Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**OFDM proposal for the IEEE 802.16a PHY draft standard**
Date Submitted	**2001-03-9**
Source(s)	The following members (in company alphabetical order) support an IEEE 802.16a physical layer with OFDM as its basis, and as such jointly submit this contribution, with the aim that the concepts of this document be considered as baseline by the 802.16a Task Group in the development of the 802.16a standard.

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Re:	TG3 call for Contributions for PHY layer; issued 2000-21-01. TG3 invitation to contribute PHY proposals, 802.16.3-01/05, 2001-26-01
Abstract	This contribution is an 802.16a PHY draft standard proposal that advocates an OFDM solution to address the functional requirements.
Purpose	This proposal is proposed as draft standard for the 802.16a PHY.
Notice	
Release	
Patent Policy and Procedures	

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OFDM/OFDMA PHY proposal for TG3 PHY Development

1 Introduction

The PHY layer described in this clause is designated for operation in the licensed frequency bands below 11 GHz. The PHY parameters cover a variety of channel widths, adapted to different regulatory domains and to the policy of the operator to subdivide that bandwidth available to him.

The PHY is based on OFDM (Orthogonal Frequency Division Multiplex) modulation, supporting both TDMA (Time Division Multiple Access) and OFDMA (Orthogonal Frequency Division Multiple Access) [1], [2]. In OFDM the information is imposed onto the medium by modulating multiple carriers transmitted in parallel. In TDMA, all carriers of an OFDM symbol are assigned to one transmitter. In OFDMA the carriers are divided into subgroups, each constituting a channel. When the OFDMA concept is applied to the uplink, it allows users to operate with smaller power amplifiers, at expense of instantaneous data rate. On the other hand it allows allocating dynamically larger amounts of bandwidth to users capable of utilizing it in terms of their link budget. When applied to the downlink, OFDMA allows transmitting to multiple users in parallel with designated data streams, and allows improving the link budget of disadvantaged users by allocating to their Sub-Channels a larger fraction of their downlink transmit power.

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. The PHY described below contains the programmability to deal with this range of applications. As the modulation is implemented using the FFT algorithm, the modes are designated by the FFT size, ranging from 64 for low bandwidth channels, up to 4096. 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 in fractions of 1/64 up to 1/4 of the FFT interval duration.

Several options of dividing the carriers into Sub-Channels are supported. In one, the carriers are allocated contiguously; in other they are interleaved in a regular manner; in third they are interleaved in a pseudo-random manner. The preference of one technique over other depends on implementation strategy and on deployment scenario.

The system is designed to support TDD, H-FDD and FDD operation. The framing structure of both OFDM and OFDMA modes is designed to support adaptive modulation both on downlink and on uplink. In OFDM mode the framing structure of each burst is optimized towards one stream of data, while in the OFDMA mode the framing is optimized towards multiple parallel streams. On downlink, the high-size FFT modes rely on the scattered pilots for channel estimation, , there is no preambles sent to the users, the users are supposed to keep track of the channel state information from frame to frame and update it with the scattered pilots on the data frame. While in small-size FFT modes a training preamble could be periodically inserted, when using variable pilot location the preamble is sent only at the beginning of the frame. On uplink, each packet starts with a preamble for channels estimation purposes.

2 Physical Layer Operation

TBD

3 Time Domain and Frequency Domain issues

In this section we focus on different aspects of the system Channel bandwidths, Regulatory masks, and a Time Domain and Frequency Domain description of the OFDM signal including the possible FFT and GI lengths.

3.1 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.

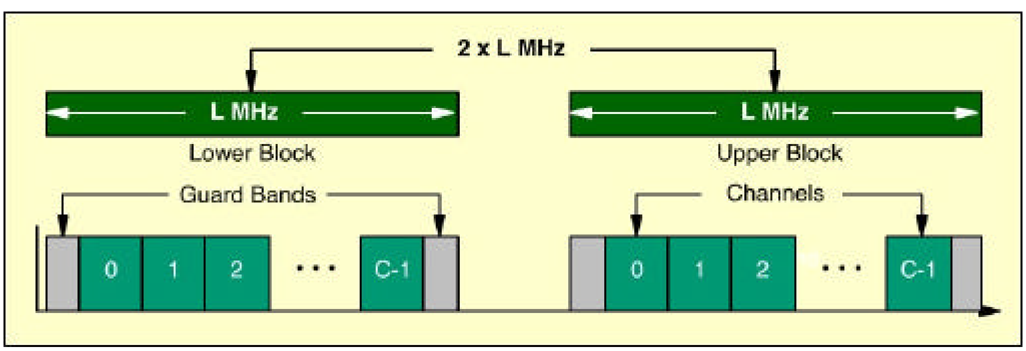

Figure 1: Generic paired Frequency block with channel splitting

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 2 [22]; the spectral mask for the WCS band is shown in Figure 3; the spectral mask for the MMDS band is shown in

Figure 4.

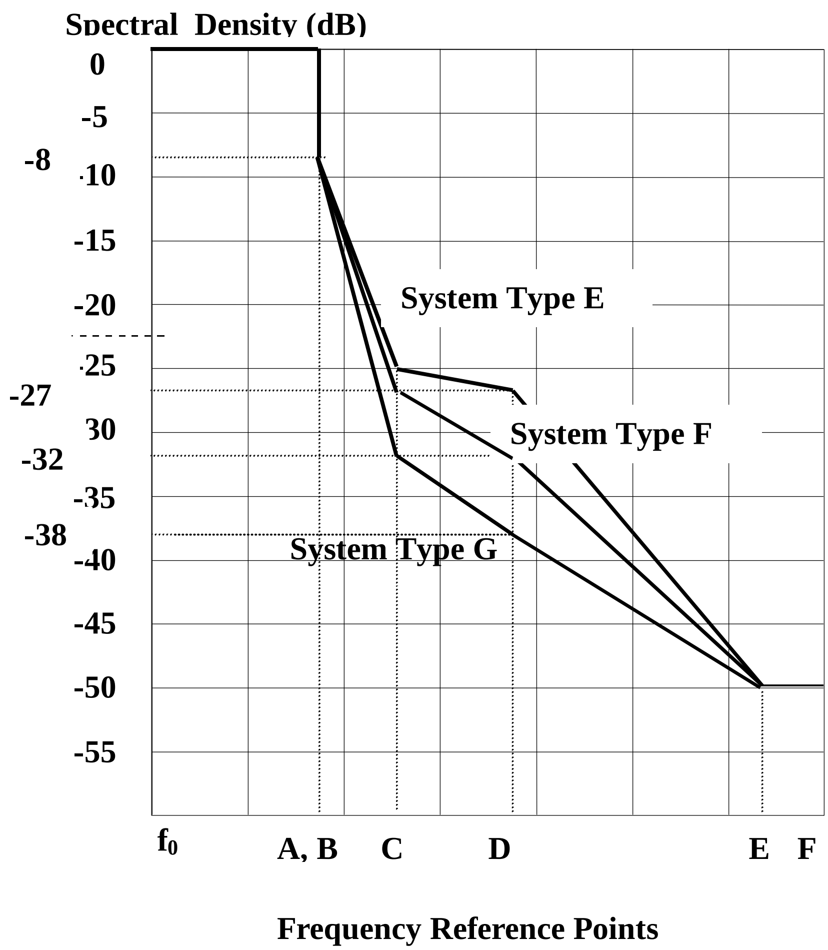

Figure 2: ETSI Spectral Mask*

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

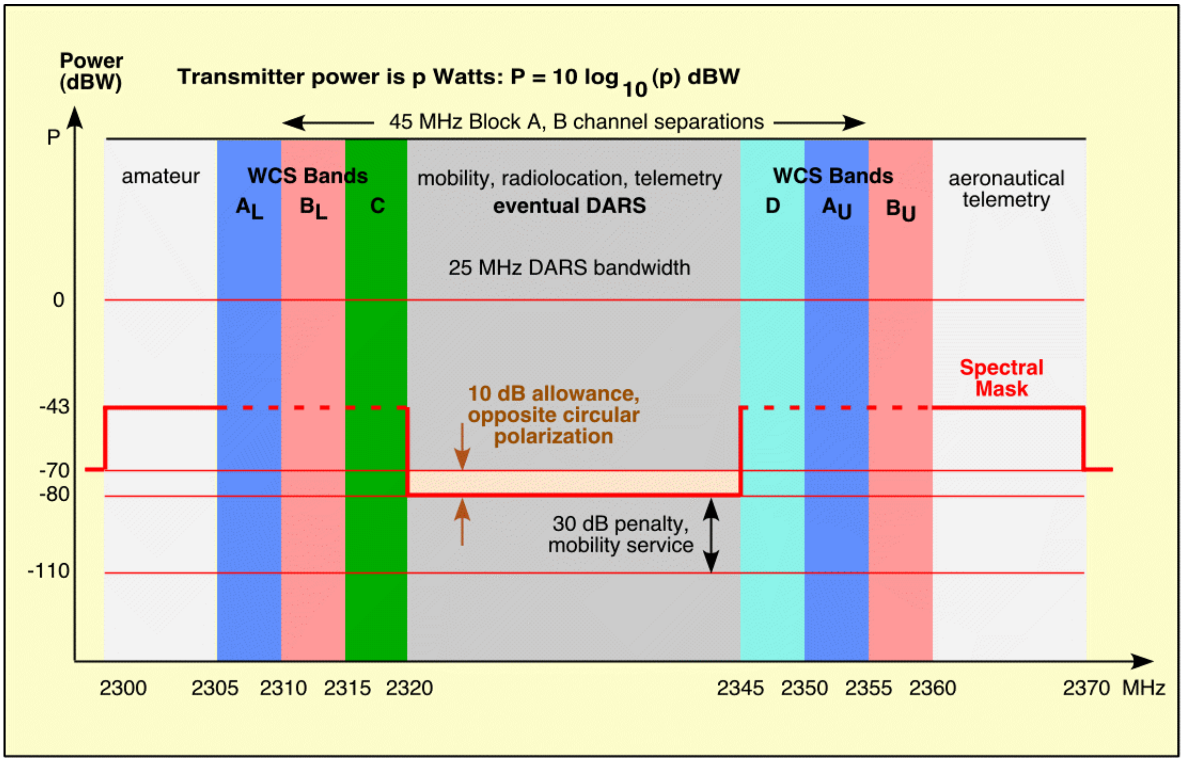

Figure 3: WCS Spectral Mask

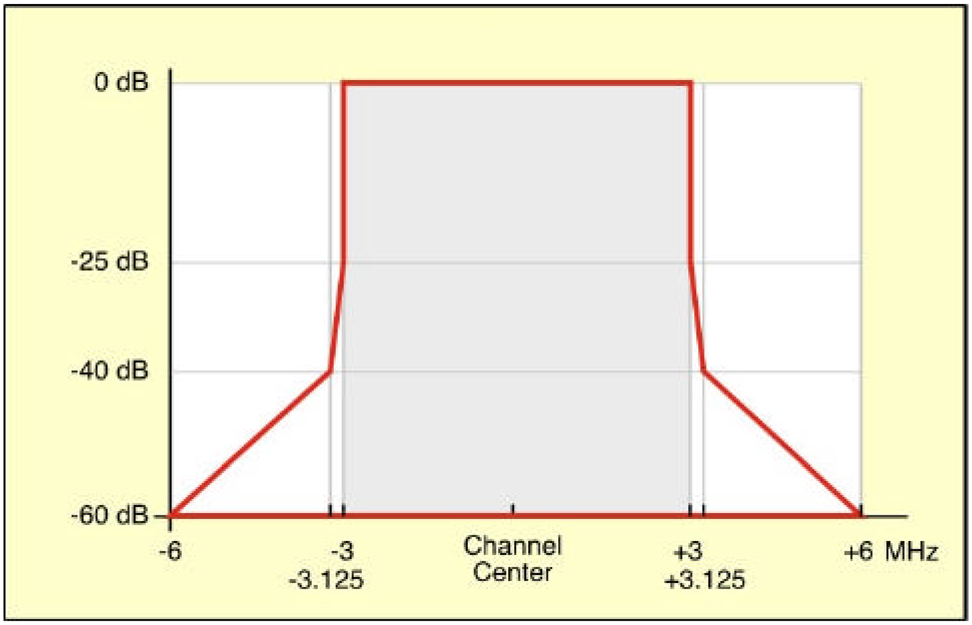

Figure 4: MMDS Spectral Mask

3.2 Supported FFT lengths and Guard Interval Lengths

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). 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 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 using the next parameters:

$$BWEfficiency = \frac{F_s}{BW} \cdot \frac{53}{64} = \frac{\Delta f \cdot N_{used}}{BW}$$

BW - Denotes the channel bandwidth

F_s - Denotes the sampling frequency

Δf - Denotes the carrier spacing

N_{used} - Denotes the number of carriers used in the FFT

The Bandwidth efficiency should always be around 93-95%, 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:

$$F_s = BWEfficiency \cdot BW \cdot \frac{64}{53}$$

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.

Number of carriers used	FFT size
53	64
106	128
212	256
424	512
848	1024
1696	2048
3392	4096

Table 1 Active carriers vs. FFT size.

The number of active carriers on the US in all modes is chosen to be 2^n*53, of which 48 data sub-carriers. Further granularity in multiples of 16 can optionally be employed to support the adaptive antenna features detailed in 4.4.

** Note that the choice of FFT size is an artificial implementation parameter – the 212 carriers modulation can be implemented either with FFT of size 256, or with 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

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

This specification allows for FFT sizes 64, 128, 256, 512, 1024, 2048, 4096. A compliant device shall implement either 64 or 256 FFT with TDMA, or alternatively 1024 or 2048 FFT with OFDMA for any bandwidth (implementing more than one compliant FFT size, or other FFT sizes is optional).

The following tables give some calculation of the Carrier Spacing, Symbol Duration and Guard Interval duration for different masks. These parameters fit the FFT modes 256 and above, were the sampling frequency is defined as: $F_s = \frac{8}{7} BW$ (when using the 64, 128 FFT sizes, the sampling rate in the MMDS and WCS masks is $F_s = BW$).

Channel(MHz)	FFT size	64	128	256	512	1024	2048	4096
1.5	Sub-carrier (kHz)	23 7/16	11 23/32	6 39/56	3 8/23	1 60/89	36/43	18/43
	occupied BW	82.81%	82.81%	94.64%	94.64%	94.64%	94.64%	94.64%
	Symbol (us)	42 2/3	85 1/3	149 1/3	298 2/3	597 1/3	1194 2/3	2389 1/3
	Guard =1/64	2/3	1 1/3	2 1/3	4 2/3	9 1/3	18 2/3	37 1/3
	1/32	1 1/3	2 2/3	4 2/3	9 1/3	18 2/3	37 1/3	74 2/3
	1/16	2 2/3	5 1/3	9 1/3	18 2/3	37 1/3	74 2/3	149 1/3
	1/8	5 1/3	10 2/3	18 2/3	37 1/3	74 2/3	149 1/3	298 2/3
	1/4	10 2/3	21 1/3	37 1/3	74 2/3	149 1/3	298 2/3	597 1/3
3	Sub-carrier (kHz)	46 7/8	23 7/16	13 11/28	6 39/56	3 8/23	1 60/89	36/43
	occupied BW	82.81%	82.81%	94.64%	94.64%	94.64%	94.64%	94.64%
	Symbol (us)	21 1/3	42 2/3	74 2/3	149 1/3	298 2/3	597 1/3	1194 2/3
	Guard =1/64	1/3	2/3	1 1/6	2 1/3	4 2/3	9 1/3	18 2/3
	1/32	2/3	1 1/3	2 1/3	4 2/3	9 1/3	18 2/3	37 1/3
	1/16	1 1/3	2 2/3	4 2/3	9 1/3	18 2/3	37 1/3	74 2/3
	1/8	2 2/3	5 1/3	9 1/3	18 2/3	37 1/3	74 2/3	149 1/3
	1/4	5 1/3	10 2/3	18 2/3	37 1/3	74 2/3	149 1/3	298 2/3
6	Sub-carrier (kHz)	93 3/4	46 7/8	26 11/14	13 11/28	6 39/56	3 8/23	1 60/89
	occupied BW	82.81%	82.81%	94.64%	94.64%	94.64%	94.64%	94.64%
	Symbol (us)	10 2/3	21 1/3	37 1/3	74 2/3	149 1/3	298 2/3	597 1/3
	Guard =1/64	1/6	1/3	7/12	1 1/6	2 1/3	4 2/3	9 1/3
	1/32	1/3	2/3	1 1/6	2 1/3	4 2/3	9 1/3	18 2/3
	1/16	2/3	1 1/3	2 1/3	4 2/3	9 1/3	18 2/3	37 1/3
	1/8	1 1/3	2 2/3	4 2/3	9 1/3	18 2/3	37 1/3	74 2/3
	1/4	2 2/3	5 1/3	9 1/3	18 2/3	37 1/3	74 2/3	149 1/3
12	Sub-carrier (kHz)	187 1/2	93 3/4	53 4/7	26 11/14	13 11/28	6 39/56	3 8/23
	occupied BW	82.81%	82.81%	94.64%	94.64%	94.64%	94.64%	94.64%
	Symbol (us)	5 1/3	10 2/3	18 2/3	37 1/3	74 2/3	149 1/3	298 2/3
	Guard =1/64	1/12	1/6	7/24	7/12	1 1/6	2 1/3	4 2/3
	1/32	1/6	1/3	7/12	1 1/6	2 1/3	4 2/3	9 1/3
	1/16	1/3	2/3	1 1/6	2 1/3	4 2/3	9 1/3	18 2/3
	1/8	2/3	1 1/3	2 1/3	4 2/3	9 1/3	18 2/3	37 1/3
	1/4	1 1/3	2 2/3	4 2/3	9 1/3	18 2/3	37 1/3	74 2/3
24	Sub-carrier (kHz)	375	187 1/2	107 1/7	53 4/7	26 11/14	13 11/28	6 39/56
	occupied BW	82.81%	82.81%	94.64%	94.64%	94.64%	94.64%	94.64%
	Symbol (us)	2 2/3	5 1/3	9 1/3	18 2/3	37 1/3	74 2/3	149 1/3
	Guard =1/64	1/24	1/12	7/48	7/24	7/12	1 1/6	2 1/3
	1/32	1/12	1/6	7/24	7/12	1 1/6	2 1/3	4 2/3
	1/16	1/6	1/3	7/12	1 1/6	2 1/3	4 2/3	9 1/3
	1/8	1/3	2/3	1 1/6	2 1/3	4 2/3	9 1/3	18 2/3
	1/4	2/3	1 1/3	2 1/3	4 2/3	9 1/3	18 2/3	37 1/3

Table 2: MMDS channelization parameters

Channel(MHz)	FFT size	64	128	256	512	1024	2048	4096
	Sub-carrier (kHz)	31 1/4	15 5/8	7 13/16	3 29/32	1 61/64	83/85	21/43
	occupied BW	94.64%	94.64%	94.64%	94.64%	94.64%	94.64%	94.64%
	Symbol (us)	32	64	128	256	512	1024	2048
1.75	Guard =1/64	1/2	1	2	4	8	16	32
	1/32	1	2	4	8	16	32	64
	1/16	2	4	8	16	32	64	128
	1/8	4	8	16	32	64	128	256
	1/4	8	16	32	64	128	256	512
	Sub-carrier (kHz)	62 1/2	31 1/4	15 5/8	7 13/16	3 29/32	1 61/64	83/85
	occupied BW	94.64%	94.64%	94.64%	94.64%	94.64%	94.64%	94.64%
	Symbol (us)	16	32	64	128	256	512	1024
3.5	Guard =1/64	1/4	1/2	1	2	4	8	16
	1/32	1/2	1	2	4	8	16	32
	1/16	1	2	4	8	16	32	64
	1/8	2	4	8	16	32	64	128
	1/4	4	8	16	32	64	128	256
	Sub-carrier (kHz)	125	62 1/2	31 1/4	15 5/8	7 13/16	3 29/32	1 61/64
	occupied BW	94.64%	94.64%	94.64%	94.64%	94.64%	94.64%	94.64%
	Symbol (us)	8	16	32	64	128	256	512
7	Guard =1/64	1/8	1/4	1/2	1	2	4	8
	1/32	1/4	1/2	1	2	4	8	16
	1/16	1/2	1	2	4	8	16	32
	1/8	1	2	4	8	16	32	64
	1/4	2	4	8	16	32	64	128
	Sub-carrier (kHz)	250	125	62 1/2	31 1/4	15 5/8	7 13/16	3 29/32
	occupied BW	94.64%	94.64%	94.64%	94.64%	94.64%	94.64%	94.64%
	Symbol (us)	4	8	16	32	64	128	256
14	Guard =1/64	1/16	1/8	1/4	1/2	1	2	4
	1/32	1/8	1/4	1/2	1	2	4	8
	1/16	1/4	1/2	1	2	4	8	16
	1/8	1/2	1	2	4	8	16	32
	1/4	1	2	4	8	16	32	64
	Sub-carrier (kHz)	500	250	125	62 1/2	31 1/4	15 5/8	7 13/16
	occupied BW	94.64%	94.64%	94.64%	94.64%	94.64%	94.64%	94.64%
	Symbol (us)	2	4	8	16	32	64	128
28	Guard =1/64	1/32	1/16	1/8	1/4	1/2	1	2
	1/32	1/16	1/8	1/4	1/2	1	2	4
	1/16	1/8	1/4	1/2	1	2	4	8
	1/8	1/4	1/2	1	2	4	8	16
	1/4	1/2	1	2	4	8	16	32

Table 3: ETSI channelization parameters

Channel(MHz)	FFT size	64	128	256	512	1024	2048	4096
2.5	Sub-carrier (kHz)	39 1/16	19 17/32	11 9/56	5 47/81	2 64/81	1 32/81	30/43
	occupied BW	82.81%	82.81%	94.64%	94.64%	94.64%	94.64%	94.64%
	Symbol (us)	25 3/5	51 1/5	89 3/5	179 1/5	358 2/5	716 4/5	1433 3/5
	Guard =1/64	2/5	4/5	1 2/5	2 4/5	5 3/5	11 1/5	22 2/5
	1/32	4/5	1 3/5	2 4/5	5 3/5	11 1/5	22 2/5	44 4/5
	1/16	1 3/5	3 1/5	5 3/5	11 1/5	22 2/5	44 4/5	89 3/5
	1/8	3 1/5	6 2/5	11 1/5	22 2/5	44 4/5	89 3/5	179 1/5
	1/4	6 2/5	12 4/5	22 2/5	44 4/5	89 3/5	179 1/5	358 2/5
5	Sub-carrier (kHz)	78 1/8	39 1/16	22 9/28	11 9/56	5 47/81	2 64/81	1 32/81
	occupied BW	82.81%	82.81%	94.64%	94.64%	94.64%	94.64%	94.64%
	Symbol (us)	12 4/5	25 3/5	44 4/5	89 3/5	179 1/5	358 2/5	716 4/5
	Guard =1/64	1/5	2/5	7/10	1 2/5	2 4/5	5 3/5	11 1/5
	1/32	2/5	4/5	1 2/5	2 4/5	5 3/5	11 1/5	22 2/5
	1/16	4/5	1 3/5	2 4/5	5 3/5	11 1/5	22 2/5	44 4/5
	1/8	1 3/5	3 1/5	5 3/5	11 1/5	22 2/5	44 4/5	89 3/5
	1/4	3 1/5	6 2/5	11 1/5	22 2/5	44 4/5	89 3/5	179 1/5
10	Sub-carrier (kHz)	156 1/4	78 1/8	44 9/14	22 9/28	11 9/56	5 47/81	2 64/81
	occupied BW	82.81%	82.81%	94.64%	94.64%	94.64%	94.64%	94.64%
	Symbol (us)	6 2/5	12 4/5	22 2/5	44 4/5	89 3/5	179 1/5	358 2/5
	Guard =1/64	1/10	1/5	7/20	7/10	1 2/5	2 4/5	5 3/5
	1/32	1/5	2/5	7/10	1 2/5	2 4/5	5 3/5	11 1/5
	1/16	2/5	4/5	1 2/5	2 4/5	5 3/5	11 1/5	22 2/5
	1/8	4/5	1 3/5	2 4/5	5 3/5	11 1/5	22 2/5	44 4/5
	1/4	1 3/5	3 1/5	5 3/5	11 1/5	22 2/5	44 4/5	89 3/5
15	Sub-carrier (kHz)	234 3/8	117 3/16	66 27/28	33 27/56	16 20/27	8 10/27	4 5/27
	occupied BW	82.81%	82.81%	94.64%	94.64%	94.64%	94.64%	94.64%
	Symbol (us)	4 4/15	8 8/15	14 14/15	29 13/15	59 11/15	119 7/15	238 14/15
	Guard =1/64	1/15	2/15	7/30	7/15	14/15	1 13/15	3 11/15
	1/32	2/15	4/15	7/15	14/15	1 13/15	3 11/15	7 7/15
	1/16	4/15	8/15	14/15	1 13/15	3 11/15	7 7/15	14 14/15
	1/8	8/15	1 1/15	1 13/15	3 11/15	7 7/15	14 14/15	29 13/15
	1/4	1 1/15	2 2/15	3 11/15	7 7/15	14 14/15	29 13/15	59 11/15

Table 4: PCS/WCS channelization parameters

3.3 Time domain description.

Inverse-Fourier-transforming creates the OFDM waveform; this time duration is referred to as the useful symbol time (T_u). 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 5 illustrates this structure:

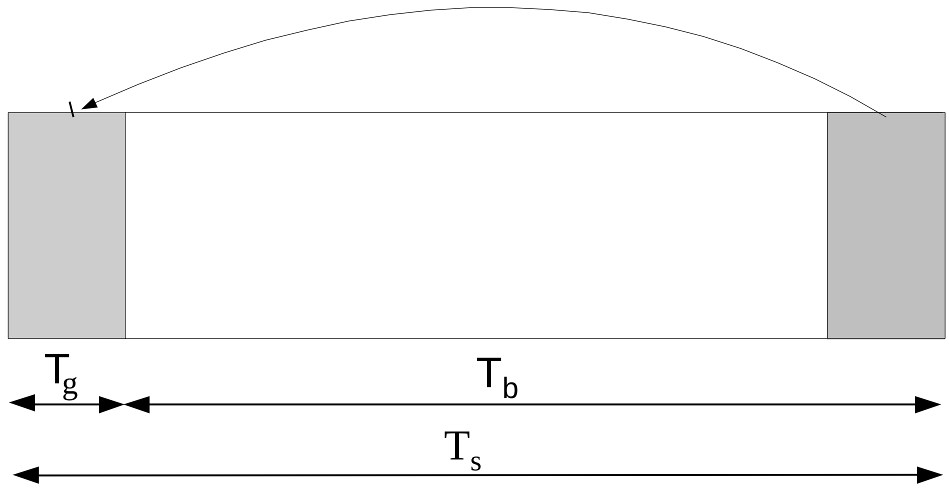

Figure 5: OFDM symbol time structure

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. The loss is about 0.3 dB when T_g = 20 µs and T_b = 320 µs, which is acceptable given the zero ICI. Using a cyclic extension, the samples required for performing the DFT 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 build from a BS transmission and SS transmission. It will be straightforward to allow more than one BS and SS transmission per frame, if a merger with the unlicensed effort is sought. The cell radius is dependent on the time left open for random system access. This time should at least equal the maximum tolerable round trip delay plus the number of OFDM symbols necessary to transmit the ranging burst. Further, in each frame, the aRxTxTurnaroundTime needs to be inserted between the downlink and uplink and at the end of each frame to allow the BS to turn around (time plan for a single frame is shown in

Figure 6)

In FDD systems there is no need for aRxTxTurnaroundTime and the Down Stream and up Stream transmit on independent frequencies.

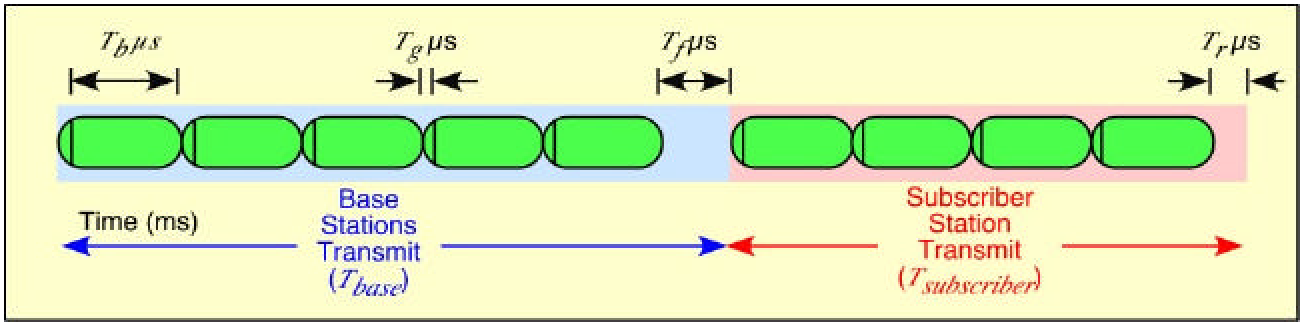

Figure 6: Time Plan – One TDD time frame

3.4 Frequency Domain Description

The frequency domain description includes the basic symbol structure of an OFDMA symbol.

3.4.1 OFDM description

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 7 illustrates such a scheme:

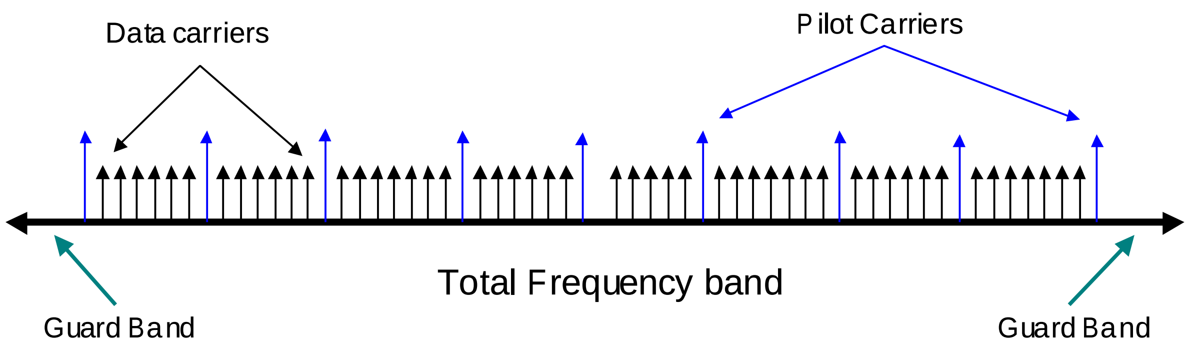

Figure 7: OFDM frequency description

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

3.4.2 OFDMA description

Further enhancement to the OFDM symbol is added, when dividing it to enable OFDMA. OFDMA concept is based on the grouping of several carriers into one entity; this logical entity is called Sub-Channel Figure 8describes such a scheme:

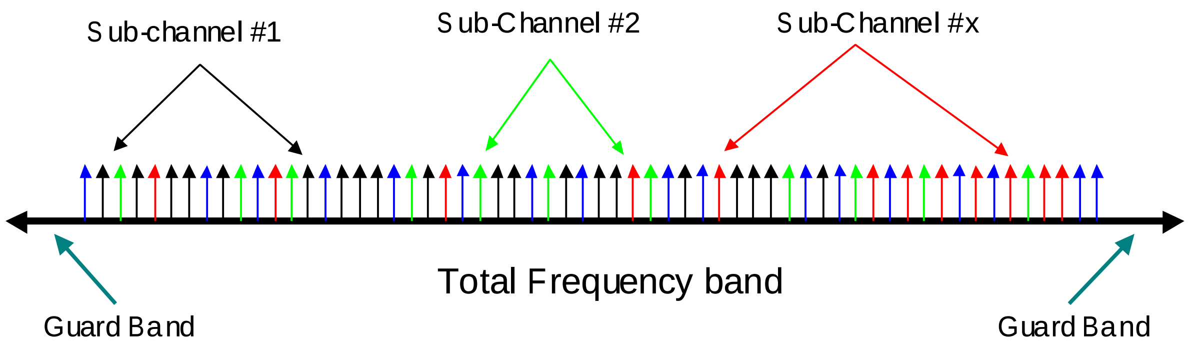

Figure 8: OFDMA frequency description

In order to use several FFT sizes but remain in the same block size (of data transmission), a basic structure of Sub-Channel is defined for the US (see section 4.3.1). The same amount of data carriers (48) is used to define a Sub-Channel for the US is the appropriate modes of operation.

The 4096, 2048, 1024 and 512 point FFT contains 64, 32, 16 and 8 Sub-Channels respectively.
This partitioning gives several powerful added values, some of the important ones are:

- Frequency diversity – due to the spreading in the frequency band
- Power concentration – which allows the concentration of all the power some of the carrier (most usable on the users side)
- Forward Power Control – by allocating digitally different power amplification to the Sub-Channels (most usable on the Base-Station side)
- Interference spreading for each Sub-Channel – due to the frequency diversity

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. This structure can be described by a tone mapping function. For wideband processing, the mapping is based upon a special permutation code, which distributes consecutive symbols across the available bandwidth. For narrowband processing and advanced solutions employing antenna array processing, the tone mapping places consecutive symbols next to adjacent tones.

A schematic drawing of the Sub-Channel is shown in Figure 9 (it describes only the logical Sub-Channels, regardless of the carrier dispersal in used carrier space):

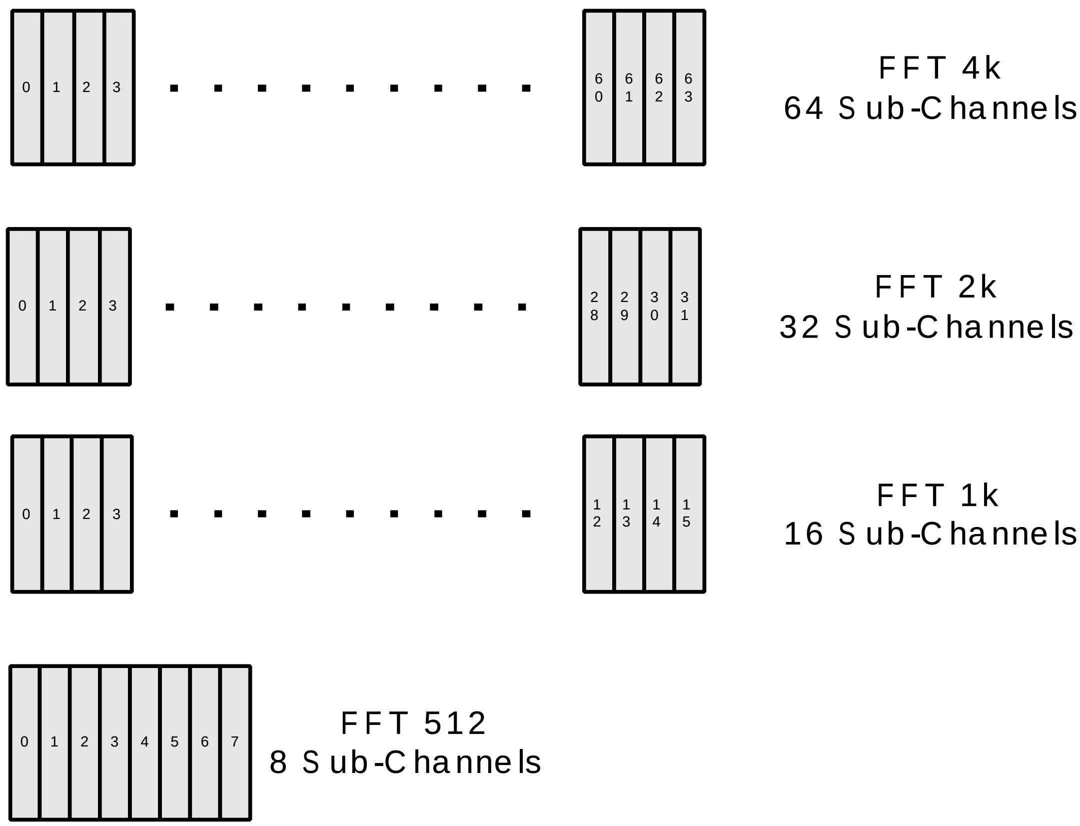

Figure 9: Sub-Channels schematic drawing within an OFDMA symbol

3.4.2.1 Power Concentration and Adaptive Power Control

The OFDMA access in the downlink and uplink has many advantages. The biggest advantage beside the long symbol duration is the power concentration it enables. The power concentration is achieved due to power emission only on the Sub-Channels allocated. Therefore the energy of the user is transmitted only on selected carriers and not on the all-useable carries. By this technique users and Base Station can manipulate the amount of energy putted on different Sub-Channels. This power concentration can add up to **15dBb** per carrier when transmitting from the user, Comparing the power that could be emitted on all the bandwidth, for one Sub-Channel using 53 carriers, combined with a Backward APC (Automatic Power control) will give the optimum performance.

The Base Station can also regulate the amount of power on the different Sub-Channels and reach as much as 4dB concentrations gain. This technique is referred to as Forward APC (Automatic Power control), and is used in order to regulate the power to the users on the down stream.

This power concentration leads to several advantages:

- Better coverage
- Enable a larger APC range which is vital for larger cells
- Excellent Reuse factor

- Better channel availability
- Can use simpler and cheaper PA
- Can have better SNR for a transmitted signal
- Reach the distances specified for the system (better distances with the same EIRP).
- Anti jamming advantages

3.5 Symbol Structuring Description

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 management data (e.g., training or synchronization) are mapped to symbols. The upper physical layer includes functions such as channel coding, bit interleaving, and modulation to form data symbols. As shown in Figure 10, the lower physical layer maps the data symbols to tones and forms OFDM symbols.

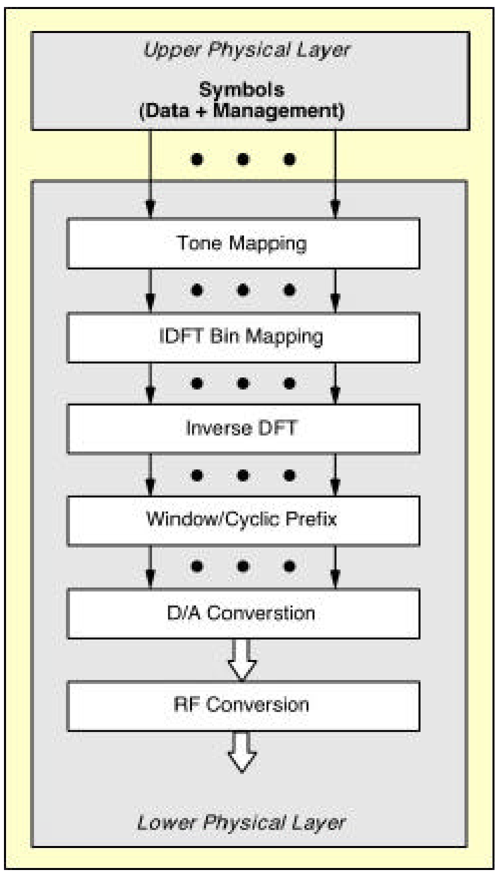

Figure 10: Lower Physical Layer

The IDFT mapping function assigns usable carriers to specific DFT bin locations and zeros for guard bins. As shown in Figure 11, the tone mapping function assigns data symbols and PHY management data to specific carriers within a specific OFDM symbol.

In the case TDMA is used as access method, the mapping assigns all sub-carriers to a single transmitter.

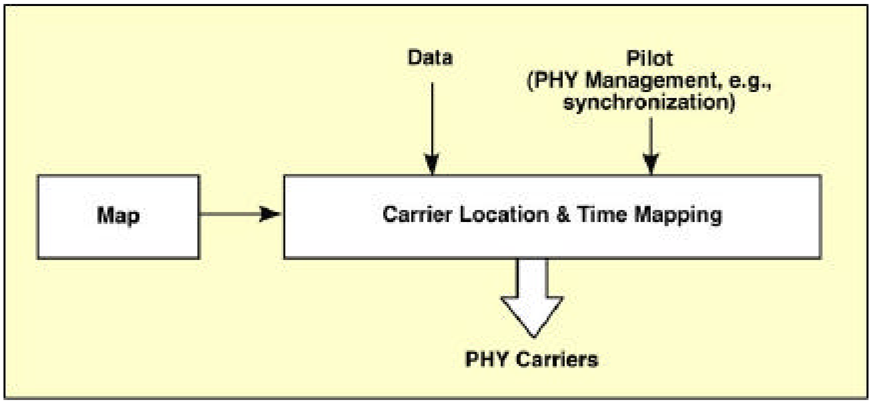

Figure 11: Tone Mapping Function

4 Multiple Access and Framing

The following description refers to the system access methods. There are two basic approaches for the system usage:

1. In OFDM mode each OFDM symbol is generated by a single station and conveys a single logical stream. The data is transmitted by different stations serially in time. This mode is used with FFT sizes from 64 up to 512.

   Figure 12 illustrates this structure:
   User Symbols: they include Sub-Channels where users transmit data
   Ranging symbols: they allow contention-based access
   Null Symbol: this optional symbol could be used to help allocate jamming and interferers

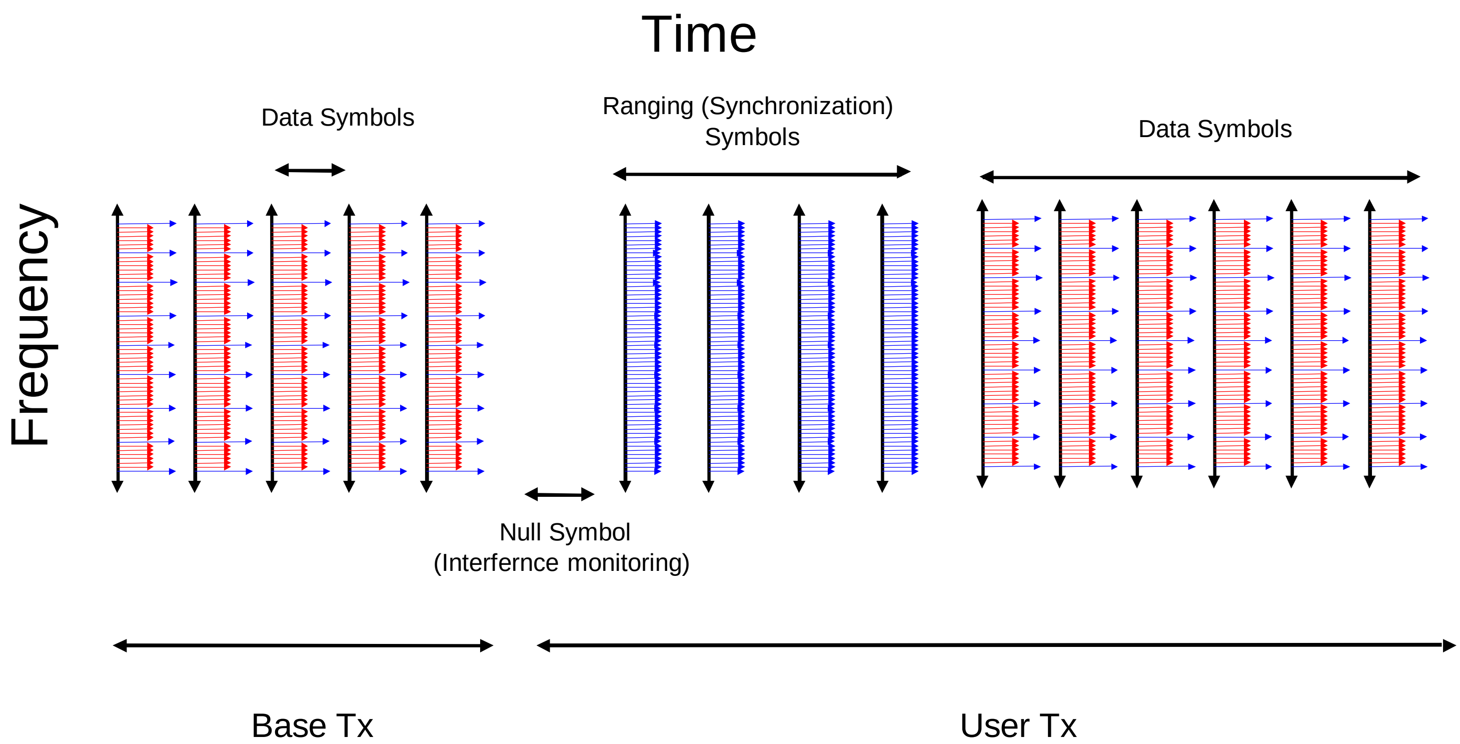

Figure 12: Conceptual Multiple Access Method for FFT size 64 to 512

2. In OFDMA mode each OFDM symbol may contain data belonging to several logical streams. On US, each stream is generated by a single station; on DS the BS generates several streams, each designated to a different group of stations. Therefore, the data is transmitted by several stations at the same time in parallel. This mode is used with FFT size 512 and above. Figure 13 illustrates this structure:

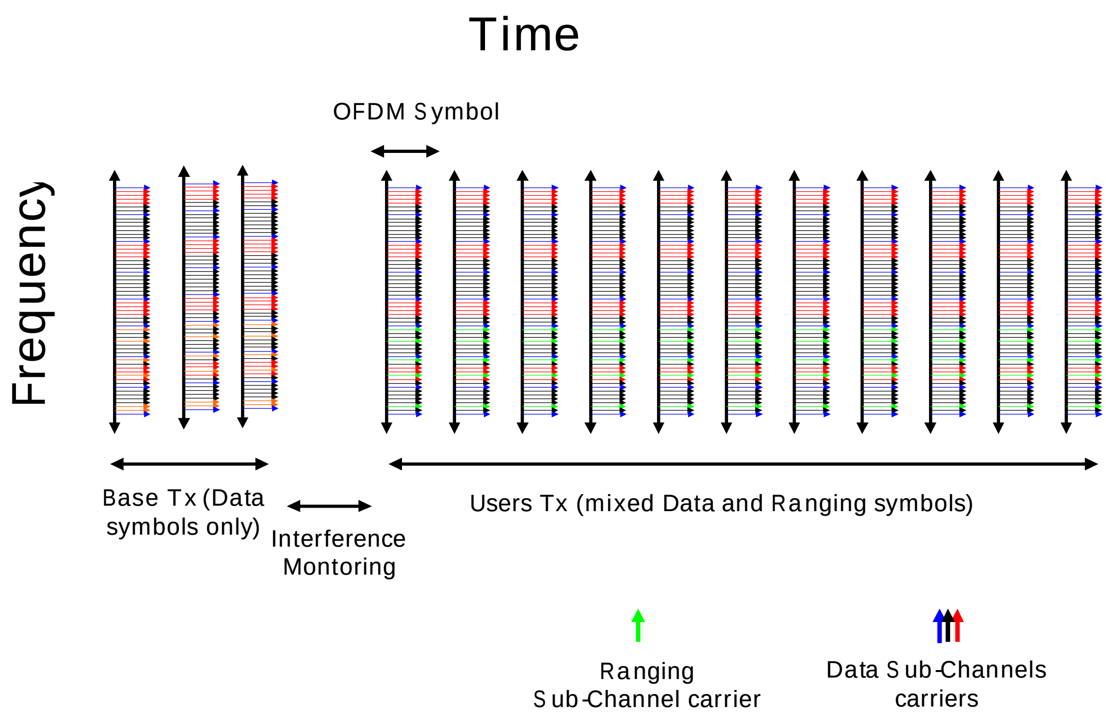

Figure 13: Conceptual Multiple Access Method for FFT size 512 and above

4.1 Duplexing

Both frequency division duplex (FDD) and time division duplex (TDD) modes provide for bi-directional operation, and much of the PHY proposal is independent of the choice

4.2 Down-Stream

4.2.1 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 14 illustrates the DS framing:

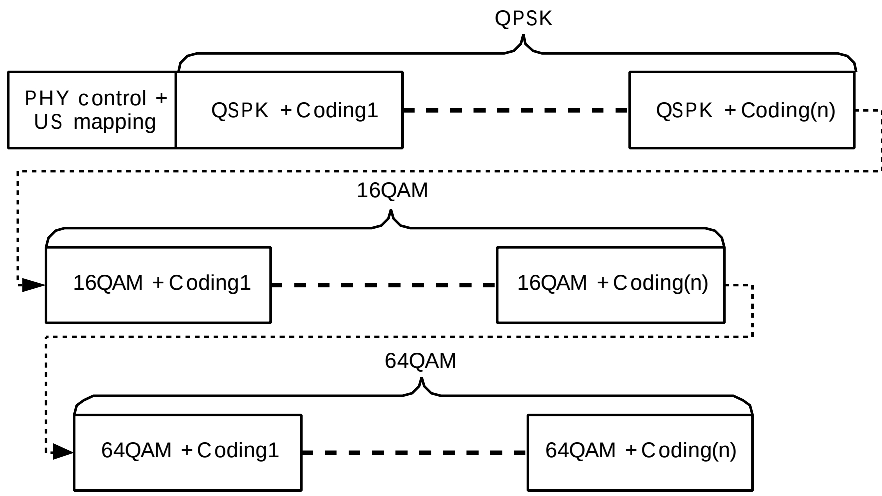

Figure 14: DS Framing

The basic resource allocation quantum is a Sub-Carrier, which contains 48 data carriers. For all FFT sizes, each OFDM symbol contains an integer number of Sub-channels, both on downlink and on uplink. The amount of data, which fits into a Sub-channel, depends on the constellation and the coding method used within this Sub-Channel.

A two dimensional map, in which one dimension denotes Sub-channel within OFDM symbol (frequency domain) can visualize the available resource, and the other denotes the consecutive OFDM symbols (time domain). This visualization disregards the fact that the carriers composing a Sub-Channel may be scattered within the OFDM symbol in non-consecutive locations.

4.2.1.1 For FFT size 64 through 512 (OFDM)

In OFDM mode the data is encoded as a single stream and the resulting stream of Sub-channel are arranged into OFDM symbols. In terms of the two-dimensional visualization of the encoding process, the “Sub-Channels” are scanned frequency-first. Figure 15 illustrates a possible two-dimensional transmission mapping (every color represents a different Modulation and coding scheme):

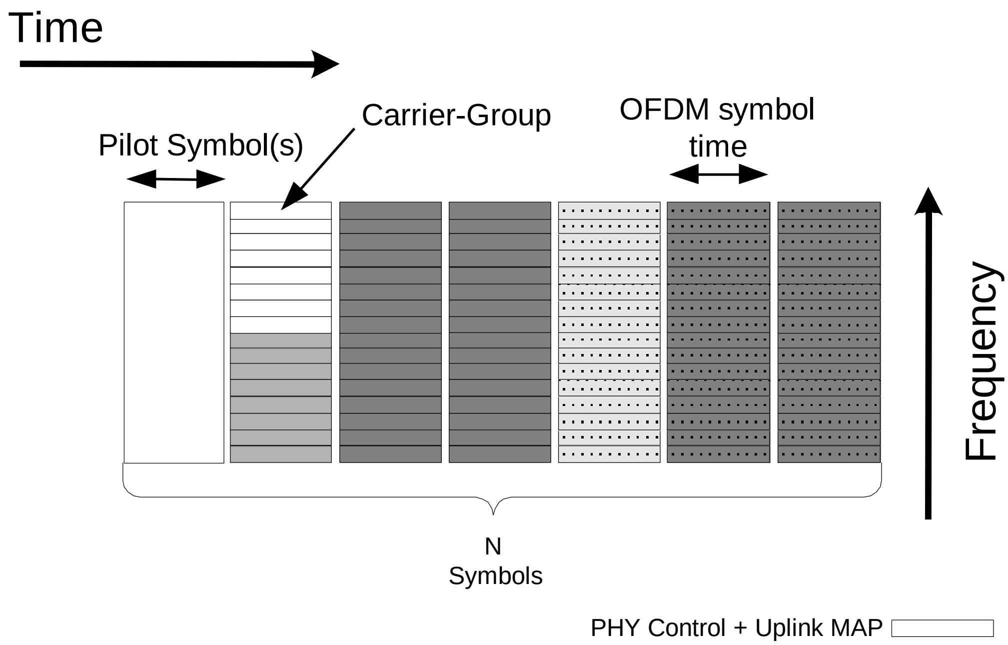

Figure 15: DS framing for FFT sizes of 64 through 512

4.2.1.2 For FFT 512 and above (OFDMA)

The transmission of the DS is performed on the Sub-Channels of the OFDMA symbol, the amount of Sub-Channels needed for the different transmissions (modulation and coding) and their mapping is defined in the PHY control. The mapping of the Sub-Channels is performed in a two-dimensional grid, involving the Sub-Channels in the frequency domain and OFDMA symbols in the time domain. Figure 16 illustrates a possible two-dimensional transmission mapping (every color represents a different Modulation and coding scheme):

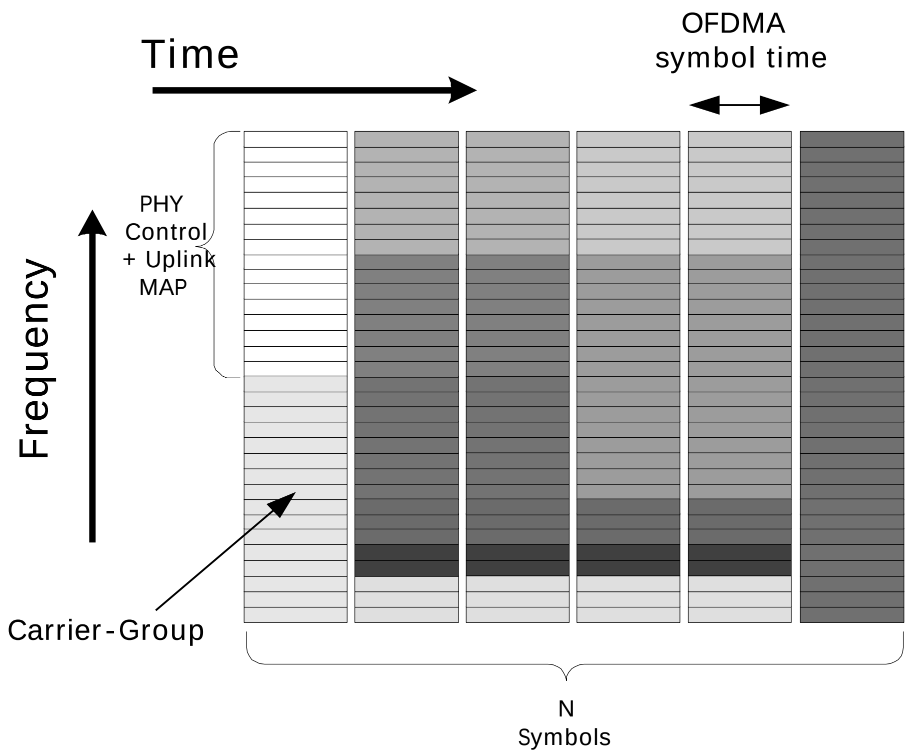

Figure 16: DS framing for FFT sizes of 512 and above

4.2.2 Symbol Structure

The symbol structure for the DS transmission is specified in the following sections.

4.2.2.1 FFT size 64 through 512 (OFDM)

When using FFT size of 64 through 256, the symbol structure for is made up of constant and variable location pilots, which are spread all over the symbol, and from data carriers, which are divided into Sub-Channels. The amount of Sub-Channels differs between the different FFT sizes.

The 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), the location of the pilot symbols are shifting for every symbol produced, the first symbol (L=0) is produced after the all-pilot symbols (preamble/midamble).

The basic pilot location differs between the different FFT sizes, we denote the first symbol variable pilot location - $\{BasicVariableLocationPilots_0\}$, then the pilot location as a function of L is - $\{BasicVariablePilotLocation_0 + ((L*2)\bmod 13)\}$ where L=0..12. Constant pilots are also defined in $\{BasicCon\tan tLocationPilots\}$. Figure 17 illustrates the symbol structure.

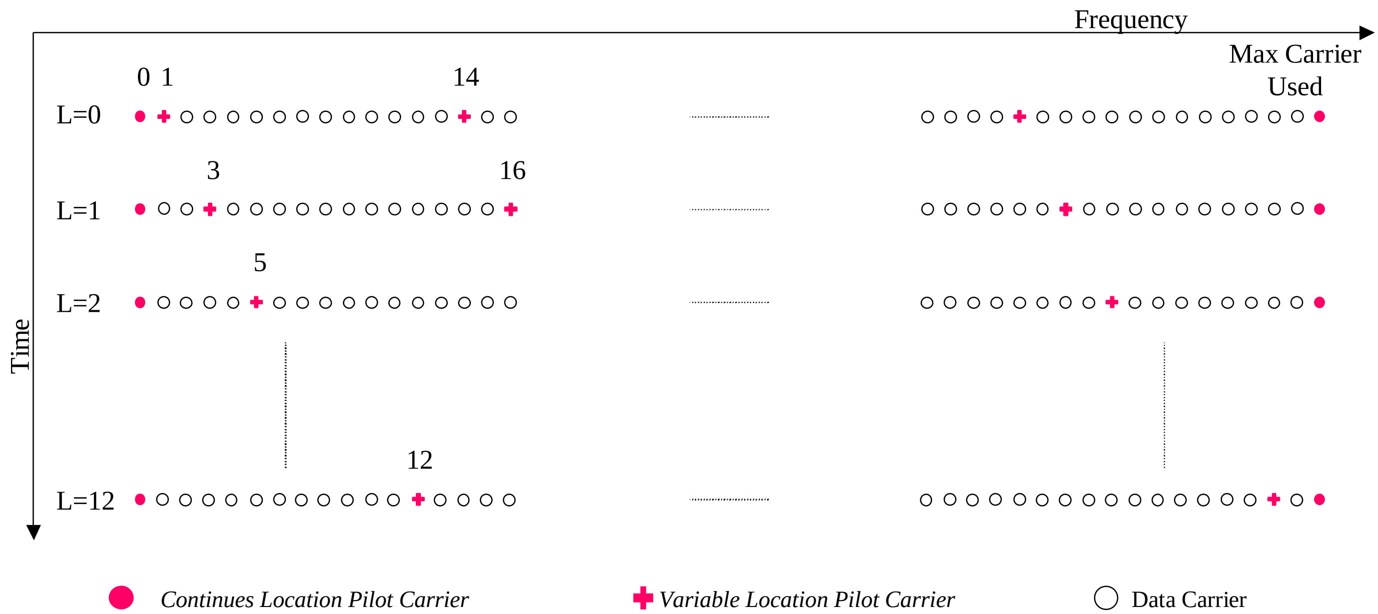

Figure 17: pilots and data carrier location the DS symbol using FFT 64 through 512

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 13).

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 are used to extract the Sub-Channels (each Sub-Channel is made up of 48 data carriers ($\{N_{Sub-Channel}\}$=48).
Then using special permutations, we achieve the carrier location of each Sub-Channel.

Figure 18 illustrates the data carriers division into basic groups:

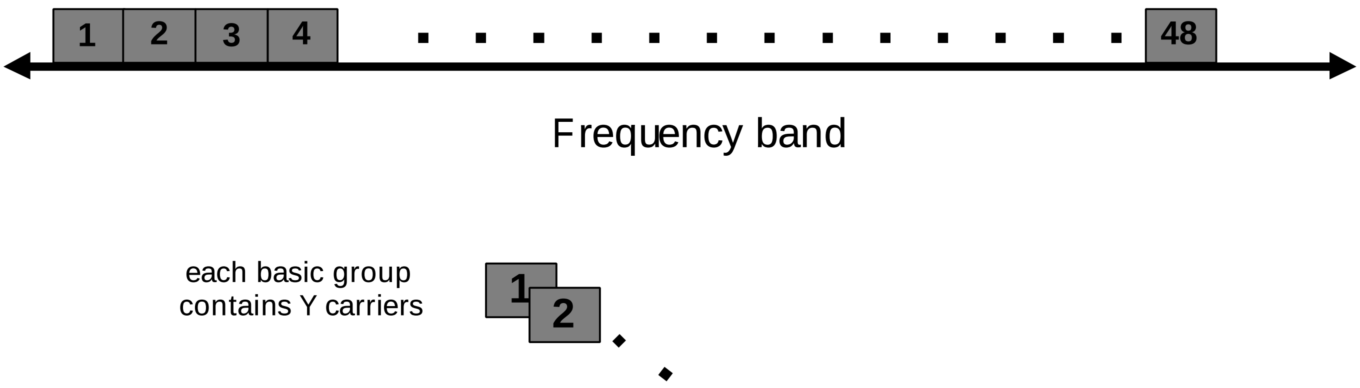

Figure 18: division of all carriers into basic groups for the DS OFDM symbol

4.2.2.1.1 Using permutation for the Sub-Channelization

Using special permutation code, which is based upon the following procedure, does the allocation of carriers to Sub-Channels (see also ANNEX A – Using the Sub-Channel Permutation):

1. The usable carrier space is divided into $\{N_{Groups}\}$ basic groups (section 4.2.2.2, 4.2.2.1, 4.3.4)
2. We define a basic permutation $\{PermutationBase_0\}$, containing $\{N_{elemets}\}$ elements
3. Different permutations ($\{PermutatedSeries\}$) are achieved by cyclically rotating the $\{PermutationBase_0\}$ to the left
4. To get a $\{N_{Sub-Channel}\}$ length series we concatenate the permutated series, until the concatenated series has at least $\{N_{Sub-Channel}\}$ elements (number of concatenations is $N_{Concatenation} = ceil(N_{Sub-Channel} / N_{elemets})$). The concatenation is performed by the next formula:
   $\left\{\begin{matrix}(PermutatedSeries + CellId)\bmod(N_{elemets});(PermutatedSeries + 2 * CellId)\bmod(N_{elemets});... \\ ...;(PermutatedSeries + N_{Concatenations} \cdot CellId)\bmod(N_{elemets});\end{matrix}\right\}$, and then we take the first $\{N_{Sub-Channel}\}$ elements ($\{CellId\}$is a MAC defined parameter, defining the current cell identification numbers, to support different cells).

5. The last step achieves the carrier numbers allocated for the specific Sub-Channel with the current Cell Id. Using the next formula we achieve the 48 carriers of the current permutation in the cell:

$$Carrier\# = N_{elements} * n + Index(n)$$

   where:
   $Carrier\#$ - denotes the carrier number for this Sub-Channel using the $\{PermutatedSeries\}$
   n - Indices 0.. $\{N_{Sub-Channel} - 1\}$
   $Index(n)$ - denotes the number at index n of the $\{N_{Sub-Channel}\}$ length series

4.2.2.1.2 64 mode characterisation

The parameters characterizing the 64 mode on the DS are as follow:

- Number of FFT points = 64
- Overall Used Carriers = 53
- Guard Bands = 6, 5 carriers on left and right sides of the spectrum respectively
- Number of Sub-Channels = 1

$\{BasicCons\tan tLocationPilots\}$ = None

$\{BasicVariableLocationPilots_0\}$ = 5, 19, 33, 47

$\{PermutationBase_0\}$ = None

4.2.2.1.3 128 mode characterisation

The parameters characterizing the 128 mode on the DS are as follow:

- Number of FFT points = 128
- Overall Used Carriers = 107
- Guard Bands = 11, 10 carriers on left and right sides of the spectrum respectively
- Number of Sub-Channels = 2

$\{BasicConstantLocationPilots\}$ = 0, 106.

$\{BasicVariableLocationPilots_0\}$ = 1, 14, 27, 40, 54, 67, 80, 93

$\{PermutationBase_0\}$ = 0,1

4.2.2.1.4 256 mode characterisation

The parameters characterizing the 256 mode on the DS are as follow:

- Number of FFT points = 256
- Overall Used Carriers = 213
- Guard Bands = 22, 21 carriers on left and right sides of the spectrum respectively
- Number of Sub-Channels = 4

$\{BasicConstantLocationPilots\}$ = 0, 53, 159, 212

$\{BasicVariableLocationPilots_0\}$ = 1, 14, 27, 40, 54, 67, 80, 93, 107, 120, 133, 146, 160, 173, 186, 199

$\{PermutationBase_0\}$ = 3, 1, 0,2

4.2.2.1.5 512 mode characterisation

The parameters characterizing the 512 mode on the DS are as follow:

- Number of FFT points = 512
- Overall Usable Carriers = 417
- Guard Bands = 47, 46 carriers on left and right sides of the spectrum respectively
- Number of Sub-Channels = 8

$\{BasicConstantLocationPilots\}$ = 0, 53, 106, 159, 265, 318, 371, 424

$\{BasicVariableLocationPilots_0\}$ = 4, 17, 30, 43, 56, 69, 82, 95, 108, 121, 134, 147, 160, 173, 186, 199, 213, 226, 239, 252, 265, 278

$\{PermutationBase_0\}$ = 7, 4, 0, 2, 1, 5, 3, 6

4.2.2.1.6 Preamble structure

The Sync OFDM symbol (Preamble) is built from the Combination of pilots and data carriers. This robust structure gives an initialization of the channel estimation with the ability to gain data transmission as well.

The carrier's indices, which are used for pilot transmission, are achieved with the next formula:

$$k = (Skip - 1) * P_v$$

$k \in$ Indices from 0 to the number of Overall Usable Carriers minus 1
$Skip$ is 1 for 64 FFT and 2 for 128, 256 FFT
$P_v \geq 0$ is an integer number

Pilot and data carrier location are illustrated in Figure 19:

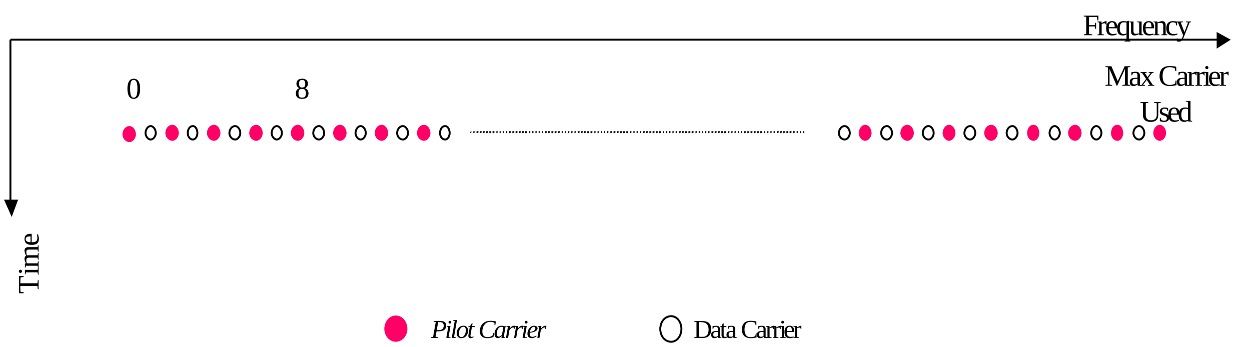

Figure 19: pilots and data carrier location for the DS preamble using 128, 256 mode

Therefore for the 128 FFT we have another Sub-Channel, for the 256 FFT we have another 2 Sub-Channels to use for data transmission (these Sub-Channels will be achieved by the same permutation parameters in section 4.2.2.1.3).

4.2.2.2 FFT size 512 and above

When using FFT size of 512 and above the DS shall use OFDMA modulation technique (see section 3.4.2). 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 Sub-Channels. 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:

- Continues 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

$L \in 0..3$ 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:

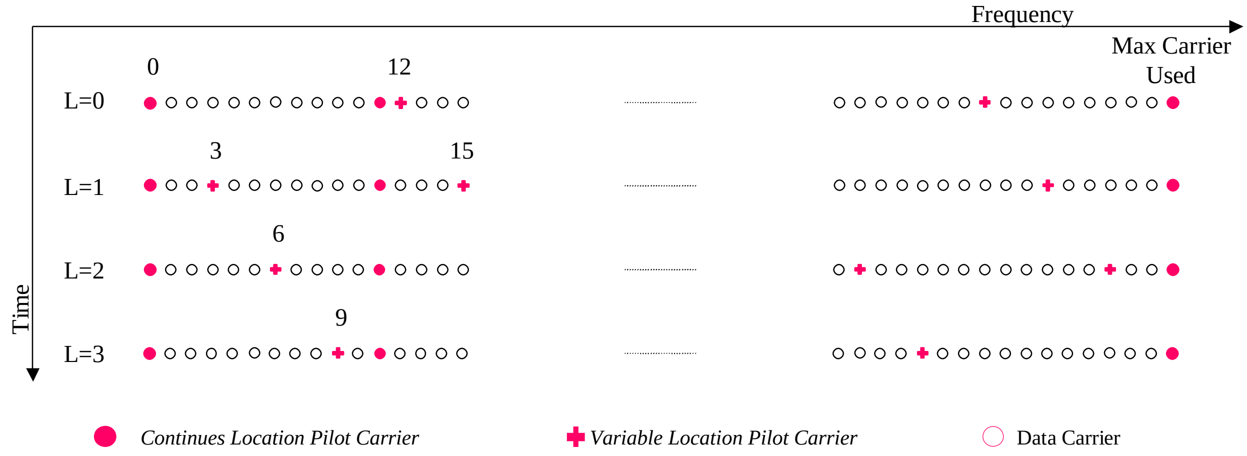

Figure 20: pilots and data carrier location the DS OFDMA symbol using FFT 512 and above

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).

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 are used to extract the Sub-Channels (each Sub-Channel is made up of 48 data carriers ($\{N_{Sub-Channel}\}$=48). Then using special permutations, we achieve the carrier location of each Sub-Channel (the procedure to user the permutation is defined in section 4.2.2.1.1).

Figure 21 illustrates the data carriers division into basic groups:

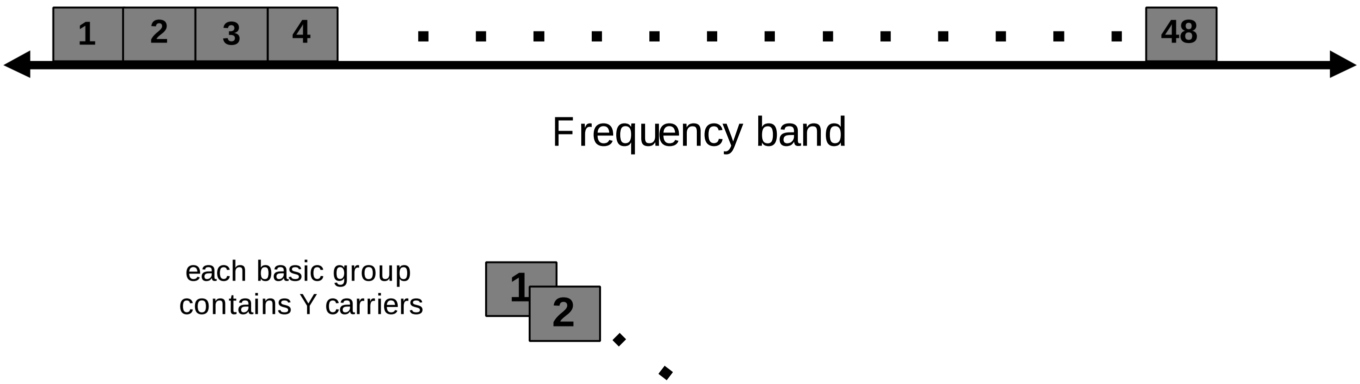

Figure 21: division of all carriers into basic groups for the DS OFDM symbol using FFT 512 and above

4.2.2.2.1 512 mode characterisation

The parameters characterizing the 512 mode on the DS are as follow:

- Number of FFT points = 512
- Overall Usable Carriers = 430
- Guard Bands = 41 carriers on both sides of the spectrum
- Number of Sub-Channels = 8

$\{BasicVariableLocationPilots_0\}$ = 0,75,174,201,214,303,366,384,429

The basic series of 8 elements is $\{PermutationBase_0\}$ = 7, 4, 0, 2, 1, 5, 3, 6

4.2.2.2.2 1K mode characterisation

The parameters characterizing the 1K mode on the DS are as follow:

- Number of FFT points = 1024 (1K)
- Overall Usable Carriers = 850
- Guard Bands = 87 carriers on both sides of the spectrum
- Number of Sub-Channels = 16
-

$\{BasicVariableLocationPilots_0\}$ = 0,39,261,330,348,351,522,645,651,726,756,849,850

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

4.2.2.2.3 2k mode characterisation

The parameters characterizing the 2K mode on the DS are as follow:

- Number of FFT points = 2048 (2K)
- Overall Usable Carriers = 1703 , 172 carriers on right an left side of the spectrum
-
- Guard Bands = 173 carriers on both sides of the spectrum
- Number of Sub-Channels = 32

$\{BasicVariableLocationPilots_0\}$ = 0, 39, 261,330,342,351,522,522,645,651,708,726,756,792,849,855,918, 1017,1143,1155,1158,1185,1206,1260, 1407,1419,1428,1461,1530,1545,1572,1701,1702
The basic series of 32 elements is $\{PermutationBase_0\}$ = 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

4.2.2.2.4 4K mode characterisation

The parameters characterizing the 2K mode on the DS are as follow:
- Number of FFT points = 4096 (4K)
- Overall Usable Carriers = TBD
- Guard Bands = TBD carriers on both sides of the spectrum
- Number of Sub-Channels = 64

$\{BasicVariableLocationPilots_0\}$ = TBD
The basic series of 64 elements is $\{PermutationBase_0\}$ = TBD

4.3 Up-Stream

4.3.1 US Sub-Channel description

The next section gives a description of the structure of a Sub-Channel. A Sub-Channel is made up of 48 usable carriers and 5 pilot carriers; this structure is used for FFT modes larger or equal to 512 for the US transmission. The DS transmission for these modes is also made of Sub-Channel 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 sub-Channel structure is shown in Figure 22.

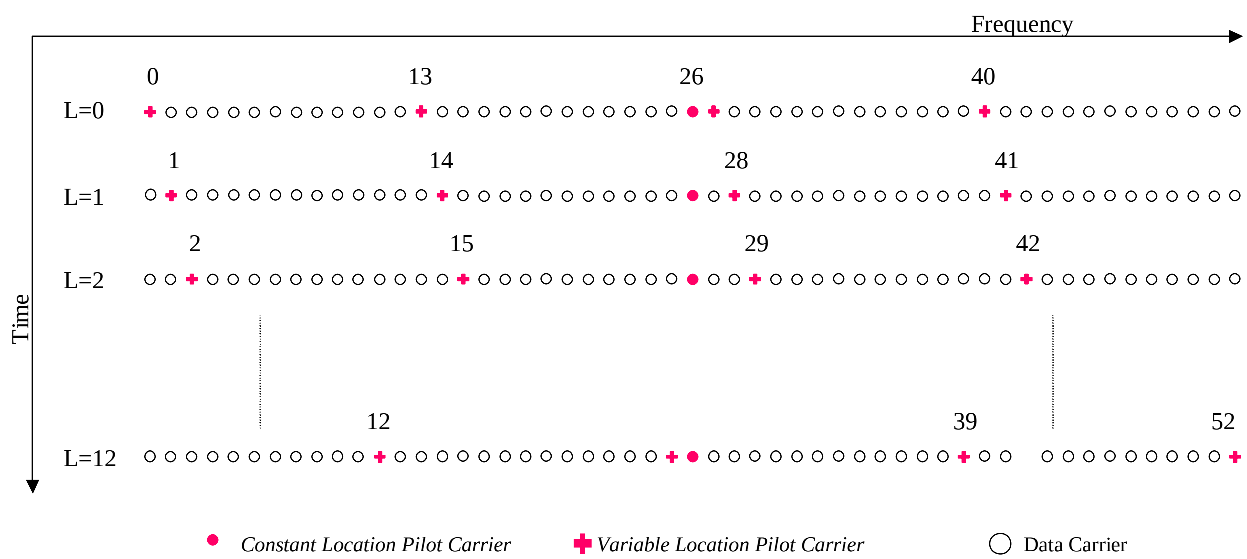

Figure 22: Allocation of data and pilot carriers for a US Sub-Channel

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 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.

4.3.2 US Allocation

The basic allocation for a user US transmission is made up of Sub-Channels, 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 Sub-Channels increases the amount of data sent by the user, while preamble is repeated every X data Sub-Channels (in the time domain), this allocation is presented in Figure 23:

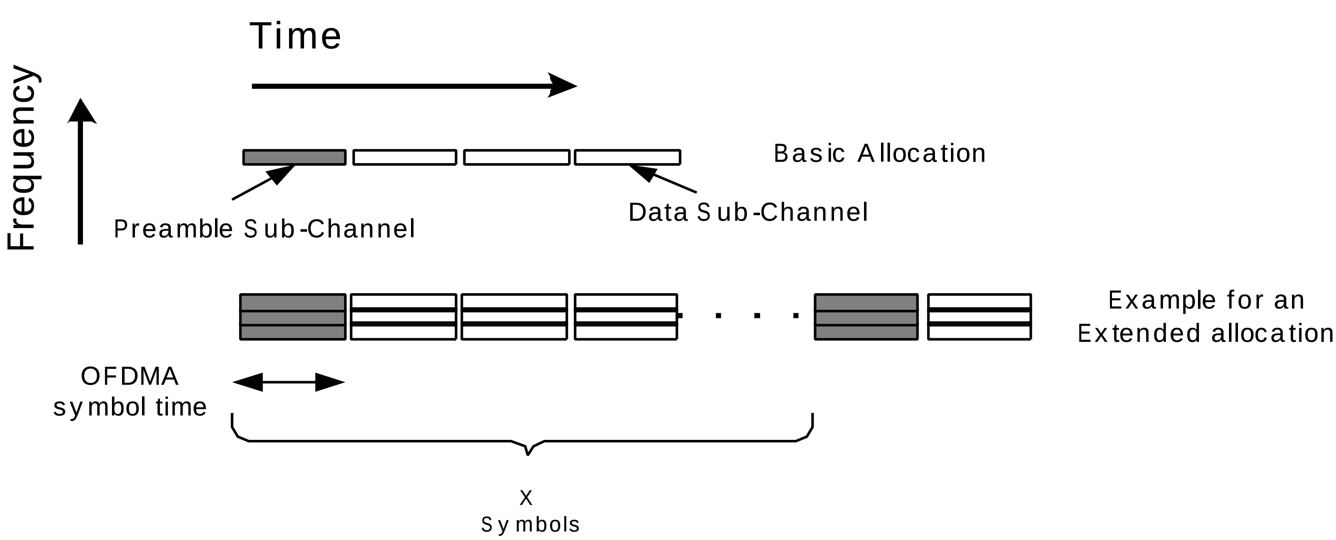

Figure 23: US User allocation for FFT sizes of 512 and above

4.3.3 Framing Structure

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.

4.3.3.1 For FFT size 64 through 512 (OFDM)

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 24:

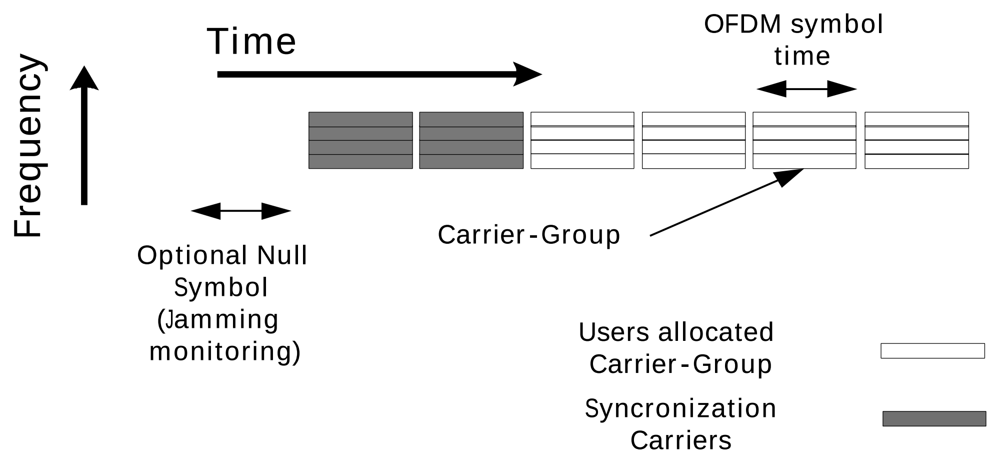

Figure 24: US framing for FFT sizes 64 through 512

4.3.3.2 For FFT 512 and above

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 25:

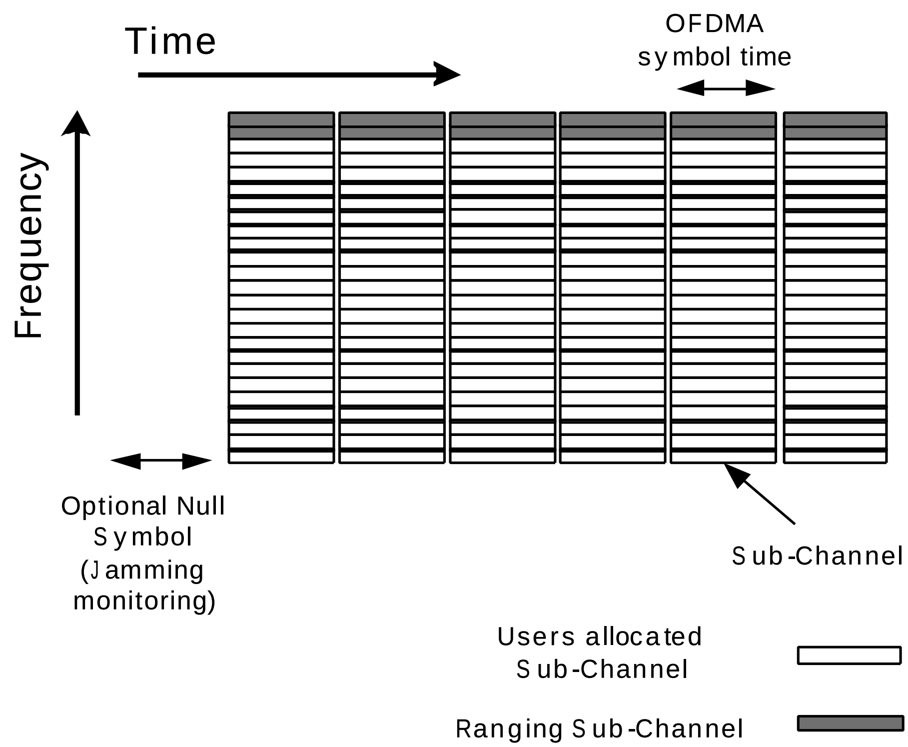

Figure 25: US framing for FFT sizes 512 and above

4.3.4 Symbol Structure

The symbol structure for is made up of Sub-Channels, by their basic structure described in section 4.3.1. 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 (Figure 26 illustrates this principle)

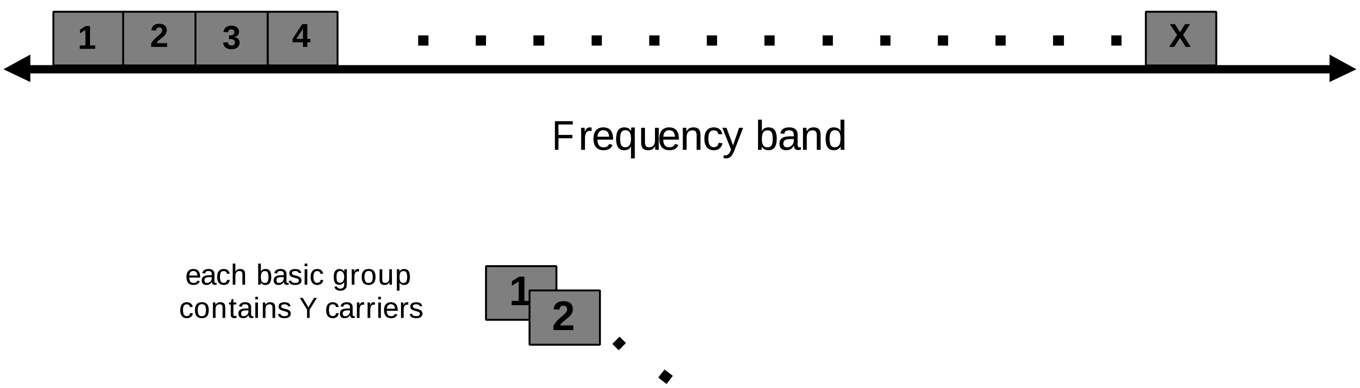

Figure 26: division of all carriers into basic groups for the US OFDMA symbol

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 4.2.2.1.1, 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 implicate 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 is achieved using the next formula:

$$Carrier\# = 53 * n + I$$

where:
$Carrier\#$ - denotes the carrier number for Sub-Channel n
n - Indices from 0 to the amount of Sub-Channels minus one
I - Indices 0..52

The last method for defining the Sub-Channels involves programming by MAC message the carrier numbers for each Sub-Channel.

4.3.4.1.1 64 mode characterisation

The parameters characterizing the 64 mode on the DS are as follow:

- Number of FFT points = 64
- Overall Usable Carriers = 53
-

- Guard Bands = 6, 5 carriers on left and right sides of the spectrum respectively
- Number of Sub-Channels = 1
- Pilot locations = 5, 19, 33, 47.

$\{PermutationBase_0\}$ = None

4.3.4.1.2 128 mode characterisation

The parameters characterizing the 128 mode on the DS are as follow:
- Number of FFT points = 128
- Overall Usable Carriers = 107
- Guard Bands = 11, 10 carriers on left and right sides of the spectrum respectively
- Number of Sub-Channels = 2

The parameters characterizing the Sub-Channels allocation:
- Y – Number of carriers in each basic group = 2
- The basic series of 2 elements is $\{PermutationBase_0\}$ = 0,1

4.3.4.1.3 256 mode characterisation

The parameters characterizing the 256 mode on the DS are as follow:
- Number of FFT points = 256
- Overall Usable Carriers = 213
- Guard Bands = 24, 23 carriers on left and right sides of the spectrum respectively
- Number of Sub-Channels = 4

The parameters characterizing the Sub-Channels allocation:
- Y – Number of carriers in each basic group = 4
- The basic series of 4 elements is $\{PermutationBase_0\}$ = 3, 1, 0 ,2

4.3.4.1.4 512 mode US characterisation

The parameters characterizing the 512 mode on the US are as follow:
- Number of FFT points = 512
- Overall Usable Carriers = 425
- Guard Bands = 44, 43 carriers on left and right sides of the spectrum respectively
- Number of Sub-Channels = 8

The parameters characterizing the Sub-Channels allocation:
- Y – Number of carriers in each basic group = 8
- The basic series of 8 elements is $\{PermutationBase_0\}$ = 7, 4, 0, 2, 1, 5, 3, 6

4.3.4.1.5 1k mode US characterisation

The parameters characterizing the 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

4.3.4.1.6 2k mode US characterisation

The parameters characterizing the 2K mode on the US are as follow:

- Number of FFT points = 2048 (2K)
- Overall Usable Carriers = 1696
- Guard Bands = 176, 175 carriers on right an left side of the spectrum
- Number of Sub-Channels = 32

The parameters characterizing the Sub-Channels allocation:

- Y – Number of carriers in each basic group = 32
- The basic series of 16 elements is $\{PermutationBase_0\}$= 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

4.3.4.1.7 4k mode US characterisation

The parameters characterizing the 4K mode on the US are as follow:

- Number of FFT points = 4096 (4K)
- Overall Usable Carriers = 3392
- Guard Bands = 352, 353 carriers on right an left side of the spectrum
- Number of Sub-Channels = 64

The parameters characterizing the Sub-Channels allocation:

- Y – Number of carriers in each basic group = 64

The basic series of 64 elements is $\{PermutationBase_0\}$= TBD (Runcom)

4.4 Optional Design Supporting Adaptive Antenna Arrays

This section describes an optional design well suited for adaptive antenna arrays or stacked carrier spread spectrum. It includes US and DS tone groupings for payload, access channels, and entry channels, as well as tone groupings in support of interference estimation and cancellation. It also includes the OFDM symbol time raster and the number of US and DS symbols/slots per frame.

4.4.1 Framing

The framing structure describes how logical channnels or subchannels are mapped into physical layer tones. Logical channels or subchannels 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, on the differences between the multiple access methodologies used in OFDM and OFDMA and on the use of adaptive antenna arrays. As such, the framing structure takes on different time/frequency maps according to the design selections made by the equipment suppliers.

These maps are accommodated in the standard by an abstraction layer called the logical channel to physical tone mapping function. In practice, this will be a simple software mapping function driven by a downloadable table. Compatible CPE may be preconfigured with the appropriate map or contain multiple maps.

Because physical layer tones may be used for different purposes as a function of time, the tone mapping specifies both location and time elements as indicated in Figure 11. The mapping discussed here is particularly suited for adaptive antenna arrays or stacked carrier spread spectrum.

4.4.1.1 Downstream Framing

The downstream framing structure is shown in Figure 27. In this example, there are twenty-four subchannels plus a twenty-fifth subchannel for each subband. Four subbands are used with a 6 or 7 MHz channel and eight subbands are used with a 12 or 14 MHz channel. The 24 subchannels are used primarily for traffic and the 25th subchannel for entry and MAC management.

16 OFDM tones are used per subchannel. Up to 4 subchannels may be logically grouped to form a larger macro-channel. The macro-channel is constructed from subchannels distributed over the subband for robust FEC performance. In this framing structure, PHY management, synchronization and preamble information is transmitted during the access slots shown as the darker squares in Figure 27. These access slots are distributed in both frequency and time for robust performance in fading channels. The access slot is interspersed with 5 bearer slots in each subchannel forming a frame.

The frame comprises 6 time slots. The slot duration is either 1.67 or 3.33 milliseconds. Thus, the frame period is 10 or 20 milliseconds and can be aligned to VoIP packets for reduced voice latency.

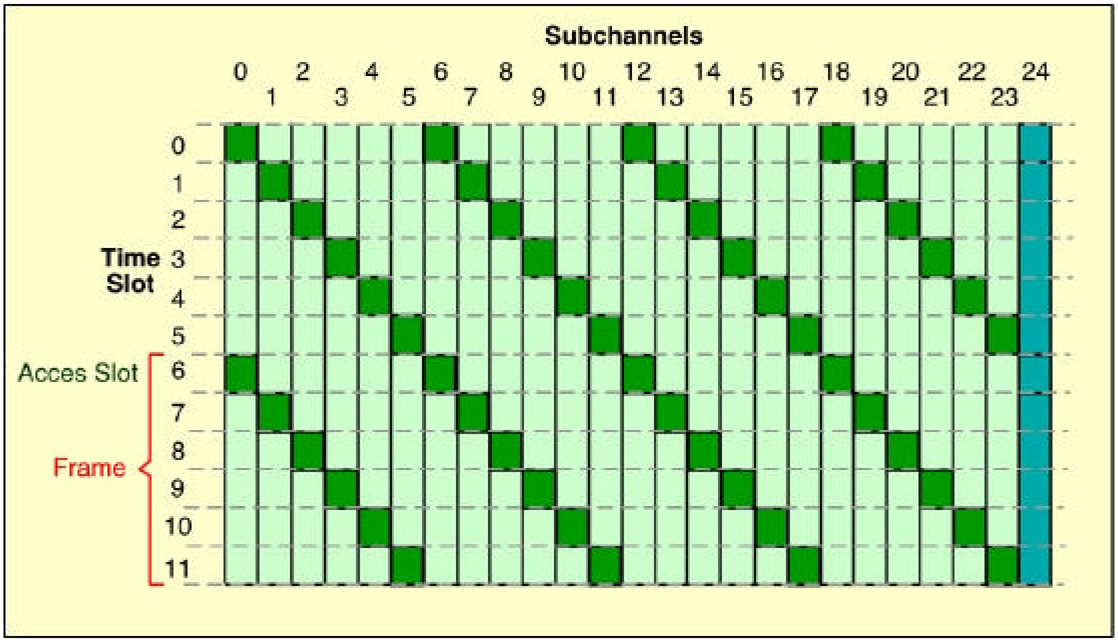

Figure 27: Time and Frequency Framing

4.4.1.2 Upstream Framing

The upstream framing is identical to the downstream framing. The access slot also carries training and preamble information called the reverse link initiation (RLI) symbol as described in the multiple access section below.

4.4.1.3 Payload and Bit Rate

Table 5 tabulates the payload Bytes per frame and the payload bit rates for the modulations listed. Both the TDD and FDD rates are shown. The bit rates are given for a 3 MHz channel using 2.5 MHz of active bandwidth. These bit rates have accounted for the overhead associated with the entry and access slots and synchronization symbols, and thus represent PHY layer payload rates. Bit rates for other channel bandwidths may be computed by scaling the active bandwidth appropriately.

Table 5: Payload and Bit Rate as a Function of Modulation Type

Modulation /Duplexing Method	Information Bits/Symbol	PHY Bytes Per Frame Fwd/Reverse Links	Bit Rate per 2.5 MHz (Mbits/sec) 3 MHz CH
16 QAM/TDD	2	100 / 80	2 / 1.6 = 3.6
16 QAM/TDD	3	160 / 128	3.2 / 2.56 = 5.76
64 QAM/TDD	4	200 / 160	4.0 / 3.2 = 7.2
64 QAM/TDD	5	250 / 200	5.0 / 4.0 = 9.0
16 QAM/FDD	2	200 / 200	4.0
16 QAM/FDD	3	320 / 320	6.4
64 QAM/FDD	4	400 / 400	8.0
64 QAM/FDD	5	500 / 500	10.0

4.4.2 Multiple Access

This section describes the details of multiple access when using adaptive arrays or stacked carrier spread spectrum. Included are the number and frequency of access (ranging) opportunities, the uplink control mechanism, and the coding structure used in support of multiple access.

Multiple access is supported by OFDMA symbol constructs located in the access slots of the subchannel. There are 5 of these OFDMA constructs (called bursts), in the forward subchannel and 4 bursts in the reverse subchannel. In the FDD realization, there is an additional burst in the reverse subchannel for a total of five. Figure 28 illustrates the access slot structure showing 3 burst types on the forward link and 1 burst type on the reverse link. Each of the burst types are described below:

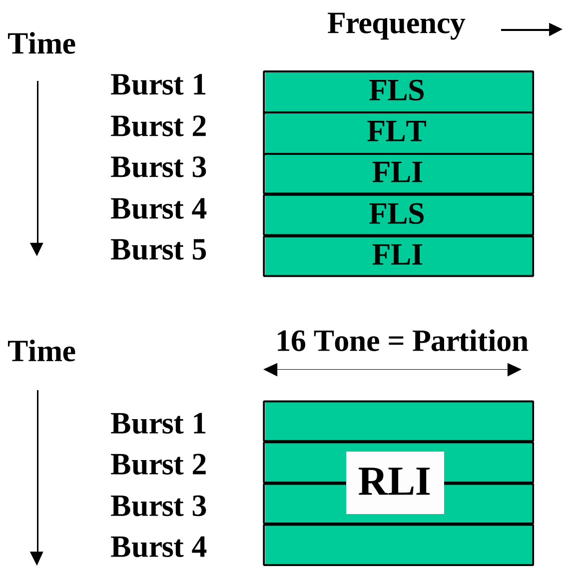

Figure 28: Access Slot Construction

4.4.2.1 Downstream Multiple Access Structure

Bursts 1 and 4 contain the SS synchronization tones. Because the access slots are staggered in time and frequency, the synchronization bursts cover every tone within the subband. This leads to robust synchronization performance in fading channels. The synchronization symbols are uniquely coded for each basestation.

Bursts 3 and 5 are forward link initiation symbols used to alert SSs to incoming traffic. The initiation symbols are uniquely coded for each user.

Burst 2 is the forward link training symbol. The training symbols are uniquely coded for each user.

4.4.2.2 Upstream Multiple Access Structure

Four bursts are used to form the reverse link initiation (RLI) symbol as shown in Figure 28. This symbol is used to alert the Basestation of incoming bandwidth requests and bearer traffic. The RLI symbols are uniquely coded for each user.

4.4.2.3 Multiple Access Structure, Subscriber Entry

In the 25th subchannel, the entry slot structure is identical to access slot in the other 24 subchannels. The entry slot is used by inactive subscribers entering the network, These subscribers then transition to the active state, and use the standard access slot mechanism available in the other 24 subchannels. The entry slot is also used for initial ranging of newly installed SSs. The coding structure is identical to the access slot symbol structures.

5 Data 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 those 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 scrambler shall be randomly initialized. Each data byte to be transmitted shall enter sequentially into the randomizer, MSB first.
The Pseudo Random Binary Sequence (PRBS) generator shall be $1+X^{14}+X^{15}$.

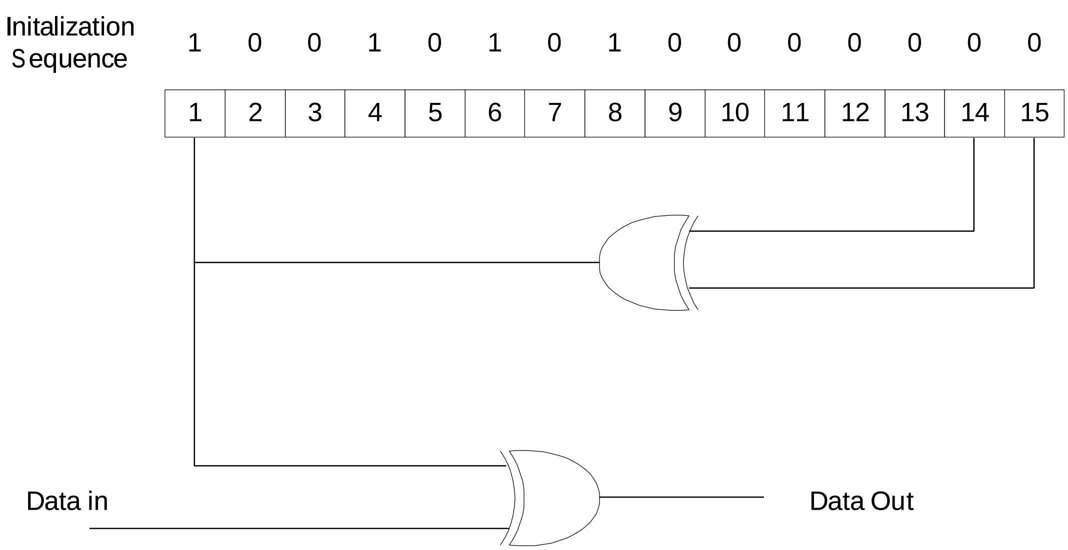

Figure 29: PRBS for data randomization

The bit issued from the randomizer shall be applied to the encoder. The first two octets in each burst shall be set to zero, to allow estimation of the initial state of the scrambler. The purpose of this method is avoiding perpetuation of PAPR problems during retransmissions.

6 Coding

Several ECC codes are defined for the system for DS transmissions and US:

1. Concatenated RS(N,K) (derived from the systematic RS(255,239,8)) concatenated with a tail biting convolutional code (k=7, G1=171, G2=133)
2. Block Turbo Codes
3. Convolutional code (k=7, G1=171, G2=133) with zero padding

6.1 Concatenated Reed Solomon and Convolutional Coding

First passing the data through the RS encoder and then passing the data in block format to a tail biting convolutional encoder perform the encoding.

6.1.1 Reed Solomon encoding

The Reed Solomon encoding process shall use the systematic RS(255,239,8), with the possibility to make a variable RS(N,K,T), where:

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

For T=0, tail-biting convolutional encoding only can be implemented.

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

The basic frame size for encoding includes 188 bytes of data using the RS(202,188,8), the data after passing the randomizer shall be divided into groups of 188 bytes and a remainder (if any), the remainder shall be encoded with a shortened code.

6.1.1.1 Shortening the RS encoding

The shortening of the code is used whenever the data to be sent is smaller the 188 bytes or if a reminder of the data exists (the data to be sent is not a multiplication of 188 bytes).
The shortening is performed by setting the T parameter and using zero padding in order to bring the block to be encoded to 188 bytes, and after encoding the zero padding is discarded. For example if T=4 and the remainder is 40 bytes, the padding of 144 bytes will be added and 4 erasures are used to shorten the protection bytes.

6.1.2 Convolutional encoding

Data bits issued from the Reed Solomon encoder, described in clause 6.1.1, shall feed the convolutional encoder depicted in Figure 30.

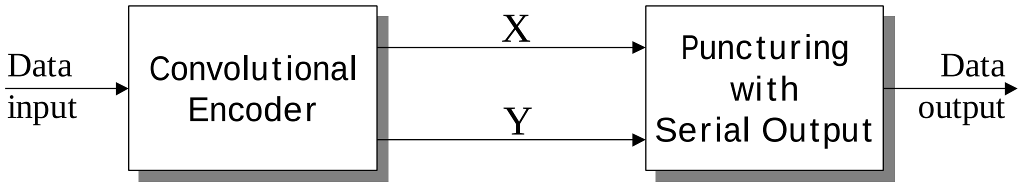

Figure 30: Convolutional encoder block diagram

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

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

$$G_1 = 133_{oct} \text{ For Y}$$

A basic convolutional encoding scheme, as depicted in Figure 31, shall be used.

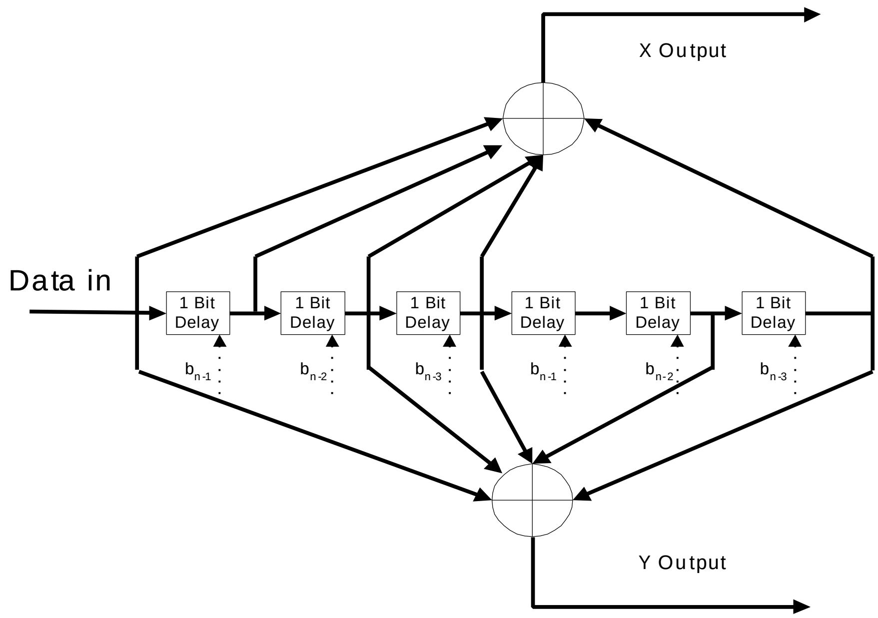

Figure 31: Convolutional encoder basic scheme

The puncturing pattern shall be as defined in Table 6.

CC Code Rate	Puncturing Pattern	Transmitted Sequence (after parallel to serial conversion)
$1/2$	X : 1 Y : 1	X_1Y_1
$2/3$	X : 1 0 Y : 1 1	$X_1Y_1Y_2$
$3/4$	X : 1 0 1 Y : 1 1 0	$X_1Y_1Y_2X_3$

Table 6: Bit-Interleaver size as a function of the Modulation and Coding Rate

6.1.2.1 Tail Biting Code Termination for OFDMA

In order to allow sharing of the ECC decoder in OFDMA mode, 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 $b_0..b_n$).

6.1.2.2 Zero Tail Code Termination for OFDM

In OFDM mode the receiver deals with a single data stream of variable length. In order to support this mode, the convolutional encoder will start the payload encoding process by resetting the shift register to an all-zero state and shall conclude the encoding process by appending 6 zero bits to the data (and pad bits to complete the 48-subcarrier "Carrier-Group"). Those 6 zero bits shall not be scrambled.

6.2 Block Turbo Coding

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 schemes supported follow the recommendation of the IEEE802.16.1 mode B. However, more flexibility in block size and code rates is enabled. 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.

6.2.1 Block Turbo Constituent Codes

As mentioned in ANNEX B - Turbo Code Description, TPCs are constructed as a product of simple component codes. The complete constituent code set is defined in Table 7

(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 7: Constituent Block Turbo Code List

6.2.2 Overall Turbo Product Codes

The defined Turbo Product Codes are all multiples of 48 bits to facilitate integration into the framing structure. Table 8 lists the possible codes, rates and block size in bits. The block sizes are achieved by bit shortening as described in ANNEX B - Turbo Code Description.

X-Code	Y-Code	Z-Code	Rate	Block Size
56,49	55,48		0.76	3072
25,19	25,19	5,4	0.46	3072
48,41	48,41		0.72	2304
24,18	24,18	4,3	0.42	2304
64,57	21,20		0.85	1296
41,34	32,26		0.67	1296
64,57	12,11		0.82	768
28,22	28,22		0.62	768
54,47	9,8		0.77	480
30,24	16,11		0.55	480
32,26	6,5		0.68	192
14,9	14,9		0.41	192

Table 8: TPC Example Codes

The codes may be shortened using the method described in ANNEX B - Turbo Code Description. Shortening should only be performed in multiples of 48 bits.

When using Turbo Product Codes additional Bit Interleaver sizes are defined:

X-Code	Y-Code	Z-Code	Bit Interleaver allocation
56,49	55,48		1024
25,19	25,19	5,4	1024
48,41	48,41		768
24,18	24,18	4,3	768
64,57	21,20		648
41,34	32,26		648
64,57	12,11		768
28,22	28,22		768
54,47	9,8		480
30,24	16,11		480
32,26	6,5		192
14,9	14,9		192

Table 9: Optimal Bit Interleaver Sizes

Termination of allocations does not have to be the multiplications of the above bit interleaver sizes. Sizes in any multiple of 48, up to a multiple of 12 can be used to terminate the allocation.

7 Bit Interleaving

The data encoded is passed through a bit interleaver; the bit interleaver size is set to the size of 3 Sub-Channel allocation (the size depends on the modulation used). Termination of allocation does not have to be in multiplications of 3 Sub-Channels therefore if 1 or 2 Sub-Channel allocation are left at the end of the encoding, a shorter bit interleaver in the size of 1 Sub-Channel allocation is used (the size depends on the modulation used). In OFDM mode, all the data shall use the “1 Sub-Channel” interleaving mode. Table 10 summarizes the bit-interleaver sizes as a function of the modulation and coding.

Modulation	3 Sub-Channel allocation	1 Sub-Channel allocation
QPSK	288	96
QAM16	576	192
QAM64	864	288

Table 10: Bit-Interleaver size as a function of the Modulation

The interleaver scrambles the order of the input bits to produce the interleaved data, which is then fed to the mapper and the Sub-Channel allocation.

The PRBS generator depicted in Figure 32 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)
- 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

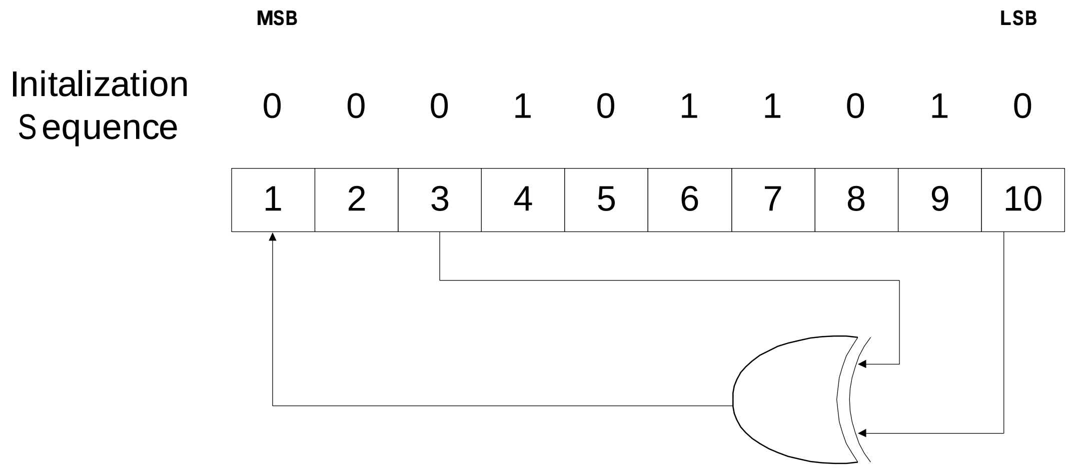

Figure 32: PRBS for Bit-Interleaver array

8 Ranging

8.1 Time and Power Ranging of the users

Ranging for time 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. This assumes Fixed Wireless Access support is mandatory and portability is optional.

During registration, a new subscriber registers during the random access channel (sub-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.

8.1.1 Using the Sub-Channels for ranging or fast bandwidth request purposes

Time and Power ranging is performed by allocating several Sub-Channels to one Ranging Sub-Channel upon this Sub-Channels users are allowed to collide, each user randomly chooses a random code from a bank of codes. These codes are modulated by BPSK upon the contention Sub-Channel. The Base Station can then separate colliding codes and extract timing and power ranging information, in the process of user code detection the base station get the Channel Impulse Response (CIR) of the code, acquiring the base station vast information about the user channel and condition. The time and power ranging allows the system to compensate the far near user problems and the propagation delay caused by large cells.

The usage of the Sub-Channels for ranging or fast bandwidth request 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 33 (the PRBS polynomial generator shall be $1+X^4+X^7+X^{15}$):

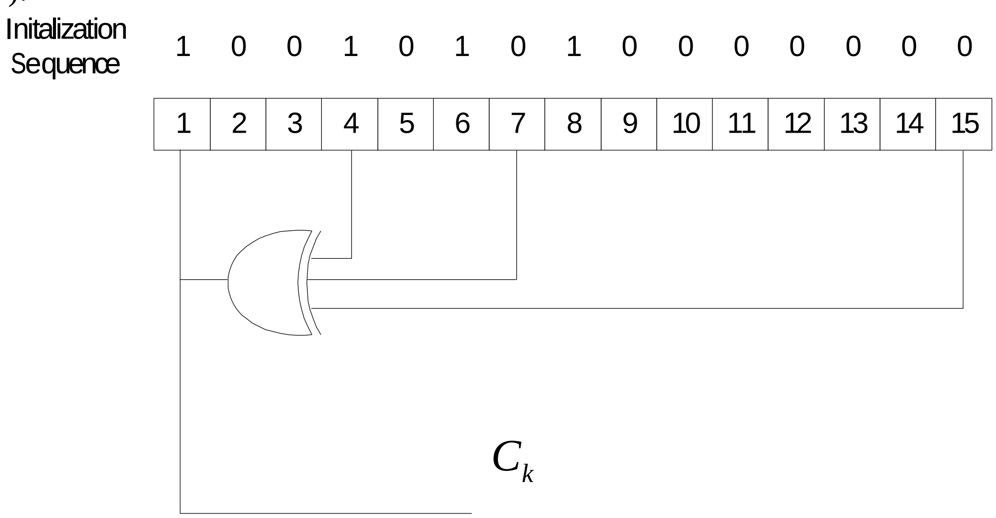

Figure 33: PRBS for ranging code production

Circulating through the PRBS (were each circulation produces one bit) produces the Ranging codes. The length of the ranging codes are multiples of 53 bits long, 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.

8.1.2 Ranging in OFDM mode

In OFDM mode 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.

[fill in the preamble structure]

8.1.3 BW requests in OFDM mode

Bandwidth request in OFDM can take two forms.

1) Contention based requests. In this mode regular uplink bursts shall be used for BW requests.
2) Subcarrier based polling. In this mode, the BTS may poll a group of stations, and each station responds by issuing an energy on a small set of subcarriers determined by station ID, if it desires to respond to a poll. (details TBD)

8.2 Frequency

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.

[Yossi: formal definitions do not even work with higher constellations, when keeping the frequency drift to 2% the carrier spacing 34dB SNR is created.]

8.3 Network Synchronization

For TDD realizations, all Base-Stations shall 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.

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.

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 requirements of paragraph 8.2. This applies during normal operation and during loss of timing reference.

8.4 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^Ntimestamp-1. The time stamp shall be synchronized to the network timing.

Time stamps shall be automatically reacquired after the loss of time or frequency synchronization.

Frame and symbol timing at the Base-Station and 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.

8.5 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 shall be adjustable in the range of TBD microseconds to TBD microseconds.

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

9 Constellation Mapping

The modulation used both for the US and DS data carrier is QPSK, 16QAM and 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 busting of 4dB, this is used for the Forward APC.

For the up stream 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.

9.1 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 34:

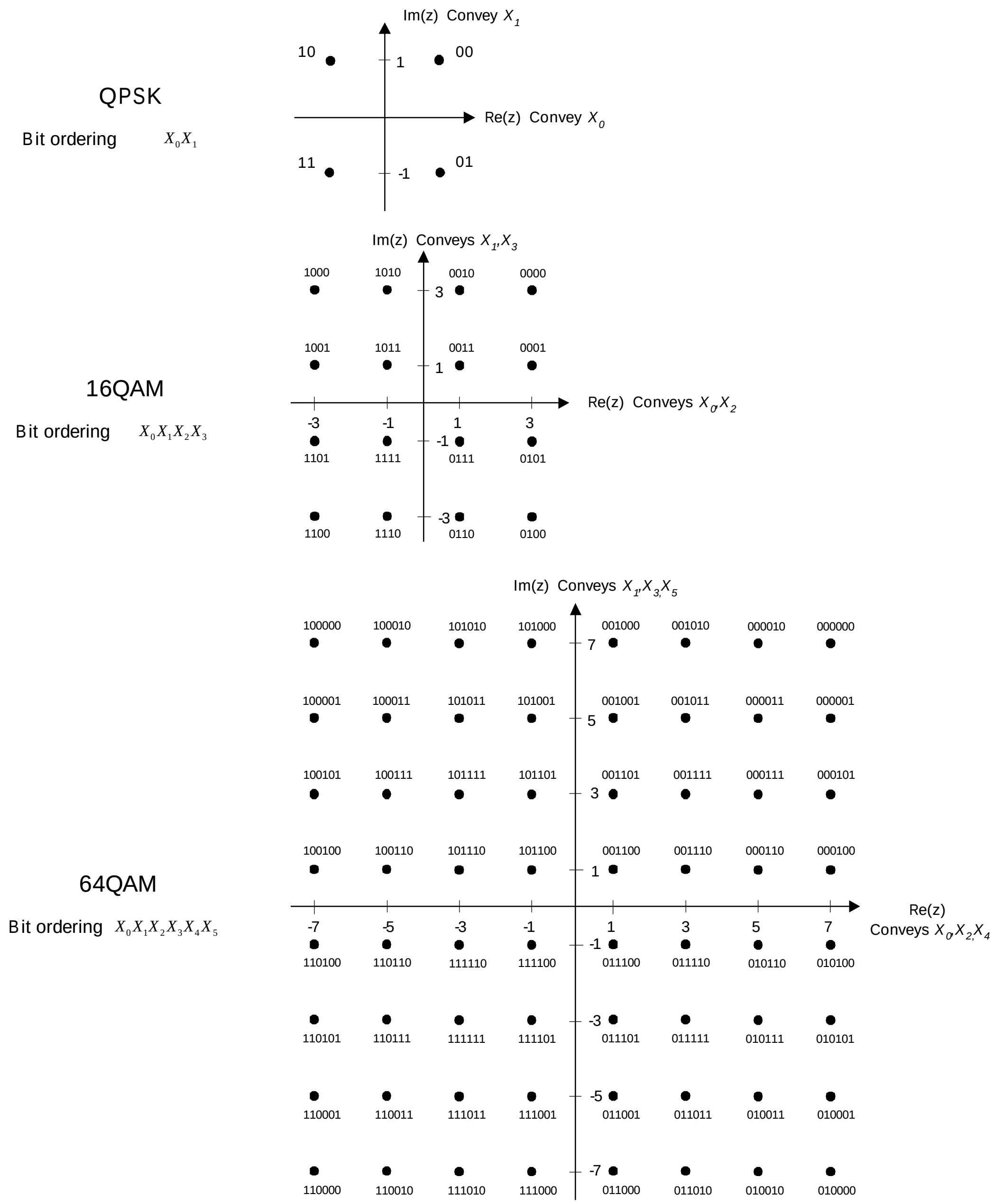

Figure 34: QPSK, 16QAM and 64 QAM constellations

The complex number *z* shall be normalized by the value *c*, before mapping onto the carriers, by using the factor defined in the next table:

Modulation scheme	Normalization Factor 4dB attenuation	Normalization Factor Reference – 0dB	Normalization Factor 4dB Busting
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	$c = z/\sqrt{164}$	$c = z/\sqrt{42}$	$c = z\sqrt{2}/\sqrt{21}$

The complex number *c*, resulting from the normalization process, shall be modulated onto the allocated data carriers. The data mapping shall be done by sequentially modulating these complex values onto the relevant carriers. The reference-normalizing factor is used for the US, and the DS defined for 0dB busting or attenuation. The normalizing factors used for attenuation and busting are for DS use only, this is defined in the DS parameters for a specific burst type and is used for Forward APC.

9.2 Pilot Modulation

Pilot carriers shall be inserted into each data burst in order to constitute the Symbol Structure (see clause 4.24.3) 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 $X^{11} + X^2 + 1$.

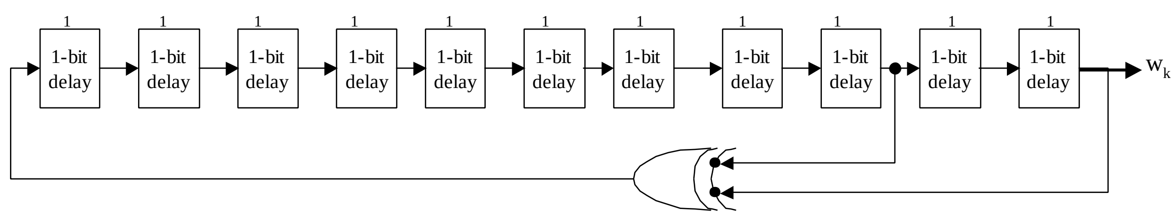

Figure 35: PRBS used for pilot modulation

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.
The pilots shall be sent with a boosting of 2.5 dB over the average energy of the data. The Pilot carriers shall be modulated according to the following formula:

$$Re\{C_k\} = 4 / 3 \times 2 (½ - w_k)$$

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

When 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:

$Re\{C_k\} = 2\,(½ - w_k)$

$Im\{C_k\} = 0$

9.3 Ranging Pilot Modulation

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

$Re\{C_k\} = (½ - w_k) / 6$

$Im\{C_k\} = 0$

C_k is derived in clause 8.1.1.

10 System Throughput

We give an example for the system throughput on a 3MHz channel bandwidth using the 2k mode. The following table gives the Net data rates (in Mbit/s) for the system (assuming all Sub-Channels use the same modulation and coding rates):

Modulation	Bits per sub-carrier	code rate	Net bit rate (Mbps) for different Guard intervals			
			1/4	1/8	1/16	1/32
QPSK	2	1/2	2.06	2.29	2.4	2.49
	2	2/3	2.74	3.05	3.21	3.33
	2	3/4	3.09	3.43	3.61	3.74
16-QAM	4	1/2	4.11	4.57	4.8	4.98
	4	2/3	5.49	6.1	6.42	6.65
	4	3/4	6.17	6.86	7.83	7.47
64-QAM	6	1/2	6.17	6.86	7.2	7.47
	6	2/3	8.23	9.15	9.63	9.98
	6	3/4	9.26	10.29	10.83	11.2

Table 11: System throughput using a 3MHz bandwidth and a 2k FFT

The allocated bandwidth for the upstream and the down stream can be different in order to satisfy different scenarios or demands. In order to compute bit rates for other channel bandwidth a good approximation will be to use this table as reference and multiplying it by the factor of: $NewBandwidth(MHz) / 3(MHz)$

Where the $NewBandwidth(MHz)$ parameter should be in MHz.

11 Transmission Convergence

TBD

12 Additional Possible Features

12.1 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 (section 4.4) 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).

12.2 Transmit diversity Alamouti's Space-Time Coding

Alamouti's scheme [25] is used on the downlink to provide (Space) transmit diversity of 2nd order.
(This is an optional mode with little overhead and good benefits!)
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.

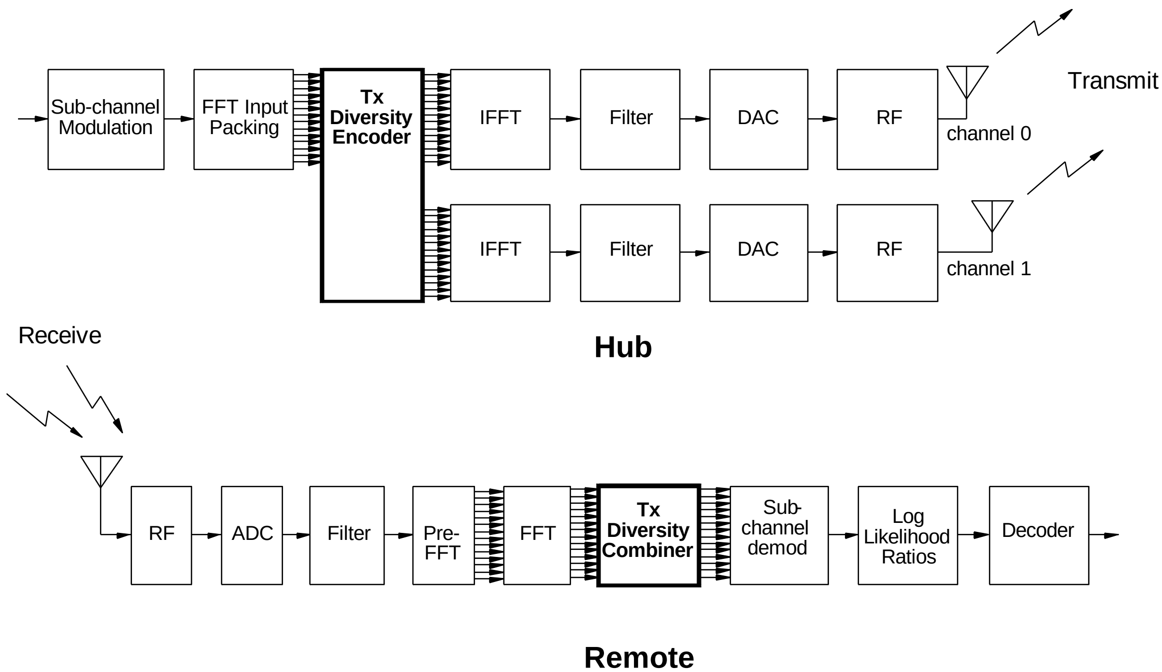

Figure 36: Illustration of the Alamouti STC

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.

12.3 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.

12.4 STC for FFT sizes 64 through 512

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).

12.5 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 same 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)

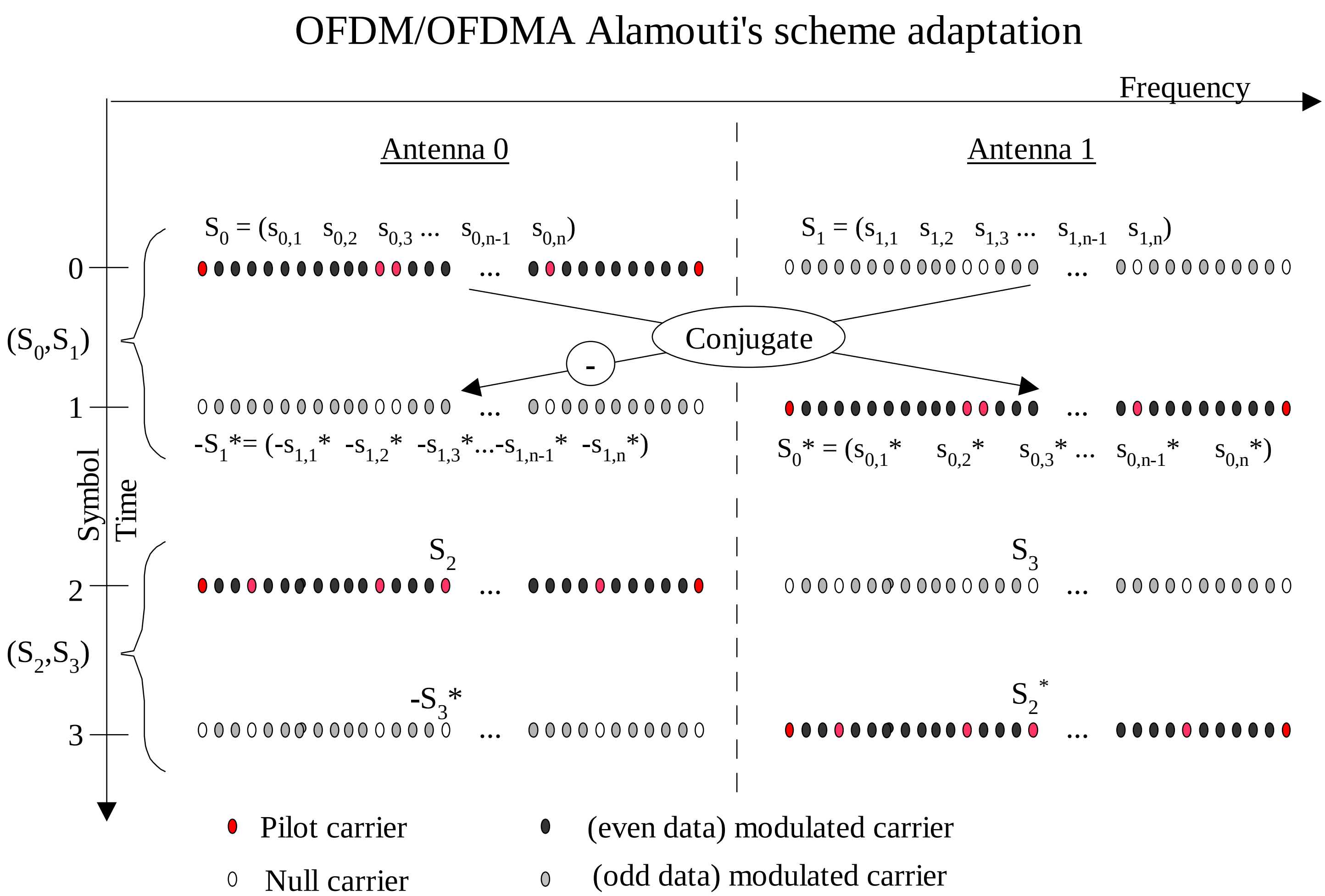

Figure 37: Using Alamouti's Scheme with OFDM/OFDMA

12.6 Alamouti STC Decoding

The receiver waits for 2 symbols, and combines them on a carrier basis according to the formula in section 12.5.

13 Comparison Matrix

#	Criteria	Proposed System
1	Meets system requirements	The proposed system gives solution to every demand of the FRD and the PAR, including broadband links of more then 10Mbit/s and distances of up to 50Km.
2	Channel Spectrum Efficiency	The full table of the system throughput is given in section 10 (for a 3 MHz bandwidth channel). To summarize the system supports adaptive modulation of QPSK, 16QAM and 64QAM and different coding rates, this will enable the system to gain the highest throughput possible for a certain scenario. The channel bandwidths proposed for the system are 1.5,1.75,3,3.5,6,7,10,12,14,15, 24, 28

		MHz, with flexibility to adjust to non-standard channel-widths. The OFDMA access enables the adaptation of the bandwidth per user for large FFT sizes, giving another dimension to user allocation flexibility and trade off between distance and peak throughput per user.
3	Simplicity of Realization	Today OFDM technology is well known, and the implementation of FFT components has become negligible. The OFDM/OFDMA access does not have effect on the MAC layer due to simple convergence layer; therefore the access system is independent of the MAC.
4	Spectrum Resource Flexibility	The system proposed can be very easily adapted to support different bandwidths by just adjusting the system clocks. This will enable the worldwide use of such a system in different world regions. The system is planned to FDD or TDD operation.
5	System Spectrum Efficiency	The usage of the OFDMA enables great robustness to cell planning, due to the fact that the Sub-Channel allocation is very robust to interference and blocking. The possibility to use the same frequency throughout the cell and just allocate different Sub-Channels to different sectors/cells, will enable the reuse factor of 1 (much like a CDMA system will do with codes). The spectral efficiency inside one cell due to the modulation, coding and overhead is about 4-4.5bps/Hz (using 64QAM), within a cell structure when averaging the throughput of cells 3.5bps/Hz/Cell (using 64QAM) could be used.
6	System Service Flexibility	The PHY is planned in such a way that the convergence layer between the PHY and MAC will enable the transparent usage of the PHY. The system is planned for great flexibility and can answer the required and potential future services, while supplying high spectral efficiency system.
7	Protocol Interfacing Complexity	The interfacing to the upper layer is done by the usage of a convergence layer. The delay of the PHY system is about 0.75-1msec for the down stream and 1.5msec for the up stream. These short delays will enable the usage of all services currently defined in the system
8	Reference System Gain	High reference system gain can be reached due to good coding gain and additional power concentration for OFDMA (which can give as

		much as 10dB more). Furthermore the adaptive modulation can trade off another 20dB, and therefore adjust the performance of the cell to the optimum.
9	Robustness to interference	The up stream is planned is such a way so that the spectral shape of the signal is very sharp for the out of band emission therefore minimizing the outer cell interference, also planning the Sub-Channel allocation differently between neighboring cells gives maximum robustness and statistically spreading interference between cells. For intra cell interference the Sub-Channels are allocated by special permutation that minimizes the neighboring carriers between two channels and statistically spreading the interference inside the cell. Other features that protect the signal is the frequency diversity of the system with an ECC planned to handle 25-30% of the frequency blocked using also time interleaving of users signal. All the above brings us to an optimal system and a very good reuse. Robustness to interference is also supported by the adaptive adaptation of bandwidth, modulation and coding, as well as additional features that can be implemented as: • Directional antennas where it is appropriate (to reduce interference to other users) • Directional antennas at the user side • Diversity antennas at the BS and at the SS (where appropriate). • Space/Time Coding are fitted very well to OFDMA/OFDMA technology
10	Robustness to Channel Impairments	OFDM is well known for its well-proven qualities dealing with tough wireless environments. The estimation that can be achieved within one symbol because of fading is about 40dB, giving excellent recovery opportunity. It is also very powerful for the location and nulling of regional interference therefore helping the decoders achieve better performances and treating up to 30% of channel frequency blocking or fading. The excellent link budget and adaptively of each user can handle large amounts of fading due to rain, flat fade, Foliage etc. other features as: • Diversity antennas at the BS and at the SS (where appropriate). • Space/Time Coding • Time Diversity of the signal • Adaptively of Code and Modulation Gives us farther advantages for the channel treatment.
11	Robustness to radio impairments	The OFDM sensitivity to phase noise is almost the same as for single carrier systems, today the same RF ends are used for OFDM and Single Carrier systems. The defined PHY layer has inherent features to help and estimate the phase noise, the user side can use a –70dBc

		at 1, 10KHz due to the fact the BS has a better phase noise then the user. The ability to change the FFT size can help reduce the phase noise demands were it is appropriate. Group Delay of filters is solved for OFDM as simple channel impairments and is estimated along with other wireless channel effects. Channel estimation solves all the problems the RF ends introduce. Power amplifiers Non-Linearity can be solved in the digital level although it has small effect in OFDM systems.
12	Support of advanced antenna technique	The proposed draft supports all the advanced coding and antenna techniques as: • Directional antennas where it is appropriate (to reduce interference to other users) • Diversity antennas at the BS and at the SS (where appropriate). • Space/Time Coding are fitted very well to OFDM/OFDMA technology • Adaptive array
13	Compatibility with existing relevant standards and regulations	The PHY is defined to be as close as possible to the IEEE802.11a, HipperLAN2 from one end (64-512 mode) and to the DVB-T (512 -4k modes).

14 Intellectual Property

Intellectual Property owned by companies participating in the writing of this document, might be required to implement the proposed PHY specification. The authors are not aware of any conditions under which the companies would be unwilling to license Intellectual Property as outlined by the IEEE-SA Standards Board Bylaws, if the proposed specification will be adopted.

15 ANNEX A – Using the Sub-Channel Permutation

In section 4.2.2.1.1, 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:

   (PermutatedSeries + CellId) mod 16; (PermutatedSeries + 2*CellId) mod 16; (PermutatedSeries + 3*CellId) mod 16; (PermutatedSeries + 4*CellId) mod 16;

   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:

$$Carrier\# = 16 * n + Index(n)$$

   where:
   $Carrier\#$ - denotes the carrier number for Sub-Channel n
   n - Index 0..52
   $Index(n)$ - denotes the number at index n of the 53 length series

16 ANNEX B - Turbo Code Description

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 38. 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 $d = d_x \times d_y$.

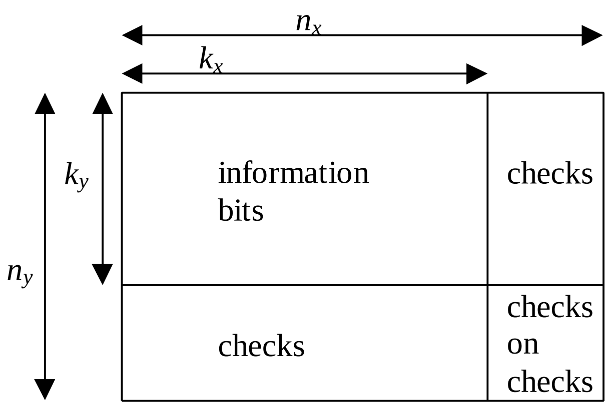

Figure 38: Two-dimensional product code matrix

16.1 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.

16.2 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 39 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 39: 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 40 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 40: 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

$D_{11}, D_{21}, D_{31}, D_{41}, E_{51}, E_{61}, E_{71}, E_{81}, D_{12}, D_{22},\ldots, E_{88}$.

Alternatively, a block based interleaver may be inserted to further improve the performance of the system.

16.2.1 3-Dimensional TPC Encoding

For a three-dimensional TPC block, the element ordering for input/output for both encoding and decoding is usually in the order of rows, columns and then the z-axis. If we consider a serial stream of (i×j×k) data bits, labeled as:

$D_{1,1,1}, D_{2,1,1}, D_{3,1,1},\ldots, D_{i,1,1}, D_{1,2,1}, D_{2,2,1},\ldots, D_{,i,j,1}, D_{1,1,2},\ldots, D_{i,j,k}$.

Note: this labeling is for convenience

Then the total size of the encoded block is ((i×j×k) + ECC bits), where there are p ECC bits for the x-axis, q ECC bits for the y-axis and r ECC bits for the z-axis, the bit order for input and output is:

$D_{1,1,1}, D_{2,1,1}, D_{3,1,1},\ldots, D_{i,1,1},\ldots, E_{p,1,1}, D_{1,2,1}, D_{2,2,1},\ldots, E_{p,2,1},\ldots, E_{p,q,1}, D_{1,1,2}, D_{2,1,2},\ldots, E_{p,1,2},\ldots, E_{p,q,2},\ldots, E_{p,q,r}$

This is shown in Figure 41.

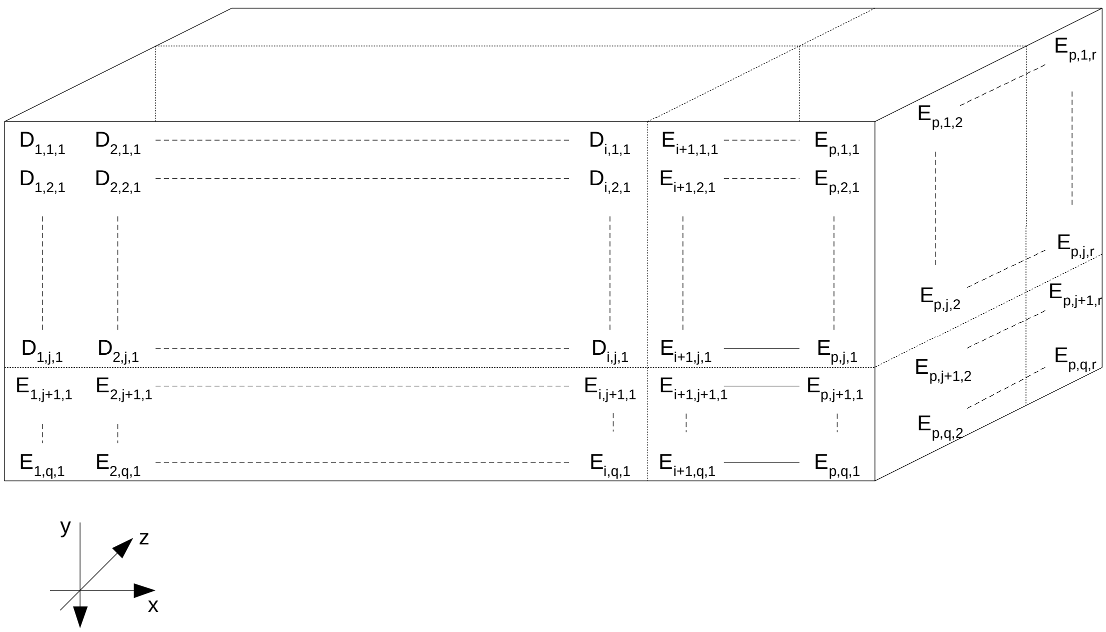

Figure 41: Structure of 3-Dimensional TPC

Notation:

- the codes defined for the rows (x-axis) are binary (n_x,k_x) block codes
- the codes defined for the columns (y-axis) are binary (n_y,k_y) block codes
- the codes defined for the z-dimension (z-axis) are binary (n_z,k_z) block codes
- data bits are noted $D_{y,x,z}$ and parity bits are noted $E_{y,x,z}$

16.3 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.

16.4 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 42 shows the structure of the resultant block.

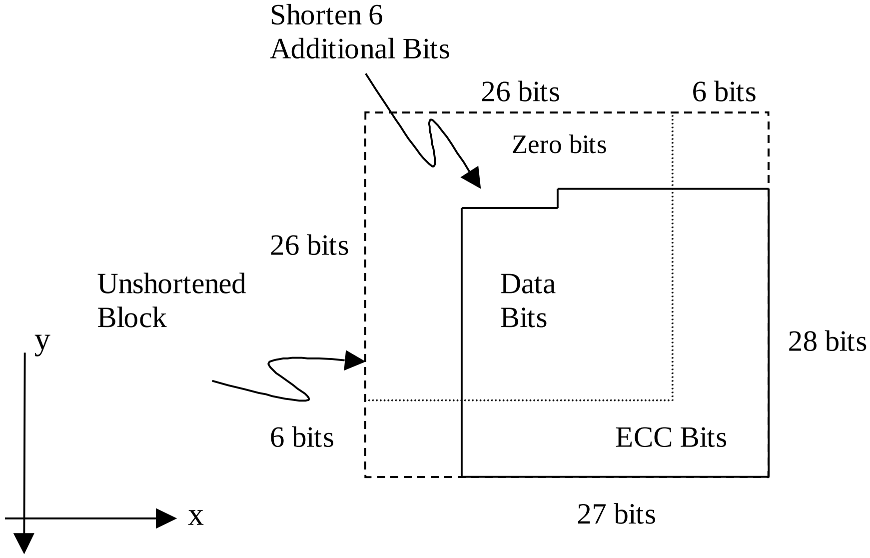

Figure 42: Structure of Shortened 2 D Block

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.

16.5 Example of a Shortened 3-Dimensional TPC

Suppose a 0.4 - 0.45 rate code is required with a data block size of 1096 bits. The following shows one possible method to create this code.

Start with a (32,26)×(32,26)×(4,3) code. The optimum shortening for this code is to remove rows and columns, while leaving the already very short z-axis alone. Therefore, since a 1096 bit 3-Dimensional code is required, the desired vector data size can be found by taking the square root of 1096/3 and rounding up. This yields a row/column size of about 20. In fact, having a row size of 20, a column size of 19, and a z-column size of 3 gives the closest block size to 1096 bits.

The code size is now a (26,20)×(25,19)×(4,3) = (2600,1140). To get the exact data size, we further shorten the first plane of the code by 44 bits. This is accomplished by shortening 2 full rows from the first (xy)-plane, with each row removing 20 bits from the data block, and shortening another 4 bits from the next row. This results in a (2544,1096) code, with rate = 0.43. The following diagram shows the original code, along with the physical location of the shortened bits.

Figure 43 shows the original code along with the physical location of the shortened bits.

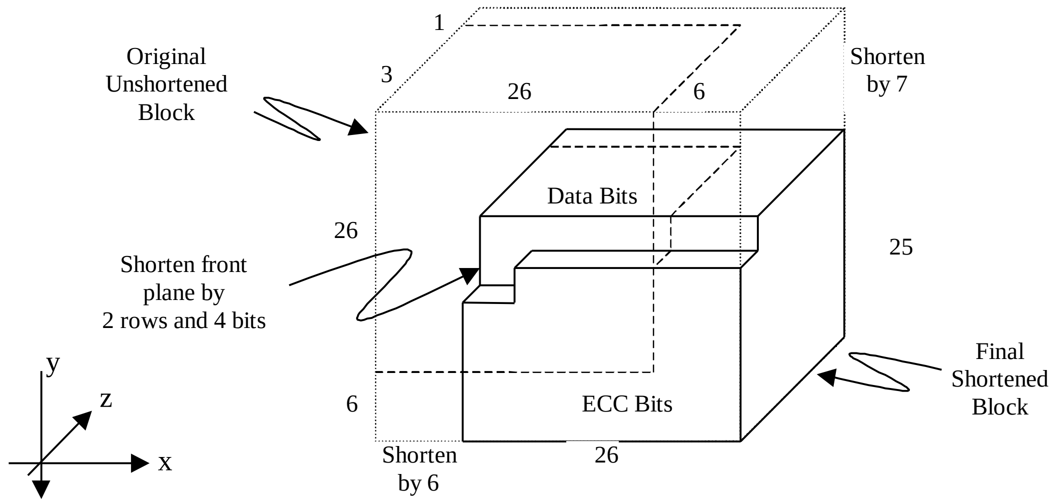

Figure 43: Structure of Shortened 3-D Block

16.6 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).

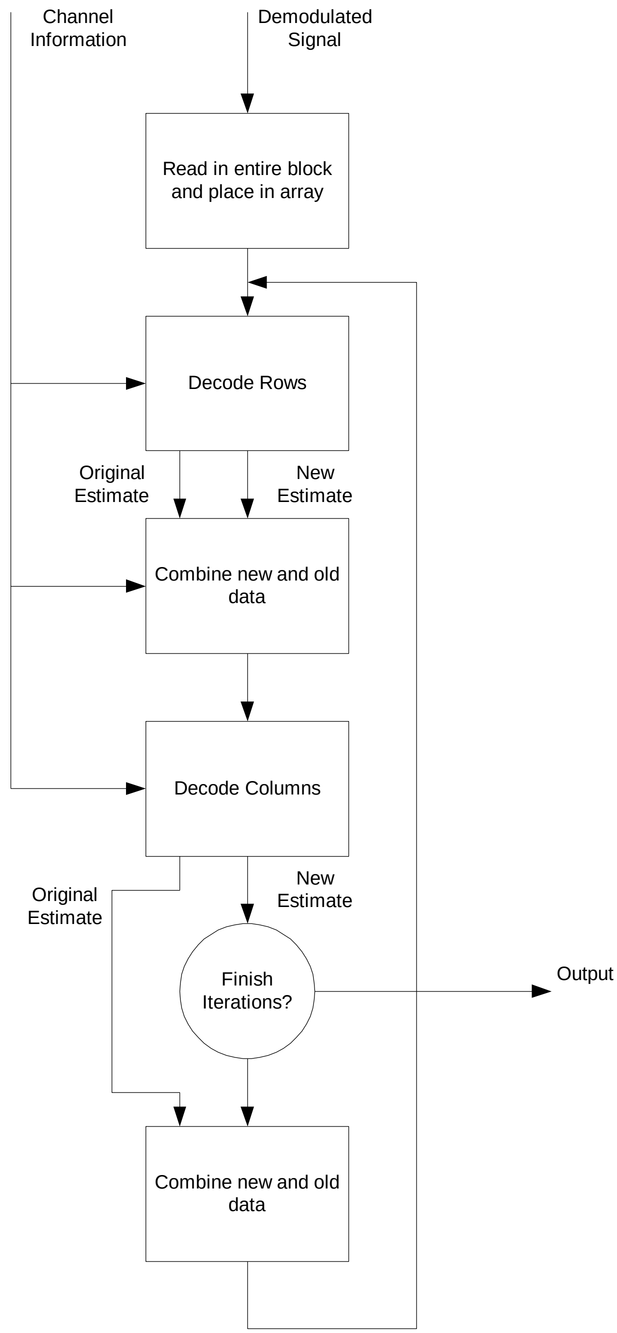

Figure 44: Procedure for decoding of 2-D TPC

It can easily be seen from Figure 44 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.

17 Annex C [Temporary] TDD/FDD co-existence: Implications on guard-band

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. This is shown in the hypothetical link susceptibility budget shown below in Table 1.
- 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. A typical SS power amplifier spectrum is shown in Figure 1.
- 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.

17.1 Link Susceptibility Example

The following table derives a link susceptibility budget for a "typical" scenario where two adjacent channel systems are deployed. In this scenario, one system uses TDD (system 1) duplexing and the other uses FDD duplexing (system 2). The system 1 SS antenna is pointed into the sidelobe of the system 2 SS antenna. The TDD system is transmitting while the FDD in receiving. The transmitted power is 0 dBm per tone.

The distance between the antennas is 100 meters. Free space propagation is assumed. The System 2 uses a 6.25 kHz resolution bandwidth, 5 dB noise figure with and additional 1 dB degradation due to RF and signal processing impairments. The susceptibility calculations assume that system 2 can tolerate an additional 1 dB degradation in the noise floor due to adjacent channel IMD noise.

The calculations assume that the out of band spurious emissions generated by the transmitter is dominated by 3rd order and 5th order IMD.

Table 13: Typical Adjacent Channel Susceptibility

Parameter	Value	Comments
Tx Power/Tone	0 dBm	400 tones, 2.5 MHz active BW, +27 dBm
Tx Antenna Gain	10 dB	Moderate Gain Antenna
Rcvr Sidelobe Level	-10 dBi	10 dBi gain, -20 sidelobe suppression
Path Loss, 100 m	80 dB	Free space path loss at 100 meters
3rd order IMD suppression	43 dB	To meet typical spectral masks
Received 3rd IMD power	-123 dBm	
Received 5rd IMD power	-138 dBm	5th Order IMD typically 15 dB 3rd Order
Receiver Sensitivity	-130 dBm	6.25 kHz BW, 5 dB NF, 1 dB impairments
Desired IMD level, 3rd IMD	-136 dBm	Level so that sensitivity is degraded = 1dB
Needed suppression, 3rd IMD	13 dB	Guard band needed
Needed suppression, 5th IMD	-2 dB	Meets requirement

In this example, the power amplifier backoff (6 dB typically) is set to meet an emission mask level of 43 dB typical of many of the masks. It is further assumed that increasing the backoff while holding the output power constant (to improve 3rd IMD suppression) is prohibitive from a cost prospective.

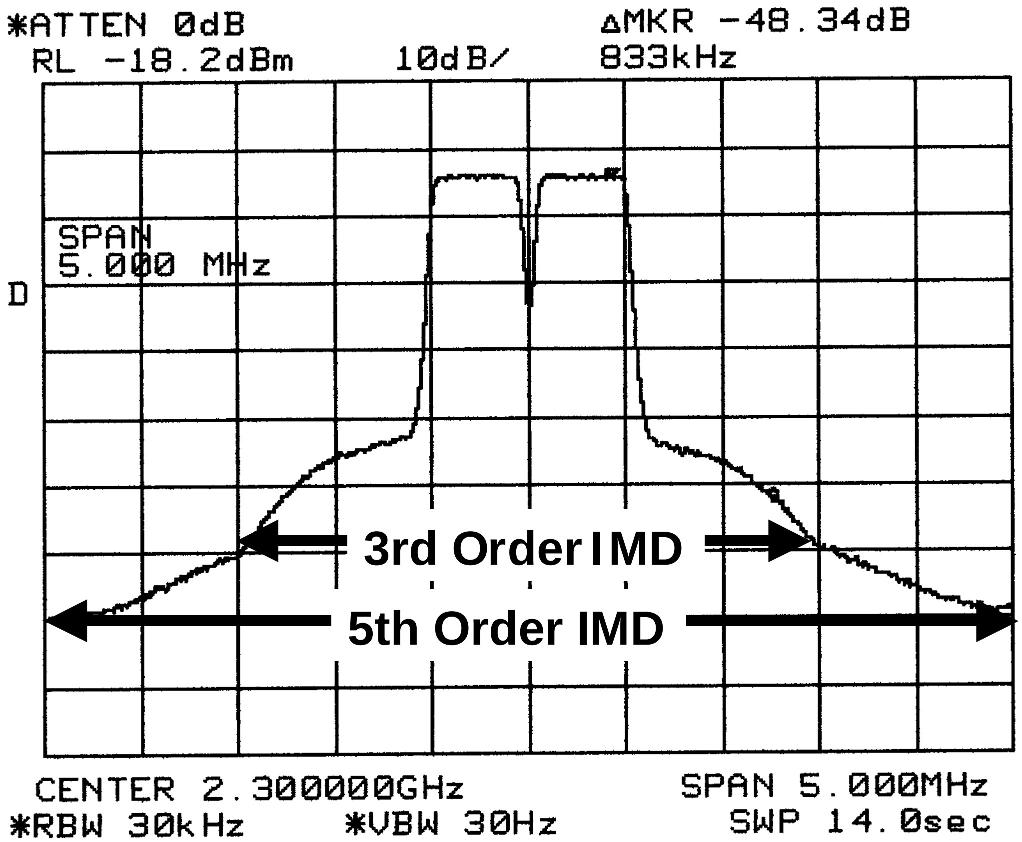

Figure 45: Typical OFDM Power Amplifier Spectrum

17.2 Guard Band Calculations

Table 2 below illustrates the guard band calculations based on the rules given above. Three bands of interest are shown the 3.5 GHz ETSI, 2.7 GHZ MMDS and WCS bands. For each band, calculations are made for channelizations used in these bands.

Active bandwidths based on multiples of 1.25 MHz are also shown. Note that BSs occupy the entire channel bandwidth (less guard bands) whereas SS are active over less bandwidth as provisioned by the service provider. By provisioning the appropriate active bandwidth on the reverse link, power amplifier costs are minimized, link budgets are improved, and coexistence is maintained.

The highlighted rows are fully compliant with guard band rules, whereas the remaining rows may require improved filtering and/or higher linearity at the BS.

Table 14: Guard Band Requirements

Channel BW, Center Freq	BS Active BW	BS Guard Band Calculation	Maximum SS Active BW	SS Guard Band Calculation	Guard Band Available
5, 2300	3.75	1.15	1.25	.625	.625
10, 2300	8.75	1.15	1.25	.625	.625
15, 2300	10	1.15	5	2.5	2.5
6, 2600	5	1.3	1.25	.625	.5
12, 2600	10	1.3	2.5	1.25	1
7, 3500	5	1.75	2.5	1.25	1
14, 3500	10	1.75	3.75	1.875	2

18 References

[1] H. Sari, Y. Levy, and G. Karam, "Orthogonal Frequency-Division Multiple Access for the Return Channel on CATV Networks," ICT '96 Conf. Rec., vol. 1, pp. 52-57, April 1996, Istanbul, Turkey.

[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.

[3] Richard V. Nee and Ramjee Prasad, “OFDM for wireless multimedia communicatons”, Artech House Publishers,2000.

[4] 802163c-00_33 – Initial OFDM/OFDMA PHY proposal for the 802.16.3 BWA

[5] 802163c-00_34 – Initial OFDMA/OFDMA PHY proposal for the 802.16.3 BWA

[6] Document to the WirelessHUMAN™ study group - Proposal for an adaptive OFDM system for the WirelessHUMAN™ standard

[7] Savo Glisic and Branka Vucteic, “Spread Spectrum CDMA Systems for Wireless Communications”, Ch. 2-6, Artech House Inc., 1997.

[8] William C. Y. Lee, “Mobile Cellular Telecommunications Systems”, Ch. 6, McGraw-Hill Book Company, 1989.

[9] Cheong Yui Wong, Roger S. Cheng, Khaled Ben Letaief and Ross D. Murch, “Multiuser OFDM with Adaptive Subcarrier, Bit, and Power Allocation”, IEEE Journal on Selected Areas in Communications, Vol. 17, No. 10, pp. 1747-1757, October 1999.

[10] Ye Li and Nelson R. Sollenberger, “Adaptive Antenna Arrays for OFDM Systems with Co-Channel Interference”, IEEE Transaction On Communications, Vol. 47, No. 2, pp. 217-229, February 1999.

[11] Heidi Steendam and Marc Moeneclaey, “Analysis and Optimization of the Performance of OFDM on Frequency Selective Time-Selective Fading Channels”, IEEE Transaction On Communications, Vol. 47, No. 12, pp. 1811-1819, December 1999.

[12] Andres Vahlin and Nils Holte, “Optimal Finite Duration Pulses for OFDM”, IEEE Transaction On Communications, Vol. 44, No. 1, pp. 10-13, January 1996.

[13] ETSI EN 300 744 (DVB-T), 1999.

[14] Scott L. Miller and Robert j. O’Dea, “Peak Power and Bandwidth Efficient Linear Modulation”, IEEE transactions on communications, Vol. 46, No. 12, pp. 1639-1648, December 1998.

[15] Kazuki Maeda and Kuniaki Utsumi, “Bit-Error of M-QAM Signal and its Analysis Model for Composite Distortions in AM/QAM Hybrid Transmission”, IEEE transactions on communications, Vol. 47, No. 8, pp. 1173-1180, August 1999.

[16] EN 301 790, Digital Video Broadcasting (DVB) Interaction Channel for Satellite distribution system.

[17] A Viterbi Algorithm with Soft-Decision Outputs and its Applications, J. Hagenauer, P. Hocher, IEEE Globecom ‘89, Nov. 1989, pp. 1680-1685.

[18] David Chase, “A Class of Algorithms for De-coding Block Codes With Channel measurement. Information,” IEEE Transactions of Information Theory, vol. 18, No 1, pp. 170-182, January 1972.

[19] RunCom Technologies, “Coding Performance of concatenated Reed-Solomon and Convolutional Coding, DVB-RCT Contribution”, August 2000

[20] DVB-RCT standard draft, October 2000

[21] G.Drury, G.Markarian, K.Pickavance. “Coding and Modulation for Digital Television”, KLUWER Academic Publishers, USA, 2001

[22] ETSI EN 301 021

[23] A. Cantoni and L.C. Godara, “Fast Algorithm for Time Domain Broad Band Adaptive Array Processing”, IEEE Trans. Aerops. Electr. Syst.AES-18, 682, September 1982.

[25] Siavash M. Alamouti, "A Simple Transmit Diversity Technique for Wireless Communications", *IEEE journal on selected areas in communications*, VOL.16, No. 8, pages 1451-1458, October 1998