Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**Initial OFDMA proposal for the 802.16.4 PHY layer**
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Source(s)	Yossi Segal Dr. Zion Hadad Itzik Kitroser RunCom Technologies LTD. 14 Moshe Levi St., Rishon Lezion, Israel Voice: 972-3-9528440 Fax: 972-3-9528805 mailto:zionh@runcom.co.il yossis@runcom.co.il itzikk@runcom.co.il
Re:	Call for Contributions for Proposed Modification of Specified MAC/PHY standards for WirelessHUMAN™ (TG4); issued 2000-11-17.
Abstract	We give a description to several modifications of the IEEE 802.11a in order to fit it to the TG4 wireless channel and working environment.
Purpose	This proposal should be used as the baseline for the PHY specification of the TG4.
Notice	
Release	
Patent Policy and Procedures	

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Initial OFDMA PHY proposal for the TG4 PHY Development

Dr. Zion Hadad, Yossi Segal and Itzik Kitroser

1 Introduction

The following contribution proposes some modifications to the IEEE 802.11a, HiperLAN2 PHY and 802.16.1 MAC layer in order to adopt it to the TG4 bands. The purposes of the proposed changes are to deal with higher delay spreads, interfering signals, coexistence with other systems, users power balance, Improved Error Correcting Code (ECC), Adaptive Power Control and Peak to Average Power Reduction (PAPR) reduction. The proposed PHY layer uses the OFDMA concept in order to construct a very robust and back-compatible layer. Many advantages are gained by using the OFDMA modulation, which are elaborated throughout the document

2 Channel bandwidth and Sampling rate

The channel bandwidth for the TG4 is 16MHz, which is inline of the IEEE 802.11a, HiperLAN2 PHY, the sampling frequency for this bandwidth is 20MHz. Therefore no modification to the channel plan are needed.

3 Supported FFT and Guard Interval (GI) lengths

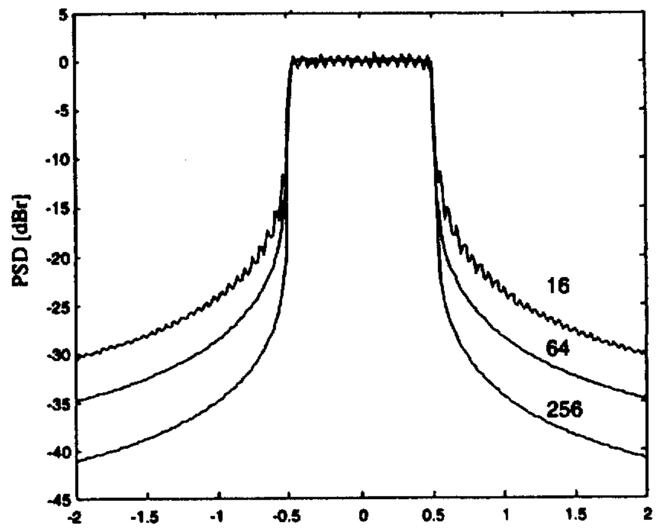
Both down stream and up stream are defined to accommodate several FFT lengths. Using several FFT sizes is an essential tool to trade off multipath mitigation and channel signal variation rate. Large FFT sizes are used to combat channels that suffer long multipath delays, short FFT's could be used for short range systems which suffer less multipath. The 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 _, 1/8, 1/16, 1/32.

The next table summarizes the possible FFT and GI sizes with the appropriate GI time (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)
1/32	N.A.	400ns	1.6us	3.2us
1/16	N.A.	800ns	3.2us	6.4us
1/8	400ns	1.6us	6.4us *	12.8us *
_	800ns *	3.2us *	12.8us	25.6us

* - Recommended modes

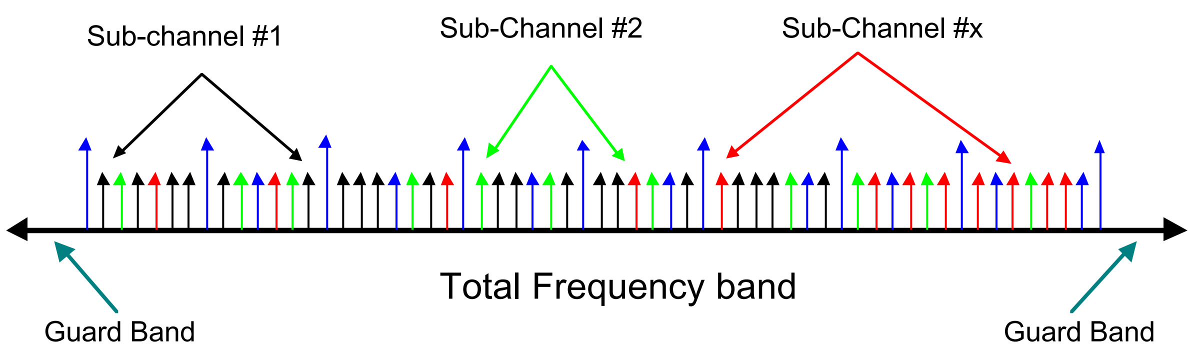
Another advantage of larger FFT size is the better spectral shape of the emitted signal. When using the 2k mode the spectral mask is lowered about 15dB then that of the 64 mode. This will allow better coexistence between systems and cleaner spectrum. An example of the shaping is taken from [1] and presented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



The figure 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-Channels. The next figure describes such a scheme:



From the figure 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 is 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.

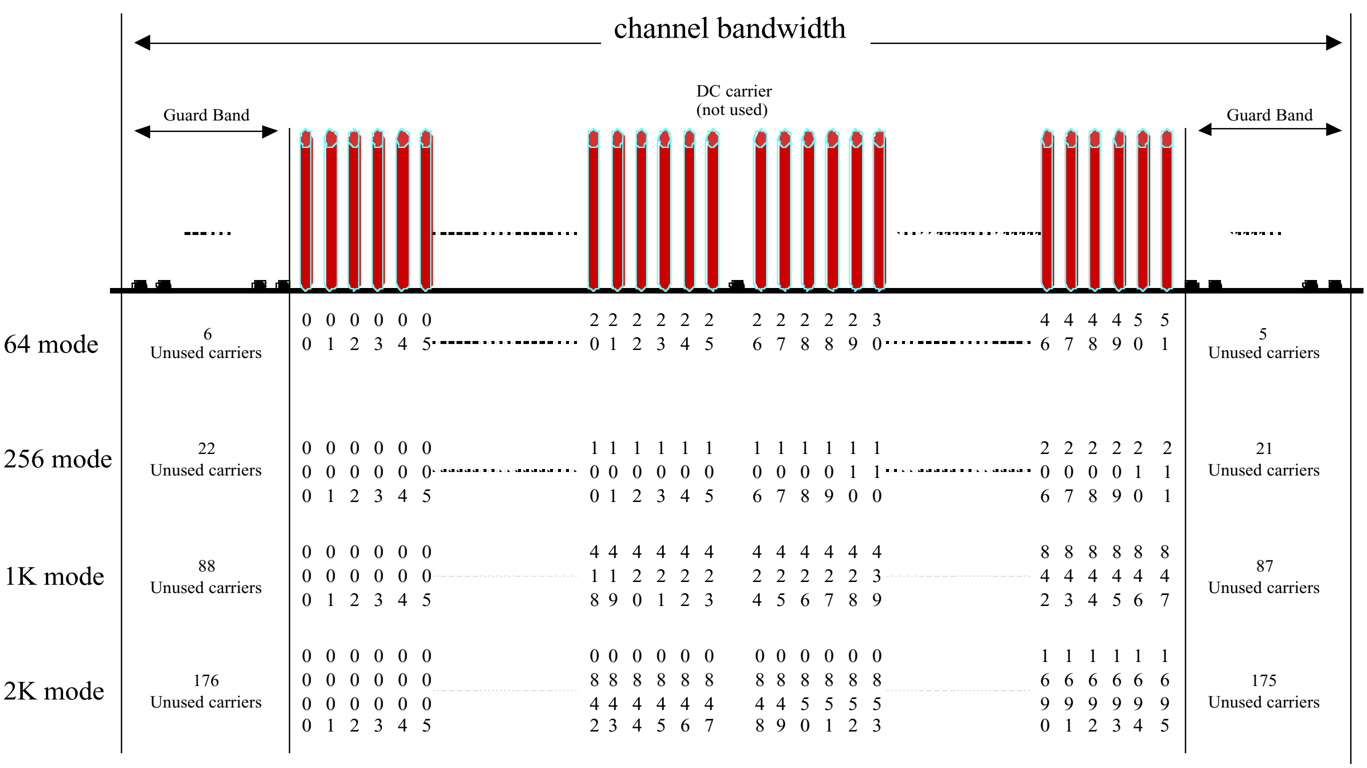
- One Sub-Channel is made of 53 carriers.

For the 64 point FFT, there exists only 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). Among all the carriers, the 2K mode offers 1696 usable carriers numbered 0 to 1695. The 1K mode offers 848 carriers, numbered 0 to 847, the 256 mode offers 212 usable carriers, numbered 0 to 211 and the 64 mode offers 52 usable carriers, In all the modes the dc carrier is not used.
One Sub-Channel contains 53 carriers (while 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 next figure:

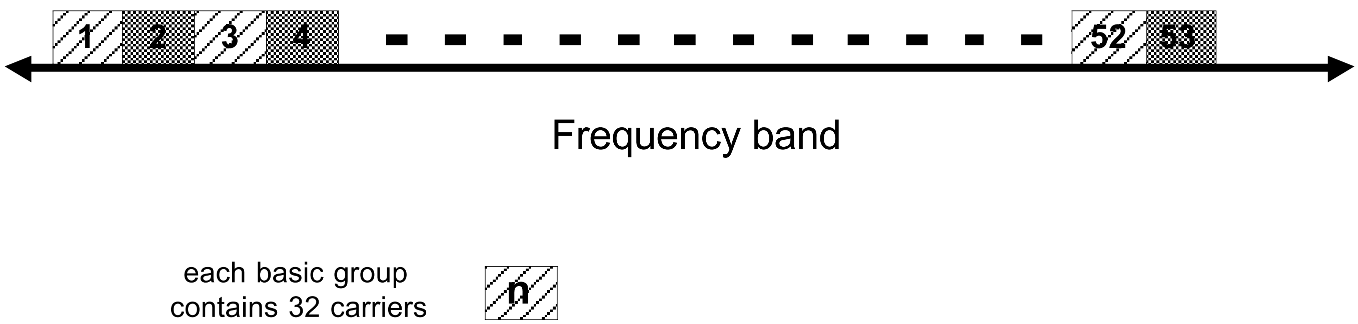


5.1.1 2K mode Structure

The parameters characterizing the 2K mode 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
- Symbol duration = 102.4us

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 32 usable carriers each. The next figure illustrates this principle.



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 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
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:

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

   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

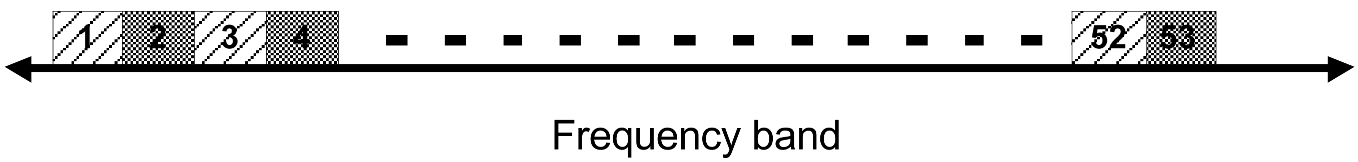
Using this procedure for the current CellId we can get 32 carrier sets (for all permutations possible), those defining the Sub-Channels

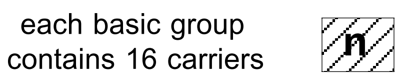
5.1.2 1K mode Structure

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
- Symbol duration = 51.2us

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. The next figure illustrates this principle.





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 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
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:

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

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

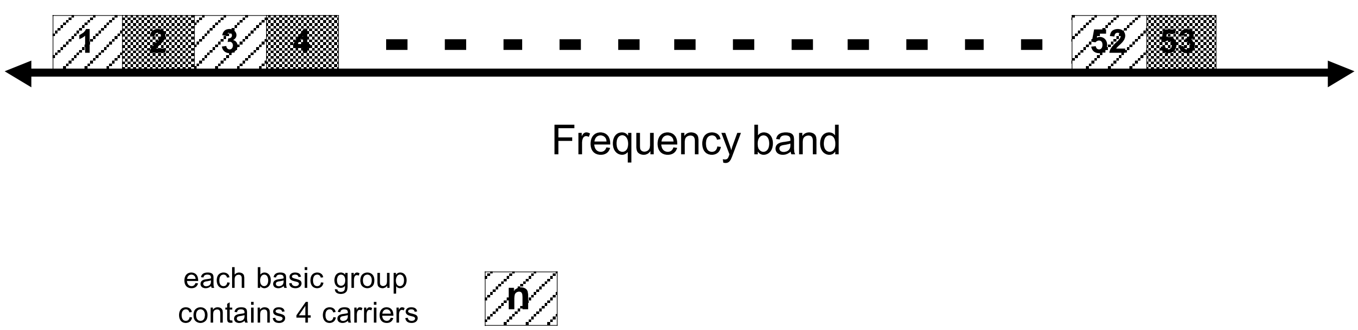
Using this procedure for the current CellId we can get 16 carrier sets (for all permutations possible), those defining the Sub-Channels.

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
- Symbol duration = 12.8us

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. The next figure illustrates this principle.



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
- Symbol duration = 3.2us

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, each contain 53 carriers, are used for two major functions:

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

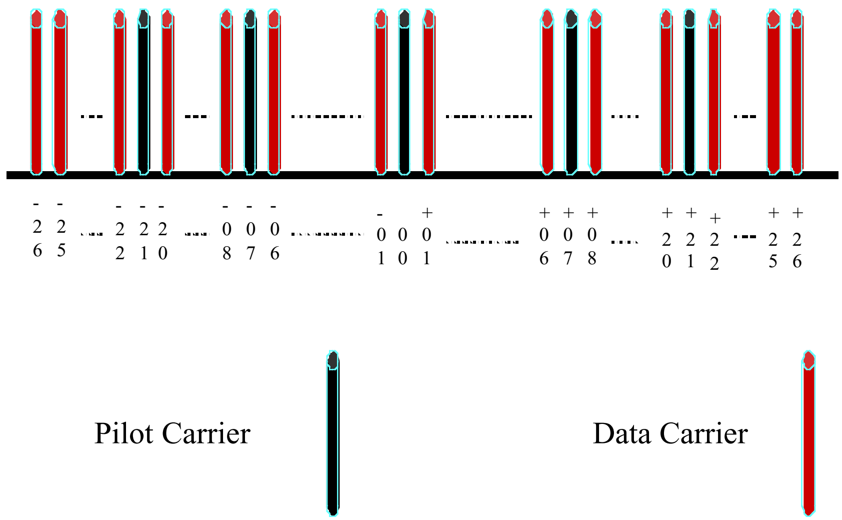
5.2.1 Using the Sub-Channels for Data Transmission

When a data OFDM symbol is to transmit, 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:

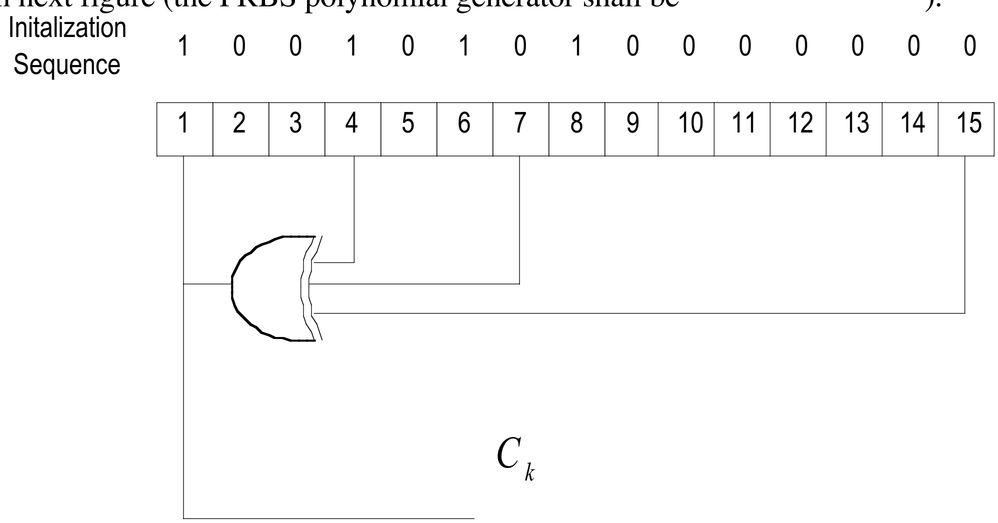
Sub-Channel Illustration



The figure describes the basic allocation of data and pilot carriers for a 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 next figure (the PRBS polynomial generator shall be $1+X^4+X^7+X^{15}$):



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 are used in the IEEE802.11a. One involves the data interleaving as it enters the system and the second involves bit interleaving after the encoding procedure. The system shall adopt both interleaving schemes and can expand the interleaving to larger blocks if stronger ECC (larger blocks when using Turbo codes) is to be used.

7 Adaptive Modulation

The modulation used both for the up stream and down stream is: BPSK, 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. For the down stream each logical Sub-Channel has its own modulation. The dedicated logical channel can include several allocations for different user, on each allocation the best fitted modulation for the specific user is used.

The next table presents the bit rates that could be achieved by the downlink and uplink (taking into account that All Sub-Channels are using the same modulation without coding, and GI=1/32):

Channel Bandwidth (MHz)	Symbol Rate (Msymbols/Sec)	Bit Rate using BPSK (Mbps)	Bit Rate using QPSK (Mbps)	Bit Rate using 16QAM (Mbps)	Bit Rate using 64QAM (Mbps)
16	14.54	14.54	29.1	58.18	87.27

For the up stream each user is allocated a modulation scheme, which is best suited for his needs. Therefore in one OFDMA symbol several modulations scheme are possible. These techniques of adaptive modulation are well known and wells supported in the MAC layers.

8 Adaptive Coding

The ECC defined for the IEEE802.11a involve the usage of the industry standard convolution code (k=7, G1=171, G2=133). The TG4 environment is much more difficult then the IEEE802.11a ones, therefore more powerful ECC should be used with the possible backward compatibility to the IEEE802.11a. The ECC code should handle besides the regular AWGN environment, more difficult channels which will surely involve jamming and interference from other systems (that means the possibility to handle burst noise).

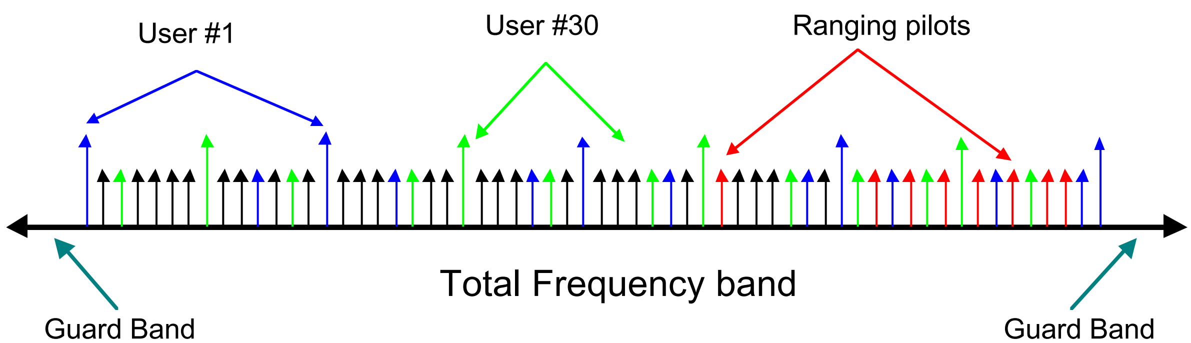
The following ECC should be used for the TG4 PHY:

1. Industry standard convolution code (k=7, G1=171, G2=133), for backward compatibility
2. Block Turbo Codes, designed for burst noise (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 as well as backward compatibility. 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 _, 2/3 and _, 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 is the performance advantage of the Turbo schemes increases (therefore maybe a scheme using longer block sizes and spreaded maybe over several OFDM symbols could be also considered).

9 Up Stream OFDMA symbol

The following description gives an example for the 2k mode OFDMA symbol on the up stream channel (other modes can be similarly derived). The symbol is divided into sub sets of carriers. We denote a sub set of carriers as a Sub-Channel. Then we can divide all-usable carriers (beside the Guard Bands) to several sub-Channels. If we use 1696 carriers and 53 carriers per Sub-Channel then we achieve 32 Sub-Channels (30 Sub-Channels are used for data transmission and 2 for ranging). These are illustrated in the next scheme:



These Sub-Channels are the basic allocation unit, and the smallest granularity that a user can be allocated. Each allocation of Sub-Channel can be allocated for several OFDM symbols in such a way that the estimation of each Sub-Channels is done in frequency and time. Moreover the allocation of carriers to Sub-Channel is done by special Reed-Solomon series, which enables the optimization and dispersion of interfering signals inside a cell and between adjacent cells. This powerful technique enables a better Reuse Factor, Better throughput as well as fighting Doppler shifts and statistically spread interferences.

10 Time and Power Ranging of the users

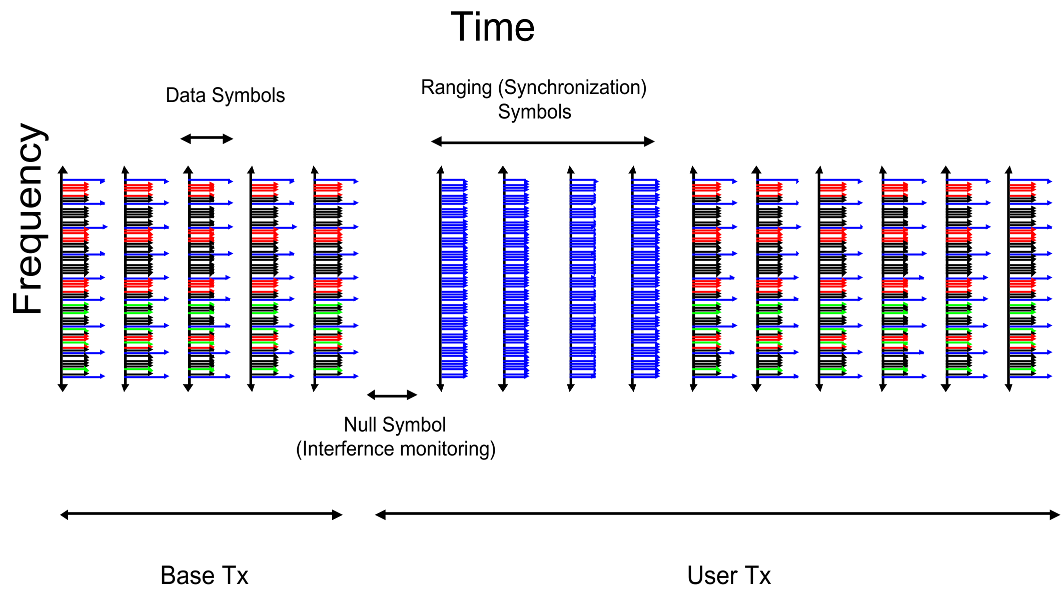
Time and Power ranging is performed by allocating several Sub-Channels to one Ranging Sub-Channel upon this Sub-Channels users are allowed to collide, each user randomly chooses a random code from a bank of codes. These codes are modulated by BPSK upon the contention Sub-Channel. The Base Station can then separate colliding codes and extract timing and power ranging information. The time and power ranging allows the system to compensate the far near user problems and the propagation delay caused by large cells.

11 Multiple Access Schemes

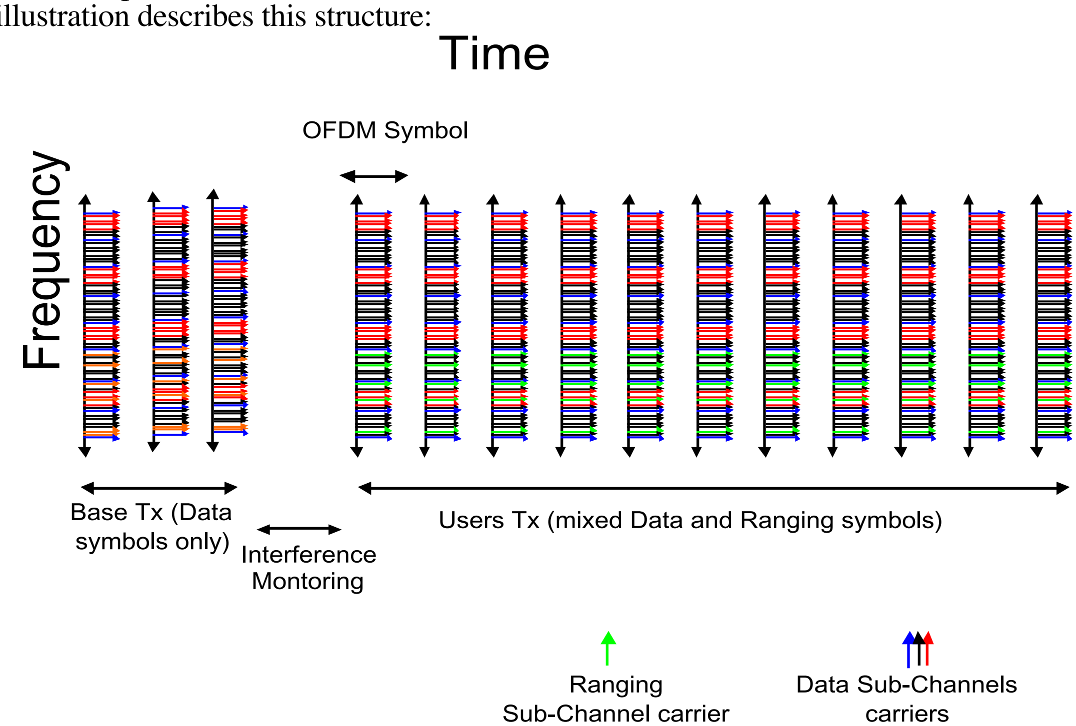
The following description refers to the down stream and up stream access methods.

There are two basic approaches when using the OFDMA concept:
One 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).
The following illustration describes 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



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.
The following illustration describes this structure:

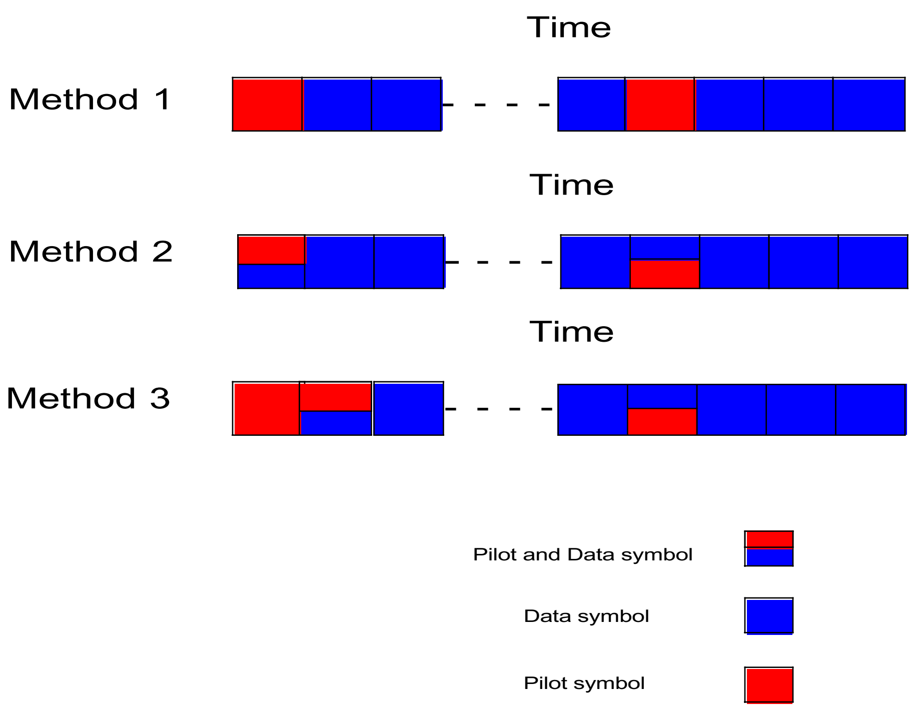


11.1 Down stream Access (All modes)

The down stream uses the first method of access described, but it uses only data symbols for the transmission. The down stream shall use the following structure for the transmission (each symbol represents the actual useful symbol time and the Guard Interval time). In order to estimate the down stream some Sub-Channels within a period of time could be allocated to pilots transmission (all the Sub-Channel carriers are allocated for pilot transmission), several techniques could be used for this purpose:

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

These methods are illustrated in the next figure:



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.

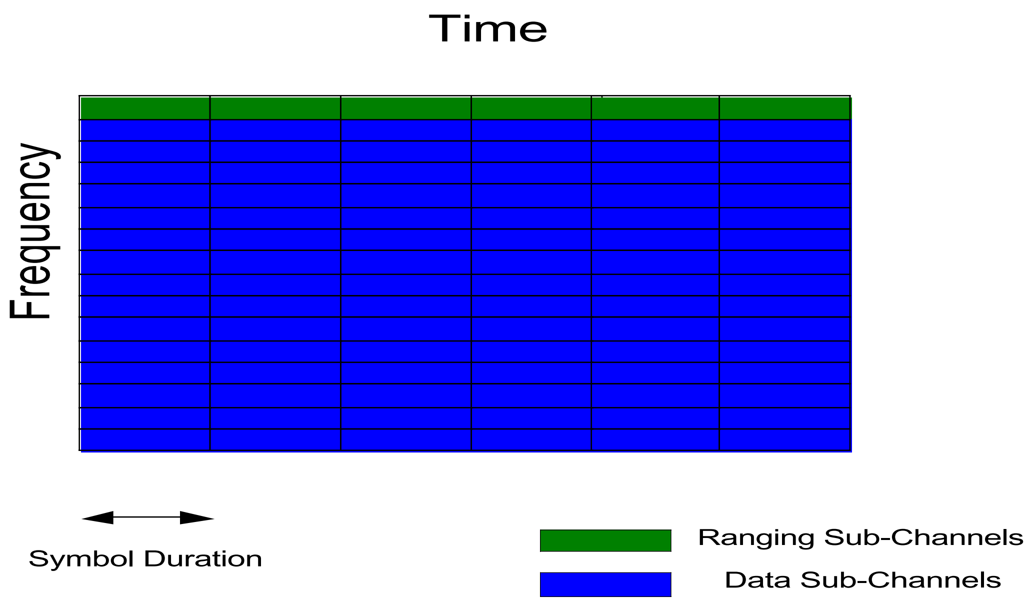
11.2 Up stream Multiple Access Schemes

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.

11.2.1 Up stream 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 described in the next figure:



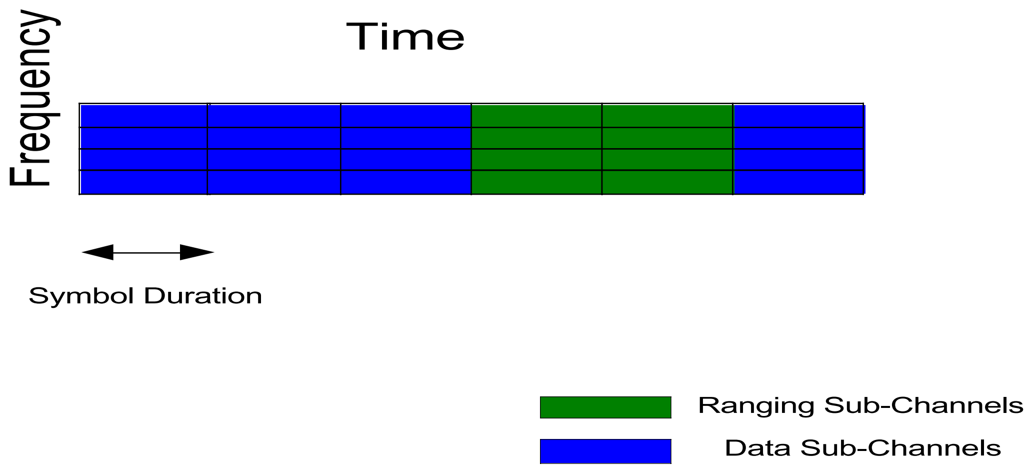
The users could use the same Data transmission patterns has for the down stream (which are described in 11.1) and consists the following methods:

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

11.2.2 Up stream 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 described in the next figure:

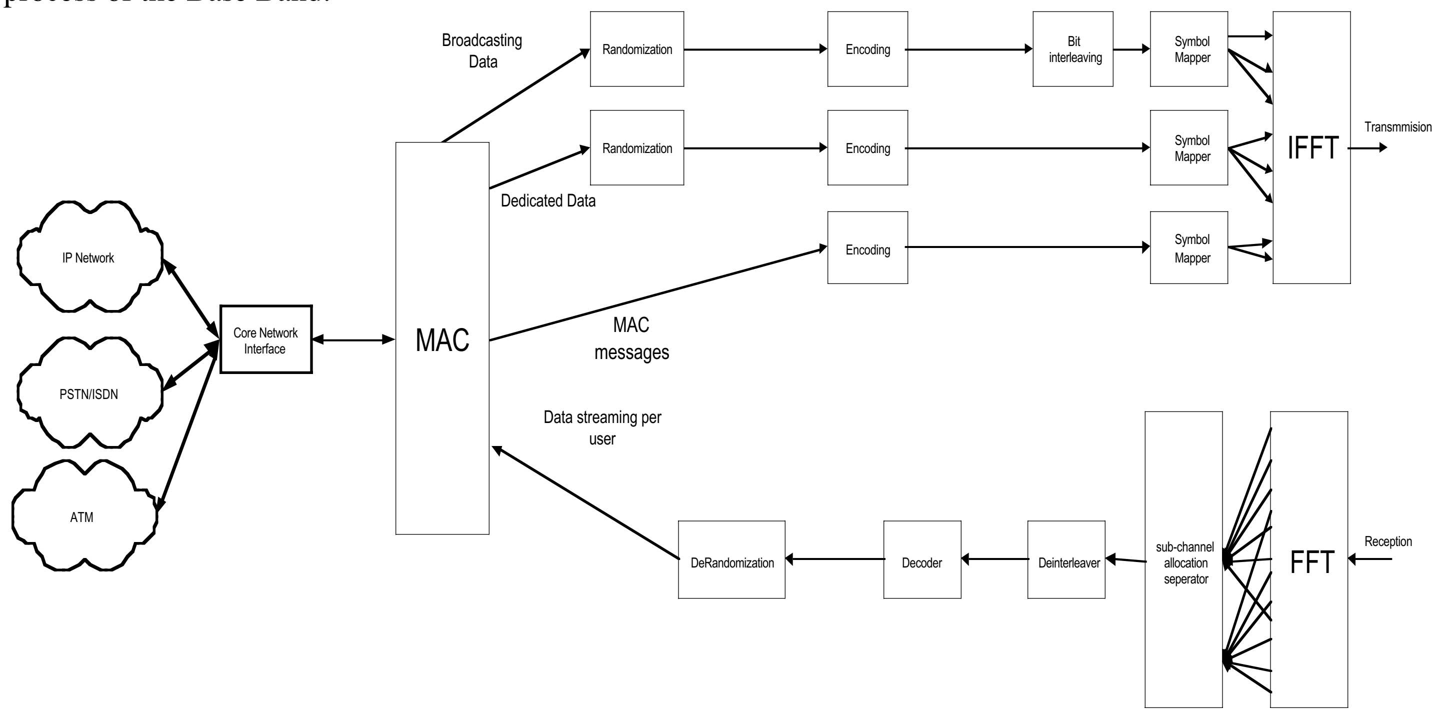


The users could use the same Data transmission patterns has for the down stream (which are described in 11.1) and consists the following methods:

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)

12 Down Stream Block Diagram

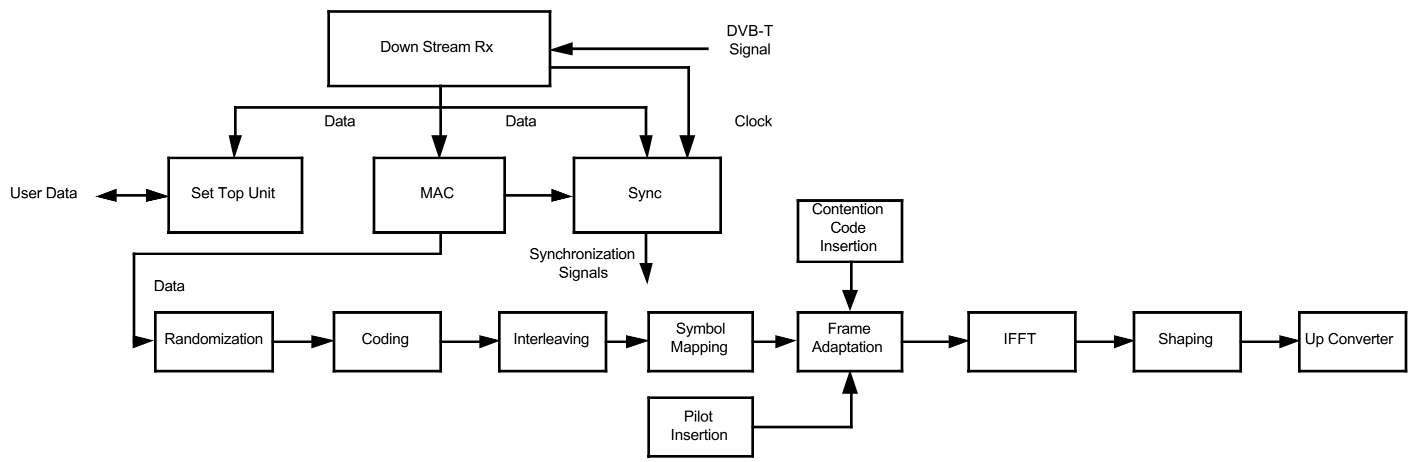
The following diagram represents an example for a full Base station block diagram; this scheme represents all process of the Base Band:



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.

13 Up Stream Block Diagram

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



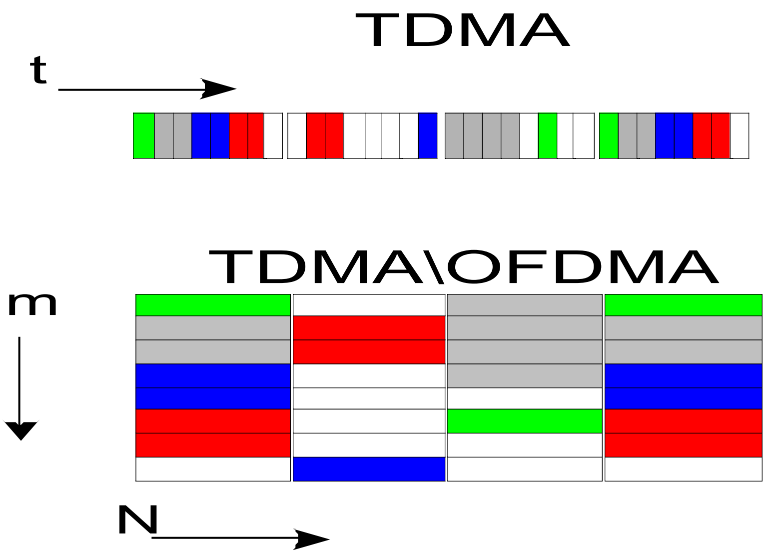
In this diagram we can notice that the user includes a down stream receiver. From the down stream, transmission parameters and clocks are extracted and used for the upstream creation.

14 Transmission Convergence

The 802.16.1 MAC protocol can be easily adapted to the proposed PHY by a convergence layer that will translate allocation of slots into TDMA\OFDMA approach. For the down stream a mapping of the Sub-Channels to the logical Sub-Channels and their parameters (ECC, modulation) is sent periodically, much like the MAC sown stream today.

The OFDMA defines a slot as a pair {N,m} that represents a combination of an OFDM time symbol (N) and number of a sub-channel (m). The allocation that the MAC should allocate are exactly as for TDMA systems taking into account that the slot number should be translate by the next formula (when using a 53 carrier Sub-Channels, and 32 working Sub-Channels per OFDM symbol, for the 2k mode): $t = 30 * N + m$

The TDMA\OFDMA can be presented as an extended TDMA approach in which several slots are transmitted in parallel as can be seen in the following diagram:



$$t = 30 * N + m$$

The given configuration will achieve slot granularity of ~9 bytes in BPSK with 1/2 code rate.

Several slots can be allocated to one user, what means that data can be transmitted in parallel resulting with flexibility that will be determined by the needed QoS restrictions.

15 System Throughput

For the Down stream 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
BPSK	1	_	6	6.67	7.06	7.27
	1	2/3	8	8.89	9.41	9.7
	1	_	9	10	10.59	10.9
QPSK	2	_	12	13.34	14.12	14.54
	2	2/3	16	17.78	18.82	19.4
	2	_	18	20	21.18	21.8
16-QAM	4	_	24	26.68	28.24	29.08
	4	2/3	32	35.56	37.64	38.8
	4	_	36	40	42.36	43.6
64-QAM	6	_	36	40.02	42.36	43.62
	6	2/3	48	53.34	56.46	58.2
	6	_	54	60	63.54	65.4

16 Operation in presence of interference in MAN environment

The interference in the MAN environment can be categorized into:

- Narrow band jamming
- Partial band jamming
- Pulse jamming
- Other operating system jamming and coexistence with IEEE802.11a, HiperLAN2.

16.1 Narrow band jamming

Narrow band jamming can be treated by:

- Using time shaping on the symbol and then equalization (the more FFT points used the better the shape is)
- Using jamming detection and then a smart ECC, which can erase bad symbols.

In any case when using large FFT sizes (especially in OFDMA), jammers at the base station are more effectively suppressed (due to the FFT filtering) and destroys less carriers (in percentage sense) then for small FFT size.

16.2 Partial band jamming

Detecting bad symbol can treat partial band jamming, which allow the usage of smart ECC, which can erase bad symbols. The OFDMA (2k mode) has a 15dB "processing gain" against wide band jammers or other 802.11a, HiperLAN2 interferers.

16.3 Pulse jamming

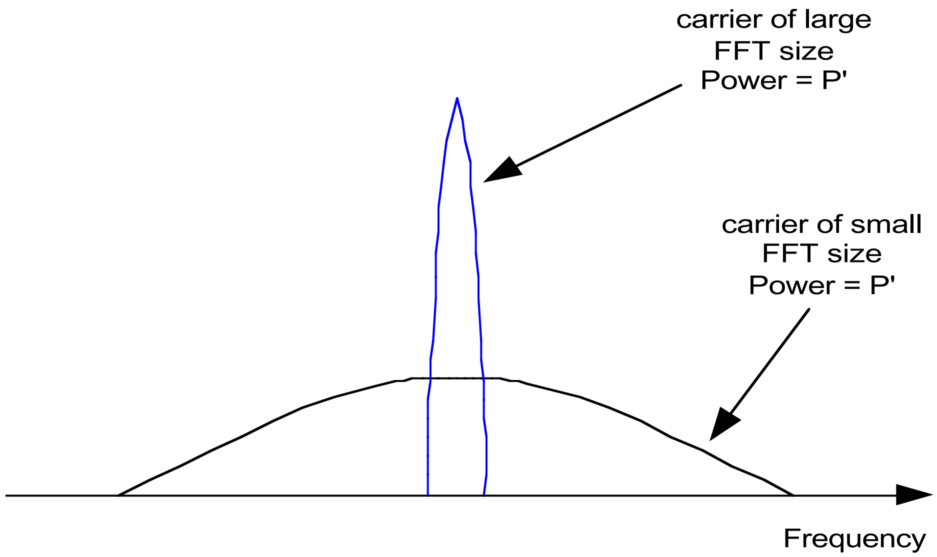
Short time interference can be sold by time interleaving the data. The usage of the Sub-Channel notion enables time interleaving of the Sub-Channel over time, the small packet length enables easy time interleaving and better statistical multiplexing.

16.4 Other operating system jamming and coexistence with IEEE802.11a, HiperLAN2

Best coexistence between the TG4 PHY and the IEEE802.1a, HiperLAN2 will occur when using large FFT sizes for TG4. When using large FFT size the carrier bandwidth is about 10KHz (compared to more then 300KHz for 64 FFT size). This bandwidth difference gains us a "processing gain" of 15dB in total.

Furthermore the FFT which is a filter help decreasing the all around interference by at least 13dB, when considering all the above in a scenario where both system are to work with the same power emittion the TG4 has a 28dB advantage in jamming rejection of the IEEE802.1a, HiperLAN2 signal. When using smaller FFT sizes the advantage decrease.

The following figure illustrates this scheme:



The figure illustrates the advantage when performing the large FFT over the small size FFT, where:

- for the large size FFT we get $\frac{S}{N} = OFDMA \big/ 802.11a - Jammer = 15dB$
- for the small size FFT we get $\frac{S}{N} = 802.11a \big/ OFDMA - Jammer = 0dB$

16.5 Other jamming rejection or Coexistence tools

There are more ways to have two systems work together without interfering one another:

- The usage of directive antennas
- The usage of adaptive array and null steering

Both are antenna-based techniques, which can remove or help prevent interferences.

17 Dynamic Frequency Selection (DFS)

In order to gain the most from DFS we recommend that a base station shall use several Base Station elements each with it's own RF head (using all together several frequencies). The Base Stations can then scan several frequencies at once (or one at a time, for one head only), this will allow choosing the best and undisturbed frequency/frequencies around, and then choose the best frequency available. This technique when combined with the OFDMA capabilities can also use the dynamic transition of users between frequencies for load balance and excellent reuse factor.

18 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 (then the IEEE802.1a, HiperLAN2)
- 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

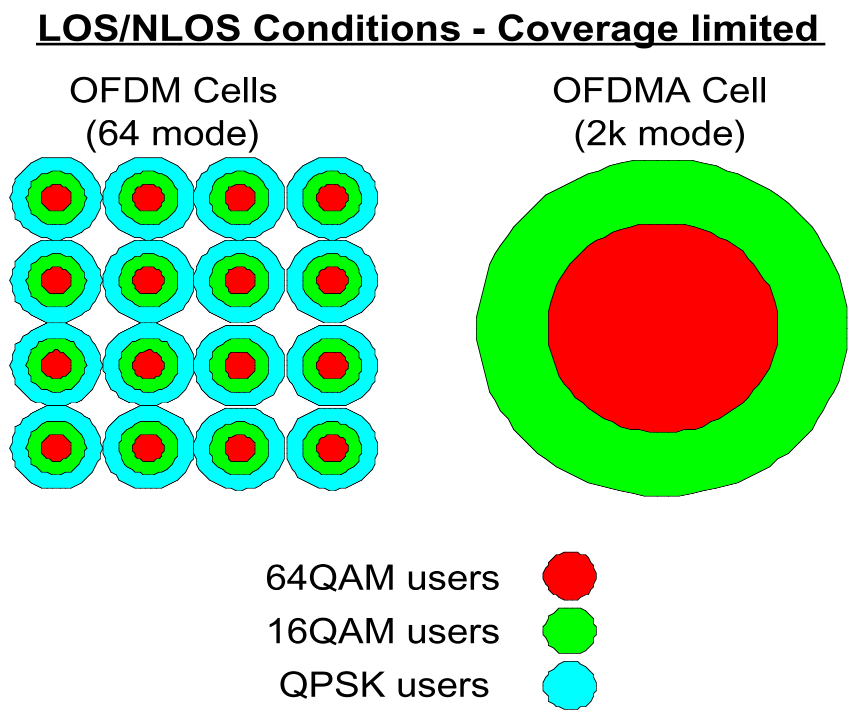
19 Cellular deployment with Sectorization and frequency reuse

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:

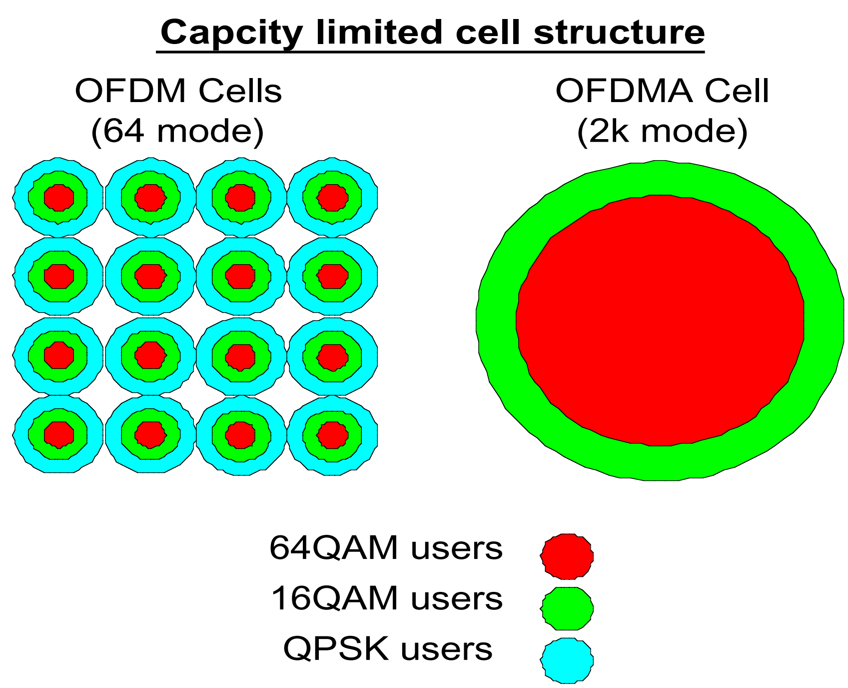
- Cell radius increases – a **15dB** advantage over a regular OFDM system (for a LOS propagation an increase by factor of 5, for NLOS condition and increase of 2.5 times the distance)
- Better penetration into houses and buildings, for simple indoor CPE (plug and play) using omni antennas.
- Over all 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.

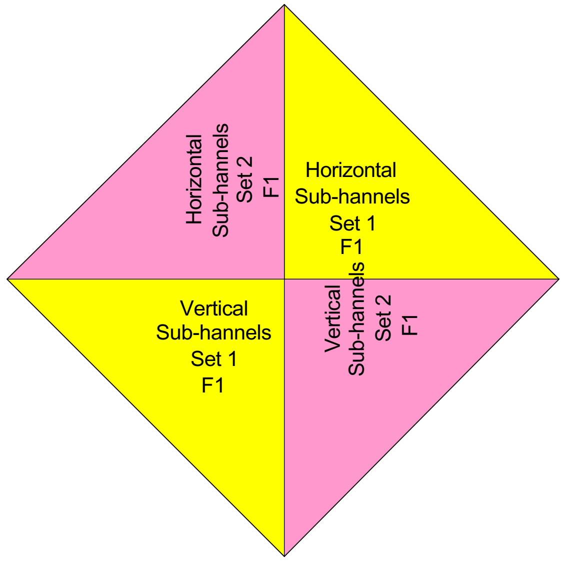
The first figure is the coverage when LOS/NLOS conditions are involved where for NLOS and LOS the OFDMA system is superior to the OFDM one. It performs better both in range and in capacity due to the power concentration. The power concentration gives us 3 to 4 times the range in LOS conditions and 50%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



The second figure 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.



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 the next figure:



The polarity is optional and enances the performance

20 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.

21 MAC compliancy

The PHY layer proposed throughout the document perfectly fits to the TG1 MAC with some hooks for several OFDMA features (Ranging, Maping, DFS etc.). More detailed description will be given in presentation during the next meeting.

22 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. Means as space-time-coding can be incorporated in an OFDM/OFDMA system in a very efficient way.

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

23 Criteria table

The criteria list suggested:

- Meets system requirements

How well does the proposed PHY protocol meet the requirements described in the current version of the 802.16.4 PAR?

- Channel spectrum efficiency

Defined in terms of single channel capacity (TDD) assuming all available spectrum is being utilized (in terms of Bits/sec/Hz). Supply details of PHY overhead.

-Modulation Scheme

-Gross Transmission Bit Rate

-Gross (Uplink/Downlink) Bit Rate @PHY to MAC Interface

-Occupied BW, including channel spacing and spectral mask

- Spectrum resource flexibility

a) Flexibility in the use of the frequency band (i.e. channelization, modularity, band pairing, and Upstream/DownStream data Asymmetry).

b) Channel Rate Flexibility data Rate adjustment capability at PHY to accommodate the channel quality variations.

- System Spectrum Efficiency

Defined in terms of available capacity, availability and coverage (in bits/sec/Hz/cell). Takes into account Re-use factor, and interference rejection capability (in the Unlicensed band). Tested with the number of cells needed to cover a predefined scenario:

- System service flexibility

How flexible is the proposed PHY/MAC to support optional services and potential future services

- Protocol interfacing complexity

Interaction with other layers of the protocol, specifically MAC and Network Management. Provide the PHY delay.

- Reference system gain

Sector coverage performance for a typical BWA deployment scenario (supply, reference system gain). Provide practical link budget analysis.

- Robustness to interference

-Resistance to intra-system interference (i.e., frequency re-use) and external interference cause by other systems.

-Provide co-channel, adjacent channel interference levels and spectral spillage resulting from modulation.

- Robustness to channel impairments

Small and large scale fading (Rain fading, multipath, N(non or near)LOS, LOS, Foliage effect, Freq.Selective fading, atmospheric effects.)

- Robustness to radio Impairments

Specify the degradation due to radio impairments such as phase noise group delay of filters, amplifier nonlinearities, etc.

- Support of advanced antenna techniques

Specify how the system would support advanced techniques, such as smart antennas, Diversity, or space-time coding.

- Coexistence relevant issues

24 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.

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