1/4	15 5/8	**7 79/81**	3 80/81	3 29/32	1 61/64	**83/85**	21/43
	BW*efficiency*	94.64%	91.96%	**91.60%**	91.37%	94.64%	94.64%	**94.64%**	94.64%
	T_b (us)	32	64	**125.387755**	250.77551	256	512	**1024**	2048
	T_g/T_b =1/32	1	2	**3 45/49**	7 41/49	8	16	**32**	64
	1/16	2	4	**7 41/49**	15 33/49	16	32	**64**	128
	1/8	4	8	**15 33/49**	31 17/49	32	64	**128**	256
	1/4	8	16	**31 17/49**	62 34/49	64	128	**256**	512
3.5	Δf (kHz)	62 1/2	31 1/4	**15 77/81**	7 79/81	7 13/16	3 29/32	**1 61/64**	83/85
	BW*efficiency*	94.64%	91.96%	**91.60%**	91.37%	94.64%	94.64%	**94.64%**	94.64%
	T_b (us)	16	32	**62 34/49**	125 19/49	128	256	**512**	1024
	T_g/T_b =1/32	1/2	1	**1 47/49**	3 45/49	4	8	**16**	32
	1/16	1	2	**3 45/49**	7 41/49	8	16	**32**	64
	1/8	2	4	**7 41/49**	15 33/49	16	32	**64**	128
	1/4	4	8	**15 33/49**	31 17/49	32	64	**128**	256
7	Δf (kHz)	125	62 1/2	**31 82/91**	15 77/81	15 5/8	7 13/16	**3 29/32**	1 61/64
	BW*efficiency*	94.64%	91.96%	**91.60%**	91.37%	94.64%	94.64%	**94.64%**	94.64%
	T_b (us)	8	16	**31 17/49**	62 34/49	64	128	**256**	512
	T_g/T_b =1/32	1/4	1/2	**48/49**	1 47/49	2	4	**8**	16
	1/16	1/2	1	**1 47/49**	3 45/49	4	8	**16**	32
	1/8	1	2	**3 45/49**	7 41/49	8	16	**32**	64
	1/4	2	4	**7 41/49**	15 33/49	16	32	**64**	128
14	Δf (kHz)	250	125	**63 77/96**	31 82/91	31 1/4	15 5/8	**7 13/16**	3 29/32
	BW*efficiency*	94.64%	91.96%	**91.60%**	91.37%	94.64%	94.64%	**94.64%**	94.64%
	T_b (us)	4	8	**15 33/49**	31 17/49	32	64	**128**	256
	T_g/T_b =1/32	1/8	1/4	**24/49**	48/49	1	2	**4**	8
	1/16	1/4	1/2	**48/49**	1 47/49	2	4	**8**	16
	1/8	1/2	1	**1 47/49**	3 45/49	4	8	**16**	32
	1/4	1	2	**3 45/49**	7 41/49	8	16	**32**	64
28	Δf (kHz)	500	250	**127 29/48**	63 77/96	62 1/2	31 1/4	**15 5/8**	7 13/16
	BW*efficiency*	94.64%	91.96%	**91.60%**	91.37%	94.64%	94.64%	**94.64%**	94.64%
	T_b (us)	2	4	**7 41/49**	15 33/49	16	32	**64**	128
	T_g/T_b =1/32	1/16	1/8	**12/49**	24/49	1/2	1	**2**	4
	1/16	1/8	1/4	**24/49**	48/49	1	2	**4**	8
	1/8	1/4	1/2	**48/49**	1 47/49	2	4	**8**	16
	1/4	1/2	1	**1 47/49**	3 45/49	4	8	16	32

Table 2: ETSI channelization parameters

		OFDM				**OFDMA**			
BW	N_{FFT}	64	128	**256**	512	512	1024	**2048**	4096
2.5	Δf (kHz)	39 1/16	19 17/32	**11 35/89**	5 62/89	5 47/81	2 64/81	**1 32/81**	30/43
	BW*efficiency*	82.81%	80.47%	**91.60%**	91.37%	94.64%	94.64%	**94.64%**	94.64%
	T_b (us)	25 3/5	51 1/5	**87 27/35**	175 19/35	179 1/5	358 2/5	**716 4/5**	1433 3/5
	T_g/T_b =1/32	4/5	1 3/5	**2 26/35**	5 17/35	5 3/5	11 1/5	**22 2/5**	44 4/5
	1/16	1 3/5	3 1/5	**5 17/35**	10 34/35	11 1/5	22 2/5	**44 4/5**	89 3/5
	1/8	3 1/5	6 2/5	**10 34/35**	21 33/35	22 2/5	44 4/5	**89 3/5**	179 1/5
	1/4	6 2/5	12 4/5	**21 33/35**	43 31/35	44 4/5	89 3/5	**179 1/5**	358 2/5
5	Δf (kHz)	78 1/8	39 1/16	**22 70/89**	11 35/89	11 9/56	5 47/81	**2 64/81**	1 32/81
	BW*efficiency*	82.81%	80.47%	**91.60%**	91.37%	94.64%	94.64%	**94.64%**	94.64%
	T_b (us)	12 4/5	25 3/5	**43 31/35**	87 27/35	89 3/5	179 1/5	**358 2/5**	716 4/5
	T_g/T_b =1/32	2/5	4/5	**1 13/35**	2 26/35	2 4/5	5 3/5	**11 1/5**	22 2/5
	1/16	4/5	1 3/5	**2 26/35**	5 17/35	5 3/5	11 1/5	**22 2/5**	44 4/5
	1/8	1 3/5	3 1/5	**5 17/35**	10 34/35	11 1/5	22 2/5	**44 4/5**	89 3/5
	1/4	3 1/5	6 2/5	**10 34/35**	21 33/35	22 2/5	44 4/5	**89 3/5**	179 1/5
10	Δf (kHz)	156 1/4	78 1/8	**45 55/96**	22 70/89	22 9/28	11 9/56	**5 47/81**	2 64/81
	BW*efficiency*	82.81%	80.47%	**91.60%**	91.37%	94.64%	94.64%	**94.64%**	94.64%
	T_b (us)	6 2/5	12 4/5	**21 33/35**	43 31/35	44 4/5	89 3/5	**179 1/5**	358 2/5
	T_g/T_b =1/32	1/5	2/5	**24/35**	1 13/35	1 2/5	2 4/5	**5 3/5**	11 1/5
	1/16	2/5	4/5	**1 13/35**	2 26/35	2 4/5	5 3/5	**11 1/5**	22 2/5
	1/8	4/5	1 3/5	**2 26/35**	5 17/35	5 3/5	11 1/5	**22 2/5**	44 4/5
	1/4	1 3/5	3 1/5	**5 17/35**	10 34/35	11 1/5	22 2/5	**44 4/5**	89 3/5
15	Δf (kHz)	234 3/8	117 3/16	**68 23/64**	34 16/89	33 27/56	16 20/27	**8 10/27**	4 5/27
	BW*efficiency*	82.81%	80.47%	**91.60%**	91.37%	94.64%	94.64%	**94.64%**	94.64%
	T_b (us)	4 4/15	8 8/15	**14 22/35**	29 9/35	29 13/15	59 11/15	**119 7/15**	238 14/15
	T_g/T_b =1/32	2/15	4/15	**16/35**	32/35	14/15	1 13/15	**3 11/15**	7 7/15
	1/16	4/15	8/15	**32/35**	1 29/35	1 13/15	3 11/15	**7 7/15**	14 14/15
	1/8	8/15	1 1/15	**1 29/35**	3 23/35	3 11/15	7 7/15	**14 14/15**	29 13/15
	1/4	1 1/15	2 2/15	**3 23/35**	7 11/35	7 7/15	14 14/15	**29 13/15**	59 11/15

Table 3: PCS/WCS channelization parameters

7.5.2 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 Guard Interval (GI); its duration is denoted as a fraction of the useful symbol time as (T_g). The two together are referred to as the symbol time (T_s). Figure 2 illustrates this structure:

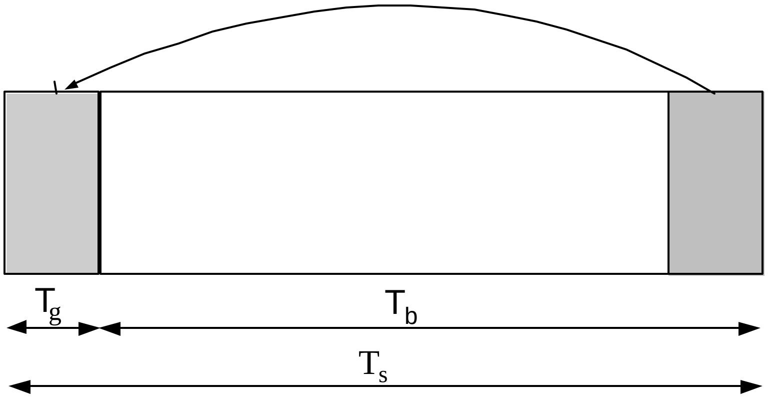

Figure 2: OFDM symbol time structure

A cyclic extension of T_g µs 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 $10 \log_{10}(1-T_g/(T_b+T_g))$ 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.

When implementing a TDD system, the frame structure is built from BS and SS transmissions. 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 3). The sum of TTG and RTG should be 2µs plus a multiple of T_s.

In FDD systems there is no need for TTG and RTG as the downstream and upstream transmit on independent frequencies (for H-FDD terminals, scheduling rules shall avoid TX and RX activity of the same terminal within the TTG and RTG gap time)

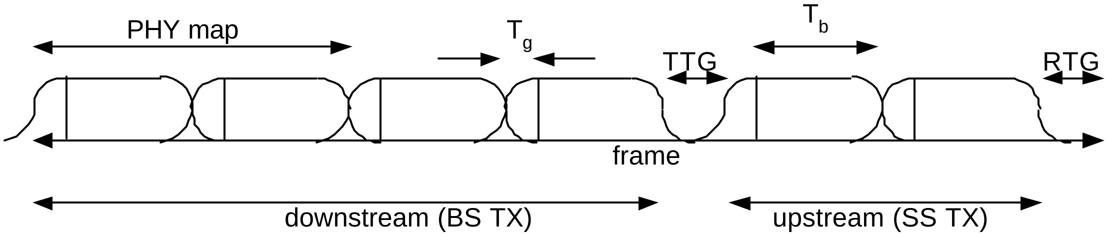

Figure 3: Time Plan – One TDD time frame

7.5.3 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 4 illustrates such a scheme:

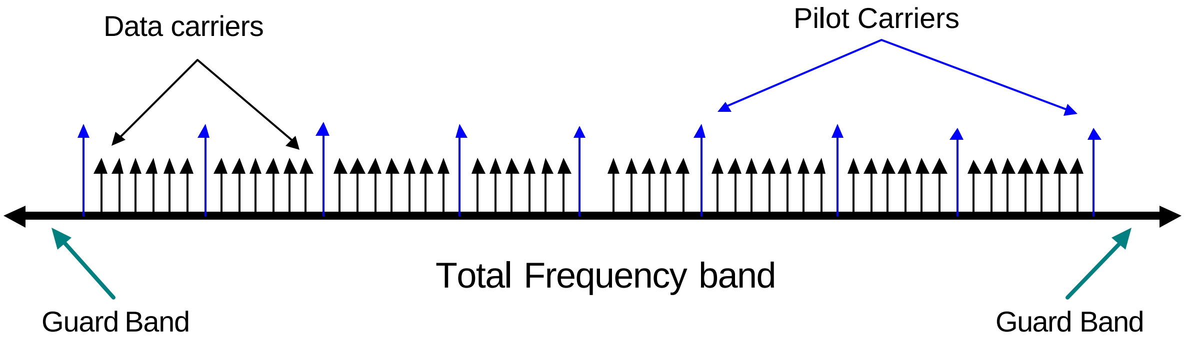

Figure 4: OFDM frequency description (schematic example)

The purpose of the guard bands is to enable the signal to naturally decay and create the FFT “brick Wall” shaping.

Within each symbol, 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.

This principle, termed OFDMA, is depicted in Figure 5 (pilots not shown).

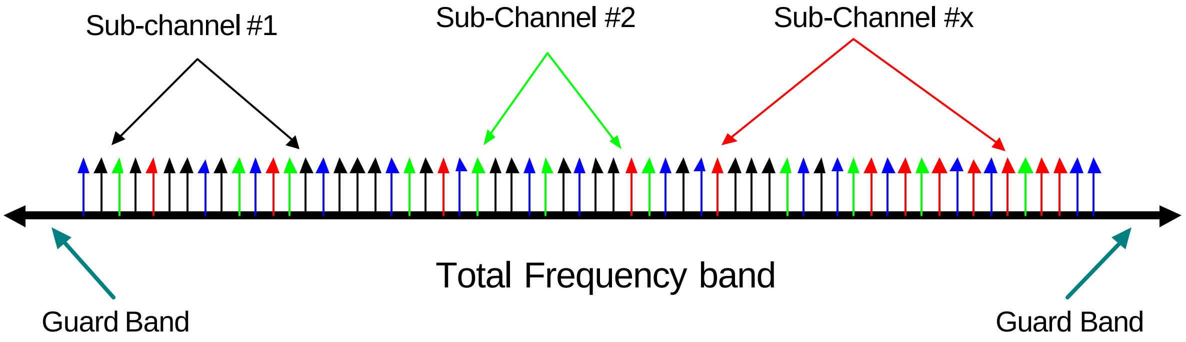

Figure 5: OFDMA frequency description

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 wideband processing, the mapping is based upon a special permutation code, which distributes consecutive symbols across the available bandwidth.

One special case of OFDMA is recognized, which is the case in which all active carriers are mapped to the same subchannel irrespective of the FFT size. This mapping will be referred to as "OFDM mapping", whereas all other mappings will be referred to as "OFDMA mappings".

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 OFDMA mappings 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.

7.6 Scrambling (Randomization)

Data randomization is performed on data transmitted on the DS and US. The randomization is performed on each allocation (DS or US), 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 $1+X^{14}+X^{15}$. Each data byte to be transmitted shall enter sequentially into the randomizer, MSB first.

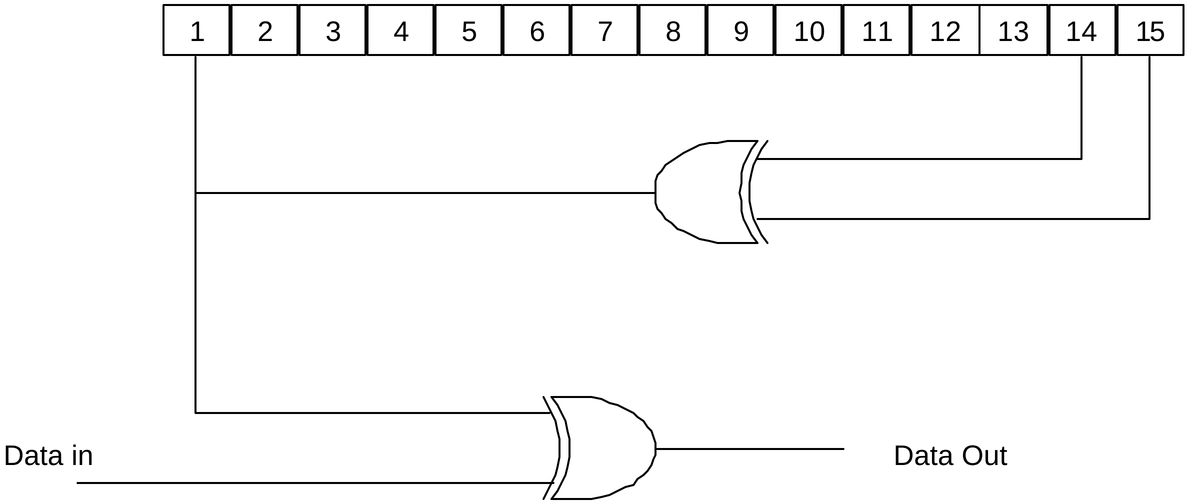

Figure 6 PRBS for data randomization

The bit issued from the randomizer shall be applied to the encoder.
The initialization vectors of the randomizer are shown in Figure 7 and Figure 8.

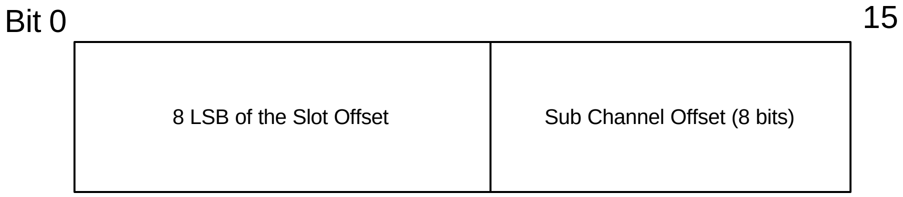

Figure 7 OFDMA Randomizer Initialization vector

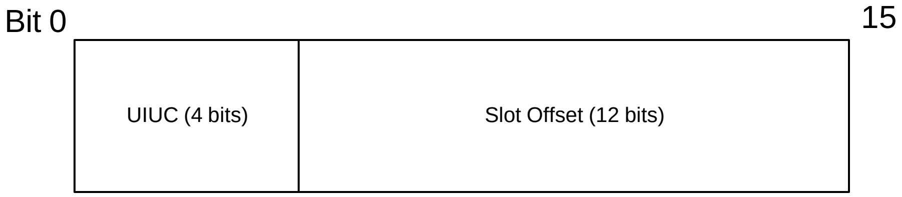

Figure 8 OFDM Randomizer Initialization vector

The above initialization is based on a proposed modification to the MAC's allocation scheme:

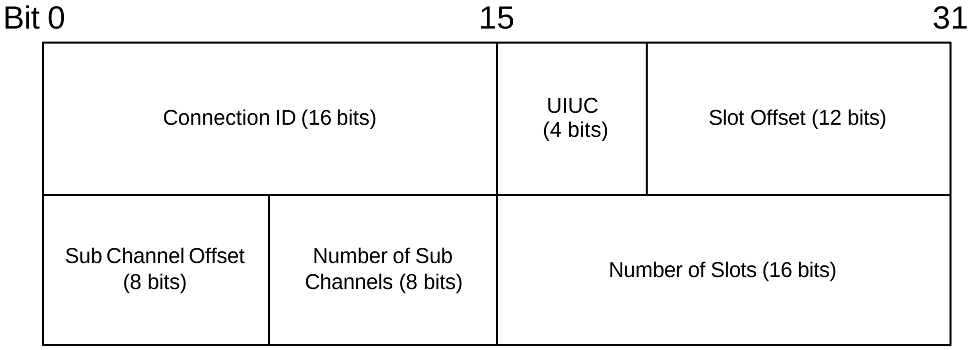

Figure 9 Two-dimensional pattern MAP IE

The pattern MAP IE shall define a two-dimensional allocation pattern by using the following parameters:

Slot Offset:	Provides an OFDM symbol time reference.
Sub Channel Offset:	Provides Initial Sub Channel offset from the start of the OFDM symbol
Number of Sub Channels:	Provides the “width” of the allocation pattern, i.e. the number of consecutive sub-channels used for this allocation pattern.
Number of Symbols:	Provides the number of time Symbols to be used for the allocation pattern.

7.7 Channel Coding and interleaving

7.7.1 Channel Coding

Code rates of ½, ¾ for QPSK and 16QAM, and 2/3, ¾ for 64QAM are required. These coding rates shall be implemented using concatenated Reed Solomon and Convolutional codes as shown in Table 4. In addition, Turbo Product Codes (TPC) may be implemented using the extended coding mode, as shown in Table 7. Specification of the concatenated Reed Solomon- Convolutional Codes is given in clause 7.7.1.2. The TPC specification is provided in clause 9.

The Reed-Solomon-Convolutional coding rate ½ shall be used as the coding mode when requesting access to the network.

7.7.1.1 Concatenated Reed Solomon and Convolutional Coding

The encoding is performed by first passing the data in block format through the RS encoder and then pass it through the a tail biting convolutional encoder.
Table 4 gives the block sizes and the code rates used for the different modulations and code rates:

Scheme	Modulation	Block Size (Bytes)	Over-All Coding Rate	RS Coding	CC Code Rate
OFDMA	QPSK	18	1/2	(24,18,3)	2/3
	QPSK	26	~3/4	(30,26,2)	5/6
	16QAM	36	1/2	(48,36,6)	2/3
	16QAM	54	3/4	(60,54,3)	5/6
	64QAM	72	2/3	(81,72,4)	3/4
	64QAM	82	~3/4	(90,82,4)	5/6
OFDM	QPSK	24	1/2	(32,24,4)	2/3
	QPSK	36	3/4	(40,36,2)	5/6
	16QAM	48	1/2	(64,48,8)	2/3
	16QAM	72	3/4	(80,72,4)	5/6
	64QAM	96	2/3	(108,96,6)	3/4
	64QAM	108	3/4	(120,108,6)	5/6

Table 4 Mandatory channel coding

Note that in Table 4, only the coding for the selected scheme must be implemented (i.e. if OFDMA is implemented, the OFDM codes need not be implemented and vice versa). As 64 QAM is optional, the codes for this modulation must only be implemented if the modulation is implemented.

7.7.1.1.1 Reed Solomon encoding

The Reed Solomon encoding process shall use the systematic RS (N,K,T) with a 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: $g(x) = (x + l^0)(x + l^1)(x + l^2)...(x + l^{2T-1}), l = 02_{hex}$
- Field Generator polynomial: $p(x) = x^8 + x^4 + x^3 + x^2 + 1$

7.7.1.1.1.1 Convolutional encoding

Data bits issued from the Reed Solomon encoder, described in clause 7.7.1.1.1, shall be fed to the convolutional encoder depicted in Figure 10.

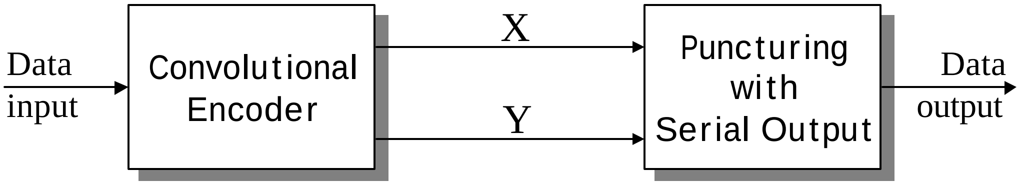

Figure 10: Convolutional encoder block diagram

The Convolutional encoder shall have a constraint length equal to k=7 and shall use the following mother codes:

$$G_1 = 171_{oct} \text{ For X}$$

$$G_2 = 133_{oct} \text{ For Y}$$

A basic convolutional encoding scheme, as depicted in Figure 11, shall be used.

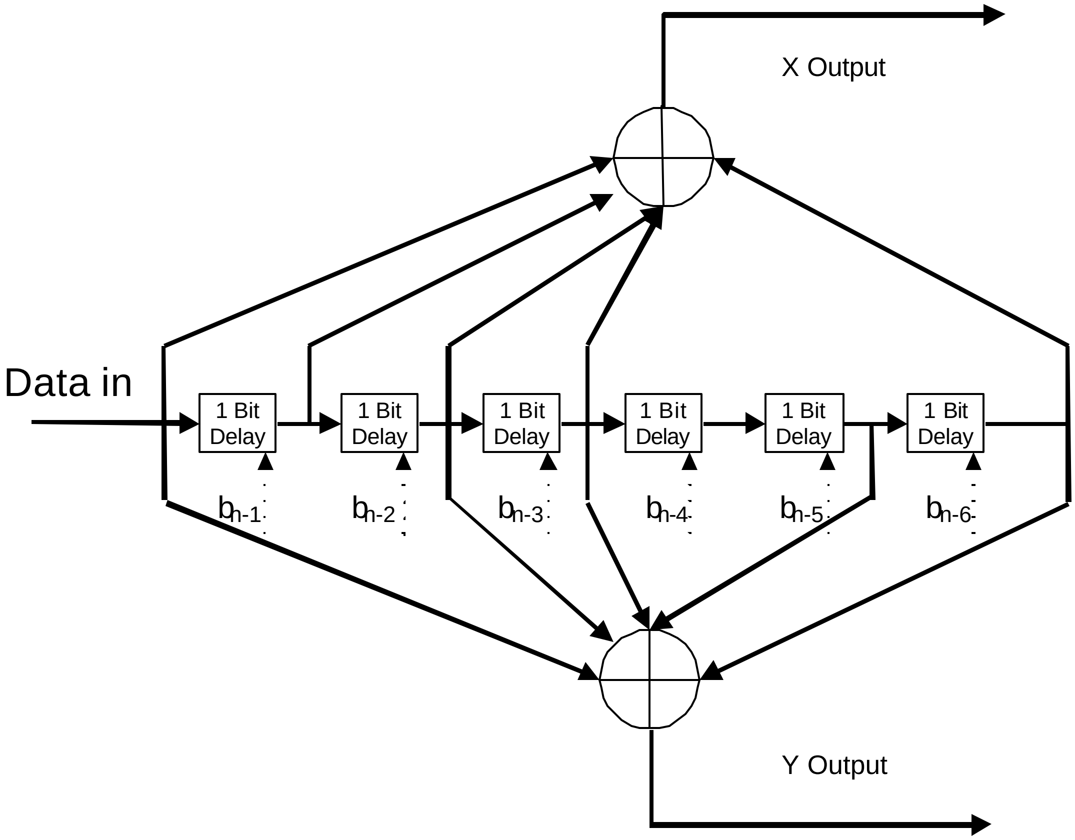

Figure 11: Convolutional encoder basic scheme

The puncturing pattern shall be as defined in Table 5.

CC Code Rate	Puncturing Pattern	Transmitted Sequence (after parallel to serial conversion)
$\frac{2}{3}$	X : 1 1 Y : 1 0	$X_1Y_1X_2$
$\frac{3}{4}$	X : 1 1 0 Y : 1 0 1	$X_1Y_1X_2Y_3$
$\frac{5}{6}$	X : 1 1 0 1 0 Y : 1 0 1 0 1	$X_1Y_1X_2Y_3X_4Y_5$

Table 5: Puncturing patterns for Convolutional Coding

7.7.1.1.1.2 Tail Biting Code Termination

In order to allow sharing of the ECC decoder, each of the multiple data streams subdivides its data into RS blocks. In this mode, each RS block is encoded by a tail-biting convolutional encoder. In order to achieve a tail biting convolutional encoding the memory of the convolutional encoder shall be initialized with the last data bits of the RS packet (the packet data bits are numbered $b_0..b_n$).

7.7.1.2 Turbo Product Codes

This type of coding based on the product of two or more simple component codes, is also called Turbo Product code, TPC. The decoding is based on the concept of Soft-in/Soft-out (SISO) iterative decoding (i.e., “Turbo decoding”). The component codes recommended for this proposal are binary extended Hamming codes or Parity check codes. The main benefits of using TPC mode are typically 2dB better performance over the Concatenated RS, and shorter decoding delays. A detailed description of Turbo Product Codes is included as Annex B. In this Section we present some particular turbo product codes that are perfectly matched for the proposed framing/modulation structure.

7.7.1.2.1 Turbo Product Constituent Codes

As mentioned in Annex 9, TPCs are constructed as a product of simple component codes. The complete constituent code set is defined in Table 6. Bit shortening to achieve the codes as defined in Table 7 is described in Annex 9.

(64, 57) Extended Hamming Code
(32,26) Extended Hamming Code
(16,11) Extended Hamming Code
(32,31) Parity Check Code
(16,15) Parity Check Code
(4,3) Parity Check Code

Table 6: Constituent Turbo Product Code List

7.7.1.2.2 Extended Coding Mode

Table 7 gives the block sizes, code rates, code parameters and channel efficiency for different modulation and coding schemes.

Scheme	Modulation	Block	Code	Efficienc	Constituent	Code

		Size (Bytes)	Rate	y Bit/S/Hz	Codes	Parameters
OFDMA	QPSK	25	0.694	1.39	(8,7)(64,57)	E=1,I_x=2,I_y=17
	16QAM	38	0.528	2.11	(64,63)(16,11)	E=1,I_x=20,I_y=3, B=40
	16QAM	55	0.764	3.06	(16,15)(64,57)	E=1,I_x=4,I_y=17
	64QAM	79	0.731	4.39	(32,31)(32,26)	E=1,I_x=2,I_y=4,B=6
	64QAM	85	0.789	4.74	(32,31)(64,57)	E=1,I_x=14,I_y=17
OFDM	QPSK	26	0.542	1.1	(32,31)(16,11)	E=1,I_x=4,I_y=3,B=8
	QPSK	41	0.854	1.71	(32,31)(32,31)	E=1,I_x=14,I_y=11,B=12
	16QAM	56	0.583	2.33	(32,26)(32,26)	E=1,I_x=6,I_y=3,B=12
	16QAM	75	0.78	3.12	(16,15)(64,57)	E=1,I_x=0,I_y=17
	64QAM	107	0.74	4.44	(64,63)(32,26)	E=1,I_x=25,I_y=3
	64QAM	115	0.8	4.8	(32,31)(64,57)	E=1,I_x=8,I_y=17

Table 7 Extended Coding Mode (optional)

7.7.2 Interleaving

7.7.2.1 Bit Interleaving

A combination of a bit interleaver and a symbol interleaver is used to interleave the data over the frequency domain. Table 8 summarises the bit interleaver sizes as a function of modulation and coding for both OFDMA and OFDM.

	OFDMA	OFDM
Modulation	144 Symbol Interleave	96 Symbol Interleave
QPSK	288	192
QAM16	576	384
QAM64	864	576

Table 8 Bit Interleaver Sizes

In the case of 64point FFT the interleaver is only the 96 Symbol allocation bit interleaver. This interleaver operates over 2 OFDM symbols.

In the case of 128 point FFT an interleaver based on the 96 Symbol allocation is proposed. The bit interleaver is sufficient on it's own and no carrier permutation is required.

In the case of 256 point FFT mode an interleaver based on the 96 Symbol allocation is proposed followed by the simple symbol interleaver. This means that each OFDM symbol contains two bit-interleaved blocks.

In the case of 512 point FFT mode an interleaver based on 96 Symbol allocation is proposed followed by the simple symbol interleaver. This means that each OFDM symbol contains four bit-interleaved blocks.

Table 9 summarises the number of bits within each block for different FFT sizes and modulation modes.

Modulation	64 Point	128 Point	256 Point	512 Point

QPSK	96	192	384	768
QAM16	192	384	768	1536
QAM64	288	576	1152	2304

Table 9 Number of bits in an OFDM symbol

The bit interleaver is defined to be the same as the OFDMA mode bit interleaver.

The PRBS generator depicted in Figure 12 is used to achieve the bit interleaver array, it is initialized with the binary value: 0001011010.

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 to be interleaved as shown in Table 9)
- 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

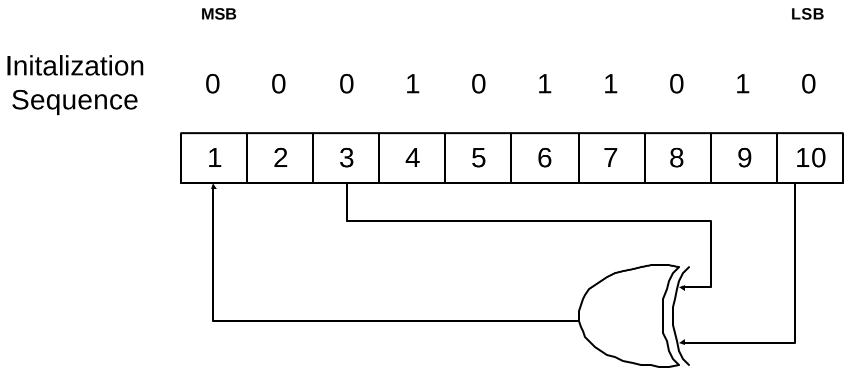

Figure 12: PRBS for Bit-Interleaver array

7.7.2.2 Symbol (Sub-carrier) Interleaving

A symbol interleaver for FFT sizes 64 and 128 is not needed, as the bit interleaver is large enough to accumulate at least one full OFDM symbol.

The bit interleaver for 256 FFT results in two (N=2) groups of 96 bits, for 512 FFT it results in four (N=4) groups of 96 bits. These are denotes as group(n,k), where n = 0,1,..,N-1 is the number of the group, and k = 0,1,…95. The symbol interleaver is then defined as:

Carrier(n+N*k) = group(n,k).

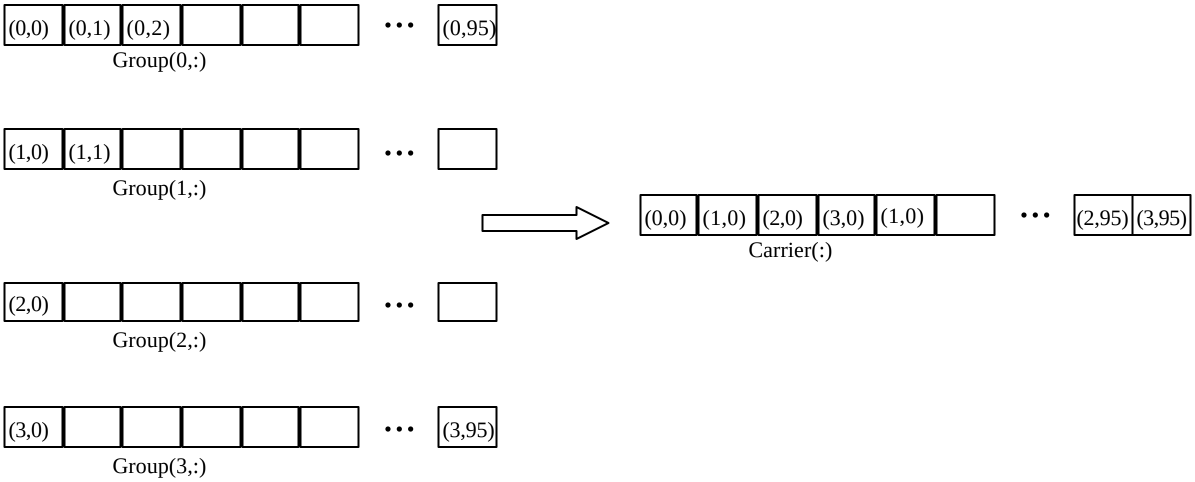

Figure 13 Symbol Interleaver for 512 FFT

7.8 Modulation

The modulation used both for the US and DS data carrier is QPSK, 16QAM and optionally 64QAM. These modulations are used adaptively in the downlink and the uplink in order to achieve the maximum throughput for each link.

The modulation on the DS can be changed for each allocation, to best fit the modulation for a specific user/users. When using OFDMA the power of the modulated carrier can also vary by attenuation or boosting of 6dB, this is used for the Forward APC.

For the US, each user is allocated a modulation scheme, which is best suited for his needs.

The pilot carriers for the US and DS are mapped using a BPSK modulation.

7.8.1 Data Modulation

The data bits entering the mapper are after bit interleaving and they enter serially to the mapper, the mapping constellations are presented here after in Figure 14:

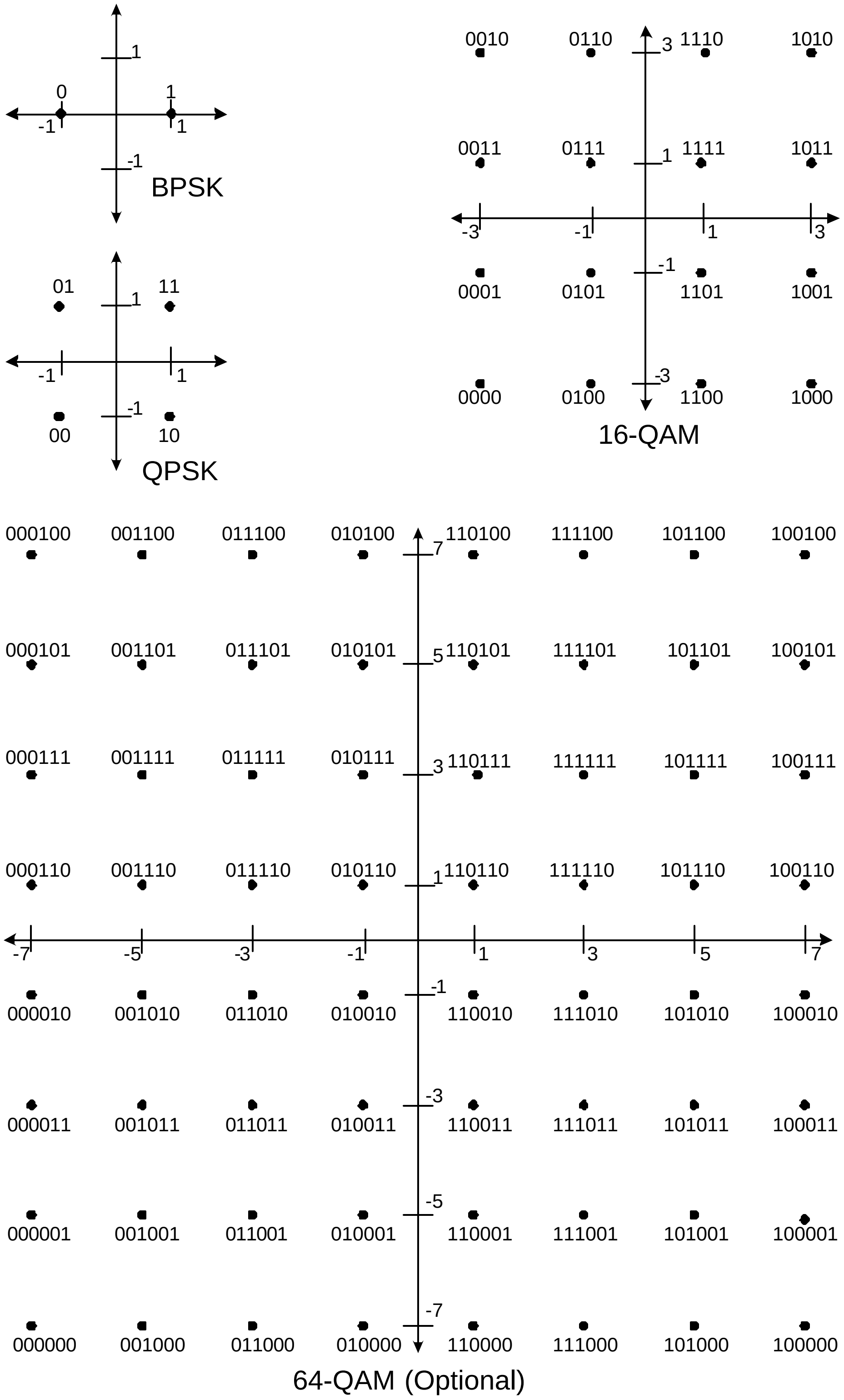

Figure 14: QPSK, 16QAM and 64 QAM constellations (Modify to .11 constellations)

The complex number z in Figure 14, before mapping onto the carriers, shall be normalized to the value c as defined in Table 10:

Modulation scheme	Normalization Factor 6dB attenuation	Normalization Factor Reference – 0dB	Normalization Factor 6dB Boosting
QPSK	$c = z/\sqrt{8}$	$c = z/\sqrt{2}$	$c = z\sqrt{2}$
16QAM	$c = z/\sqrt{40}$	$c = z/\sqrt{10}$	$c = z\sqrt{2}/\sqrt{5}$
64QAM	$c = z/\sqrt{168}$	$c = z/\sqrt{42}$	$c = z\sqrt{2}/\sqrt{21}$

Table 10 Normalization factors

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 US, and the DS defined for 0dB boosting or attenuation. The normalizing factors used for attenuation and boosting are for DS use only, this is defined in the DS parameters for a specific burst type and is used for Forward APC.

7.8.2 Pilot Modulation

Pilot carriers shall be inserted into each data burst in order to constitute the Symbol Structure (see clause 7.10.2.1, 7.10.2.2) 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 $X^{11} + X^2 + 1$.

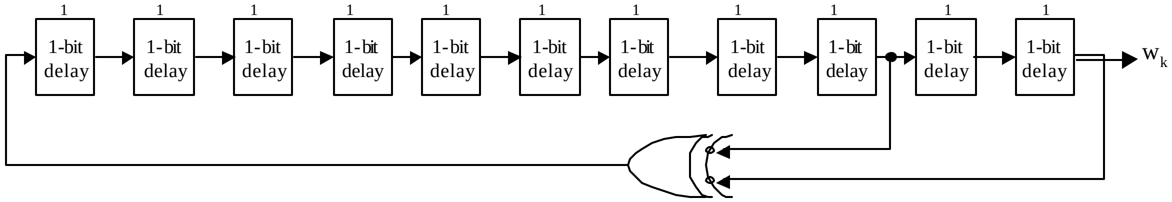

Figure 15: PRBS used for pilot modulation

The value of the pilot modulation, on carrier k, shall be derived from w_k.
When using data transmission on the DS the initialization vector of the PRBS will be: [11111111111]
When using data transmission on the US 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. 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. (For OFDM, the amount of boosting requires further study. The Pilot carriers shall be modulated according to the following formula:

$$\mathrm{Re}\{C_k\} = 4 / 3 \times 2 (\tfrac{1}{2} - w_k)$$

$$\mathrm{Im}\{C_k\} = 0$$

When OFDM symbols or Sub-Channels are used for pilots transmission only (preamble or midamble) the pilots shall not be boosted. The Pilot carriers shall be modulated according to the following formula:

$\mathrm{Re}\{C_k\} = 2\,(½ - w_k)$

$\mathrm{Im}\{C_k\} = 0$

7.8.3 Ranging Pilot Modulation

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

$\mathrm{Re}\{C_k\} = (½ - w_k) / 6$

$\mathrm{Im}\{C_k\} = 0$

C_k is derived in clause 7.12.2.

7.9 Time Domain Processing

7.9.1 Framing Structure

The framing structure used for the DS includes the transmission of a PHY control and US 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 DS transmission frame length and the length of the different transmission parts. Figure 16 illustrates the DS framing:

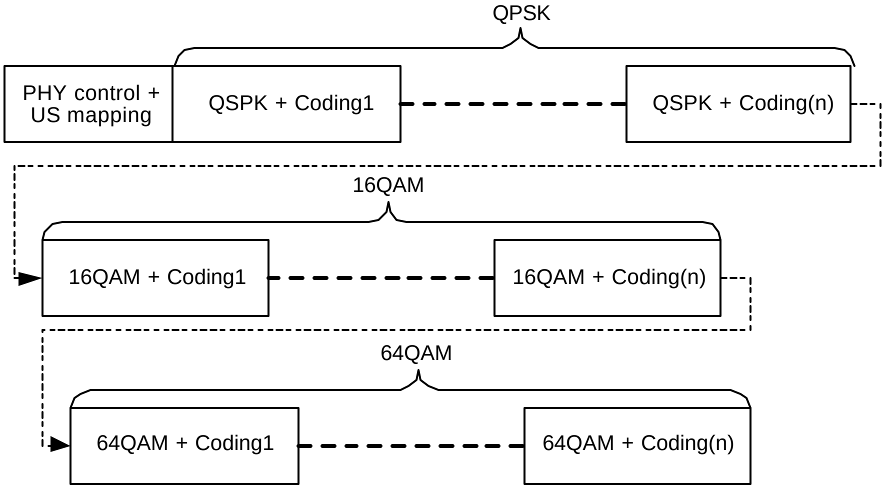

Figure 16: DS Frame structure

7.10 Time/Frequency Map Parameters

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.

7.10.1 Map I

This map specifies the OFDM mapping. It is defined for FFT sizes 64, 128, 256 and 512, of which the 256 mode is mandatory. The basic resource allocation quantum is an OFDM symbol. The amount of data, which fits into an OFDM symbol, depends on the constellation and the coding method used within this symbol.

7.10.1.1 Downstream

7.10.1.1.1 Frame structure

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 17 illustrates a possible two-dimensional transmission mapping (every color represents a different Modulation and coding scheme).

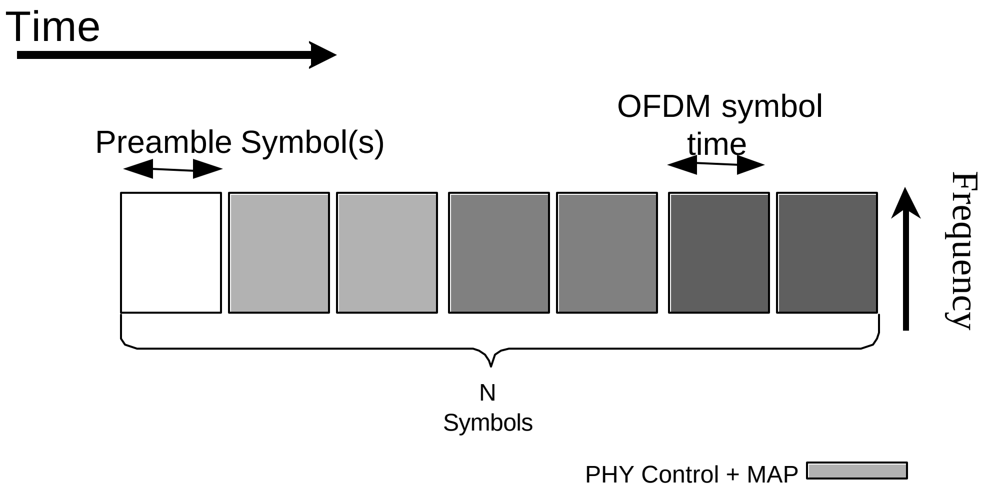

Figure 17: DS framing

As shown in Figure 17, the DS frame starts with a preamble consisting of one or more pilot symbols.

7.10.1.1.1.1 Preamble structure

TBD

7.10.1.2 Upstream

7.10.1.2.1 Frame structure

The basic allocation for a user US transmission is made up of a preamble and an integer number of OFDM data symbols, adding more data symbols prolongs the transmission, while preamble is repeated every X data symbols transmission. Therefore the US mapping is illustrated in Figure 18:

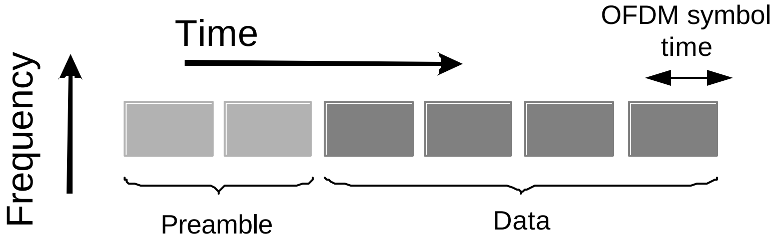

Figure 18: Map I US framing

7.10.1.2.1.1 Preamble structure

TBD

7.10.1.3 DS/US Symbol structure

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

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

Parameter	Value	
N_{FFT}	128	
N_{used}	102	
Guard Carriers: Left, Right	13	12
BasicConstantLocationPilots	{-45,-27,-9,9,27,45}	

Parameter	Value	
N_{FFT}	256	
N_{used}	200	
Guard Carriers: Left, Right	28	27
BasicConstantLocationPilots	{-84,-60,-36,-12,12,36,60,84}	

Parameter	Value	
N_{FFT}	512	
N_{used}	401	
Guard Carriers: Left, Right	57	54
BasicConstantLocationPilots	{-171,-133,-95,-57,-19,19,57,95,133,171}	

Table 11 Map I, Symbol parameters

7.10.2 Map II

This map specifies the OFDMA mapping. It is defined for FFT sizes 512, 1K, 2K and 4K of which the 1K mode is mandatory.

7.10.2.1 Downstream

7.10.2.1.1 Frame structure

The transmission of the DS 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 19 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.

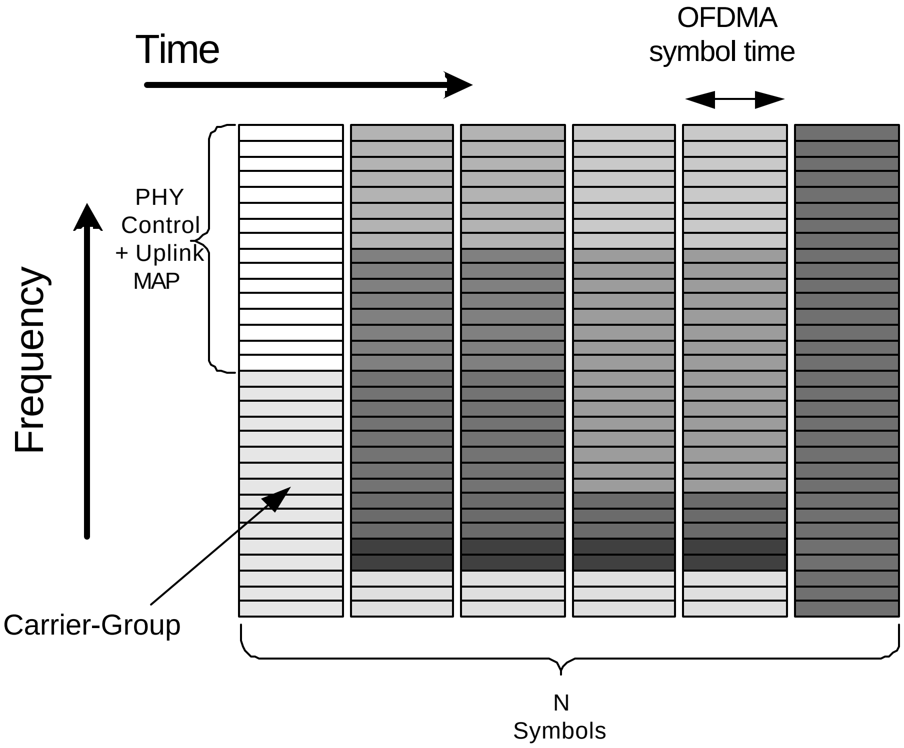

Figure 19: Map II, DS framing

7.10.2.1.2 Symbol Structure

When using FFT size of 1024 and above the DS shall use OFDMA modulation technique. Using 512 FFT, either OFDM or OFDMA shall be used. 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:

$$k = 3 * L + 12 * P_V$$

$k \in$ Indices from 0 to the number of Overall Usable Carriers minus 1 (excludes guard and DC carriers)
$L \in 0..3$ 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 20:

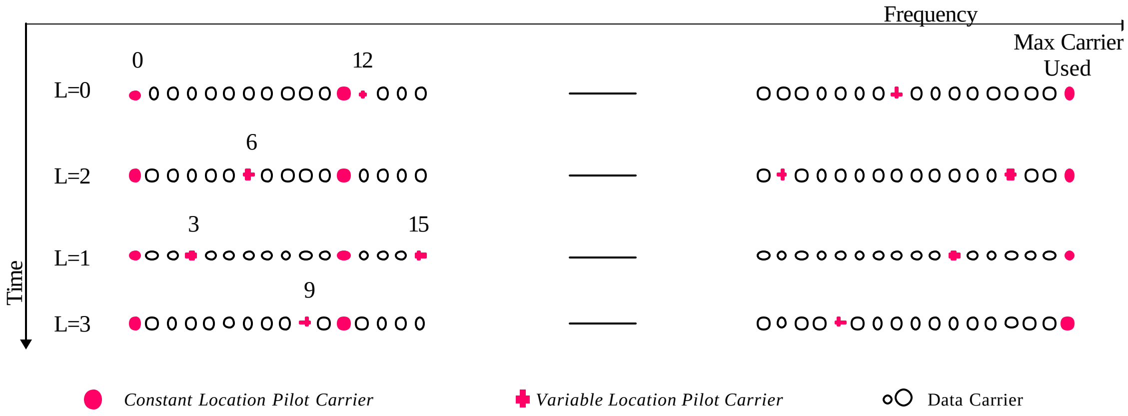

Figure 20: pilots and data carrier location the DS OFDMA symbol using FFT 512 and above

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).

Using special permutation code, which is based upon the procedure described below, does the allocation of carriers to Sub-Channels (see also Annex 8). *CellId* 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. The number of basic groups, N_{Groups}, is equal to the number of data carriers per subchannel (48 in DS and 53 in US). Each basic group is made up of adjunct 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 ($\{PermutatedSeries_{CellId}\}$) are achieved by cyclically rotating *CellId* times the $\{PermutationBase_0\}$ to the left.

3. To get a $N_{Sub-Channel}$ length series ($N_{Sub-Channel}$ being the number of data carriers per subchannel) the permutated series are concatenated, until the concatenated series has at least $N_{Sub-Channel}$ elements.
4. Let $p_s[j]$ (j starting from 0) be the j-th element of $\{PermutatedSeries_{CellId}\}$. The k-th element of the resulting concatenated series, $c_s[k]$ is obtained by:
   $c_s[k] = \left\{ p_s[k_{\mathrm{mod}(N_{elements})}] + \mathrm{ceil}[(k+1)/N_{elemens}] \cdot CellId \right\}_{\mathrm{mod}(N_{elements})}$
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 $N_{Sub-Channel}$ carriers (48 in DS, 53 in US) of the current permutation in the cell:

   carrier(n, s) = N_elements*n + c_s[n].

   Here carrier(n, s) is the n-th carrier of subchannel number s; n = 0,1..., $N_{Sub-Channel} - 1$.

In order to achieve the DS 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.

Parameter	Value	
N_{FFT}	512	
N_{used}	430	
Guard Carriers: Left, Right	41	41
Subchannels: nr, data carriers/subchannel	8	48
BasicConstantLocationPilots	{0,75,174,201,214,303,366,384,429}	
PermutationBase$_0$	{7, 4, 0, 2, 1, 5, 3, 6}	

Parameter	Value	
N_{FFT}	1024 (1K)	
N_{used}	850	
Guard Carriers: Left, Right	87	87
Subchannels: nr, data carriers/subchannel	16	48
BasicConstantLocationPilots	{0,39,261,330,348,351,522,645,651,726,756,849,850}	
PermutationBase$_0$	{6, 14, 2, 3, 10, 8, 11, 15, 9, 1, 13, 12, 5, 7, 4, 0}	

Parameter	Value	
N_{FFT}	2048 (2K)	
N_{used}	1703	
Guard Carriers: Left, Right	172	172
Subchannels: nr, 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}

Parameter	**Value**	
N_{FFT}	4096(4K)	
N_{used}	TBD	
Guard Carriers: Left, Right	TBD	TBD
Subchannels: nr, data carriers/subchannel	64	48
BasicConstantLocationPilots$_0$	{TBD}	
PermutationBase$_0$	{TBD}	

7.10.2.2 Upstream

7.10.2.2.1 Subchannel description

The next section gives a description of the structure of a subchannel. A subchannel is made up of 48 usable carriers and 5 pilot carriers. The DS transmission for these modes is also made of subchannel transmissions, but the Sub-Channel is made up of 48 data carriers only, while pilot carriers are spread all over the OFDMA symbol, to be used for channel estimation. The US subchannel structure is shown in Figure 21.

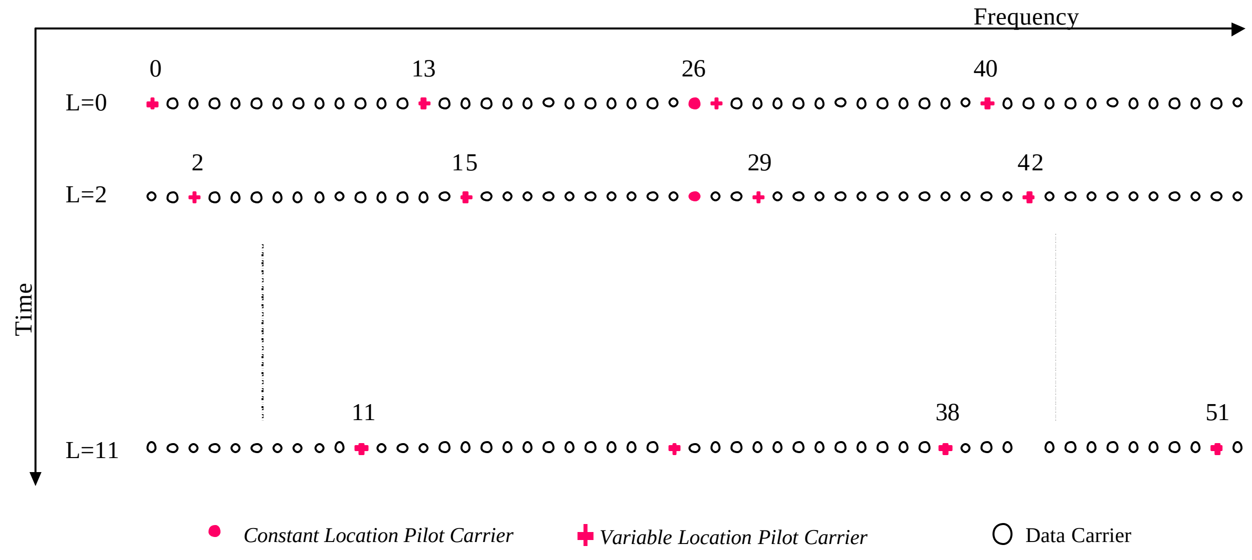

Figure 21: Allocation of data and pilot carriers for a US Sub-Channel

The US 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). 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 US 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 all-pilot symbols (preamble) consist of permutated carriers modulated according to 7.8.2.

7.10.2.2.2 Framing Structure

The basic allocation for a user US 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 22:

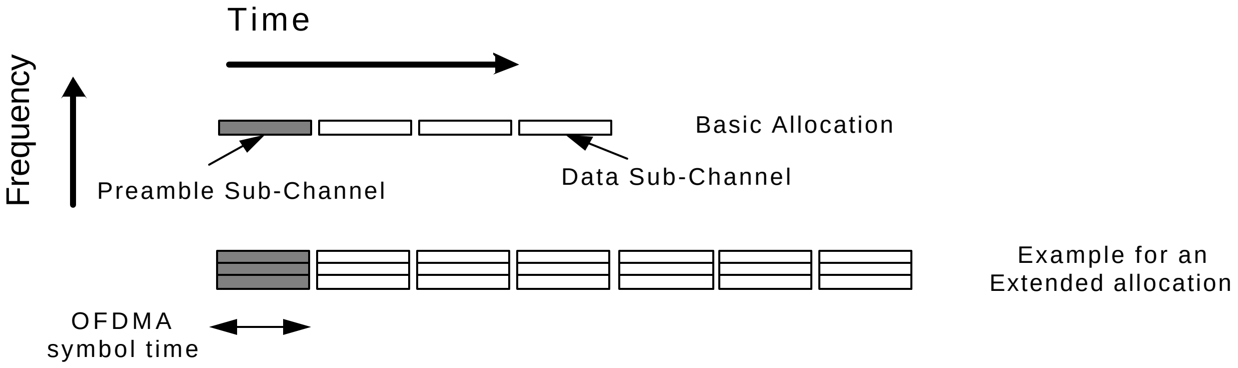

Figure 22: Map II US User allocation

The framing structure used for the US 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 US framing, and the US 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 US mapping is illustrated in Figure 23:

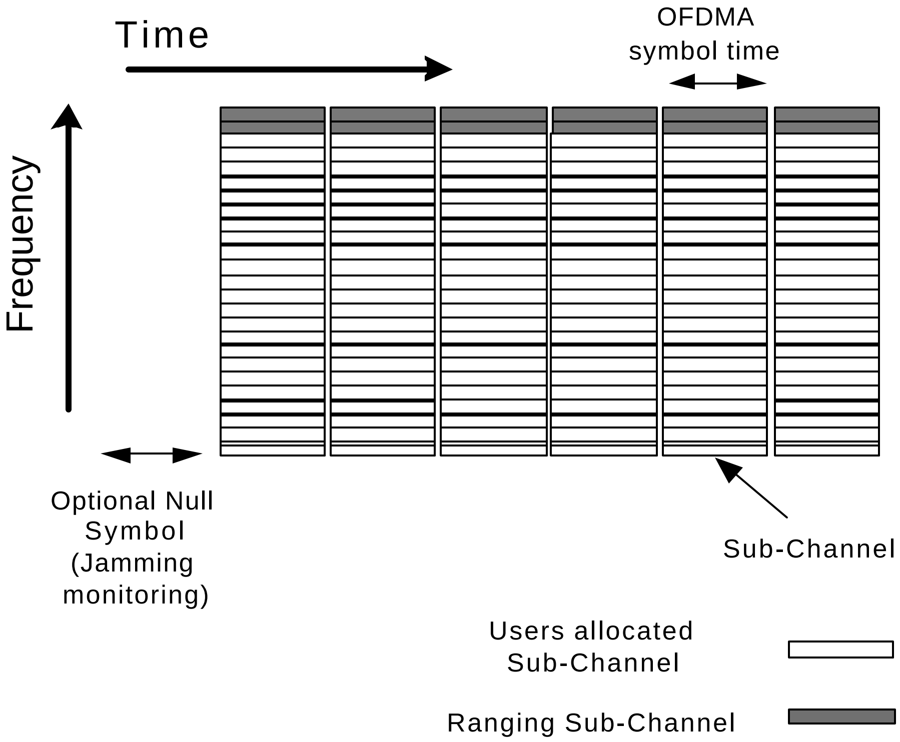

Figure 23: US framing for FFT sizes 512 and above

7.10.2.2.3 Symbol Structure

The symbol structure is made up of Sub-Channels, by their basic structure described in section 7.10.2.2.1. There are several methods splitting the whole US OFDMA symbol into Sub-Channels, the first two methods are performed by first dividing the used carriers into basic groups (not including the DC carrier, which is not used), each containing a certain amount of carriers:

Then the following methods exist:

1. 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. Then special permutations are used to extract the Sub-Channels (the procedure to use the permutation is defined in section 7.10.2.1.2, and each Sub-Channel is made up of 53 data carriers $N_{Sub-Channel}$ =53).
2. Defining each basic group as a Sub-Channel, which implies that the number of carriers Y=53 and that the carriers within the Sub-Channel are allocated adjunct. The carrier indices for each Sub-Channel are achieved using the next formula:
   carrier(n, s) = 53*s + n,

where carrier(n, s) is the n-th carrier of sub-channel number s; s = 0,1,...($N_{elements}$ -1); and n = 0, 1, ..., 52.

The last method for defining the Sub-Channels involves programming by MAC message the carrier numbers for each Sub-Channel. When using method 1 (default) then the following parameters should be used:

Parameter	Value	
N_{FFT}	512	
N_{used}	425	
Guard Carriers: Left, Right	44	43
Subchannels: nr, data carriers/subchannel	8	48
PermutationBase_0	{7, 4, 0, 2, 1, 5, 3, 6}	

Parameter	Value	
N_{FFT}	1024 (1K)	
N_{used}	849	
Guard Carriers: Left, Right	88	87
Subchannels: nr, data carriers/subchannel	16	48
PermutationBase_0	{6, 14, 2, 3, 10, 8, 11, 15, 9, 1, 13, 12, 5, 7, 4, 0}	

Parameter	Value	
N_{FFT}	2048 (2K)	
N_{used}	1696	
Guard Carriers: Left, Right	176	175
Subchannels: nr, 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}	

Parameter	Value	
N_{FFT}	4096(4K)	
N_{used}	3392	
Guard Carriers: Left, Right	352	353
Subchannels: nr, data carriers/subchannel	64	48
PermutationBase_0	{TBD}	

7.10.3 MAP III (optional)

This section specifies a mapping for advanced antenna array processing. It supports the mandatory and optional FFT sizes.

Change above paragraph to: Map III is based on a subchannel structure with 48 data carriers.

This mapping has the same fundamental subchannel tone utilization as Map II. The main distinction between Map II and Map III is that the symbol data is assigned to adjacent carriers as indicated in the framing figures shown below. With Map II, the framing figures depict logical subchannels since the carriers are actually distributed across the available frequency spectrum to mitigate against frequency selective fading. With Map

III, 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.

7.10.3.1 Downstream

7.10.3.1.1 Frame Format

The frame format is described by a two-dimensional layout with subchannels in the frequency domain and OFDM symbols in the time domain. Figure 24 illustrates a generic two-dimensional downstream transmission mapping where the different colors and shading reflect different modulation and coding schemes. Figure 25 shows a specific example as an overlay to a Map II mapping.

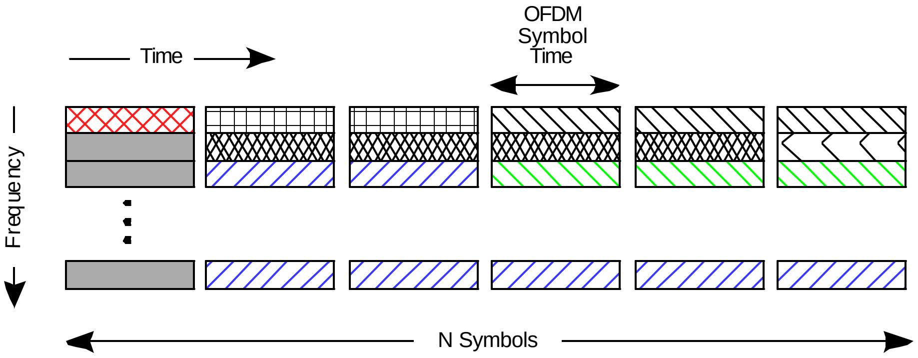

Figure 24:Map III Downstream Framing

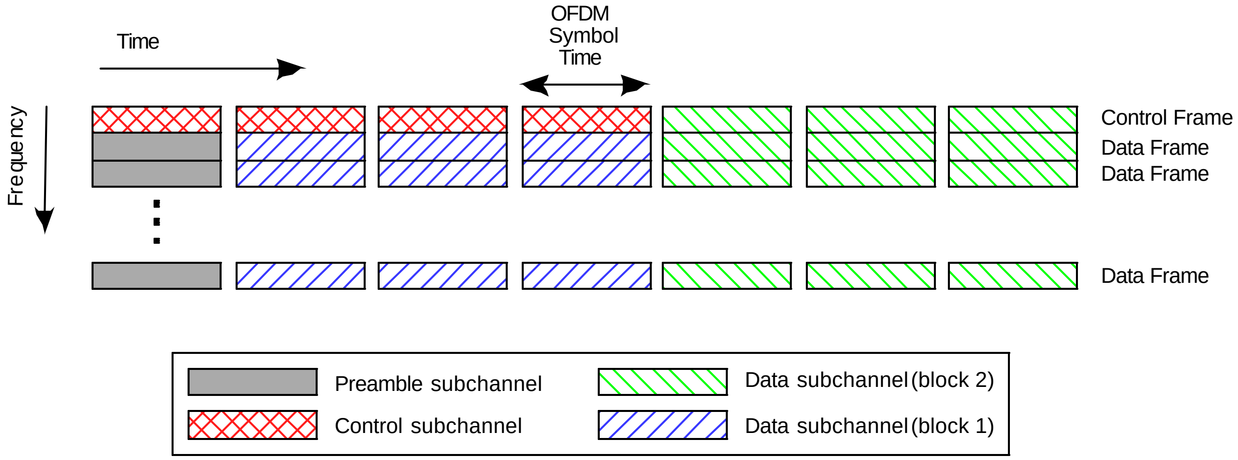

Figure 25: MAP III Using Map II Framing Parameters, Downstream Framing

7.10.3.1.2 Symbol Structure

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

7.10.3.2 Upstream

7.10.3.2.1 Frame Format

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 26 shows the generic upstream 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 27 with four OFDM symbols is one example, where the data frame is identical to the basic allocation in Map II.

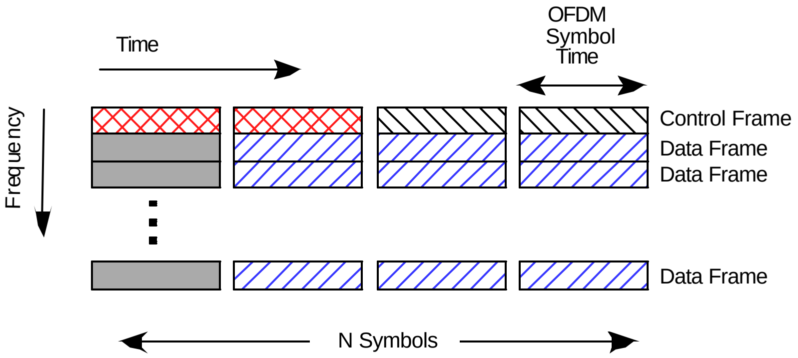

Figure 26: Map III Upstream Framing

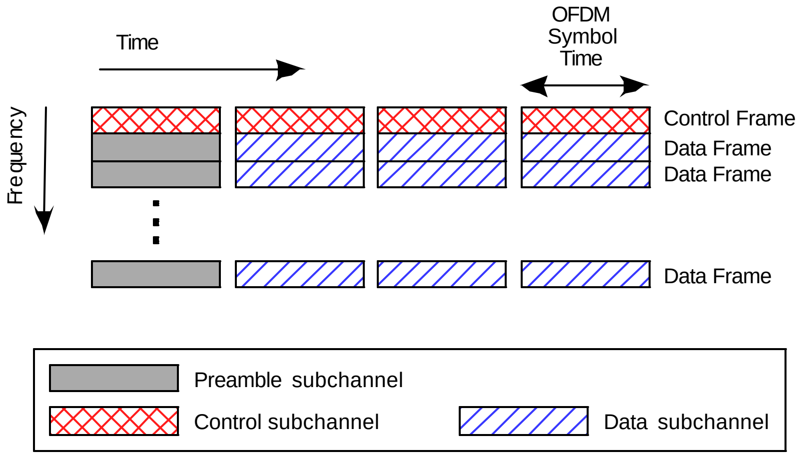

Figure 27: Example Map III Upstream Framing

7.10.3.2.2 Symbol Structure

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

7.10.3.3 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 28, a superframe is defined as a control frame followed by one or more data frames.

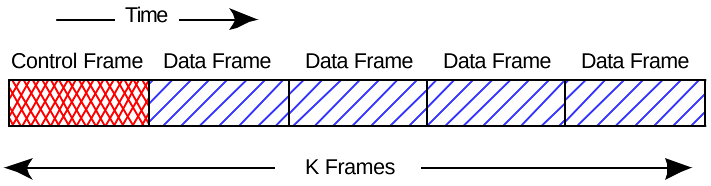

Figure 28: Superframe Structure

This superframe structure can be applied as shown in Figure 29. As with Map II, 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.

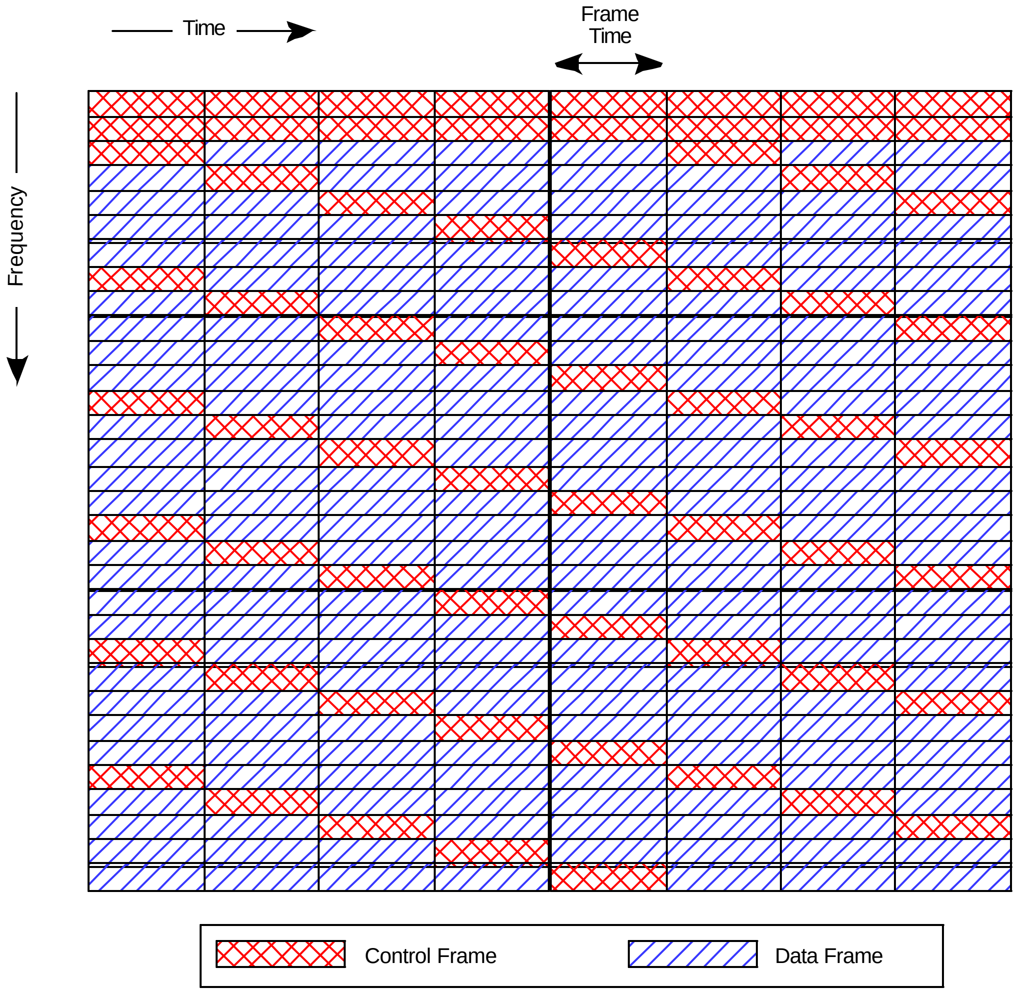

Figure 29: Superframe Layout

7.11 RF Transceiver

7.12 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.

7.12.1 Synchronization

7.12.1.1 Network 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. 7.12.1.2. This applies during normal operation and during loss of timing reference.

7.12.1.1.1 Time Stamp, Frame Timing Reference

Each Base-Station and CPE 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 $2^{\wedge N_{timestamp}}-1$. 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 CPE shall be derived from the synchronized timing epoch and the time stamp.

CPE 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.

7.12.1.1.2 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 CPE transmission (RTG) shall be adjustable in the range of TBD microseconds to TBD microseconds.

The TDD guard timing between CPE transmission and Basestation transmission (TTG) shall be adjustable in the range of TBD microseconds to TBD microseconds.

7.12.1.2 Subscriber Station Synchronization

For any duplexing all CPEs shall acquire and adjust their timing such that all upstream 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 DS and extract his clock from it, after synchronization the RF frequency would be accurate to 2% of the carrier spacing.

7.12.2 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.

This method is suitable for OFDM, OFDMA, FDD, and TDD operation.

7.12.2.1 Ranging using an OFDMA mapping

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 30 (the PRBS polynomial generator shall be $1+X^4+X^7+X^{15}$):

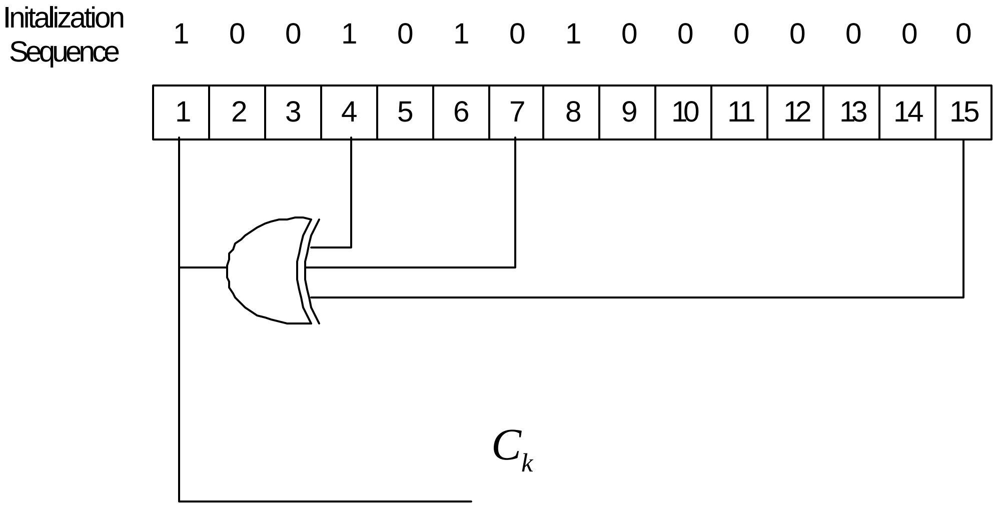

Figure 30: PRBS for ranging code production

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.

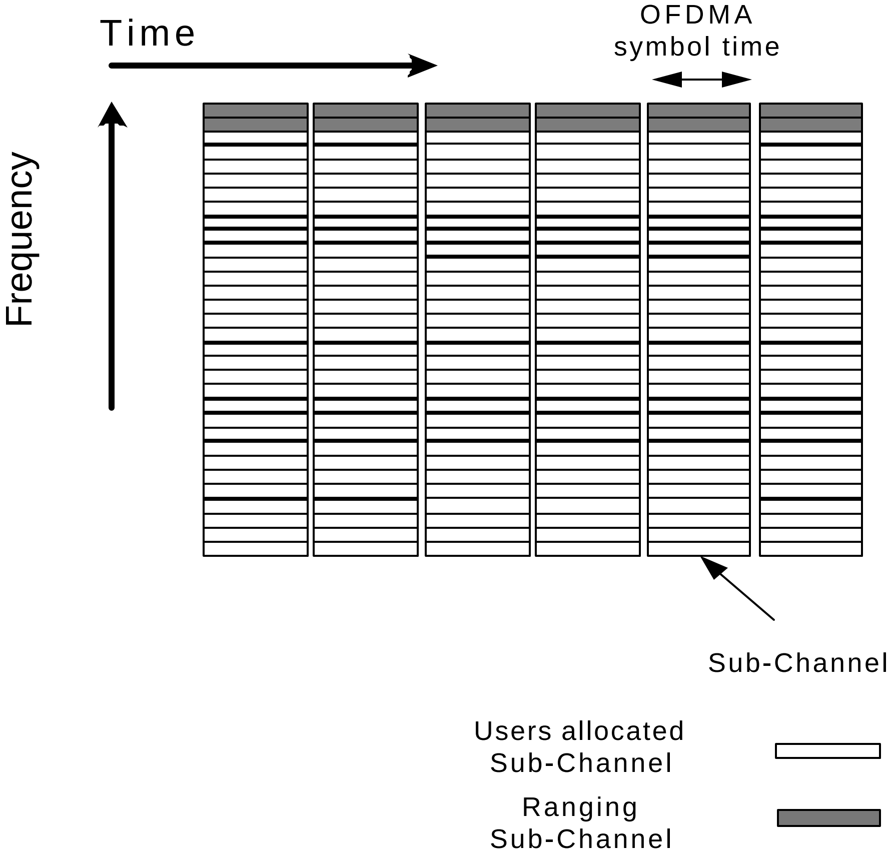

Figure 31: Ranging subchannel allocation for OFDMA mapping (2k mode default configuration)

7.12.2.1.1 Long Ranging transmission

The Long Ranging transmission shall be used by any SU 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 US 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.

7.12.2.1.2 Short Ranging transmission

The Short Ranging transmission shall be used only by a SU 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 SU 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.

7.12.2.2 Ranging using the OFDM mapping

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.

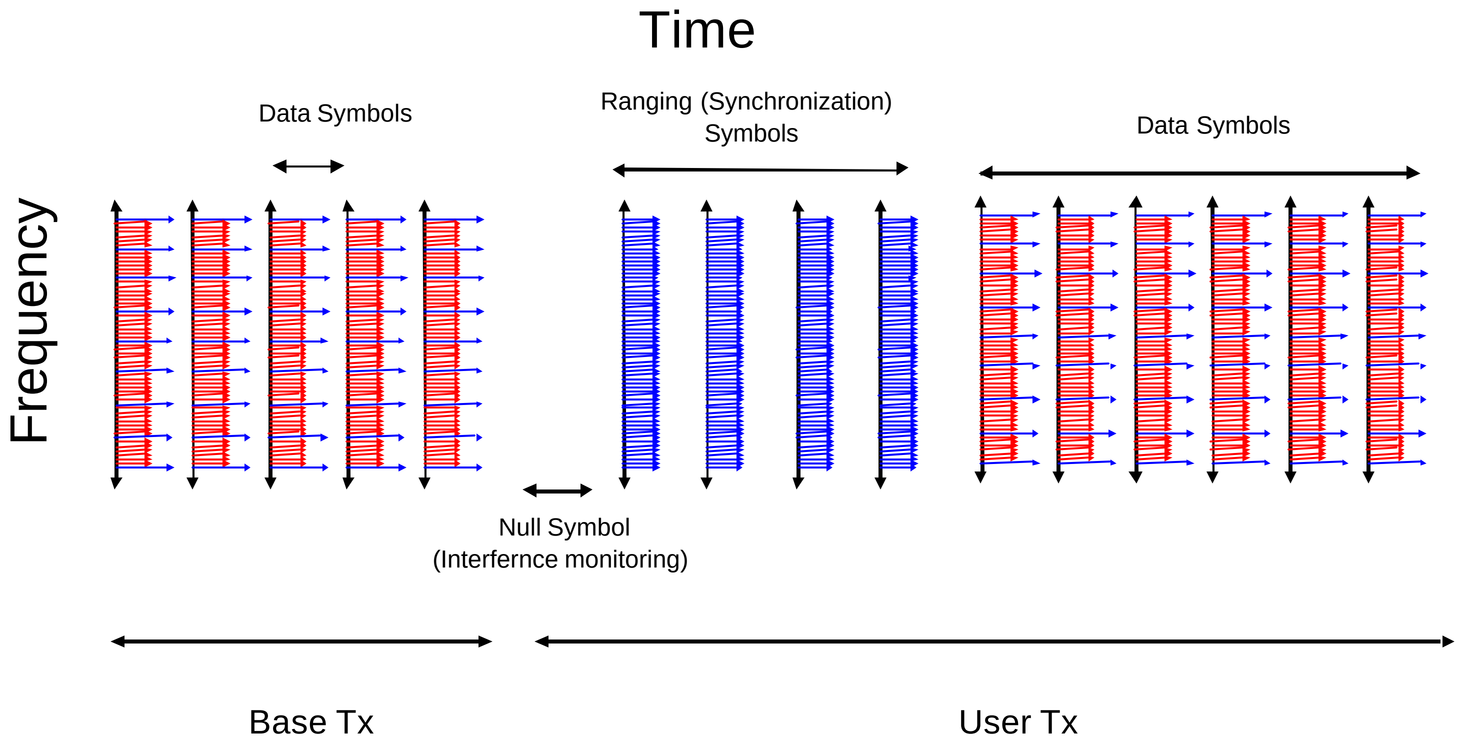

Figure 32: Ranging Symbol allocation for OFDM mapping

[fill in the preamble structure]

7.12.3 Bandwidth Requesting

7.12.3.1 Fast bandwidth requests using an OFDMA mapping

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 7.12.2.1).

7.12.3.2 Bandwidth requests using an OFDM mapping

Bandwidth request in OFDM takes the following form:

- Contention based requests. In this mode regular uplink bursts shall be used for BW requests.

7.12.4 Power Control

7.13 Transmission convergence (TC) Sublayer

7.13.1 Uplink Transmission Convergence Sublayer

7.13.2 Downlink Transmission Convergence Sublayer

7.14 Additional Possible Features

7.14.1 Adaptive Arrays

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 upstream and downstream 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.

The framing methods outlined in previous sections addressing adaptive arrays are designed to exploit these advantages.

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 [23], 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).

7.14.2 Transmit diversity Alamouti's Space-Time Coding

Alamouti's scheme [25] 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 CPE side. This scheme requires Multiple Input Single Output -MISO- channel estimation. Decoding is very similar to maximum ratio combining.
Next figure 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.

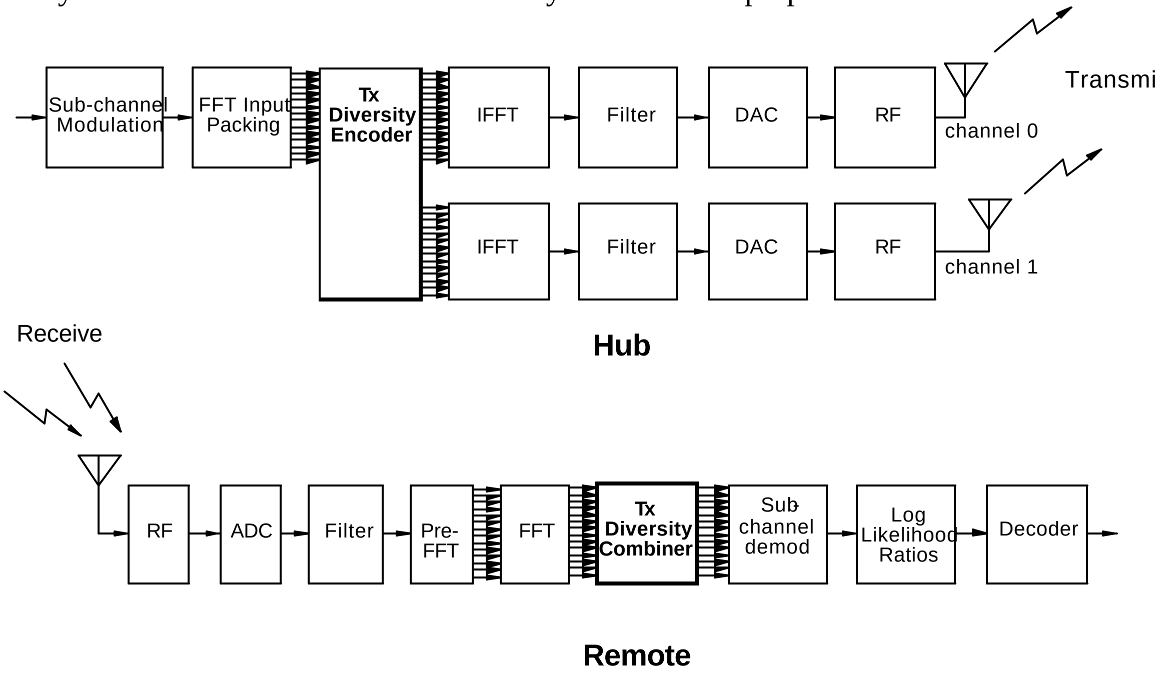

Figure 33: Illustration of the Alamouti STC

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.

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.

7.14.3 STC for FFT sizes 64 through 512

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 frequencies, and antenna 1 odd frequencies. 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.

7.14.4 STC for FFT sizes 512 to 4k

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).

7.14.5 Alamouti STC Encoding

s* denotes complex conjugate of s.
(Scheme explanation) The basic scheme [25] transmits 2 complex symbols s_0 and s_1, 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:
$s_0 = h_0^* r_0 + h_1 r_1^*$.
$S_1 = h_1^* r_0 - h_0 r_1^*$.
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.

Next figure 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)

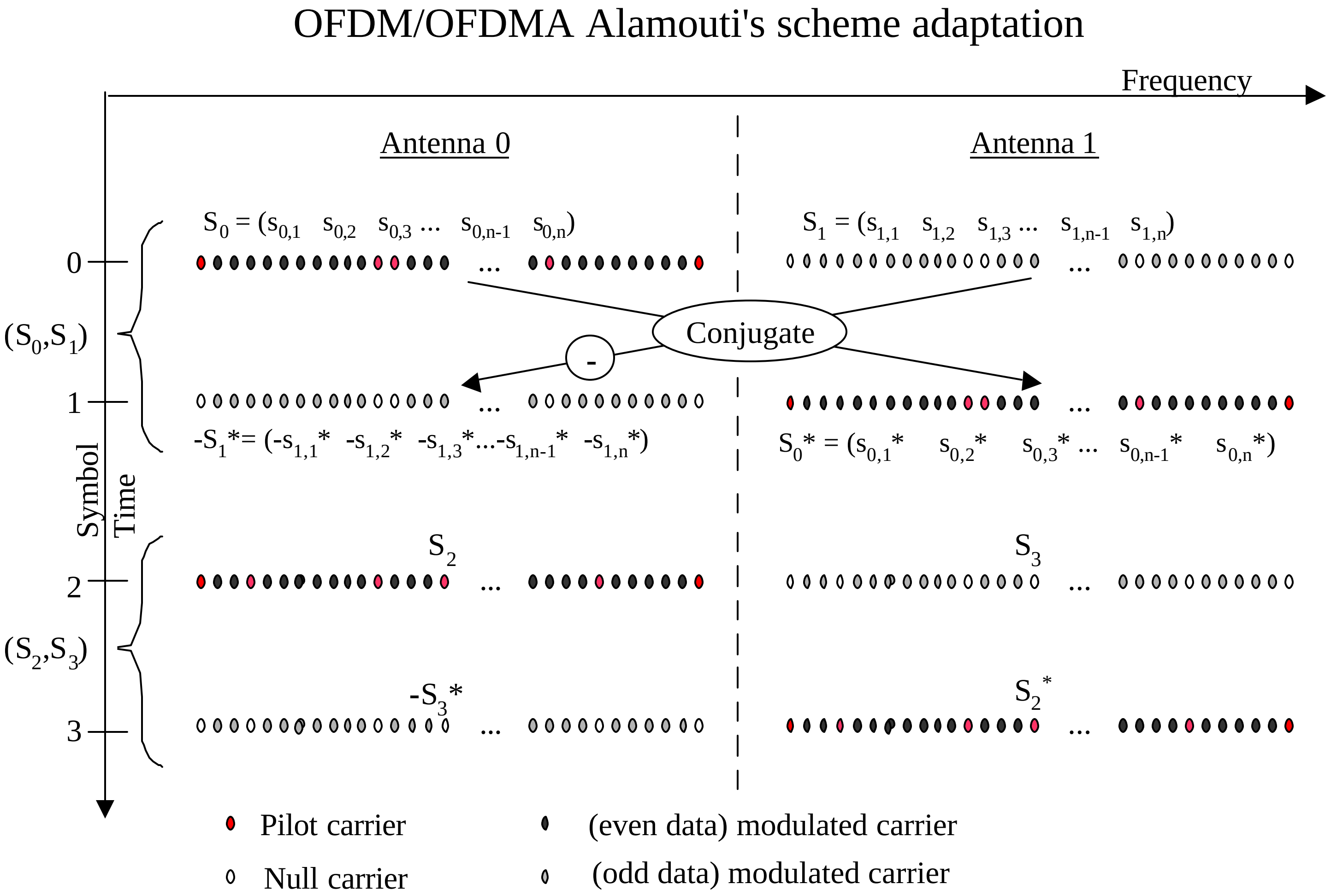

Figure 34: Using Alamouti’s Scheme with OFDM/OFDMA

7.14.6 Alamouti STC Decoding

The receiver waits for 2 symbols, and combines them on a carrier basis according to the formula in section 7.14.5.

8 (Annex A) Sub-Channel Permutations

In section 7.10.2.1.2, the permutation procedure was explained. We give an example for using the procedure with the US 1k mode.

The parameters characterizing the US 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:

- Y – Number of carriers in each basic group = 16
- The basic series of 16 elements is $\{PermutationBase_0\}$= 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. 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 by the next formula:

   $$c_s[k] = \left\{p_s[k_{\mathrm{mod}_{16)}}] + \mathrm{ceil}[(\mathrm{k}+1)/\mathrm{N}_{\mathrm{elements}}]\cdot CellId\right\}_{\mathrm{mod}(16)} \text{ with } k=0,1,\ldots,63$$

   for example when using permutation 1 with CellId=2 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, 10, 4, 8, 9, 0, 14, 1, 5, 15, 7, 3, 2, 11, 13, 10, 6, 12, 6, 10, 11, 2, 0, 3

1. 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:

   $$\text{Carrier(n,1)} = 16\cdot n + p_1[n]$$

   Where carrier(n, 1) is the n-th carrier of subchannel number 1; $p_1[n]$ is the n-th element of $\{PermutatedSeries_1\}$ and n = 0, 1, ..., 52.

9 (Annex B) Turbo Product Coding

The Block Turbo Code is a Turbo decoded Product Code (TPC). The idea of this coding scheme is to use well-known product codes in a matrix form for two-dimensional coding, or in a cubical form for three dimensions.

The matrix form of the two-dimensional code is depicted in Figure 35. The k_x information bits in the rows are encoded into n_x bits, by using a binary block (n_x, k_x) code. The binary block codes employed are based on extended Hamming codes.

The redundancy of the code is $r_x = n_x - k_x$ and d_x is the Hamming distance. After encoding the rows, the columns are encoded using another block code (n_y, k_y), 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 $d = d_x \times d_y$.

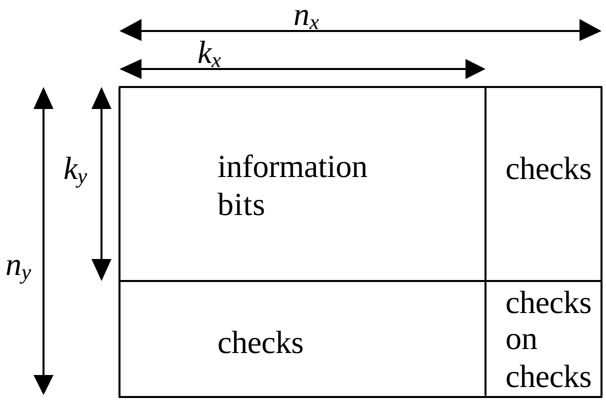

Figure 35 Two-dimensional product code matrix

9.1 Encoding of a Turbo Product Code

The encoder for TPCs has near zero latency, and is constructed of linear feedback shift registers (LFSRs), storage elements, and control logic. Encoding of a product code requires that each bit be encoded by 2 or 3 codes.

The constituent codes of TPCs are extended Hamming or parity only codes. Table 12 gives the generator polynomials of the Hamming codes used in TPCs. For extended Hamming codes, an overall even parity check bit is added at the end of each code word.

n	**k**	**Generator Polynomial**
7	4	$x^3 + x + 1$
15	11	$x^4 + x + 1$
31	26	$x^5 + x^2 + 1$
63	57	$x^6 + x + 1$
127	120	$x^7 + x^3 + 1$
255	247	$x^8 + x + 1$

Table 12 Generators Polynomials of Hamming Codes

In order to encode the product code, each data bit is input both into a row encoder and a column encoder. Only one row encoder is necessary for the entire block, since data is input in row order. However, each column of the array is encoded with a separate encoder. Each column encoder is clocked for only one bit of the row, thus a more efficient method of column encoding is to store the column encoder states in a $k_x \times (n_y - k_y)$ storage memory. A single encoder can then be used for all columns of the array. With each bit input, the appropriate column encoder state is read from the memory, clocked, and written back to the memory.

The encoding process will be demonstrated with an example.

9.2 Example of a 2-Dimesional Product Code

Assume a two-dimensional (8,4) × (8,4) extended Hamming Product code is to be encoded. This block has 16 data bits, and 64 total encoded bits. Figure 36 shows the original 16 data bits denoted by D_{yx}. Of course the usual way is to have a serial stream of data of 16 bits and then label them as D_{11}, D_{21}, D_{31}, D_{41}, D_{12},…, D_{44}.

D_{11}	D_{21}	D_{31}	D_{41}
D_{12}	D_{22}	D_{32}	D_{42}

D_{13}	D_{23}	D_{33}	D_{43}
D_{14}	D_{24}	D_{34}	D_{44}

Figure 36 Original Data for Encoding

The first four bits of the array are loaded into the row encoder in the order D_{11}, D_{21}, D_{31}, D_{41}. Each bit is also fed into a unique column encoder. Again, a single column encoder may be used, with the state of each column stored in a memory. After the fourth bit is input, the first row encoder error correction coding (ECC) bits are shifted out.

This process continues for all four rows of data. At this point, 32 bits have been output from the encoder, and the four column encoders are ready to shift out the column ECC bits. This data is also shifted out row-wise. This continues for the remaining 3 rows of the array. Figure 37 shows the final encoded block with the 48 generated ECC bits denoted by E_{yx}.

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 37 Encoded Block

Transmission of the block over the channel may occur in a linear fashion, for example 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)×(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 may be inserted to further improve the performance of the system.

9.3 Shortened TPCs

To match packet sizes, a product code may be 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, helping to keep the code rate high.

There are two steps in the process of shortening of product codes. The first is to remove an entire row or column from a 2-dimensional code, or an entire X, Y, or Z plane from a 3-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 a 2-dimensional code, or from the top plane of a 3-dimensional code.

9.4 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 38 shows the structure of the resultant block.

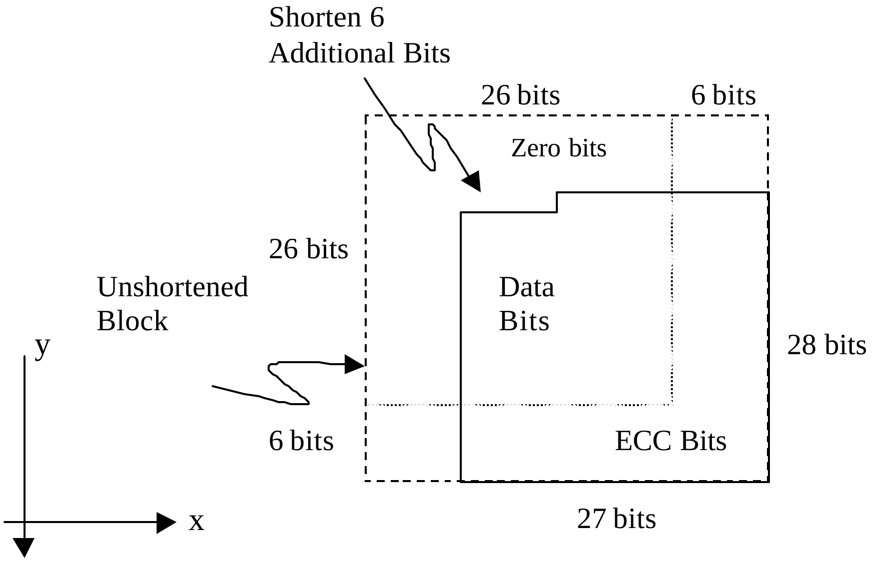

Figure 38: Structure of Shortened 2 D Block

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.

9.5 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 $(n_x \times n_y \times n_z, k_x \times k_y \times k_z)$, 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:

1) Soft-Output Viterbi Algorithm (SOVA) [21]
2) The modified Chase algorithm [22]
3) The BCJR algorithm [25],

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 7A 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).

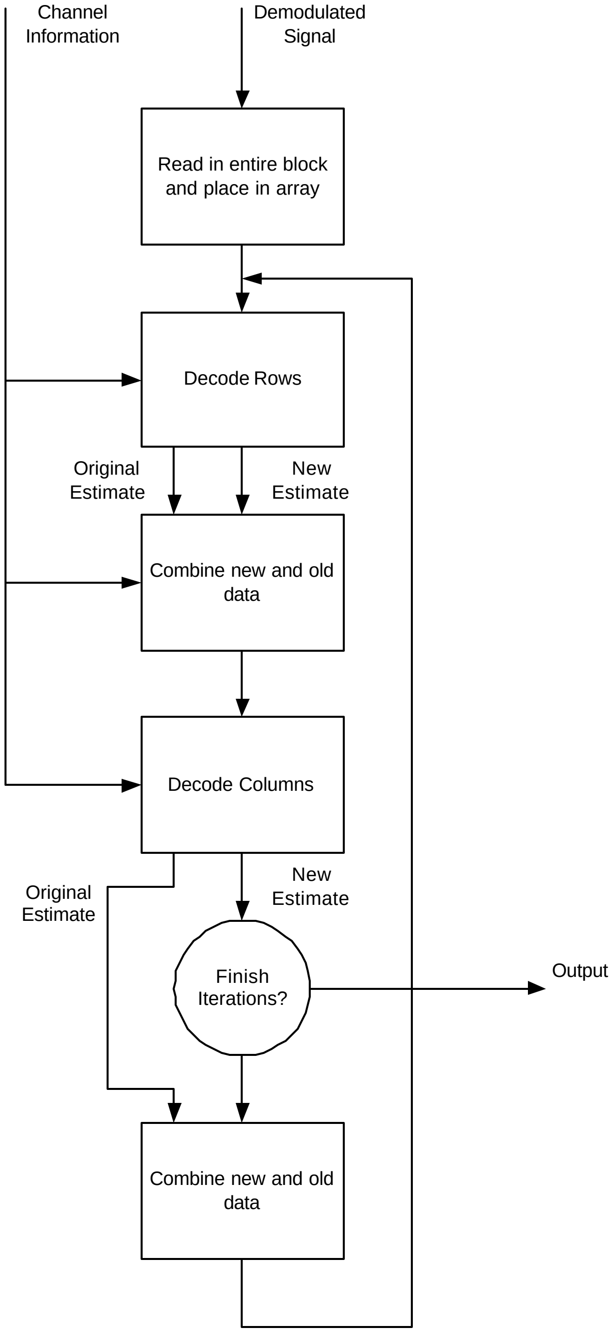

Figure 39: Procedure for decoding of 2-D TPC

It can easily be seen from Figure 39 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.

10 Regulatory Constraints

10.1 FCC and ETSI regulatory masks

Channel bandwidths for frequencies below 11GHz differ between several areas of the world. ETSI band plans generally vary from 7 to 28 MHz. Within the United States, band plans in the PCS and WCS frequency bands are 5, 10 or 15 MHz, and band plans in the MMDS frequency band are organized in multiples of 6 MHz channels.

In general, when the available number of channels is too limited to deploy a network, splitting of these bands is possible. In this document, splitting in factors of 2 for the ETSI and MMDS allocations to a minimum of 1.75, respectively 1.5 MHz is taken into consideration. For the PCS and WCS, the only split is 2.5 MHz. These sub-allocations are (apart from their size) physically no different then 'regular' channel-widths and will hence not be addressed separately.

In general, frequency band plans provide paired frequency blocks. Examples include the PCS band with 80 MHz separation between blocks, the WCS band with 45 MHz separation between blocks A and B, the 3.5 GHz band with 50 or 100 MHz separation, and the 3.4 to 3.6 GHz bands in Europe that include 50, 70 and 100 MHz separations. The MMDS band does not have defined blocks, but a separation on the order of 6 to 48 MHz is possible.

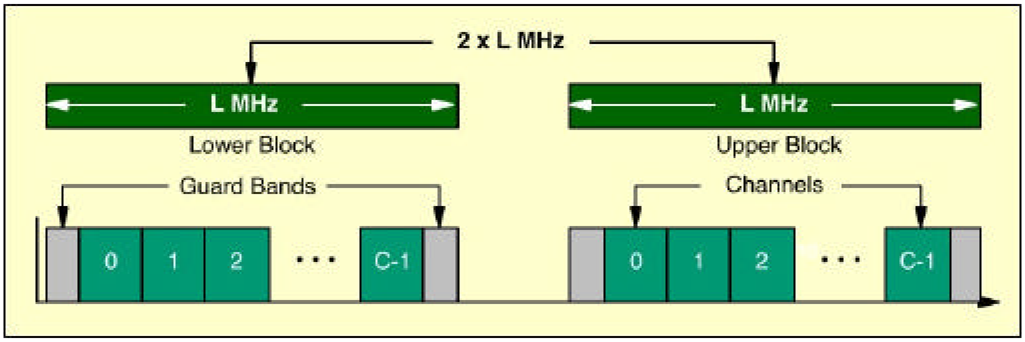

Figure 40: Generic paired Frequency block with channel splitting

The active bandwidth is less than the channel bandwidth to meet spectral mask designations associated with out-of-band spectral interference requirements. The key contribution to out-of-band interference is typically third and fifth order intermodulation distortion resulting from RF circuitry, but signal roll-off is also a consideration. The ETSI mask is shown in Figure 41 [22]; the spectral mask for the WCS band is shown in Figure 42; the spectral mask for the MMDS band is shown in Figure 43.

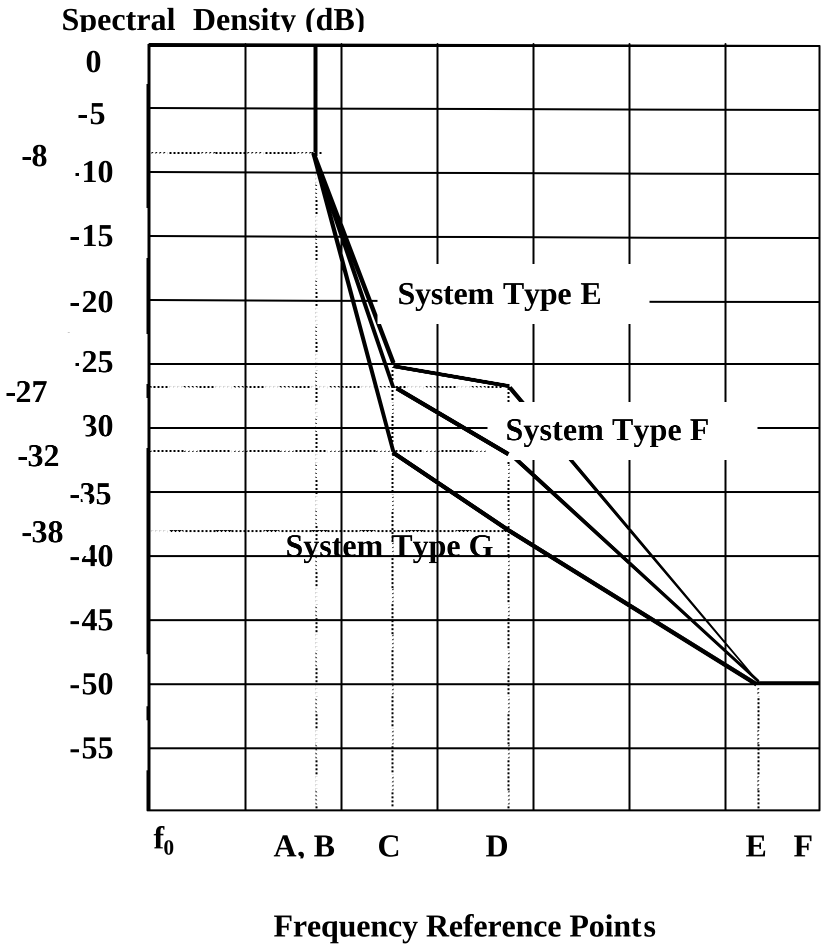

Figure 41: ETSI Spectral Mask[*]

[*] Different masks relate to different system throughput requirements. The higher the throughput, the more relaxed the mask. See [22] for details.

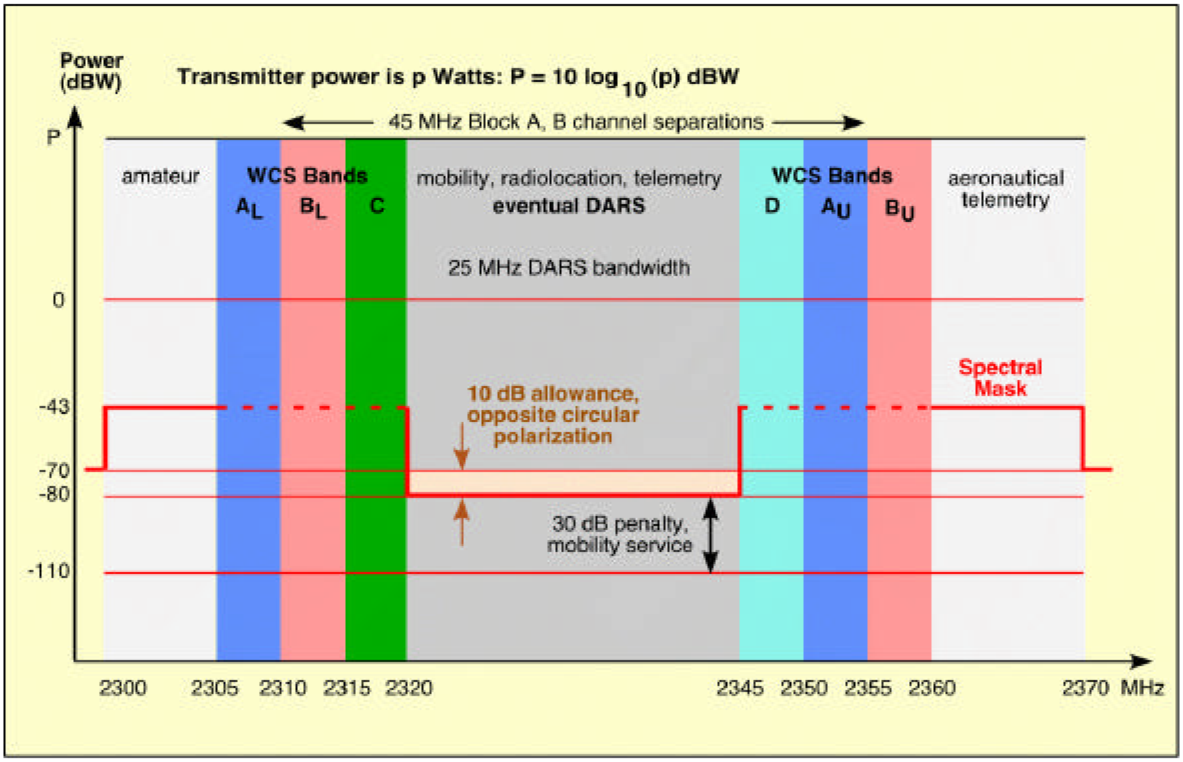

Figure 42: WCS Spectral Mask

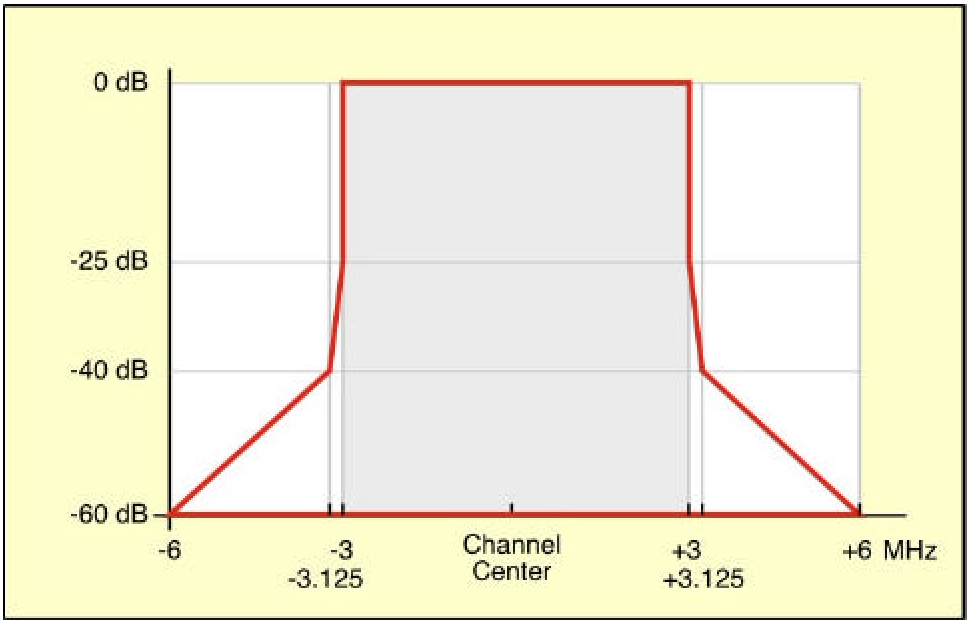

Figure 43: MMDS Spectral Mask

10.2 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.

Normative references

This part to be inserted to chapter 2 of the 802.16 standard

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[2] H. Sari and G. Karam, "Orthogonal Frequency-Division Multiple Access and its Application to CATV Networks," European Transactions on Telecommunications (ETT), vol. 9, no. 6, pp. 507-516, November - December 1998.

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