Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**OFDMA PHY proposal for the 802.16.3 PHY layer**
Date Submitted	**17/01/2001**
Source(s)	Yossi Segal Dr. Zion Hadad Itzik Kitroser RunCom Technologies LTD. 14 Moshe Levi St., Rishon Lezion, Israel Olivier Seller Sacet, Ker Lann, Bat Alliance, 35170 Bruz. France Dave Williams Advanced Hardware Architecture Voice: 972-3-9528440 Fax: 972-3-9528805 mailto:[zionh@runcom.co.il] [yossis@runcom.co.il] [itzikk@runcom.co.il] Voice: 33-2-99571656 Fax: 33-2-99571617 mailto:[olivier.seller@sacet.com] Voice: 1-509-334-1000 mailto:[davew@aha.com]
Re:	TG3 call for Contributions for PHY layer; issued 2000-12-02.
Abstract	We give a description of an OFDMA system, which fits to the TG3 wireless channel environment, and includes several modes based on the DVB-T and the IEEE802.11a PHY layers. The contribution includes features as: OFDMA for the uplink and downlink, Turbo Coding, Time Space Coding, CDMA based synchronization, compatibility to the TG1 MAC, and support for both TDD and FDD modes.
Purpose	This proposal should be used for the PHY specification of the TG3.
Notice	
Release	
Patent Policy and Procedures	

Table of Contents

Table of Figures

OFDMA PHY proposal for TG3 PHY Development

1 Introduction

The following contribution proposes a PHY layer based on the OFDMA concept (the OFDM is a sub-set of the OFDMA). It was designed to be very robust, in order to tackle the TG3 wireless channel. We describe the OFDMA system, which includes several modes based on the DVB-T and the IEEE802.11a PHY concepts. The PHY layer includes features as: OFDMA for the uplink and downlink, Turbo Coding, Time Space Coding, CDMA based synchronization, compatibility to the TG1 MAC, and support for both TDD, FDD and H-FDD modes. Many advantages are gained by using the OFDMA modulation; those are elaborated throughout the document. The relationship and interfaces to the TG1 MAC layer are farther explained in a document also submitted to the TG3 titled "Proposed enhancements to the 802.16.1 MAC accommodating OFDMA PHY".

2 Channel bandwidth

The channel bandwidths for the frequencies below 11GHz differ between several areas of the world:

- In the US and other places in the world 1.5, 3, 6, 12MHz are recommended
- ETSI recommends channel bandwidth of 1.75, 3.5, 7, 8, 14, 28MHz

For these bandwidths several symbol rates could be considered

Symbol Rate (MSymbols/Sec)	Channel Bandwidth (MHz)
1.4	1.5
1.65	1.75
2.85	3
3.3	3.5
5.7	6
6.6	7
7.6	8
11.4	12
13.2	14
26.4	28

3 Supported FFT and Guard Interval (GI) lengths

Both down stream and up stream are defined to accommodate several FFT lengths. Using several FFT sizes is an essential tool to trade off multipath mitigation and channel signal variation rate. Large FFT sizes are used to combat channels that suffer long multipath delays, short FFT's could be used for short range systems which suffer less multipath. The Guard Interval (GI) size (in percentage) is responsible to this channel multipath handling on the expense of throughput reduction. The FFT sizes which will be supported are 2048, 1024, 256, 64 (one or some) and the GI for some modes are ¼, 1/8, 1/16, 1/32.

The next table summarizes, for several channel bandwidths, the GI duration for different FFT sizes (which determines the excess delay spread handled, the delay spread is about 1/4 of the excess delay spread):

FFT size / GI	64 (64 mode)			256 (256 mode)			1024 (1k mode)			2048 (2k mode)		
	3 MHz	6 MHz	12 MHz	3 MHz	6 MHz	12 MHz	3 MHz	6 MHz	12 MHz	3 MHz	6 MHz	12 MHz
1/32	N.A.	N.A.	N.A.	*2.6us	*1.3us	*0.6us	10.6us	*5.3us	*2.6us	21.3us	*10.6us	*5.3us
1/16	N.A.	N.A.	N.A.	*5.3us	*2.6us	*1.3us	21.3us	*10.6us	*5.3us	42.6us	21.3us	10.6us
1/8	*2.6us	*1.3us	*0.6us	*10.6 us	*5.3us	*2.6us	42.6us	21.3us	*10.6 us	85.3us	42.6us	21.3us
1/4	*5.3us	*2.6us	*1.3us	21.3us	*10.6us	*5.3us	85.3us	42.6us	21.3us	170.6us	85.3us	42.6us

* Not recommended for bad multipath channels

Another advantage of larger FFT size is the better spectral shape of the emitted signal. When using the 2k mode the spectral mask is lowered about 15dB then that of the 64 mode. This will allow better coexistence between systems and cleaner spectrum. An example of the shaping is taken from [1] and presented hereafter:

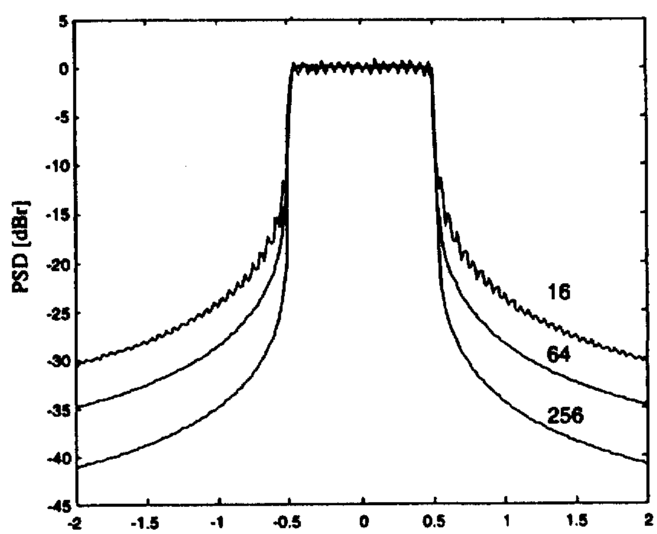

Figure 1: spectrum of OFDM symbol with using different FFT sizes

Figure 1 illustrates the decay of the OFDM symbol when using different sizes of FFT.

4 Modulation scheme

Both up stream and down stream shall use OFDMA modulation technique [2]. OFDMA concept is based on the division of the usable carrier into small groups, each contains several carriers, and called Sub-Channel. Figure 2 describes such a scheme:

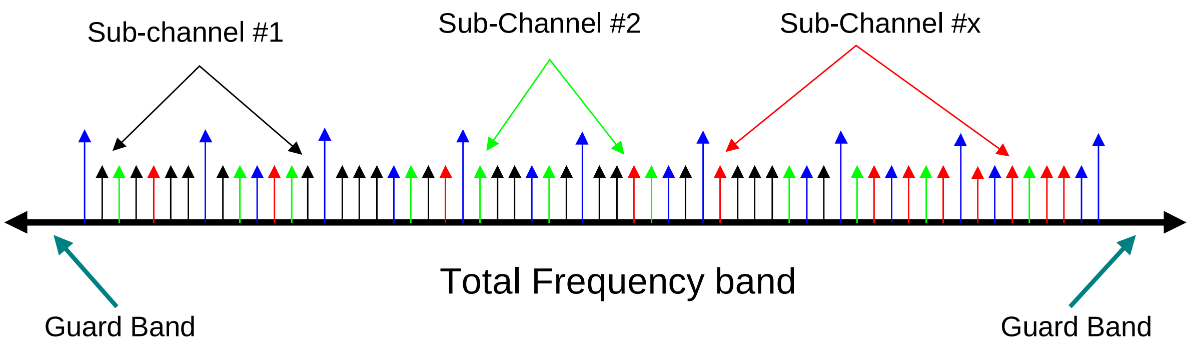

Figure 2: an OFDMA symbol structure

From Figure 2 we can see that the symbol in frequency is build from carriers which are zeroed, these regions are called Guard Bands, the purpose of the guard bands are to enable the signal to naturally decay and create the FFT "brick Wall" shaping. This partitioning also gives several powerful added value, 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

5 Basic Sub-Channel structure

In order to use several FFT sizes but remain in the same block size (of data transmission) we shall define a basic structure of a Sub-Channel.

- One Sub-Channel is made of 48 usable carriers.

The 64-point FFT is made up of one Sub-Channel, which contains all the usable carriers (and is back compatible to the IEEE 802.11a, HiperLAN2 PHY).
The 2048, 1024, 256 point FFT contains 32, 16, 4 Sub-Channels respectively (aggregating the Sub-Channels carriers gives all the usable carriers for a specific FFT size).

5.1 Sub-Channel allocation

The carriers constituting the Sub-Channels are spread over the Used Carrier space by using spatial permutation. Depending on the transmission mode, one OFDM symbol is made of 2048 carriers (2K mode), 1024 carriers (1K mode), 256 carriers (256 mode) or 64 carriers (64 mode). The different modes offer:

- 2K mode - 1701 usable carriers numbered 0 to 1701 for the Down Stream (DS)
  1696 usable carriers numbered 0 to 1696 for the Up Stream (US)
- 1K mode - 849 usable carriers numbered 0 to 849 for the DS
  848 usable carriers numbered 0 to 848 for the US
- 256 mode - 212 usable carriers numbered 0 to 212 for the DS and US
- 64 mode - 53 usable carriers numbered 0 to 53 for the DS and US

For all the modes the DC carrier is always not used.
One Sub-Channel contains 48 data carriers, furthermore the US in the 2k, 1k modes and for the 64 and 256 modes the Sub-Channel is build from 53 carriers which include 5 pilot carriers (the 64 mode is unique in this sense, to fit to the IEEE802.11a without any change, a carrier pilot for this mode is ignored because it falls on the dc carrier).

The unused carriers, located on each edges of the channel, provide a guard band.
This organization of the OFDM symbol is depicted in the Figure 3:

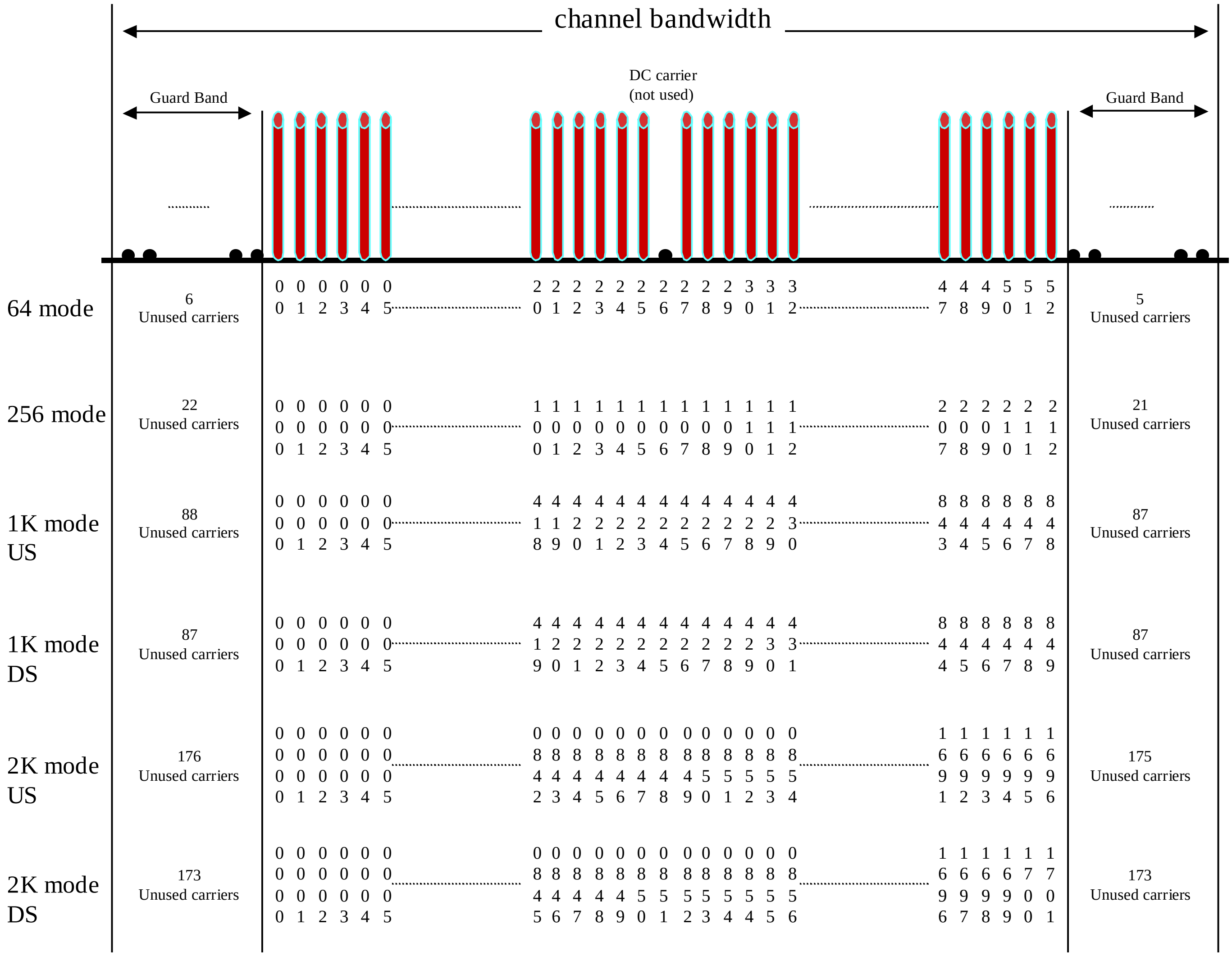

Figure 3: organization of the OFDM symbol for different FFT sizes

5.1.1 2K mode Structure

The 2k mode DS and US are build up on two concepts:

- DS – OFDMA used in a structure much like the DVB-T, where pilots build the basic structure and then the Sub-Channels complete the data carriers
- US – OFDMA used in a structure where the Sub-Channels set the pilots and data carriers.

5.1.1.1 2k mode DS characterization

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

- Number of FFT points = 2048 (2K)
- Overall Usable Carriers = 1701
- Guard Bands = 173 carriers on both sides of the spectrum
- Number of Sub-Channels = 32
- Number of data carriers per Sub-Channel = 48
- Pilots structure = Continues and variable location pilots

First allocating the pilots and then mapping the rest of the carriers to Sub-Channels construct the OFDM 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

In every frame there are 32 continues pilots which are spread all over the usable spectrum.
The variable pilots are inserted in the locations defined by the next formula:

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

$k \in 0..1700$ and denotes the carrier number
$L \in 0..3$ and denotes the symbol number with a cyclic period of 4
$P_v \geq 0$ is an integer number
The pilot location is illustrated in Figure 4:

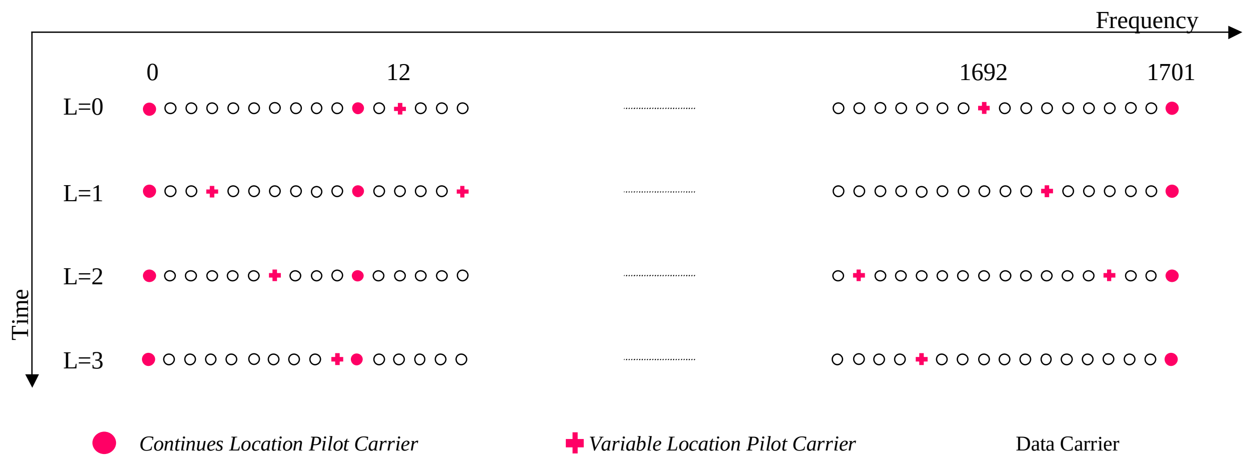

Figure 4: pilots and data carrier location for the DS 2k mode

After mapping the pilots, there are still 1536 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 construct the Sub-Channels we group the 1536 remaining carriers into one logical group. We split this group into 48 smaller groups, called basic groups, which are made of 32 data carriers each. Figure 5 illustrates this principle.

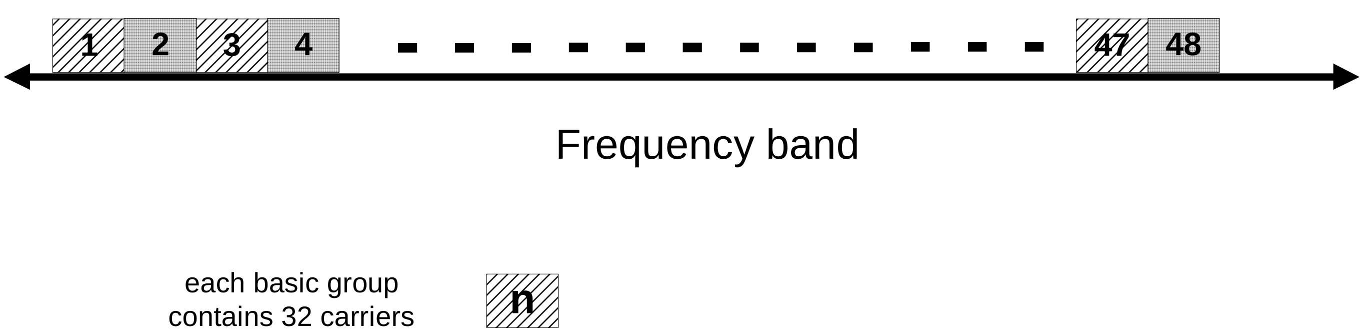

Figure 5: division of the data carriers into basic groups for the DS 2k mode

The allocation of carriers to Sub-Channels are done by special permutation code which is based upon the following procedure:

1. The basic series of 32 numbers is 3, 18, 2, 8, 16, 10, 11, 15, 26, 22, 6, 9, 27, 20, 25, 1, 29, 7, 21, 5, 28, 31, 23, 17, 4, 24, 0, 13, 12, 19, 14, 30
2. In order to get 32 different permutations 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: 18, 2, 8, 16, 10, 11, 15, 26, 22, 6, 9, 27, 20, 25, 1, 29, 7, 21, 5, 28, 31, 23, 17, 4, 24, 0, 13, 12, 19, 14, 30, 3
3. To get a 48 length series we concatenate the permutated series 2 times (to get a 64 length series) and take the first 48 numbers only, the concatenation depends on the cell Id (which characterizes the working cell and can range from 0 to 31), the concatenated series is archived by the next formula: (PermutatedSeries + CellId) mod 32; (PermutatedSeries + 2*CellId) mod 32

   for example when using permutation 1 with CellId=2 we get the next concatenated series:
   20, 4, 10, 18, 12, 13, 17, 28, 24, 8, 11, 29, 22, 27, 3, 31, 9, 23, 7, 30, 1, 25, 19, 6, 26, 2, 15, 14, 21, 16, 0, 5, 22, 6, 12, 20, 14, 15, 19, 30, 26, 10, 13, 31, 24, 29, 5, 1, 11, 25, 9, 0, 3, 27, 21, 8, 28, 4, 17, 16, 23, 18, 2, 7

   therefore the 48 length series is:
   20, 4, 10, 18, 12, 13, 17, 28, 24, 8, 11, 29, 22, 27, 3, 31, 9, 23, 7, 30, 1, 25, 19, 6, 26, 2, 15, 14, 21, 16, 0, 5, 22, 6, 12, 20, 14, 15, 19, 30, 26, 10, 13, 31, 24, 29, 5, 1
4. 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:

5. $$Carrier\# = 32 * n + Index(n)$$

   where:
   $Carrier\#$ - denotes the carrier number for this Sub-Channel
   n - Index 0..47
   $Index(n)$ - denotes the number at index n of the 48 length series

Using this procedure for the current CellId we can get 32 carrier sets (for all permutations possible), those defining the Down Stream Sub-Channels

5.1.1.2 2k mode US characterization

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
- Number of carriers per Sub-Channel = 53

In order to construct the whole US OFDM symbol, the entire Used Carrier space shall be divided into 53 groups, called basic groups and made of 32 usable carriers each. Figure 6 illustrates this principle.

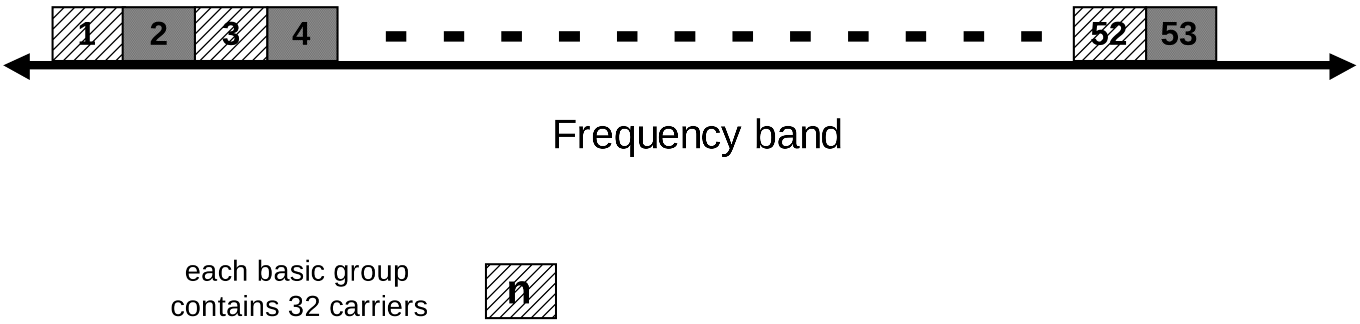

Figure 6: division of all carriers into basic groups for the US 2k mode

The allocation of carriers to Sub-Channels are done by special permutation code which is based upon the following procedure:

6. The basic series of 32 numbers is 3, 18, 2, 8, 16, 10, 11, 15, 26, 22, 6, 9, 27, 20, 25, 1, 29, 7, 21, 5, 28, 31, 23, 17, 4, 24, 0, 13, 12, 19, 14, 30
7. In order to get 32 different permutations 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: 18, 2, 8, 16, 10, 11, 15, 26, 22, 6, 9, 27, 20, 25, 1, 29, 7, 21, 5, 28, 31, 23, 17, 4, 24, 0, 13, 12, 19, 14, 30, 3
8. To get a 53 length series we concatenate the permutated series 2 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 31), the concatenated series is archived by the next formula: (PermutatedSeries + CellId) mod 32; (PermutatedSeries + 2*CellId) mod 32

   for example when using permutation 1 with CellId=2 we get the next concatenated series:
   20, 4, 10, 18, 12, 13, 17, 28, 24, 8, 11, 29, 22, 27, 3, 31, 9, 23, 7, 30, 1, 25, 19, 6, 26, 2, 15, 14, 21, 16, 0, 5, 22, 6, 12, 20, 14, 15, 19, 30, 26, 10, 13, 31, 24, 29, 5, 1, 11, 25, 9, 0, 3, 27, 21, 8, 28, 4, 17, 16, 23, 18, 2, 7

   therefore the 53 length series is:
   20, 4, 10, 18, 12, 13, 17, 28, 24, 8, 11, 29, 22, 27, 3, 31, 9, 23, 7, 30, 1, 25, 19, 6, 26, 2, 15, 14, 21, 16, 0, 5, 22, 6, 12, 20, 14, 15, 19, 30, 26, 10, 13, 31, 24, 29, 5, 1, 11, 25, 9, 0, 3
9. 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 53 carriers of the current permutation in the cell:

   10. $Carrier\# = 32 * n + Index(n)$

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

Using this procedure for the current CellId we can get 32 carrier sets (for all permutations possible), those defining the US Sub-Channels

5.1.2 1K mode Structure

The 2k mode DS and US are build up on two concepts:

- DS – OFDMA used in a structure much like the DVB-T, where pilots build the basic structure and then the Sub-Channels complete the data carriers
- US – OFDMA used in a structure where the Sub-Channels set the pilots and data carriers.

5.1.2.1 1K mode DS characterization

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

- Number of FFT points = 2048 (2K)
- Overall Usable Carriers = 849
- Guard Bands = 87 carriers on both sides of the spectrum
- Number of Sub-Channels = 16
- Number of data carriers per Sub-Channel = 48
- Pilots structure = Continues and variable location pilots

First allocating the pilots and then mapping the rest of the carriers to Sub-Channels construct the OFDM 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

In every frame there are 16 continues pilots which are spread all over the usable spectrum.
The variable pilots are inserted in the locations defined by the next formula:

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

$k \in 0..849$ and denotes the carrier number
$L \in 0..3$ and denotes the symbol number with a cyclic period of 4
$P_v \geq 0$ is an integer number
The pilot location is illustrated in the next figure:

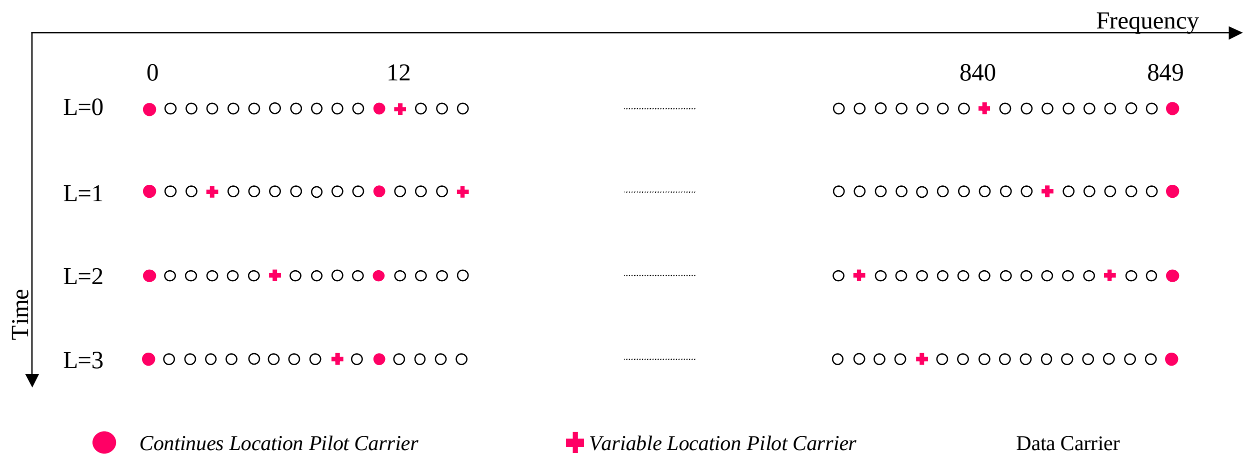

Figure 7: pilots and data carrier location for the DS 1k mode

After mapping the pilots, there are still 768 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 construct the Sub-Channels we group the 768 remaining carriers into one logical group. We split this group into 48 smaller groups, called basic groups, which are made of 16 data carriers each. Figure 8 illustrates this principle.

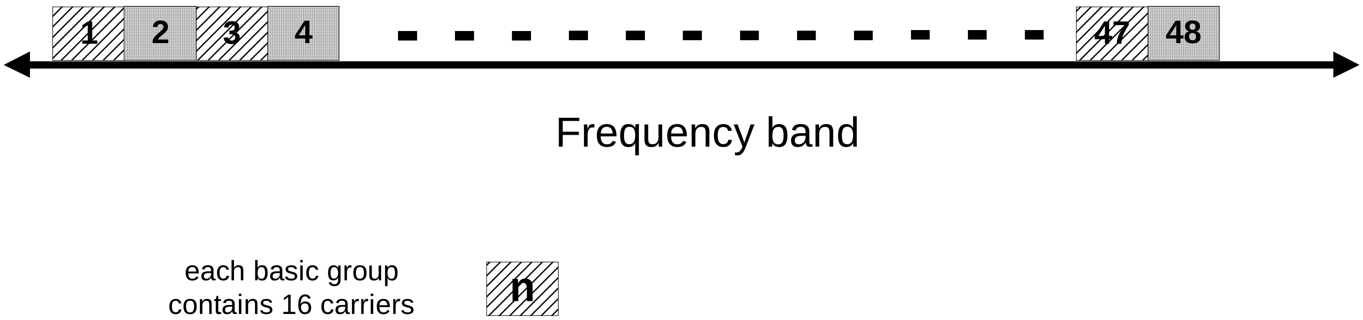

Figure 8: division of the data carriers into basic groups for the DS 1k mode

The allocation of carriers to Sub-Channels are done by special permutation code which is based upon the following procedure:

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 48 length series we concatenate the permutated series 5 times (to get a 64 length series) and take the first 48 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 48 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
4. 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:

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

   where:
   $Carrier\#$ - denotes the carrier number for this Sub-Channel
   n - Index 0..47
   $Index(n)$ - denotes the number at index n of the 48 length series

Using this procedure for the current CellId we can get 16 carrier sets (for all permutations possible), those defining the Down Stream Sub-Channels

5.1.2.2 1k mode US characterization

The parameters characterizing the 1K mode are as follow:

- Number of FFT points = 1024 (1K)
- Overall Usable Carriers = 848
- Guard Bands = 88, 87 carriers on right an left side of the spectrum
- Number of Sub-Channels = 16
- Number of carriers per Sub-Channel = 53

In order to construct the whole US OFDM symbol, the entire Used Carrier space shall be divided into 53 groups, called basic groups and made of 16 usable carriers each. Figure 9 illustrates this principle.

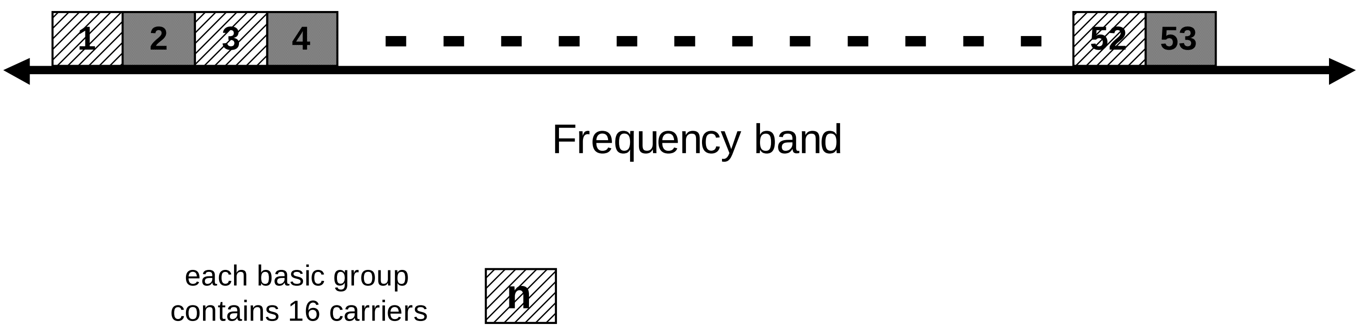

Figure 9: division of all carriers into basic groups for the US 1k mode

The allocation of carriers to Sub-Channels are done by special permutation code which is based upon the following procedure:

5. The basic series of 16 numbers is 6, 14, 2, 3, 10, 8, 11, 15, 9, 1, 13, 12, 5, 7, 4, 0
6. 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
7. 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
8. 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 53 carriers of the current permutation in the cell:

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

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

Using this procedure for the current CellId we can get 16 carrier sets (for all permutations possible), those defining the US Sub-Channels.

5.1.3 256 mode Structure

The parameters characterizing the 256 mode are as follow:
- Number of FFT points = 256
- Overall Usable Carriers = 212
- Guard Bands = 22, 21 carriers on right an left side of the spectrum
- Number of Sub-Channels = 4
- Number of carriers per Sub-Channel = 53

In order to construct the whole OFDM symbol, the entire Used Carrier space shall be divided into 53 groups, called basic groups and made of 16 usable carriers each. Figure 10 illustrates this principle.

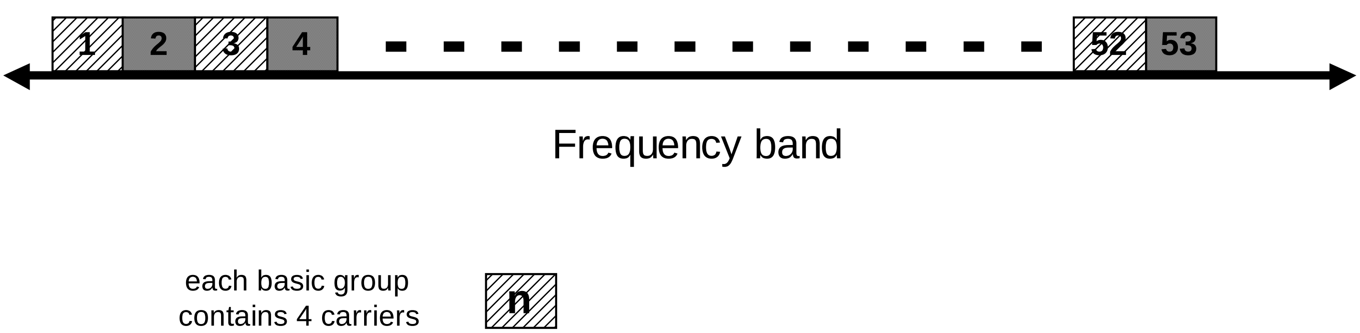

Figure 10: division of all carriers into basic groups for the 256 mode

The allocation of carriers to Sub-Channels are done by special permutation code which is based upon the following procedure:
1. The basic series of 4 numbers is 3, 1, 0, 2
2. In order to get 4 different permutation the series is rotated to the left (from no rotation at all up to 3 rotations), for the first permutation we get the following series: 1, 0, 2, 3
3. To get a 53 length series we concatenate the permutated series 14 times (to get a 56 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 3) , the concatenated series is achieved by the next formula:

   (PermutatedSeries + CellId) mod 4; (PermutatedSeries + 2*CellId) mod 4; (PermutatedSeries + 3*CellId) mod 4; (PermutatedSeries + 4*CellId) mod 4; … ; (PermutatedSeries + 13*CellId) mod 4;

   for example when using permutation 1 with CellId=2 we get the next concatenated series:

3, 2, 0, 1, 1, 0, 2, 3, 3, 2, 0, 1, 1, 0, 2, 3, 3, 2, 0, 1, 1, 0, 2, 3, 3, 2, 0, 1, 1, 0, 2, 3, 3, 2, 0, 1, 1, 0, 2, 3, 3, 2, 0, 1, 1, 0, 2, 3, 3, 2, 0, 1, 1, 0, 2, 3,

therefore the 53 length series is:
3, 2, 0, 1, 1, 0, 2, 3, 3, 2, 0, 1, 1, 0, 2, 3, 3, 2, 0, 1, 1, 0, 2, 3, 3, 2, 0, 1, 1, 0, 2, 3, 3, 2, 0, 1, 1, 0, 2, 3, 3, 2, 0, 1, 1, 0, 2, 3, 3, 2, 0, 1, 1

4. 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 53 carriers of the current permutation in the cell:

$$Carrier\# = 4 * n + Index(n)$$

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

Using this procedure for the current CellId we can get 16 carrier sets (for all permutations possible), those defining the Sub-Channels.

5.1.4 64 mode Structure

The parameters characterizing the 64 mode are as follow:

- Number of FFT points = 64
- Overall Usable Carriers = 52
- Guard Bands = 6,5 carriers on right an left side of the spectrum
- Number of Sub-Channels = 1
- Number of carriers per Sub-Channel = 53

In order to be aligned to IEEE802.11a but keep the same structural behavior described in the last section, the Sub-Channel length is kept the same, but the dc carrier is always ignored and zeroed therefore the overall usable carries is only 52 (as IEEE802.11a).

5.2 Using the Sub-Channels

The Sub-Channels are used for several major functions:

- Data transmission (including any preamble and postamble) for the US and DS
- Power and Time (Synchronization) Ranging with possibility for fast bandwidth request on the US

5.2.1 Using the Sub-Channels for Data Transmission

The data transmission for DS and US for all the modes is based on transmitting data on the 48 data carriers of each Sub-Channel. Due to the different structure and basic concept between the DS for the 1k, 2k modes and the rest of the DS, US modes, we shall elaborate how data transmission is performed for each relevant mode.

The Sub-Channels are also used for frequency, time and power ranging as well as for fast bandwidth request.

5.2.1.1 DS Data Transmission for 1k, 2k modes

When data is transmitted in the DS for the 1k, 2k modes, the structure of the OFDM symbol is set by the procedure explained in 5.1.1.15.1.2.1). The Sub-Channels defined contain only data carriers and the mapping of data onto the Sub-channel is straightforward.

The MAC sets the number of Sub-Channels allocated to the users for the FDD-B mode (defined in the TG1 MAC) in the DS mapping. If all Sub-Channels are allocated in a broadcasting manner then the FDD-C mode (defined in the TG1 MAC) is used. Both allocations could be used also in the TDD, and H-FDD modes.

5.2.1.2 DS Data Transmission for 64, 256 modes and US Data transmission for all modes

When this kind of data OFDM symbol is to be transmitted, it shall follow the well-known scheme of the IEEE 802.11a. This scheme is comprised from two kinds of carriers:

- Data carriers - which are used for data transmission
- Pilot carriers – which are used for estimation purpose

The following figure describes the basic Sub-Channel structure:

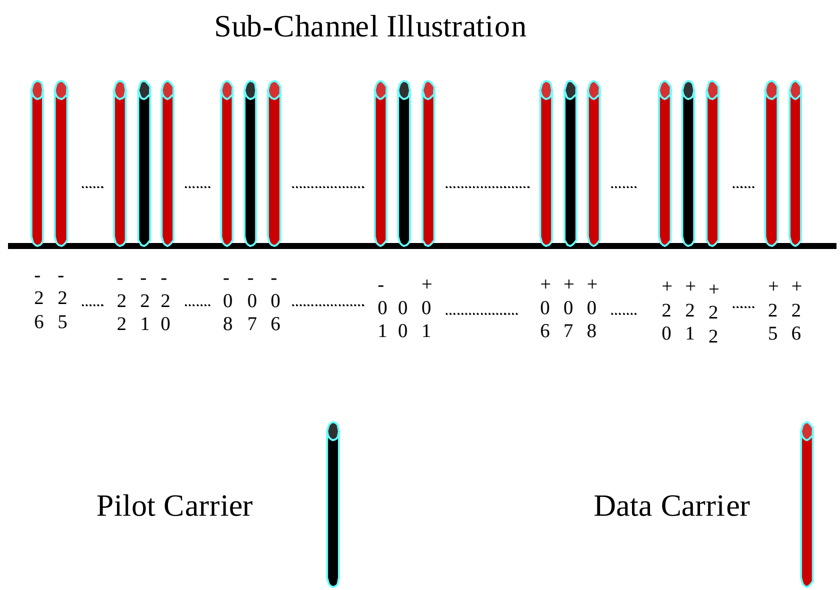

Figure 11: basic allocation of data and pilot carriers for a US Sub-Channel

Figure 11 describes the basic allocation of data and pilot carriers for a US Sub-Channel, it should be mentioned that for the 64 carrier mode the 0 located pilot (dc carrier) is always zeroed, so it is completely compliant to the IEEE802.11a.

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

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 carriers. The code is always BPSK modulated and is produced by the PRBS described in Figure 12 (the PRBS polynomial generator shall be $1+X^4+X^7+X^{15}$):

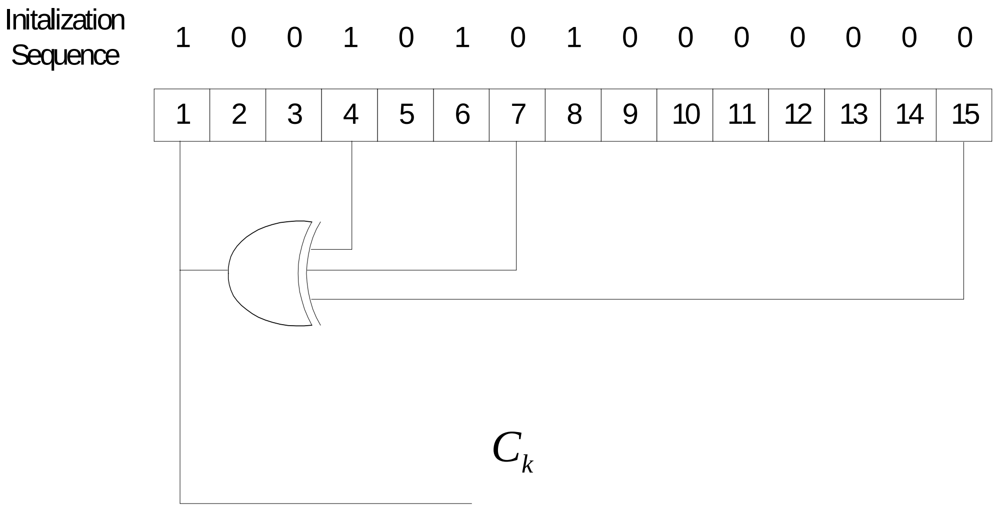

Figure 12: PRBS for ranging code production

Circulating through the PRBS, each circulation produces one bit, produces the Ranging codes. The length of the ranging codes are 53 (for 1K, 64 modes) and 106 (for 2k, 256 modes) bits long, the codes produced are used for the next purposes:

- The first 16 (2k, 256 modes) or 8 (1k,64) codes produced are for First Ranging, it shall be used by a new user entering the system.
- The next 16 (2k, 256 modes) or 8 (1k,64) codes produced are used for maintenance Ranging for users that are already entered the system.
- The last 16 (2k, 256 modes) or 8 (1k,64) codes produced are for users, already connected to the system, issuing bandwidth requests.

These 48 (2k, 256 modes) or 24 (1k,64) codes are denoted as Ranging Codes and are numbered 0..47 (2k, 256 modes) or 0..23 (1k,64).
The Ranging Codes are used on the concatenation of 2 Sub-Channels (2k, 256 modes) or a single Sub-Channel (1k, 64 modes)

6 Interleaving

Two interleaving procedures will be used in the system. One involves the data interleaving as it enters the system (called also Data randomization) and the second involves bit interleaving after the encoding procedure.

6.1 Data Randomization

Data randomization is performed on data transmitted on the DS and US. The randomization is performed on each Sub-Channel allocation (DS or US), that 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.

The shift-register of the randomizer shall be initialized for each new allocation on the following operation modes:

- US all modes
- DS TDD for all modes
- DS FDD-B for all modes

For the DS FDD-C of transmission the randomizer shall be initialized for a predefined data block.

The randomizer shall be initialized with the binary value: 100101010000000 (45200 in octal). Each data byte to be transmitted shall enter sequentially into the randomizer, MSB first.
The Pseudo Random Binary Sequence (PRBS) generator shall be $1+X^{14}+X^{15}$.

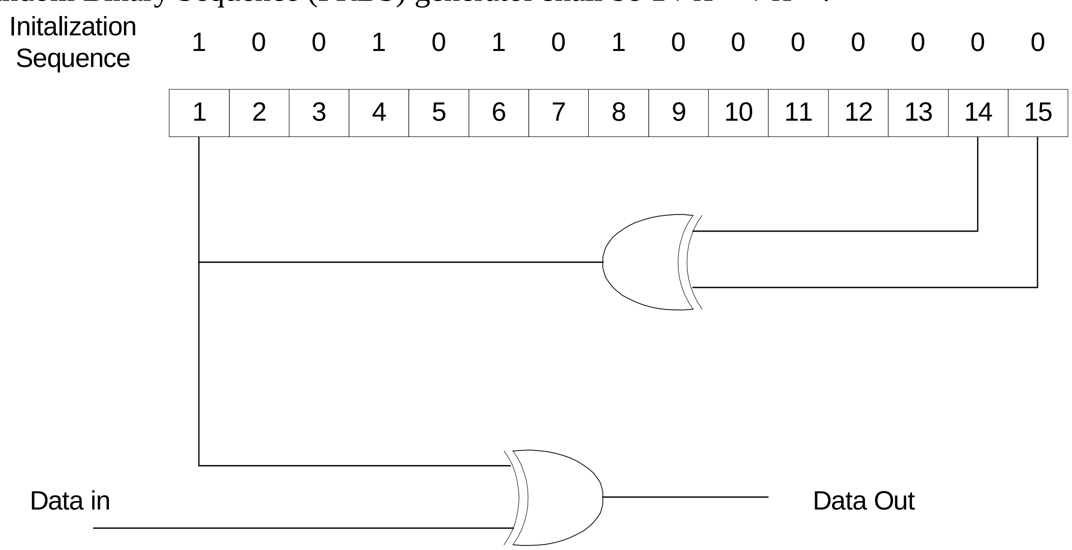

Figure 13: PRBS for data randomization

The bit issued from the randomizer shall be applied to the encoder.

6.2 Bit Interleaving

Before mapping the encoded data on the allocated Sub-Channels, it shall be interleaved in order to spread errors on interfered carriers.

7 Adaptive Modulation

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 (Sub-Channels on the frequency domain and OFDM symbols on the time domain) to best fit the modulation for a specific user/users.

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.

7.1 Data Modulation

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

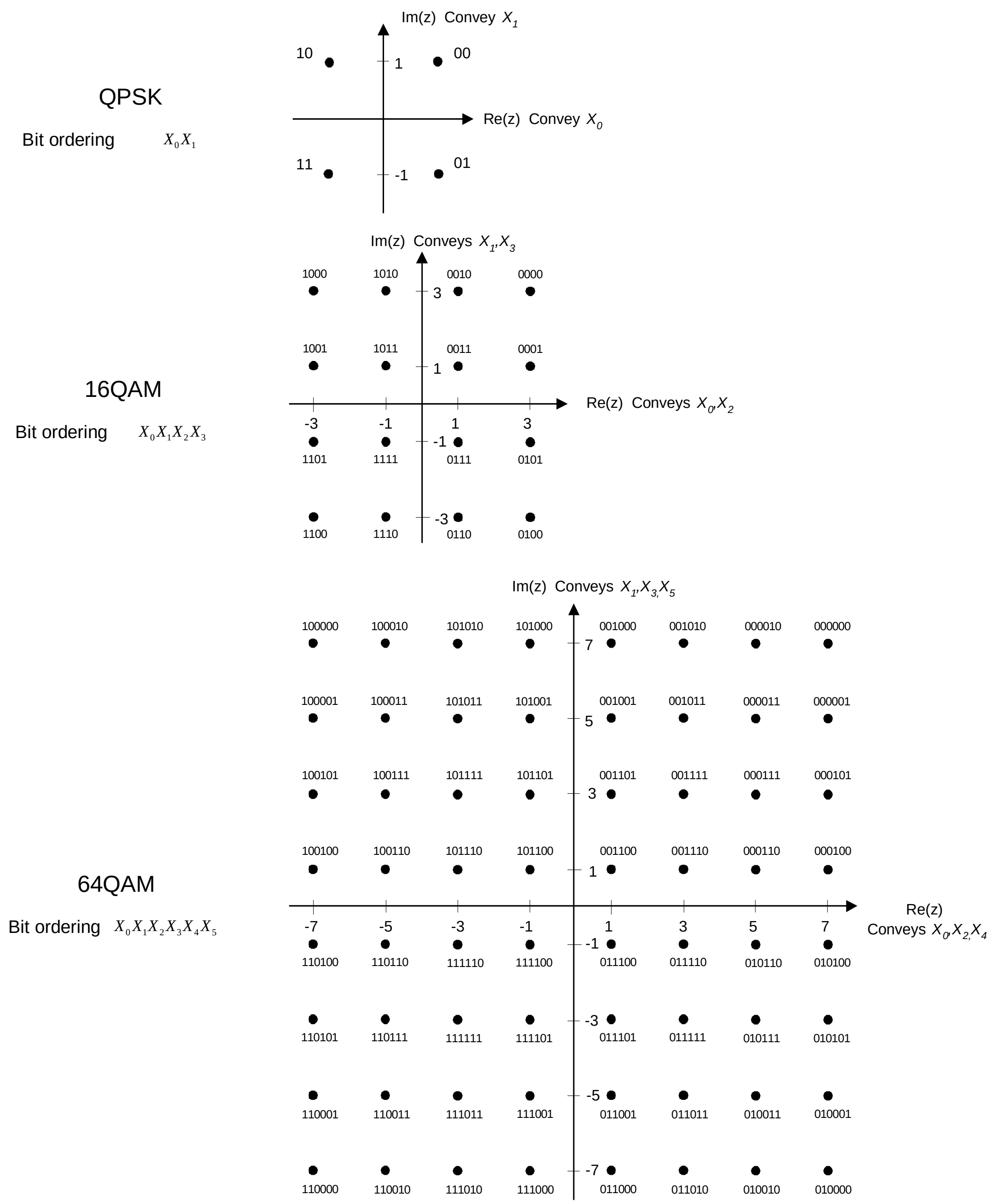

Figure 14: QPSK, 16QAM and 64 QAM constellations

In order to keep the energy of the constellation constant ($E[c \times c^*] = 1$), the complex number *z* shall be normalized to the value *c*, before mapping onto the carriers, by using the factor defined in the next table:

Modulation scheme	Normalization Factor
QPSK	$c = z/\sqrt{2}$
16QAM	$c = z/\sqrt{10}$
64QAM	$c = z/\sqrt{42}$

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.

7.2 Pilot Modulation

Pilot carriers shall be inserted into each data burst in order to constitute the Burst Structure (see clause 5) and they shall be modulated according to their carrier location within the OFDM symbol.
The Pseudo Random Binary Sequence (PRBS) generator depicted hereafter, shall be used to produce a sequence, w_k. The polynomial for the PRBS generator shall be $X^{11} + X^2 + 1$.

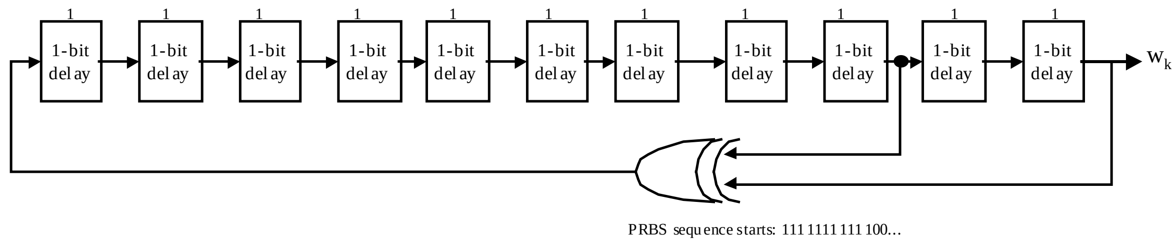

Figure 15: PRBS used for pilot modulation

The value of the pilot modulation, on carrier k, shall be derived from w_k.
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:

$$\mathrm{Re}\{C_k\} = 4 / 3 \times 2 (½ - w_k)$$
$$\mathrm{Im}\{C_k\} = 0$$

7.3 Ranging Pilot Modulation

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

$$\mathrm{Re}\{C_k\} = 2 (½ - w_k)$$
$$\mathrm{Im}\{C_k\} = 0$$

C_k is derived in clause 5.2.2.

8 Adaptive Coding

The ECC code should handle besides the regular AWGN environment, more difficult channels therefore the following ECC would be used:

1. Concatenated RS(255,239,8) and convolutional coding (k=7, G1=171, G2=133) including a convolutional interleaver if needed
2. Block Turbo Codes (the same BTC as for TG1)
3. Convolutional Turbo Codes (new scheme from France Telecom suggested for TG1, BRAN HA, DVB-RCT and DVB-RCS)

All of the option will enable vast flexibility. The new Turbo schemes can improve 2-3dB when testing under AWGN, and much more when used and designed for burst noise. The coding rates that are supported are ½, 2/3 and ¾, the actual parameter that is in relevant to the Turbo schemes are the block lengths. It should be mentioned that the longer the block size the performance advantage of the Turbo schemes over the more classical scheme increases.

9 Time and Power Ranging of the users

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.

10 Multiple Access Schemes

The following description refers to the down stream and up stream access methods.

There are two basic approaches when using the OFDMA concept:

1. The first, where several OFDM symbols are used for data transmission (all Sub-Channels in the OFDM symbol are used for data only) and other OFDM symbols are used for synchronization (all Sub-Channels in the OFDM symbol are used for ranging only).

   Figure 16 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

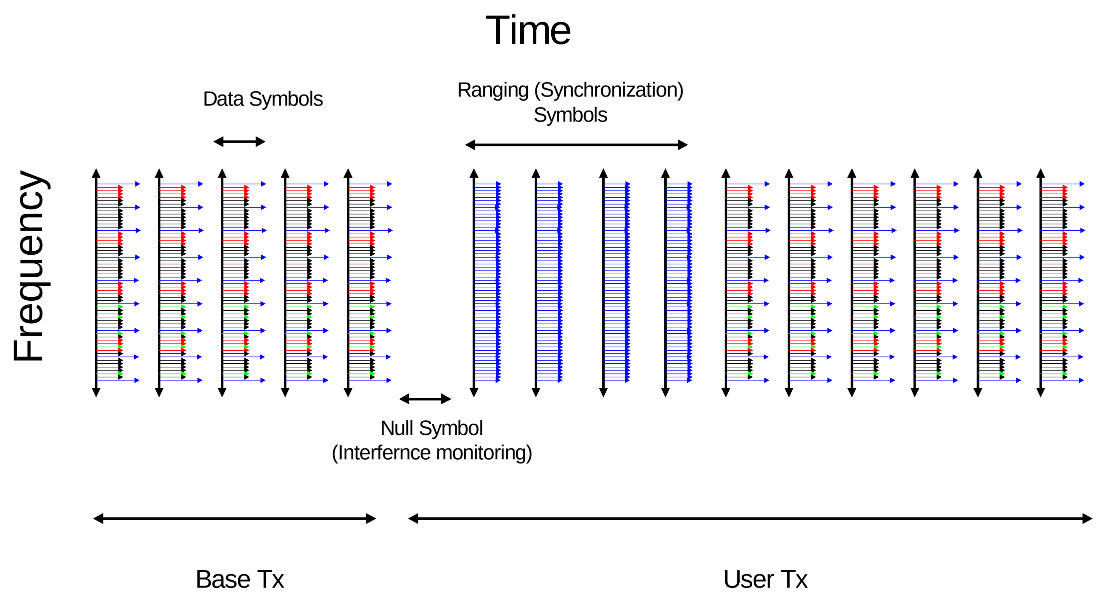

Figure 16: Conceptual First Multiple Access Method

2. The second uses all OFDM symbols to transmit both data and ranging signals (some Sub-Channels are used for data transmission and the other are used for ranging transmission), the number of symbols allocated to up stream and down stream are adaptable.
   Figure 17 illustrates this structure:

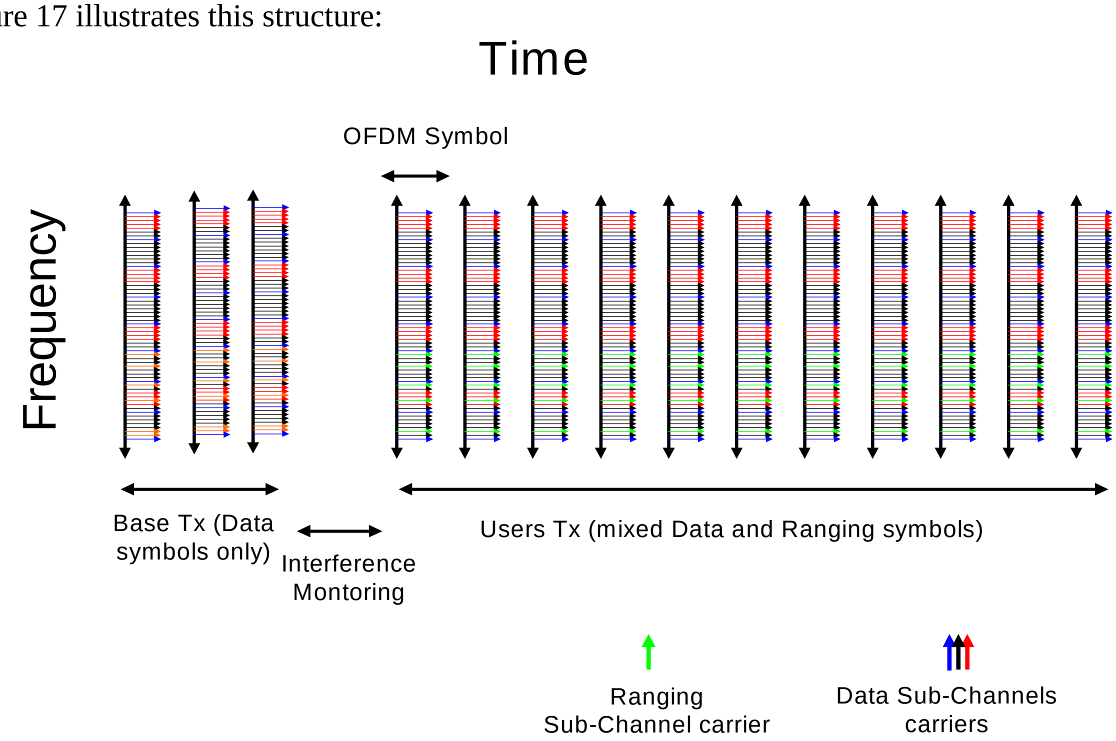

Figure 17: Conceptual second Multiple Access Method

10.1 DS Access (All modes)

The DS uses the first method of access described, but it uses only data symbols for the transmission. The DS shall use the following structure for the transmission (each symbol represents the actual useful symbol time and the Guard Interval time).

There are several estimation mechanisms, which can be used, in order to estimate the DS:

1. Allocating a full symbol of pilots (all Sub-Channels are transmitted with pilots)
2. Allocating some Sub-Channels to pilots and the rest for data transmission
3. Combination of the previous two
4. 2k, 1k mode could be based on the continues and variable location pilots only

These methods are illustrated in Figure 18:

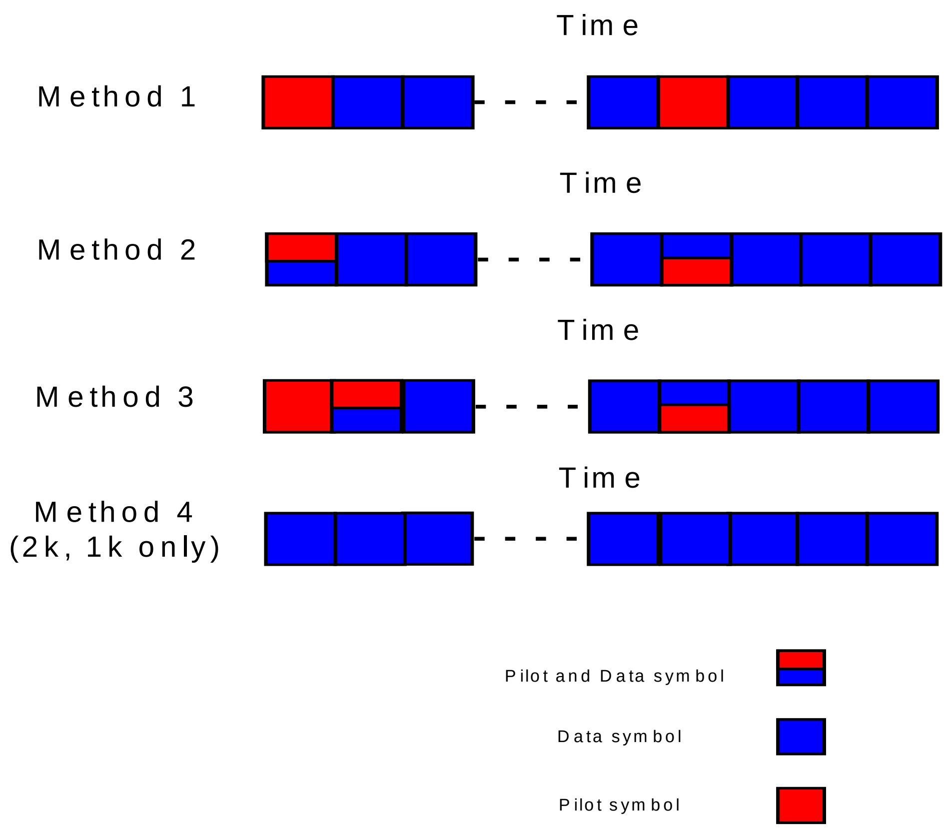

Figure 18: Several DS framing structures

The down stream can use the Sub-Channels for TDM or TDMA access.

- When using TDM access, the data is transmitted as a continues stream over all the Sub-Channels.
- When using TDMA access, each Sub-Channel for a certain period of time could be transmitted to a specific user/users. Each Sub-Channel is characterized by it's own modulation and coding scheme, for the specified time period. The Sub-Channels power can also be controlled digitally in order to

achieve the outmost power efficiency for the system (using less power on Sub-Channels, which have good SNR at the receiving user).

The system in this way can perfectly fit the TG1 MAC.

10.1.1 DS Space Time Block Coding

Space-Time Coding can be used for the DS transmission. The usage can differ between the different modes due to their inherent structure.

10.1.1.1 Using Space Time Block Coding for the 2k, 1k modes

Figure 19describes the utilization of the OFDM frame structure in order to use the Space-Time Coding technique. As we can notice, by controlling the pilot transmission from one symbol to the other we can gain the state channel information needed in order to decode the coding at the user side.

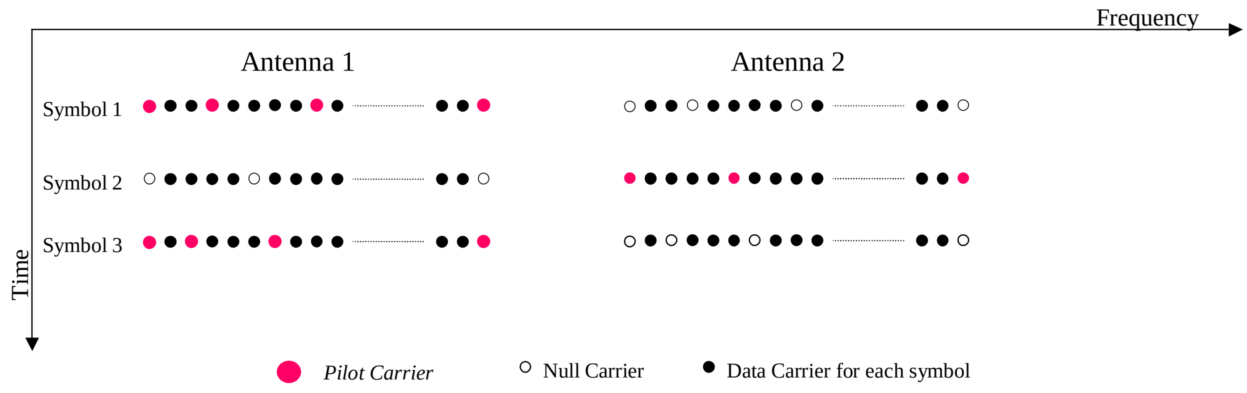

Figure 19: Space-Time Block coding scheme for the 2k, 1k modes

10.1.1.2 Using Space Time Block Coding for the 256, 64 modes

Figure 20describes the utilization of the OFDM frame structure in order to use the Space-Time Coding technique. In this scheme we first transmit all pilots and then start the transmission of data frames, which is coherent to the DS access mode for these modes (section 10.1):

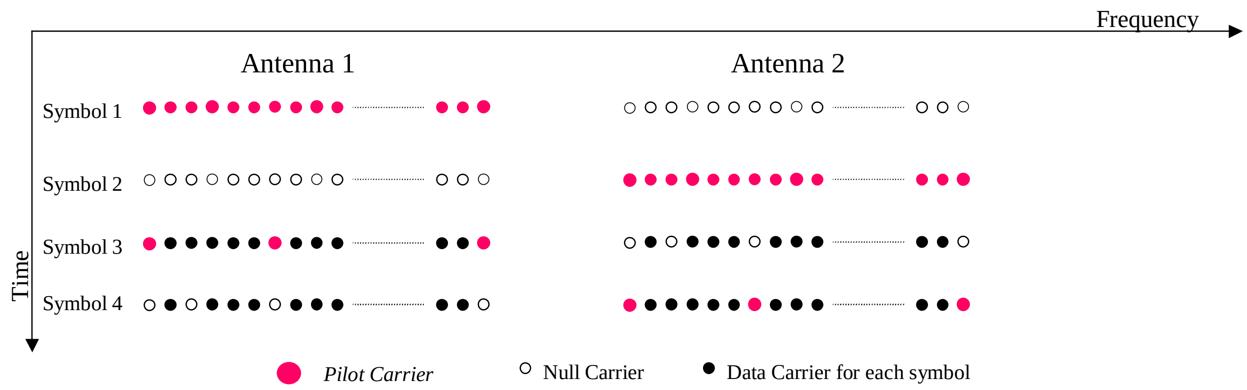

Figure 20: Space-Time Block coding scheme for the 256, 64 modes

10.1.1.3 Space Time Coding using trellis modulation

Another option for using the Space-Time Coding is by using the encoded data with a trellis scheme, helping the demodulator to use

10.2 US Multiple Access Schemes

There are two Multiple Access Schemes used in the up stream, Multiple Access Scheme 1 is used in 1k, 2k modes and Multiple Access Scheme 2 is used in 256, 64 modes.

10.2.1 US Multiple Access Scheme 1

This Multiple Access Scheme is used for the 1k, 2k modes. For these access modes the up stream symbols are used for the transmission of both data and ranging signals. For the 2k mode 2 Sub-Channels (concatenated) are used for Ranging and 30 are used for Data transmission. For the 1k mode 1 Sub-Channel is used for Ranging and 15 are used for Data transmission.

The MAC maps the up stream Data Sub-Channel in time to different users, each user can use on his Sub-Channels a specific modulation and coding. This allocation method is illustrated in Figure 21:

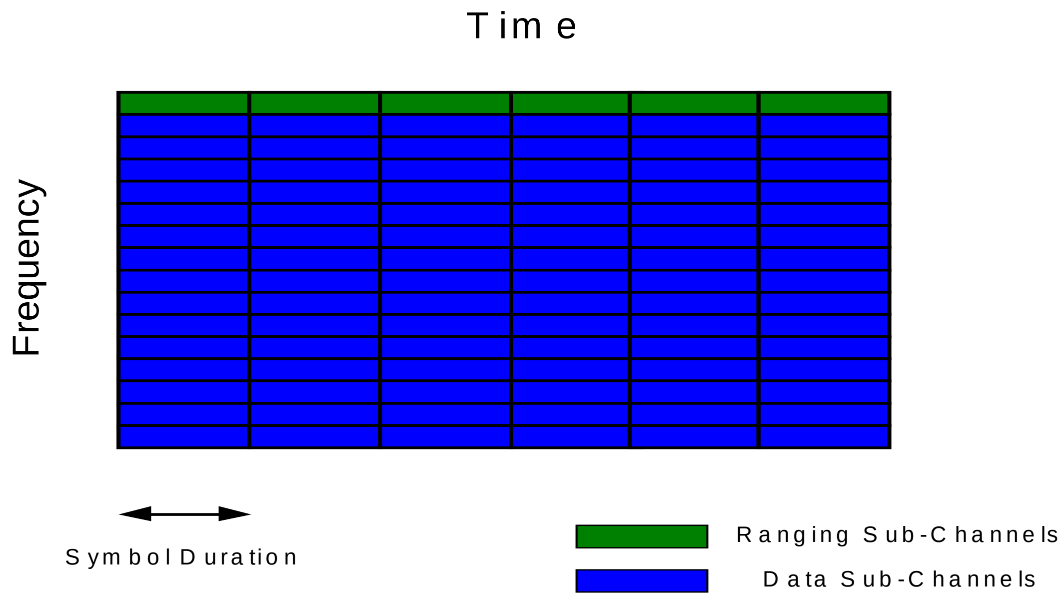

Figure 21: US Multiple Access Scheme 1

The users could use the same Data transmission patterns defined for the down stream (which are described in 10.1) and consists the following methods:

1. Allocating a full symbol of pilots (on the user specified Sub-Channels pilots are transmitted)
2. Allocating some Sub-Channels to pilots and the rest for data transmission (if the user is allocated more then one Sub-Channel)
3. Combination of the previous two

10.2.2 US Multiple Access Scheme 2

This Multiple Access Scheme is used for the 256, 64 modes. For these access modes the up stream symbols are used for Data transmission some of the time and ranging transmission for the rest. The Sub-Channels could be allocated in time to different users when Data OFDM symbols are transmitted.

The MAC maps the up stream Data Sub-Channel in time to different users, each user can use on his Sub-Channels a specific modulation and coding. This allocation method is illustrated in Figure 22:

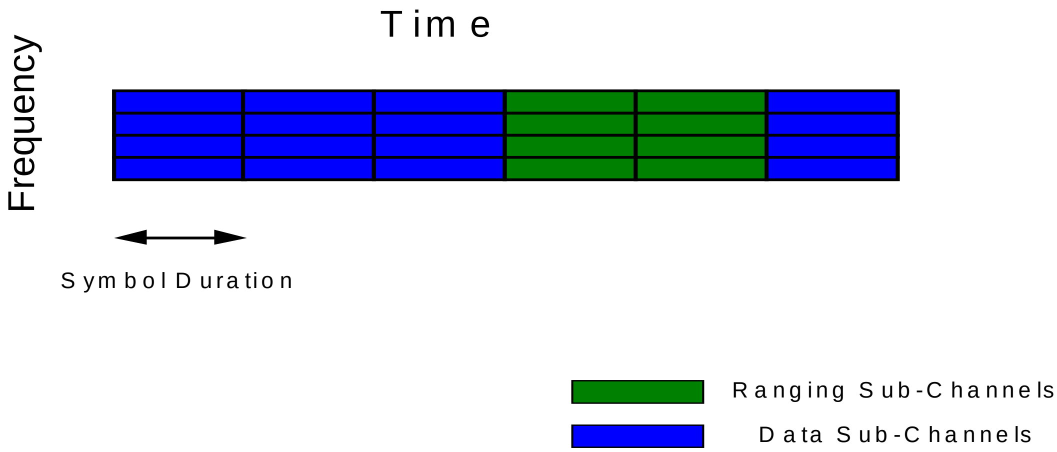

Figure 22: US Multiple Access Scheme 2

The users could use the same Data transmission patterns defined for the down stream (which are described in 10.1) and consists the following methods:

1. Allocating a full symbol of pilots (on the user specified Sub-Channels pilots are transmitted, must for the 64 mode)
2. Allocating some Sub-Channels to pilots and the rest for data transmission (if the user is allocated more then one Sub-Channel and only in the 256 mode)
3. Combination of the previous two (if the user is allocated more then one Sub-Channel and only in the 256 mode)

11 Down Stream Block Diagram

Figure 23 represents an example for a full Base station block diagram; this scheme represents all process of the Base Band:

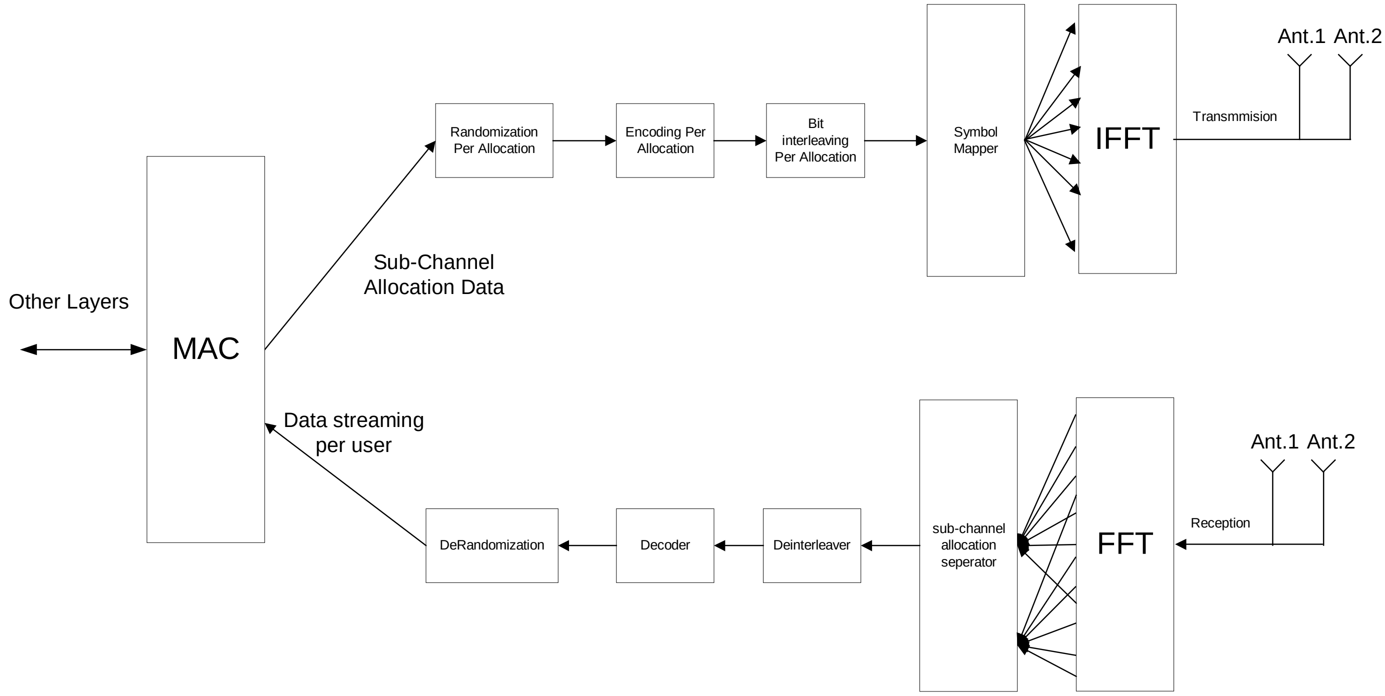

Figure 23: DS Conceptual Block Diagram

In this diagram we can see that user's Data is extracted at the Base Station and transferred by a convergence layer to the MAC for the US, while for the DS the data is handled per allocation.

12 Up Stream Block Diagram

Figure 24 represents an example for a user block diagram; this scheme represents all process of the Base Band:

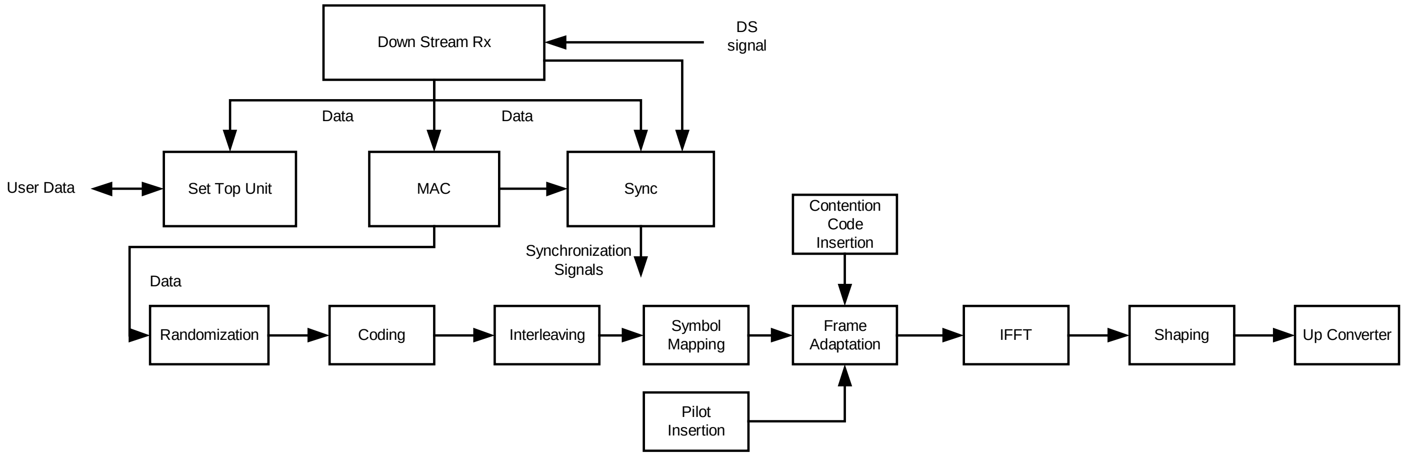

Figure 24: US Conceptual Block Diagram

In this diagram we can notice that the user includes a down stream receiver. From the down stream, transmission parameters and clocks are extracted and used for the upstream creation.

13 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

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.

14 Transmission Convergence

The transmission convergence and the changes needed in the MAC layer are elaborated in a document also submitted to the TG3. The document title is “Proposed enhancements to the 802.16.1 MAC accommodating OFDMA PHY”.

15 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 he puts 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 of 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 10dB concentrations gain; this is called Forward APC (Automatic Power control), and is used in order to regulate the power to the users on the down stream optimizing the power, modulation and coding per user or a group of users..

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

16 Cellular deployment with Sectorization and frequency reuse

Due to previous sections, some conclusions about the coverage of the cell arise. Due to the power concentration of the OFDMA, several advantages can be achieved:

- Cell radius increases – a **15dB** advantage over a regular OFDM system (for a LOS propagation an increase by factor of 5, for NLOS condition and increase of 2.5 times the distance)
- Better penetration into houses and buildings, for simple indoor CPE (plug and play) using omni antennas.
- Over all throughput increases – users now can use higher order modulation due to better SNR, and also receive higher modulation due to BS power concentration
- Long symbol but small granularity enables better channel mitigation with small overhead and high efficiency.
- Repeaters can be added easily, signals from several places are translated at the receiver side just as an ordinary Multipath.

The next figures illustrate the differences between OFDM and OFDMA based systems.

Figure 25 illustrates coverage when LOS/NLOS conditions are involved where for NLOS and LOS the OFDMA system is superior to the OFDM one. It performs better both in range and in capacity due to the power concentration. The power concentration gives us 3 to 4 times the range in LOS conditions and 50% to 100% more for NLOS conditions.

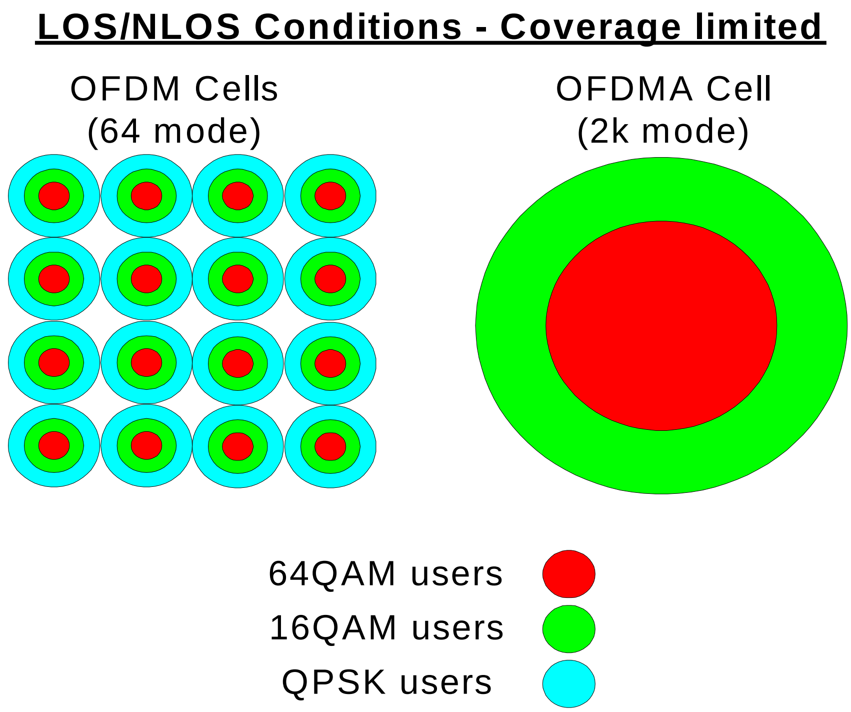

Figure 25: Illustration of Coverage limited cell

Figure 26 deals with the capacity issue of cells where capacity limitations are the main problem and the OFDMA system performs better due to the use of higher constellations.

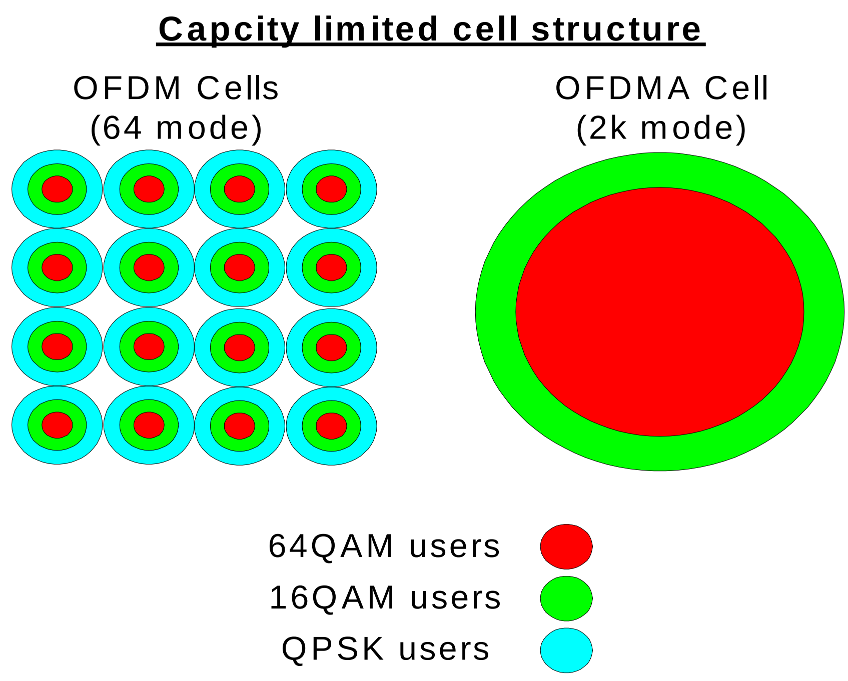

Figure 26: Illustration of Capacity limited cell

Another factor that we should examine is the reuse factor, when working with an OFDMA system a reuse factor of 1 is possible, by allocating different Sub-Channels to different sectors (enhancing the allocation by using polarization). Although this lowers the throughput per sector the coexistence, DFS and load balancing of the sectors becomes much simpler. Such a scheme is shown in Figure 27:

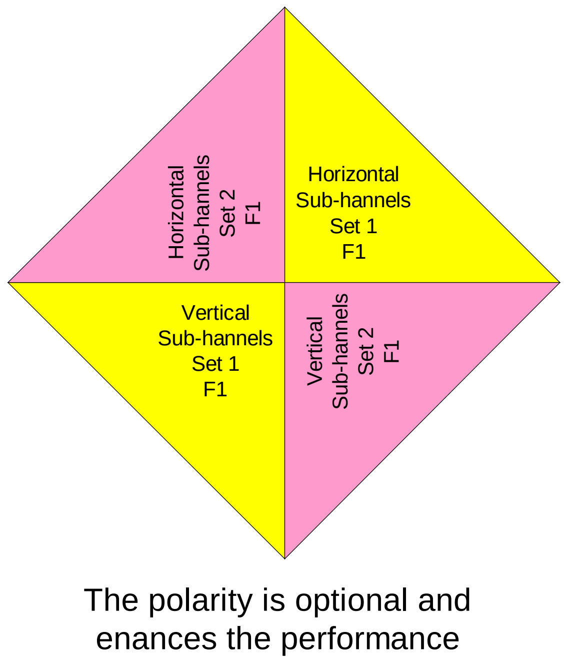

Figure 27: Illustration of sectorized cell using a reuse factor of 1

The figure shows the usage of a 4-sector cell, by farther splitting the number of Sub-Channel used we could reach up to 12 sectors per cell.

17 PAPR Reduction

One quite simple and most effective techniques to reduce the PAPR, is locating high power peaks, which are few in an OFDM signal (fewer for larger FFT sizes) and shaping the signal in those points by a smoothing function (for example a Gauusian function). The smoothing function reduces the PAPR but in the same time tries to relax the spectrum disturbances that are caused by that.

Another option is to use some of the pilots allocated for the US Sub-Channel for PAPR reduction.

18 Additional possible features

For even better coverage and throughput, mechanisms like antenna diversity at the Base station and at user side (where it is appropriate) are very effective against channel fading and Multipath.

Directional antennas at the user side are also a feature that can be implemented for better coverage and interference rejection.

19 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 13 (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 1.5,1.75,3,3.5,6,7,8,12,14,25MHz. The OFDMA access enables the adaptation of the bandwidth per user, 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. Today ASIC manufacturers produce chips in the same technology (DVB-T). The RF ends for the subscriber unit can be built with off the shelf RF ends or components. The large production of Base station will enable cost reduction and simple interfaces to the base station enables it's cost reduction.
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 with an excellent spectral mask allowing very sharp spectral mask and less out of band interference.
5	System Spectrum Efficiency	The usage of the OFDMA enables great robustness to cell planning, due to the fact that the Sub-Channel allocation are 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 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 for the downstream can be reached due to good coding gain and power concentration (which can give as much as 10dB more). Excellent coding gain is achieved for the upstream due to power concentration, which can give up to 15dB additional gain. 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	The OFDM is well known for its well-proven qualities dealing with tough wireless environments. The estimation that can be achieved within one OFDMA/OFDMA symbol because of fading is about 40dB, giving excellent recovery opportunity. The OFDMA/OFDMA technique 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 OFDMA technique 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 system proposed here is based upon new and very sophisticated system today planned in Europe, the basic concept of OFDAM is well known in many researches and it is now standardized in the DVB-RCT which is the return channel for the DVB-T. The PHY is defined to be as close as possible to the IEEE802.11a, HipperLAN2 from one end (64 mode) and to the DVB-T (1k, 2k modes).

20 Intellectual Property

Intellectual Property owned by RunCom Technologies LTD. may be required to implement the proposed PHY specification. The authors are not aware of any conditions under which RunCom Technologies LTD. would be unwilling to license Intellectual Property as outlined by the IEEE-SA Standards Board Bylaws, if the proposed specification will be adopted.

21 References

[1] Richard V. Nee and Ramjee Prasad, "OFDM for wireless multimedia communicatons", Artech House Publishers,2000.

[2] 802163c-00_33 – Initial OFDM/OFDMA PHY proposal for the 802.16.3 BWA

[3] 802163c-00_34 – Initial OFDMA/OFDMA PHY proposal for the 802.16.3 BWA

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

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

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

[7] 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.

[8] 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.

[9] 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.

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

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

[12] 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.

[13] 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.

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

[15] France Telecom R&D, "Turbo-Codes: another FEC alternative for HA", Bran18d39, May 2000

[16] France Telecom R&D, "Additional Information on convolutional turbo codes", Bran19d84, August 2000

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

[17] DVB-RCT standard draft, October 2000