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Source(s)	Yossi Segal Itzik Kitroser Yigal Leiba Zion Hadad Runcom Technologies Ltd. 2 Hachoma St. 75655 Rishon Lezion, Israel Voice: +972-3-9528440 Fax: +972-3-9528805 yossis@runcom.co.il itzikk@runcom.co.il yigall@runcom.co.il zionh@runcom.co.il
Re:	Call for contributions issued in document 802.16e-03/02
Abstract	This document presents the modifications for the OFDMA PHY/MAC layers, which adapts them to function/function better in a mobile environment.
Purpose	To be integrated into P802.16e-03/07r1 2003 draft document
Notice	
Release	
Patent Policy and Procedures	

OFDMA Modification for Mobility

Yossi Segal
Itzik Kitroser
Yigal Leiba
Zion Hadad

Runcom

1 Introduction

The following contribution brings the details of the changes to the OFDMA system, which will allow it to work in a very fast mobility (up to 200Km/h in the 2.7GHz band) scenario as well as in a frequency reuse of 1 scenario. The system will also support better granularity (down to 6bytes).

1.1 Reuse of 1 scenario

When using a reuse factor which is >1 (regular scenarios defined in the 802.16a) the same physical layer defined in the 802.16a can be used for the 802.16e, but in order to satisfy requirement of reliability, coverage, capacity, and mobility the system is configured to work in a reuse of 1, which means the same RF frequency is allocated to all sectors in the cell, then a new scheme of work must be introduced in order to achieve the needed performance. A scenario using a reuse of 1 is given in Figure 1:

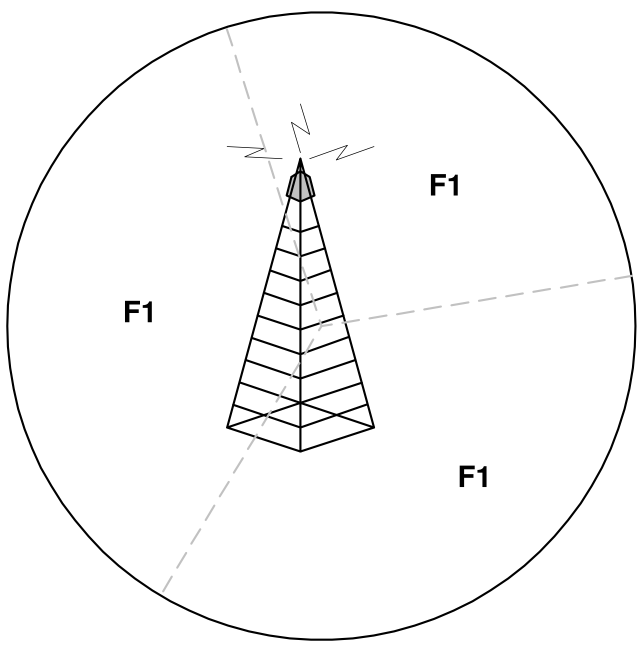

Figure 1: Reuse of 1 configuration, 3 sectors per cell

There are three options of operation in the reuse of 1 scenario:

- Asynchronous mode- in this configuration every base-station uses it's own permutation, the frames length and starting time are also not synchronized between the base-stations. Therefore orthogonality is kept within the base-station but not between base-stations. In this scenario the base-stations could be synchronized or not to the same reference clock. This mode will introduce interference between base-station (sub-carriers from different sub-channels collide in a controlled way, determined by the different permutations).
- Synchronous mode- in this configuration all base-stations use the same reference clock (e.g. GPS), the frames duration and starting time is also synchronized between the base-stations but still each base station uses different permutations. Therefore the time/frequency orthogonality is kept between and within the base-stations operation but still interference between the same sub-channels of different base-station occurs. Due to the time synchronization in this scenario and the long symbol duration of the OFDMA symbol fast H.O. as well as soft H.O. are possible.
- Coordinated Synchronous mode- in this configuration all base-stations work in the synchronous mode but uses also the same permutations. An upper layer is responsible for the handling of sub-channels allocations within the sectors of the base-station, making sure that better handling of the bandwidth is achieved and the system could handle and balance load between the sectors and within the system. This mode is identical in performance as the regular coverage scenarios [1], besides the fact that the bandwidth allocated to each sector is only a portion of the overall bandwidth, but when using the load balancing additional system gain is achieved.

The preferred scenario is of course the Coordinated Synchronous mode; such a scenario is presented in Figure 2

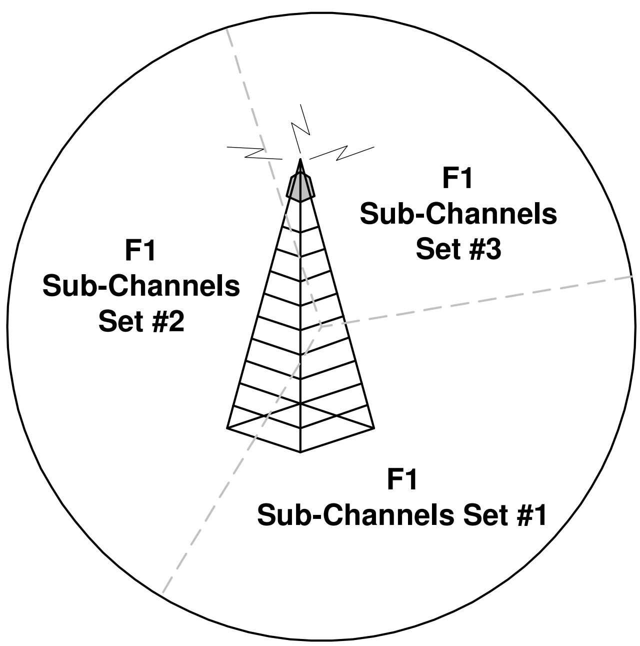

Figure 2: Reuse of 1 configuration using sub-channalization, 3 sectors per cell

1.2 Interoperability

Interoperability with the 802.16a can be done using the TDMA scheme in the time domain, or using the FDMA scheme in the frequency domain.

2 PHY definition

The following section deals with the PHY layer specification for the reuse of 1 scenario.

2.1 Down-Link

The downlink supports up to 3 sectors and includes a preamble which begins the transmission, this preambles divides the used carriers into 6 sections, each 2 sections are used by a single sector, the motivation of this split is to allow the usage of 6 different preambles in the Space-Time Coding mode (STC).

A downlink period will follow Figure 3:

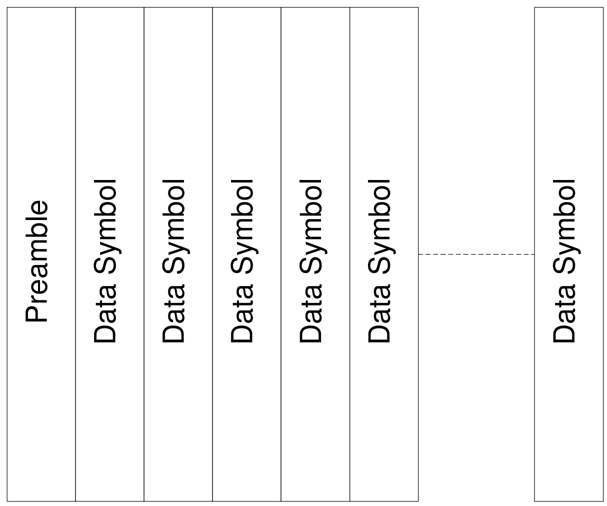

Figure 3: Downlink transmission basic structure

2.1.1 Preamble

The first symbol of the down link transmission is the preamble; there are 6 types of preambles. The preamble types are defined by allocation of different sub-carriers for each one of them; those sub-carriers are modulated after that using a non-boosted BPSK modulation with a specific Pseudo-Noise (PN) code.

The preambles are defined using the following formula:

$$\Pr eamble_n = n + 6 * k$$

where:

$\Pr eamble_n$ - specifies all carriers allocated to the specific preamble

n - specifies the number of the preamble indexed 0..5

k - is a running index 0..283/284 (the index is used while carrier number is ≤1702 – overall used carrier index)

Each sector uses 2 types of preamble out of the 6 sets in the following manner:

- Sector 1 uses preamble 0 and 3
- Sector 2 uses preamble 1 and 4
- Sector 3 uses preamble 2 and 5

Therefore each sector eventually modulates each 3'rd carrier, Figure 4 depicts as an example the preamble of sector 1:

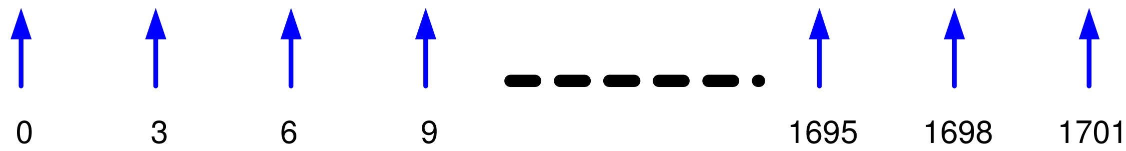

Figure 4: Downlink basic structure

The PN series modulating the pilots is the one defined in section 8.5.9.4.3 of the IEEE802.16a. The initialization sequence for each preamble type is given in Table 1

Preamble Type (PNId)	PRBS Initialization	Wk (partial)
0	[01010101010]	010101010100000…
1	[00011101010]	000111010100000101…
2	[10011010011]	10011010011111001…

Table 1: Initialization sequence for the preamble PRBS

The modulation used on the preamble is in section 8.5.9.4.3.1 of the IEEE802.16a, therefore the number of combination of PNId and preambles types are 9.

2.1.2 Symbol Structure

The symbol structure is constructed using pilots, data and zero carriers. The symbol is first allocated with the appropriate pilots and with zero carriers, and then all the remaining carriers are used as data carriers (these will be divided into sub-channels).

There are 6 possible allocations of pilots, in regular transmission each sector shall use 2 allocations each, in STC mode each antenna uses one out of those two, Table 2 summarizes the parameters of the symbol:

Parameter			Value	Remark
Number of DC Carriers			1	Index 1024
Number of Guard Carriers, Left			173	
Number of Guard Carriers, Right			172	
Number of Used Carriers (N_{used})			1702	Number of all carriers used within a symbol, including all allocated pilots for each sector
Number of Pilots	Sector 1	Antenna 0	28	0,39,72,144,216,288,360,432,504,576, ,645,648,720,792,864,936,1008,1017,1080,1152, ,1224,1296,1368,1407,1440,1512,1584,1656
		Antenna 1	28	36,108,180,252,261,324,396,468,540,612, ,651,684,756,828,900,972,1044,1116,1143,1188, ,1260,1332,1404,1419,1476,1548,1620,1692

	Sector 2	Antenna 0	28	12,84,156,228,300,330,372,444,516,588, ,660,726,732,804,876,948,1020,1092,1155,1164, ,1236,1308,1380,1452,1461,1524,1596,1668
		Antenna 1	27	48,120,192,264,336,342,408,480,552,624, ,696,768,840,849,912,984,1056,1128,1158,1200, ,1272,1344,1416,1488,1530,1560,1632
	Sector 3	Antenna 0	28	24,96,168,240,312,351,384,456,528,600, ,672,744,816,855,888,960,1032,1104,1176,1185, ,1248,1320,1392,1464,1536,1545,1608,1680
		Antenna 1	27	60,132,204,276,348,420,492,522,564,636, ,708,780,852,918,924,996,1068,1140,1206,1212, ,1284,1356,1428,1500,1572,1644,1701
Number of data carriers			1536	
Number of data carriers per sub-channel			48	
Number of Sub-Channels			32	

Table 2: Initialization sequence for the preamble PRBS

The pilots allocation are derived from the following formula:

$$Pilots_{n,k} = 12*n + 36*k + 72*i$$

where:

$Pilots_{n,k}$ - pilots indices allocated for sector n and antenna k

i - is a running index 0..26/27 (the index is used while carrier number is ≤1702 – overall used carriers index)

For regular transmission Each sector uses both types of antenna pilots for its transmission, therefore:

- Sector 1 uses 56 pilots
- Sector 2 uses 55 pilots
- Sector 1 uses 55 pilots

Figure 5 depicts as an example of the symbol allocation for sector 1:

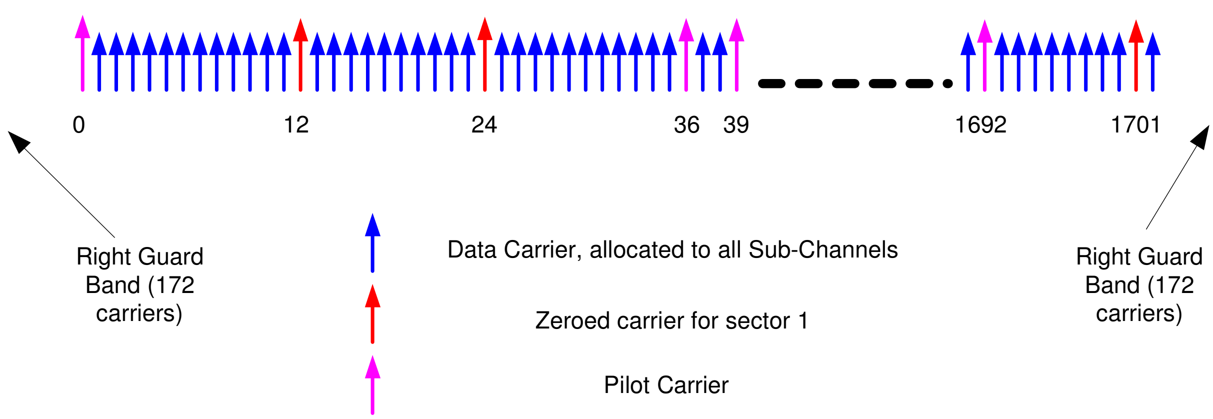

Figure 5: Downlink symbol structure for sector 1

The PN series modulating the pilots is the one defined in section 8.5.9.4.3 of the IEEE802.16a.
The initialization sequence for each Sector type is given in Table 3

PNId	Initialization B
0	[10111000101]
1	[00011101010]
2	[11001010111]

Table 3: Initialization sequence for the PRBS used to modulate the symbol pilots

The modulation used on the preamble is in section 8.5.9.4.3 of the IEEE802.16a.

2.1.2.1 Downlink Sub-Channels carrier allocation

Each Sub-Channel is composed of 48 carriers, and is an independent entity in the base-band processing (each sub-channel data is randomized, encoded and interleaved separately, therefore it can be decoded separately).
The sub-channel indices are formulated using a Reed-Solomon series, and is allocated out of the data sub-carriers domain. The data sub-carriers domain includes 48*32=1536 carriers, which are the remaining carriers after removing from the carrier's domain (0-2047) all possible pilots and zero carriers (including the DC carrier).
After allocating the data sub-carriers domain the procedure specified in section 8.5.6.1.2 of the IEEE802.16a.

2.1.3 Allocation of sub-channels for DL Frame Prefix, and logical sub-channel numbering

The minimal allocation of sub-channels for a sector (if the sector is used) is 3 sub-channels, these sub-channels are always modulated using QPSK and has coding rate of 1/2. The data enclosed in those sub-channels, called the DL Frame Prefix, is specified in section **Error! Reference source not found.**, for sector 1 Sub-channels 0-2 are used as the basic allocated Sub-Channels, for Sector 2 Sub-channels 11-13, for sector 3 Sub-channels 22-24, Figure 6 depicts this structure

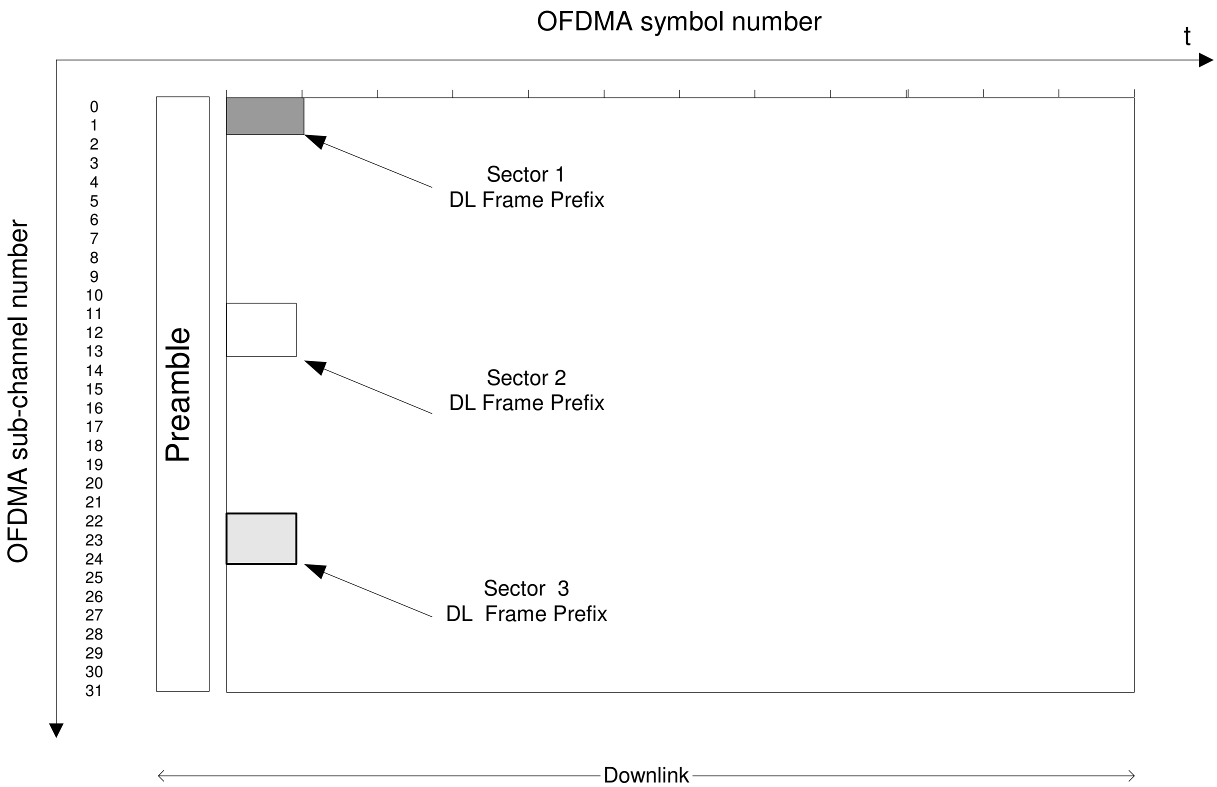

Figure 6: DL Frame Prefix sub-channel allocation with for all 3 sectors

After decoding the DL Frame Prefix the SU has the knowledge of how many and which sub-channels are allocated to the sector. In order to observe the allocation of the sub-channels as a contiguous block of allocation the sub-channels shall be renumbered, the renumbering shall start from the DL Frame Prefix sub-channels (renumbered to values 0..2), then continue numbering the sub-channels in a cyclic manner to the last allocated sub-channel and from the first allocated sub-channel to the DL Frame Prefix Sub-Channels, figure YY gives an example of such renumbering for sector 2.

	Physical Enumeration	Logical Enumeration (Renumbered)
	SC 7	SC 7
DL Prefix	SC 11	SC 0
DL Prefix	SC 12	SC 1
DL Prefix	SC 13	SC 2
	SC 14	SC 3
	SC 18	SC 4
	SC 27	SC 5
	SC 31	SC 6

Figure 7: Example of renumbering the allocated sub-channels for sector 2

2.1.3.1 DL_Frame_Prefix

The DL_Frame_Prefix is a data structure transmitted at the beginning of each frame and contains information regarding the current frame.
The DL_Frame_Prefix is always transmitted using QPSK-1/2 with the mandatory coding scheme.

Table 4 defines the structure of DL_Frame_Prefix.

Syntax	Size	Notes
DL_Frame_Prefix_Format() {		
Ranging_Change_Indication	1 bits	
DL_Map_Length	7 bits	
Sub_Channel_Bitmap	32 bits	
Prefix_CS	8 bits	
}		

Table 4: OFDMA DL Frame Prefix format

DL_Map_Length
Defines the length in slots of the DL_Map message that follows immediately the DL_Frame_Prefix.

Ranging_Change_Indication
A flag that indicates whether this frame contains a change of the allocation of Periodic Ranging/BW Request UL regions comparing to the previous frame. A value of '1' means that a change has occurred, and value of '0' means that the allocation of Periodic Ranging/BW Request regions in the current frame are same as in previous frame.

Sub_Channel_Bitmap
An 32-bit field that defines a bitmap representing the sub-channels which are allocated to this sector. Each bit represent a sub-channel which same enumerated value, a value '1' means that the sub-channel represented by the bit is allocated to the sector.

Prefix_CS
An 8-bit checksum for the DL-Frame prefix fields. The generator polynomial shall be:
$g(x) = x^8 + x^2 + x + 1$.

2.2 Up-Link

The following section defines the uplink transmission and symbol structure.
The uplink follows the downlink model, therefore it also supports up to 3 sectors. Two formats of transmission in the uplink are supported:

- Regular Sub-Channel of 53 carriers (32 Sub-Channels overall)
- Mini Sub-Channel of 21/22 carriers (80 mini Sub-Channels overall)

Each transmission uses 48 symbols as their minimal block of processing, each new transmission commences with a preamble (which is modulated on the allocated Sub-Channels only), allocations of sub-channels to users are done with the granularity of one Sub-Channel / mini Sub-Channel.

2.2.1 Symbol Structure

The symbols structure supported in the uplink are specified hereafter.

2.2.1.1 Symbol Structure for regular Sub-Channel

The symbol structure shall follow section 8.5.6.1 of the IEEE802.16a.

2.2.1.2 Symbol Structure for mini Sub-Channel

The regular Sub-Channel in the DL shall be further divided to create the mini sub-channels, every to adjunct sub-channels (where the first one is the even sub-channel) shall be divided into 5 mini sub-channels. The 106 carriers will be divided into 5 groups, 4 of them containing 21 carriers and the last containing 22 carriers. In each mini sub-channel 16 carriers are allocated for data and the rest are allocated as pilots.

The carriers which obey the following formula, are allocated to one mini sub-channel:

$$\mathrm{mod}(Carrier(j,i),5) = k$$

where:

$Carrier(j,i)$ - defines carrier j of sub-channel i, as defined in 8.5.6.1.2 of the IEEE802.16a

k - defines mini sub-channel k, 0..4.

The overall numbering of the mini sub-channels shall start from the first two sub-channels divided into 5 mini sub-channels and follow each two adjunct sub-channels which are divided, for a total of 80 mini sub-channels numbered 0..79.

Error! Reference source not found. and Figure 9 depicts the mini sub-channel organization:

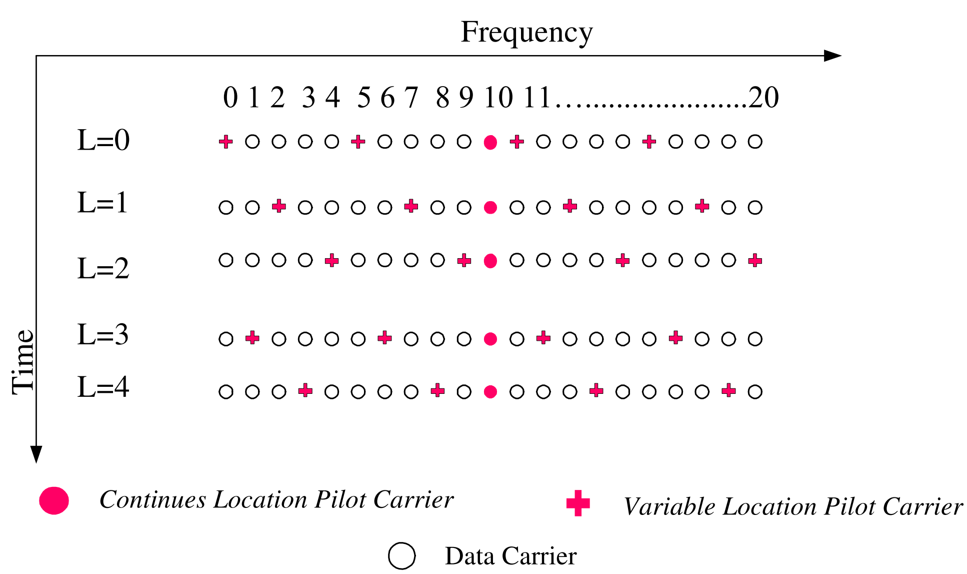

Figure 8: Mini Sub-Channel (of 21 carriers) organization and structure

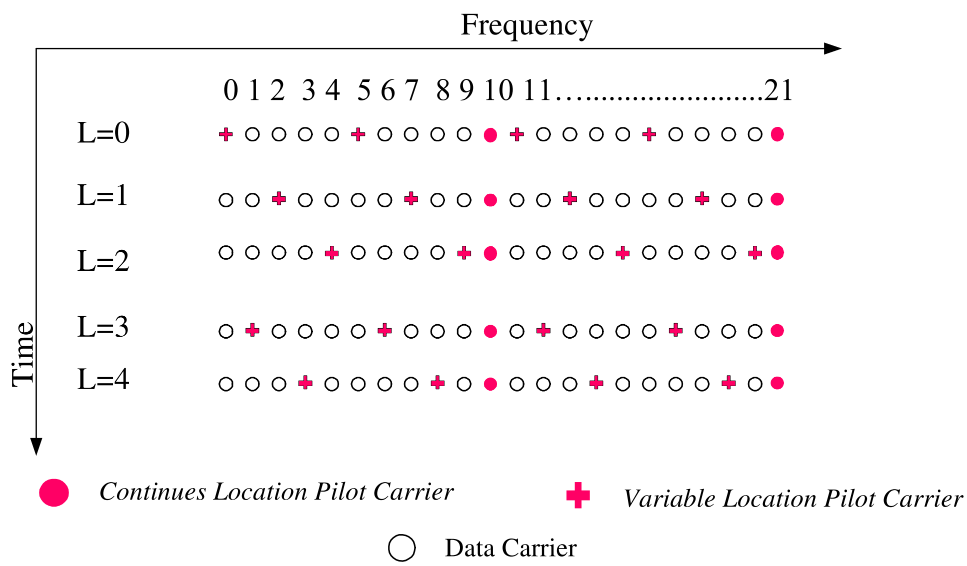

Figure 9: Mini Sub-Channel (of 21 carriers) organization and structure

The structure proposed will enable a module 5 frame structure, with maximum frequency diversity.

2.2.1.3 Burst Structure using regular sub-channels

The burst structure consists of the preamble and one time symbol following it as the basic structure. Allocating more sub-channels or/and time symbols could expand the burst; in any case the preamble is transmitted at the beginning of the burst on all allocated sub-channels. This is depicted in Figure 10

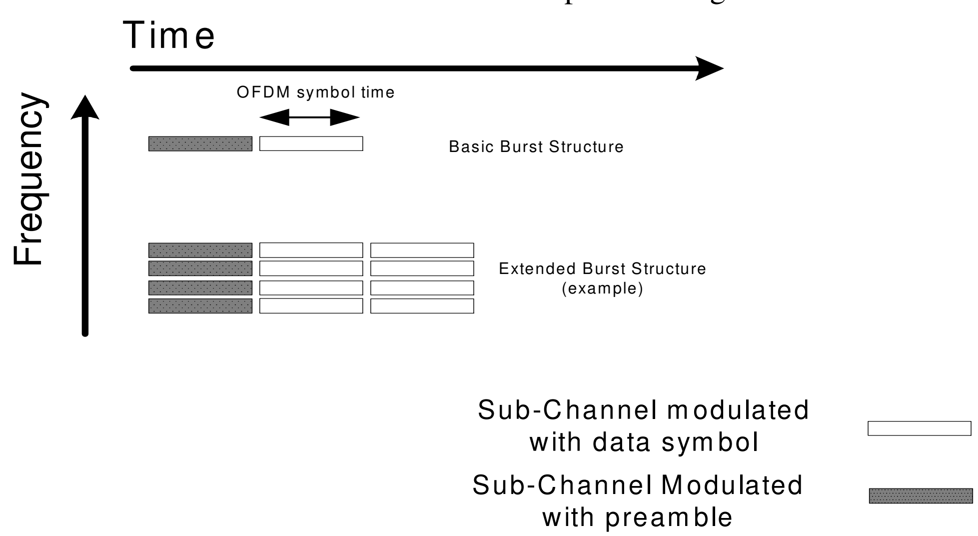

Figure 10: Burst Structure using regular sub-channel

2.2.1.4 Burst Structure using mini sub-channels

The burst structure consists of the preamble and 3 time symbols following it as the basic structure. Allocating more sub-channels or/and multiples of 3 time symbols could expand the burst; in any case the preamble is transmitted at the beginning of the burst on all allocated mini sub-channels. This is depicted in Figure 11

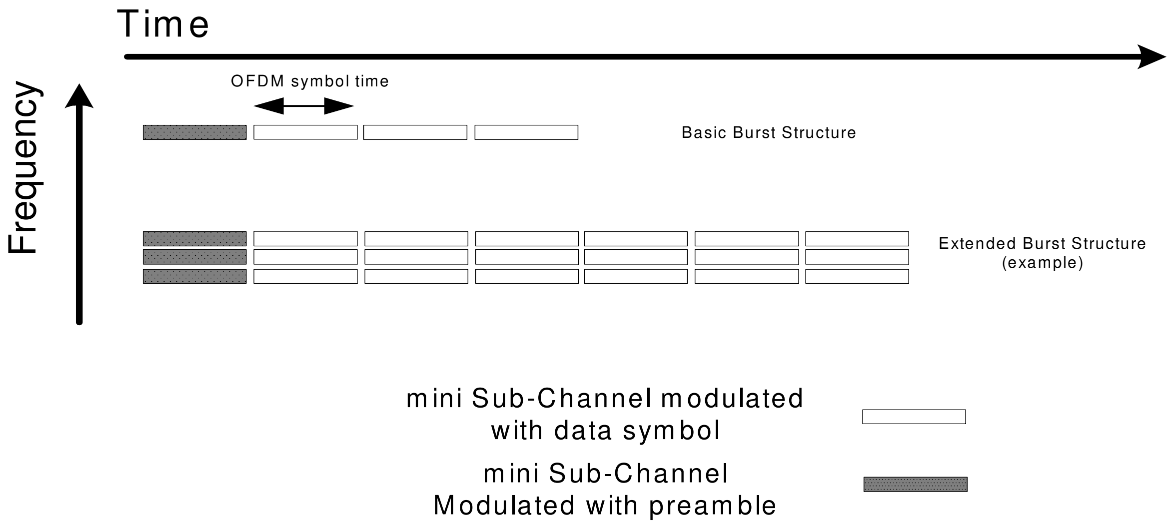

Figure 11: Burst Structure using mini sub-channel

2.3 Base-Band Processing

The base-band processing includes the following processes:

- Randomization
- Encoding
- Bit-Interleaving
- Modulation

These processes are performed in the uplink and downlink in the same manner.

2.3.1 Randomization

As in section 8.5.9.1 specified in the IEEE802.16a.

2.3.2 Encoding

The coding method used as the mandatory scheme will be the tail biting convolutional encoding specified in section 8.5.9.2.1 and the optional modes of encoding in sections 8.5.9.2.2 and 8.5.9.2.2 shall be also supported, all sections as defined in the IEEE802.16a.

The encoding block size shall depend on the number of sub-channels/mini sub-channels allocated and the modulation specified for the current transmission.

Concatenation of a number of sub-channels/mini sub-channels shall be performed when using QPSK modulation in order to make larger blocks of coding where it is possible, with the limitation of not passing the largest block under the same coding rate (the block defined by 64QAM modulation). Table 5 specifies the concatenation of sub-channels for different allocations and modulations.

Number of Sub-Channel / mini Sub-Channels allocated	Modulation	Sub-Channels concatenated	Remarks

1	QPSK	1	When using 1 Sub-channel concatenation is not performed
2	QPSK	2	Using the 16QAM configuration
3	QPSK	3	Using the 64QAM configuration
4	QPSK	2,2	Using twice the 16QAM configuration
5	QPSK	3,2	Using the 64QAM then the 16QAM configuration
6	QPSK	3,3	Using twice the 64QAM configuration
n>6 (mod(n,3)=1)	QPSK	3,..,3,2,2	Using 64QAM, last two encoding done with 16QAM configuration
n>6 (mod(n,3)=2)	QPSK	3,..,3,3,2	Using 64QAM, last encoding done with 16QAM configuration
n>6 (mod(n,3)=0)	QPSK	3,..,3,3,3	Using only the 64QAM configuration
Not relevant	16QAM	1	Concatenation is never performed
Not relevant	64QAM	1	

Table 5: Encoding Sub-Channel concatenation for different allocations and modulations

2.3.2.1 Tail-Biting Convolutional Encoding

The convolutional encoding scheme is specified in section 8.5.9.2.1 (without the RS encoding part) specified in the IEEE802.16a.
Table 6 defines the basic sizes of the useful data payloads to be encoded in relation with the selected modulation type and encoding rate.

	QPSK		16 QAM		64 QAM	
Encoding rate	R=1/2	R=3/4	R=1/2	R=3/4	R=2/3	R=3/4
Data payload in 48 symbols	6 bytes	9 bytes	12 bytes	18 bytes	24 bytes	27 bytes

Table 6: useful data payload for a sub-channel

2.3.2.2 Block Turbo Code (BTC)

The BTC scheme is specified in section 8.5.9.2.2 specified in the IEEE802.16a.
The parameters used for the encoding process shall follow TBD

2.3.2.3 Convolutional Turbo Code (CTC)

The BTC scheme is specified in section 8.5.9.2.3 specified in the IEEE802.16a.
The parameters used for the encoding process shall follow TBD

2.3.3 Bit-Interleaving

Using the same scheme as defined in the IEEE802.16a with the parameters defined in Table 7:

Modulation	Coded Bits per Bit Interleaved Block (N_{cbps})	Modulo used (d)
QPSK	96	16
16 QAM	192	16
64 QAM	288	16

Table 7: Bit-Interleaver Block Sizes

2.3.4 Modulation

As in section 8.5.9.4 specified in the IEEE802.16a.

2.4 OFDMA Soft Handoff

TBD.

3 References

[1] IEEE C802.16e-03/22r1 "Coverage simulations for OFMDA PHY mode"
[2] IEEE Std 802.16-2001 "Part 16: Air Interface for Fixed Broadband Wireless Access Systems"
[3] IEEE P802.16a/D7-2002 "Part 16: Air Interface for Fixed Broadband Wireless Access Systems – Medium Access Control Modifications and Additional Physical Layer Specifications for 2-11 GHz"
[4] IEEE C802.16-SGM-02/23 "802.16a OFDMA PHY suitability for mobile applications"
[5] IEEE 802.16.3c-01/30r1 "Traffic Model for 802.16 TG3 MAC/PHY Simulations"
[6] IEEE 802.16.3c-01/39 "Analysis and calculations of re-use factors and ranges for OFDMA in comparison to TDMA systems"