OFDMA PHY proposal for the 802.16.3 PHY layer

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Purpose:

This proposal should be used as the baseline for the PHY specification of the TG3.

OFDMA PHY proposal for TG3

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Advanced Hardware Architecture

And Others

Contents

System Characteristics

¥ FFT size is either of: 2048, 1024, 256, 64

¥ Guard Intervals :1/4, 1/8, 1/16, 1/32

¥ Adaptive Coding (rates 1/2, 2/3, 3/4):

— Concatenated RS GF(256) flexible (N,K,t) and convolutional coding (k=7, G1=171, G2=133) including a flexible convolutional interleaver if needed

— Block Turbo Codes

— Convolutional Turbo Codes

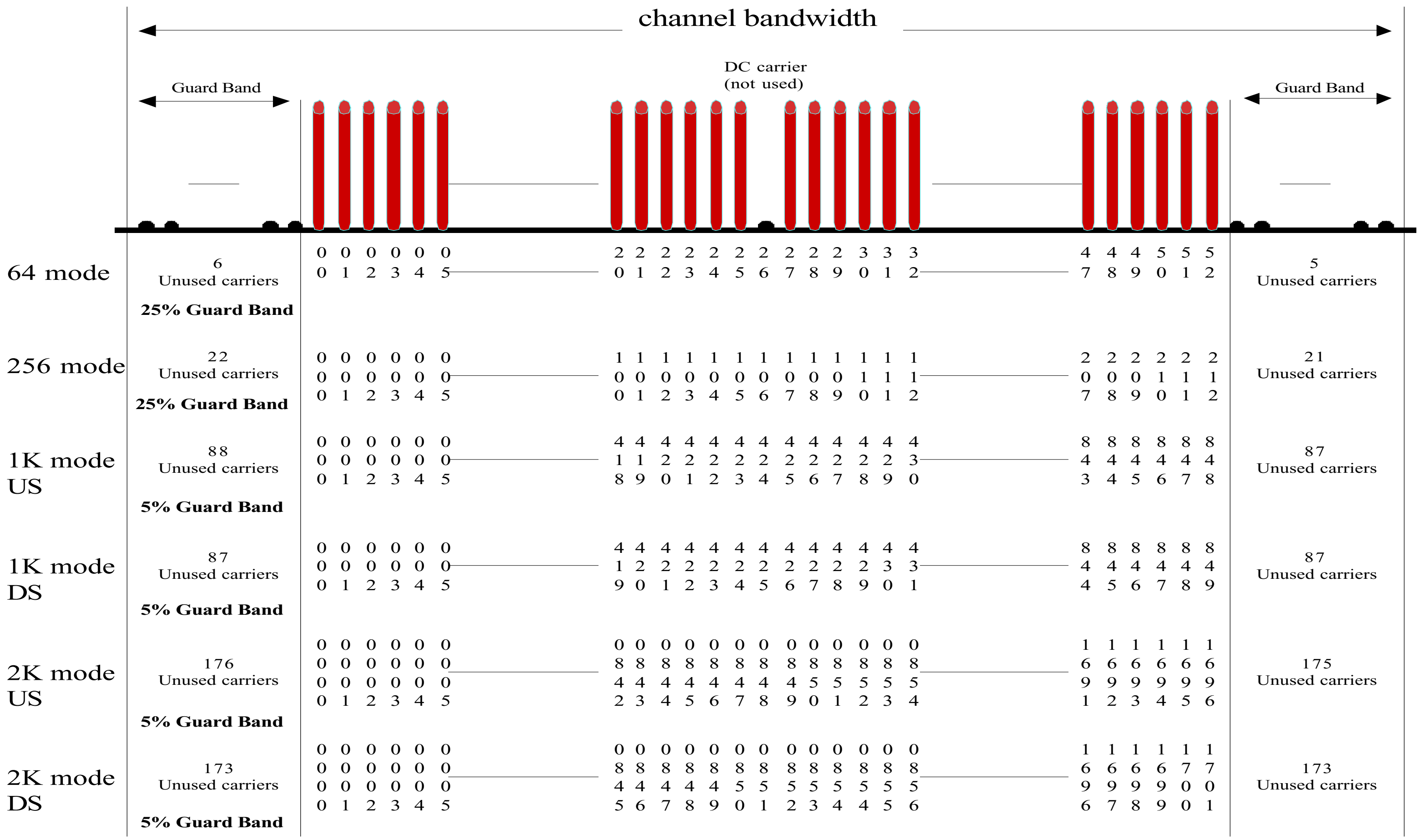
System Characteristics

- ¥ Adaptive Modulations:
  - —QPSK, 16QAM and 64QAM, optional 256QAM
- ¥ Adaptive Sub-Channels allocations
- ¥ Adaptive FAPC/BAPC and Adaptive ASC
- ¥ Space Time code enabled
- ¥ Adaptive array enabled
- ¥ Antenna diversity enabled

Combined Several FFT Sizes

Combined FFT Sizes

The usable carriers in the symbol does not include the frequency guard bands and the DC carrier.



Multipath Channels, BW and FFT Sizes

The next table shows the GI length for different FFT sizes and some BW allocations

(*not recommend for bad multipath channels)

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	*10.6us	*5.3us	*2.6us	42.6us	21.3us	*10.6us	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

OFDM FFT Size Planning (optimization for higher capacities)

¥ Larger FFT size give longer GI and better multipath handling and better spectrum efficiency !!!!

¥ Smaller granularity for each user, gives better throughput (higher system capacity), Improved with OFDMA.

¥ Allows working with broader bandwidth

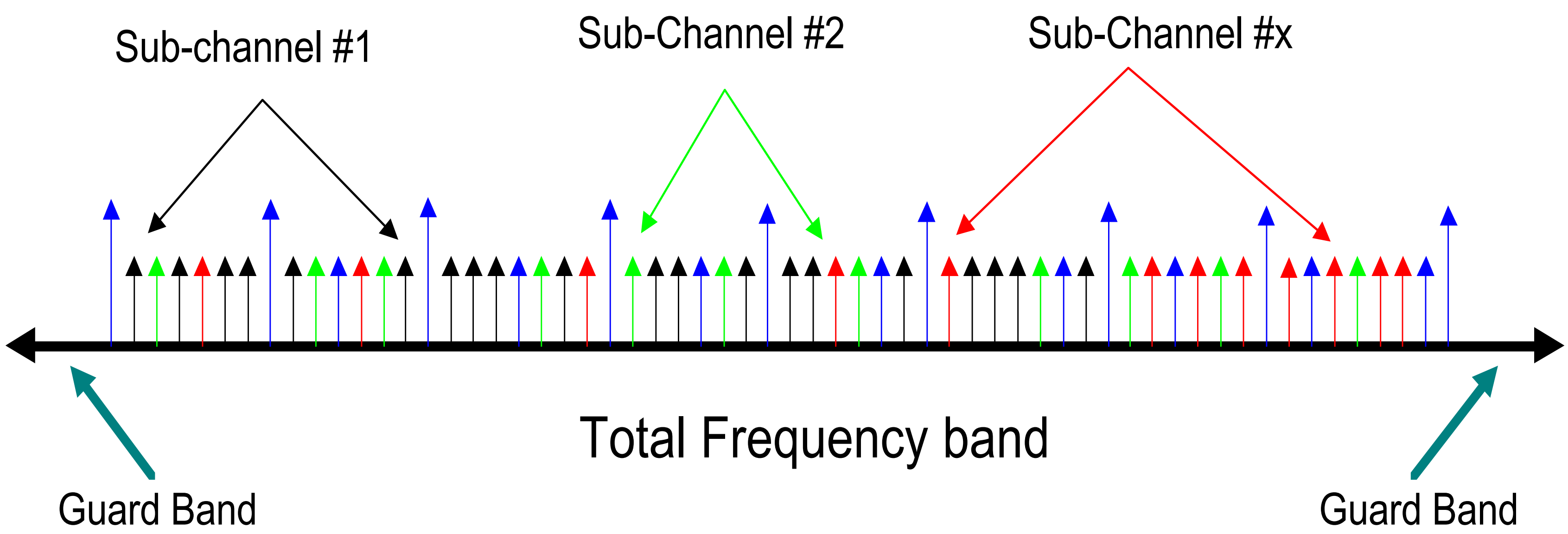
¥ Allocation of high data rates and small granularity has better multiplexing gain (higher system capacity)

OFDMA Symbol Structure

OFDMA Symbol Structure

For downlink and uplink for FDD-C, FDD-B, HFDD-B and TDD :

The usable carriers are divided into groups called Sub-Channels.

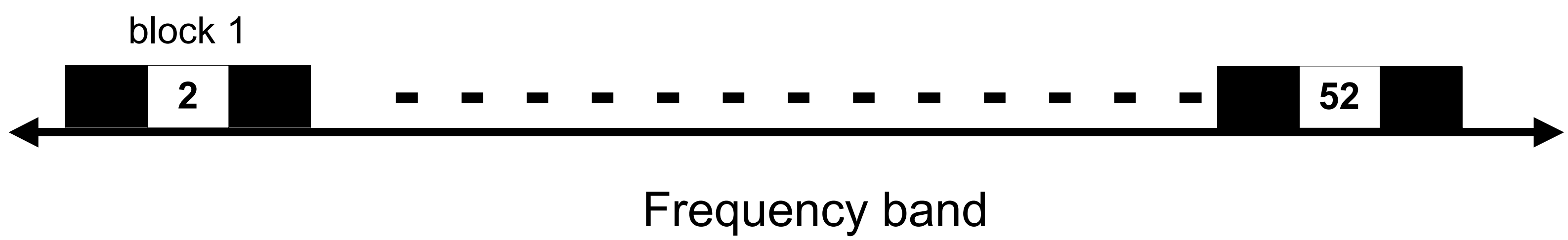


OFDMA Symbol Structure (cont.)

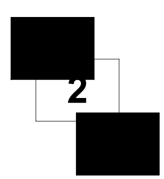
Using special permutations for carrier allocations:

All usable carriers are divided into 53 (or 48) carrier groups named basic group, each main group contains several carrier (depending on the mode used):

- ¥ 32 carriers for the 2k mode
- ¥ 16 carriers for the 1k mode
- ¥ 4 carriers for the 256 mode
- ¥ 1 carrier for the 64 mode



each group contains several carriers



OFDMA Symbol Structure (cont.)

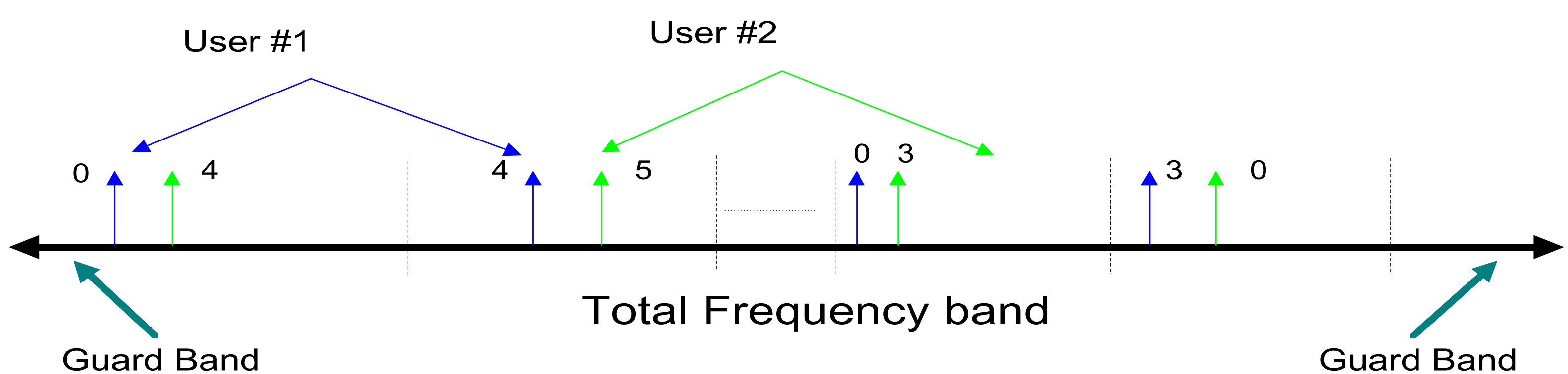
Carriers are allocated by concatenating a basic series, and cyclic permutations of it, for example (1k mode):

¥ Basic 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

¥ After One cyclic permutation we get:

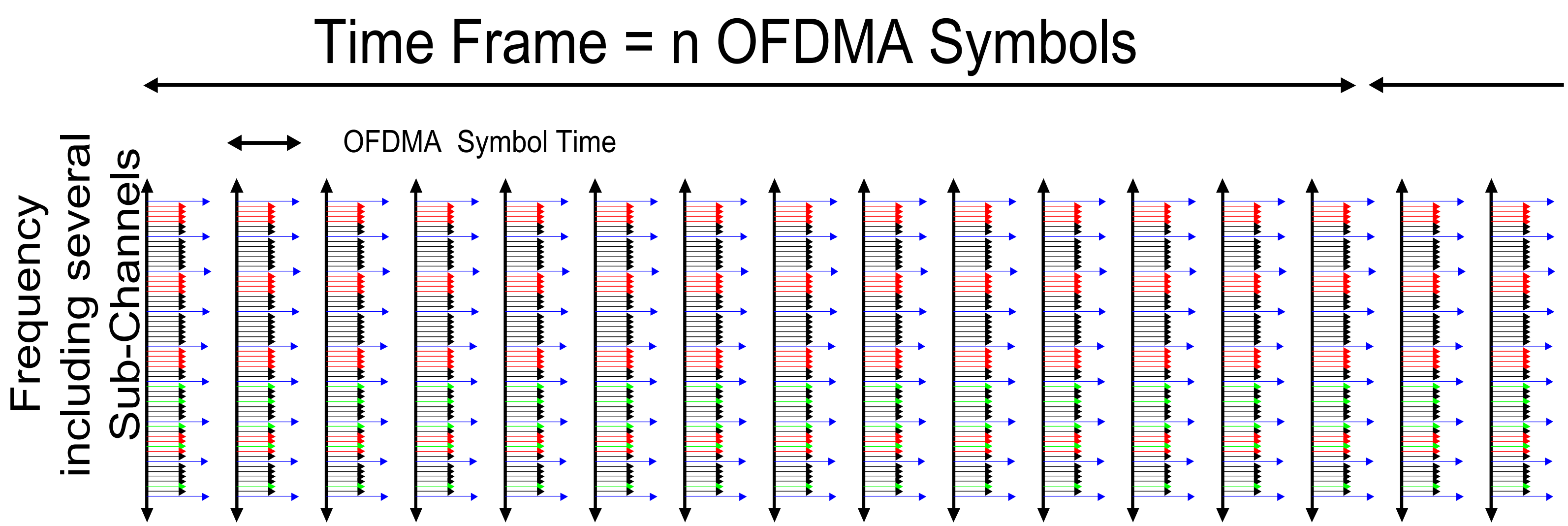
4 ,5 , 12, 10, 13, 1, 11, 3, 15, 14, 7, 9, 6, 2, 8, 2, 6, 7, 14, 12, 15, 3, 13, 5, 1, 0, 9, 11, 8, 4, 10, 4, 8, 9, 0, 14, 1, 5, 15, 7, 3, 2, 11, 13, 10, 6, 12, 6, 10, 11, 2, 0, 3,0



User 1 = 0 ,4 ,5 , 12, 10, 13, 1, 11, 3, 15, 14, 7, 9, 6 ....0, 3
User 2 = 4 ,5 , 12, 10, 13, 1, 11, 3, 15, 14, 7, 9, 6, 2....3, 0

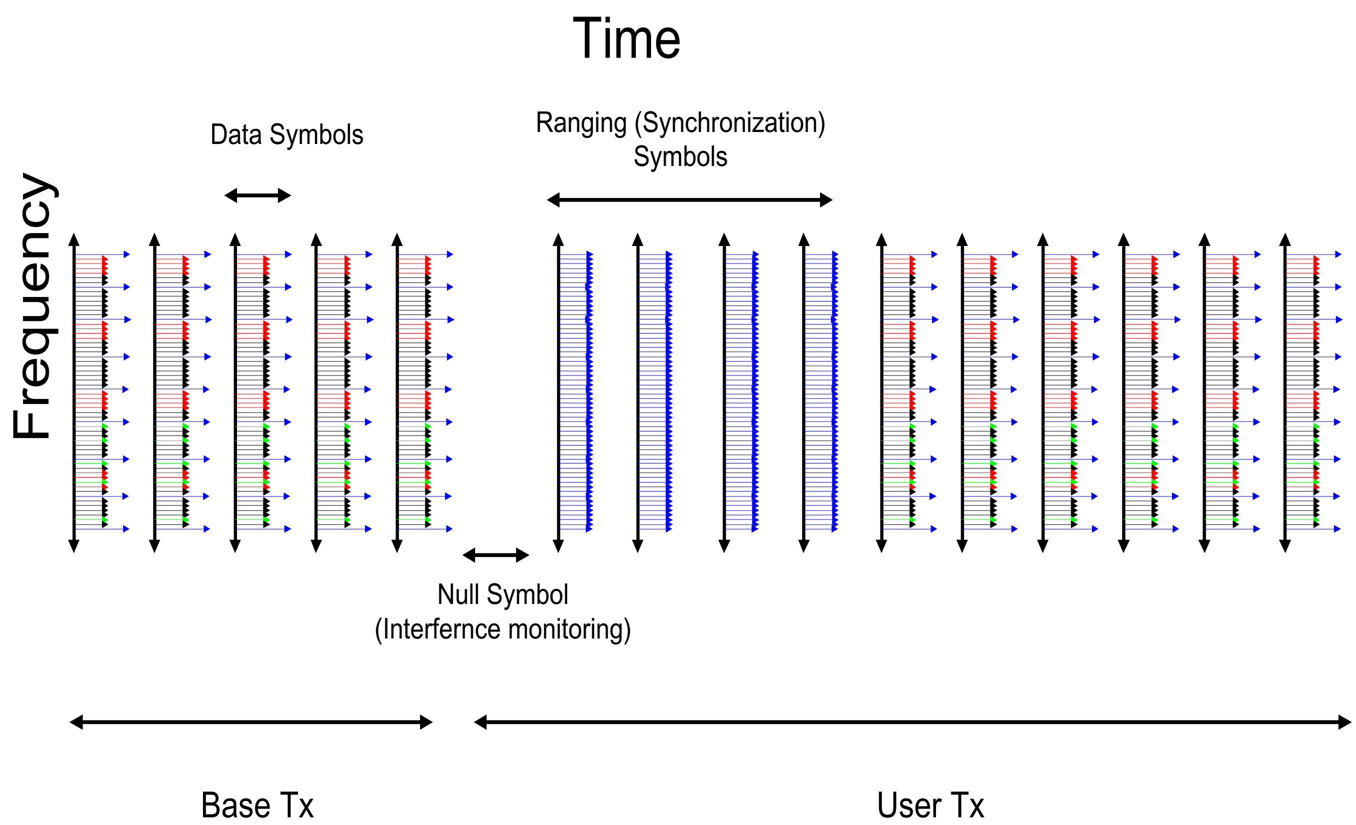
OFDMA Symbol Structure (cont.)
For FDD/TDMA

Using OFDMA/TDMA, Sub Channels are allocated in the Frequency Domain, and OFDM Symbols allocated in the Time Domain.



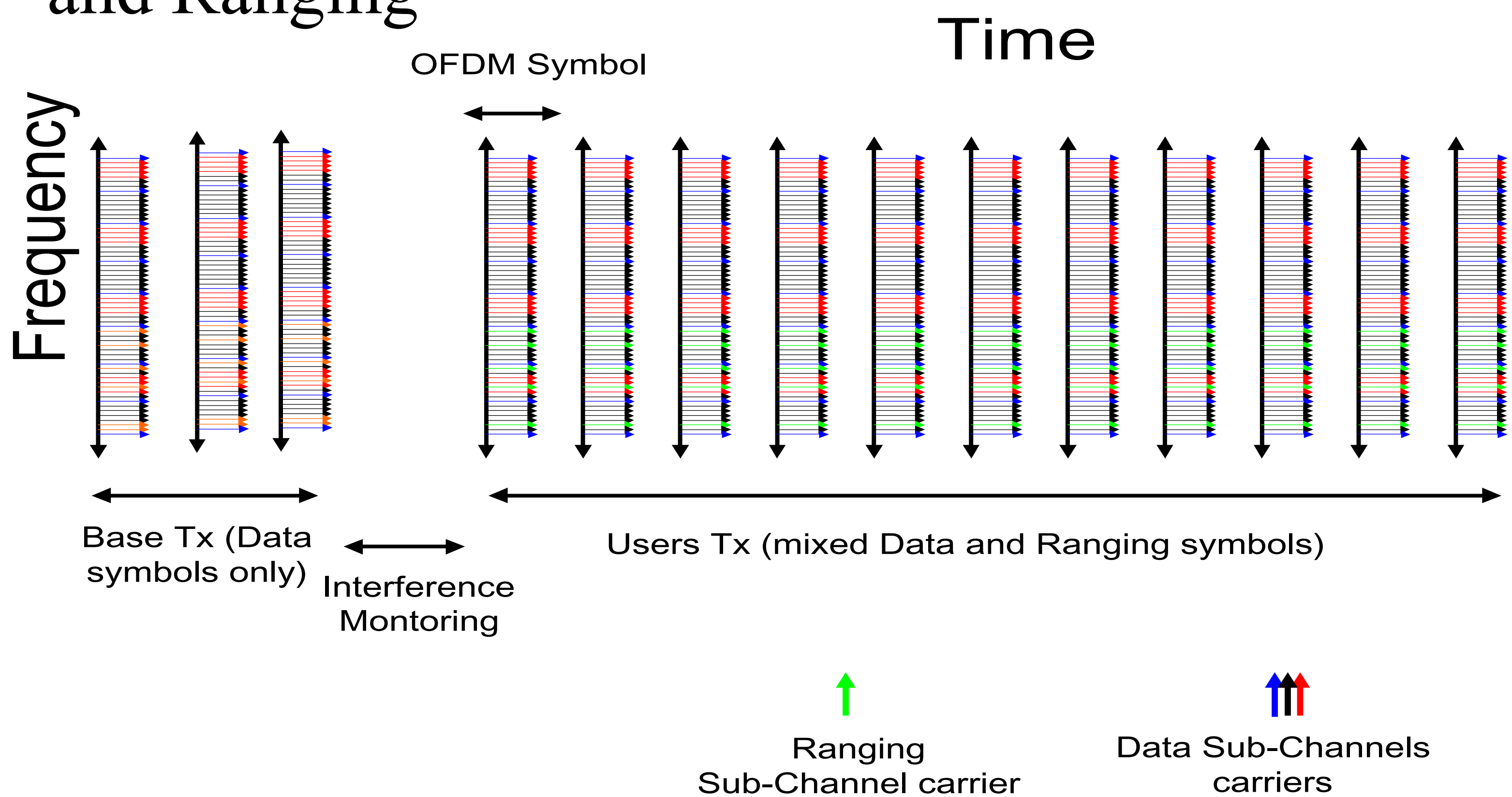
OFDMA Symbol Structure (cont.) with TDD/TDMA for the 256,64 modes

All Sub-Channels within a symbol are allocated for data or Ranging only



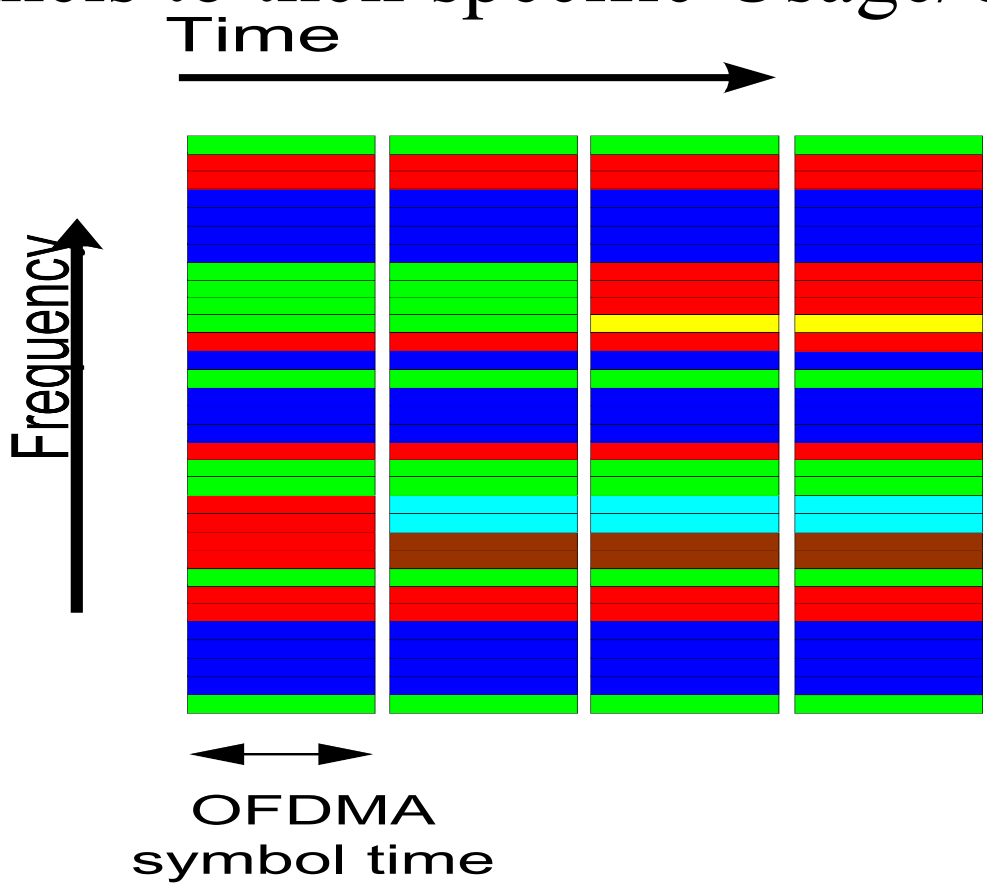
OFDMA Symbol Structure (cont.) with TDD/TDMA for the 1K, 2K modes

DS symbols are allocated for data only, US Sub-Channels within a symbol are allocated for data and Ranging

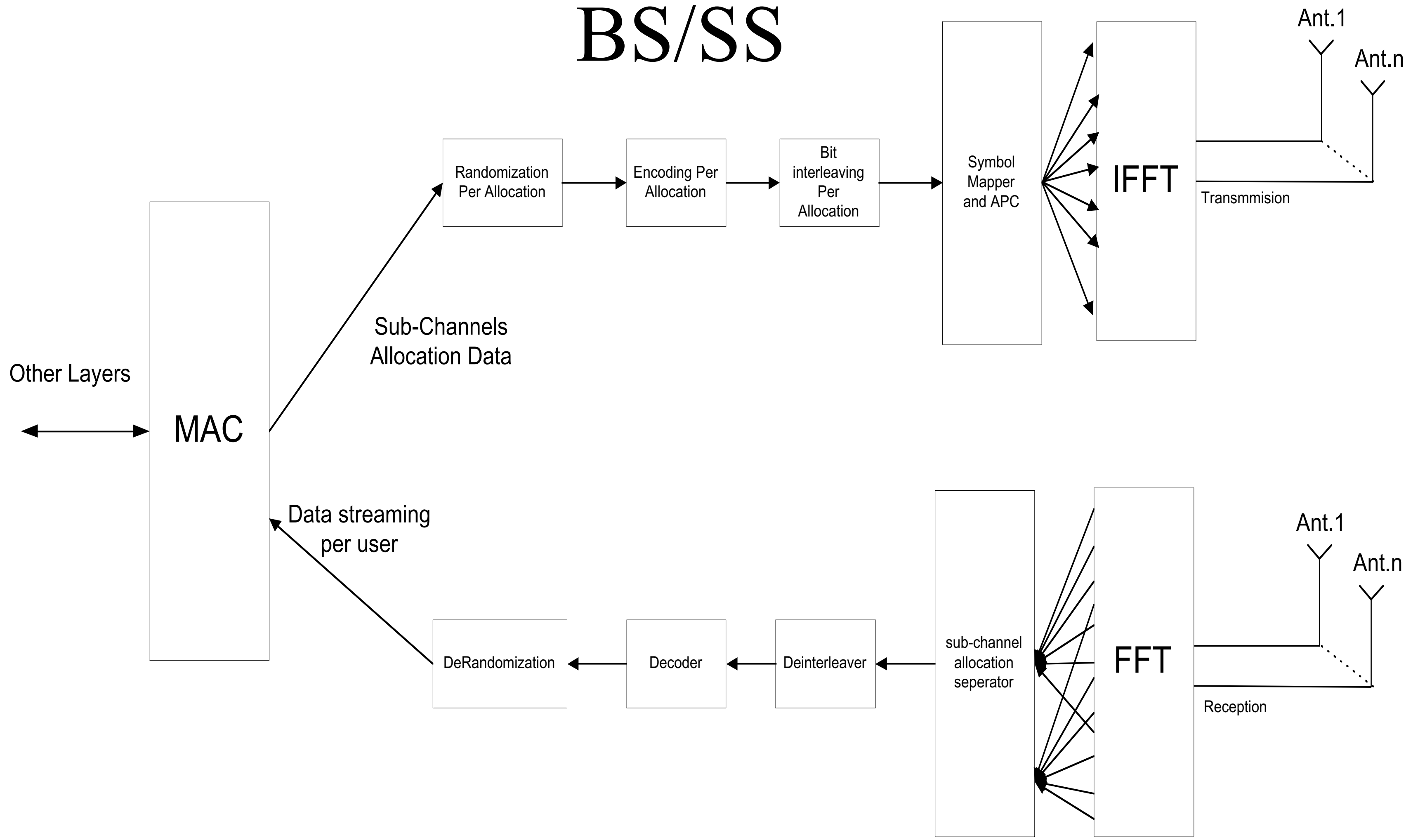


Down Stream OFDMA/TDMA - Principles

MAC Mapping maps the down stream Sub-Channels to their specific Usage/Users.



OFDMA(*) Transceiver Block Diagram BS/SS

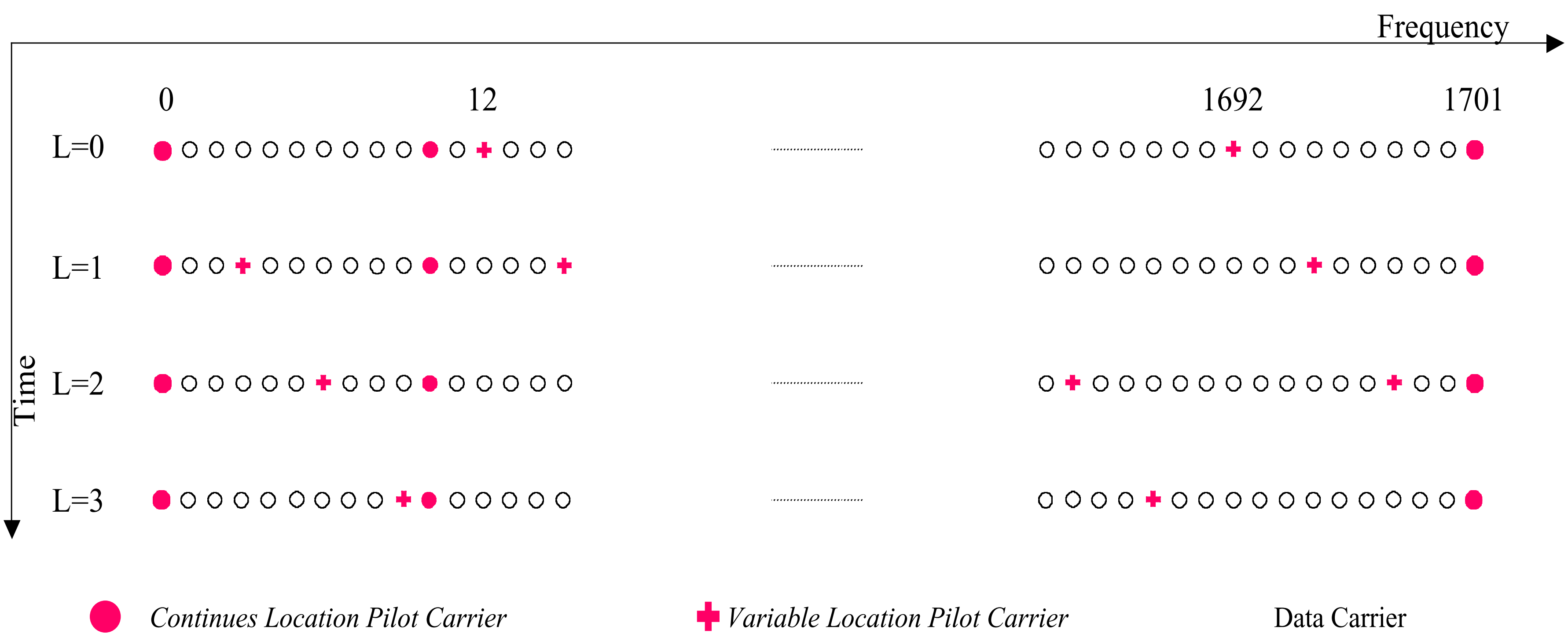


(*) If all Sub-Channels are allocated to one user then it is the case of regular OFDM

Down Stream Properties

2k, 1k mode — based on the DVB-T

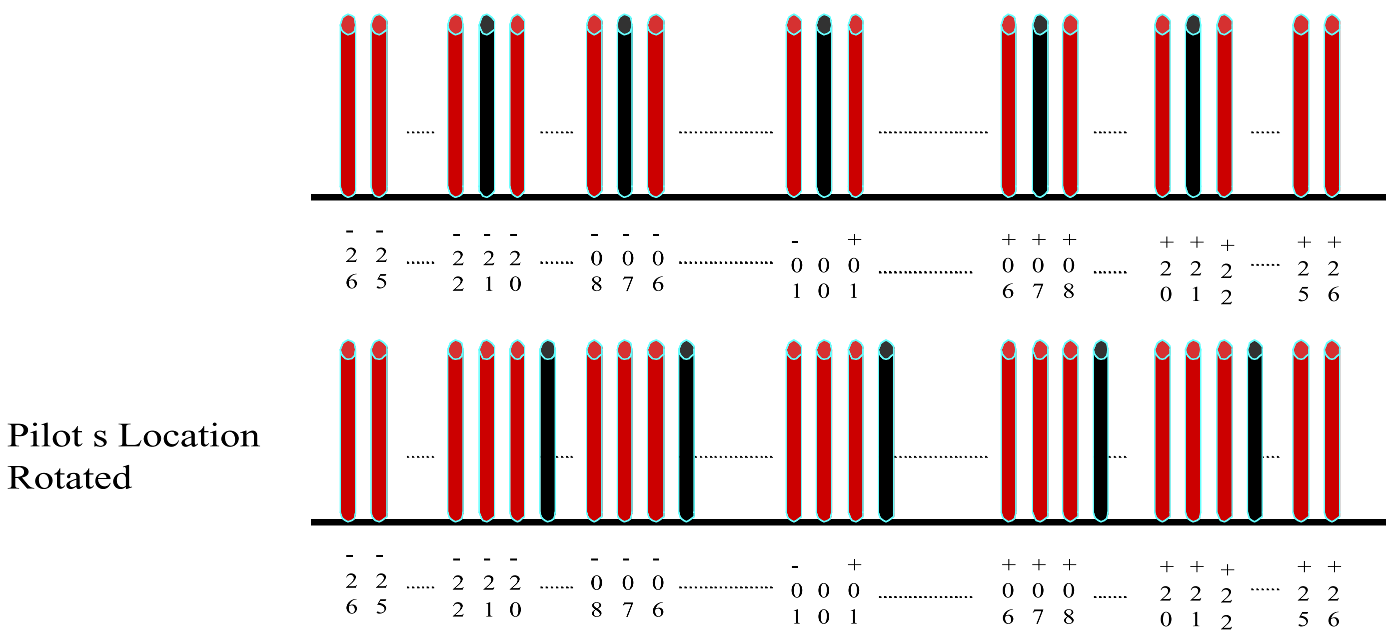
Continues and variable location pilots are spread all over the used spectrum. In OFDMA The data carriers are divided into Sub-Channels (48 data carriers each).



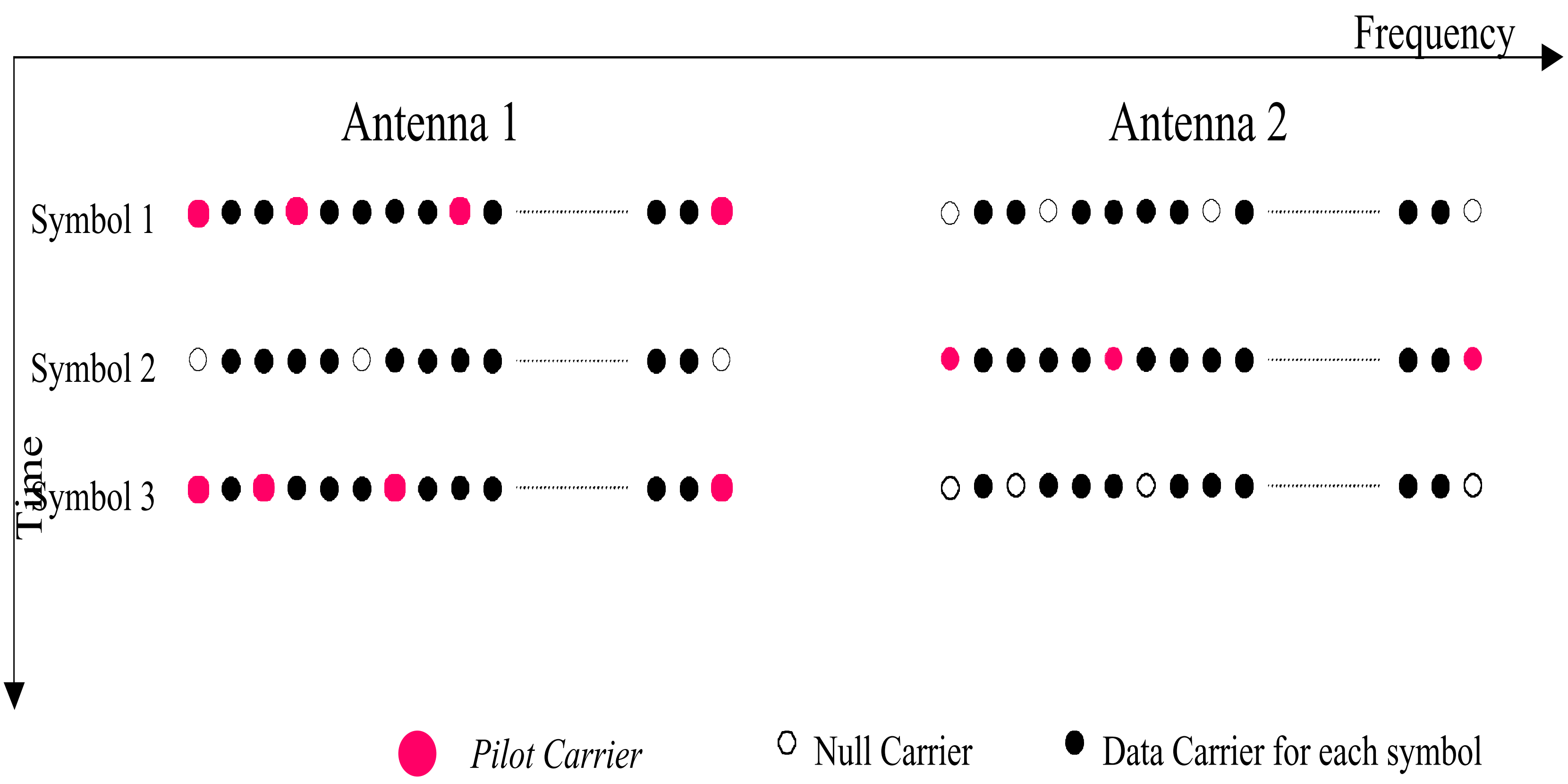
Sub-Channel structure

All spectrum used is divided to Sub-Channels. Every Sub-Channel contains 53 carriers (5 pilot carriers and 48 data carriers)

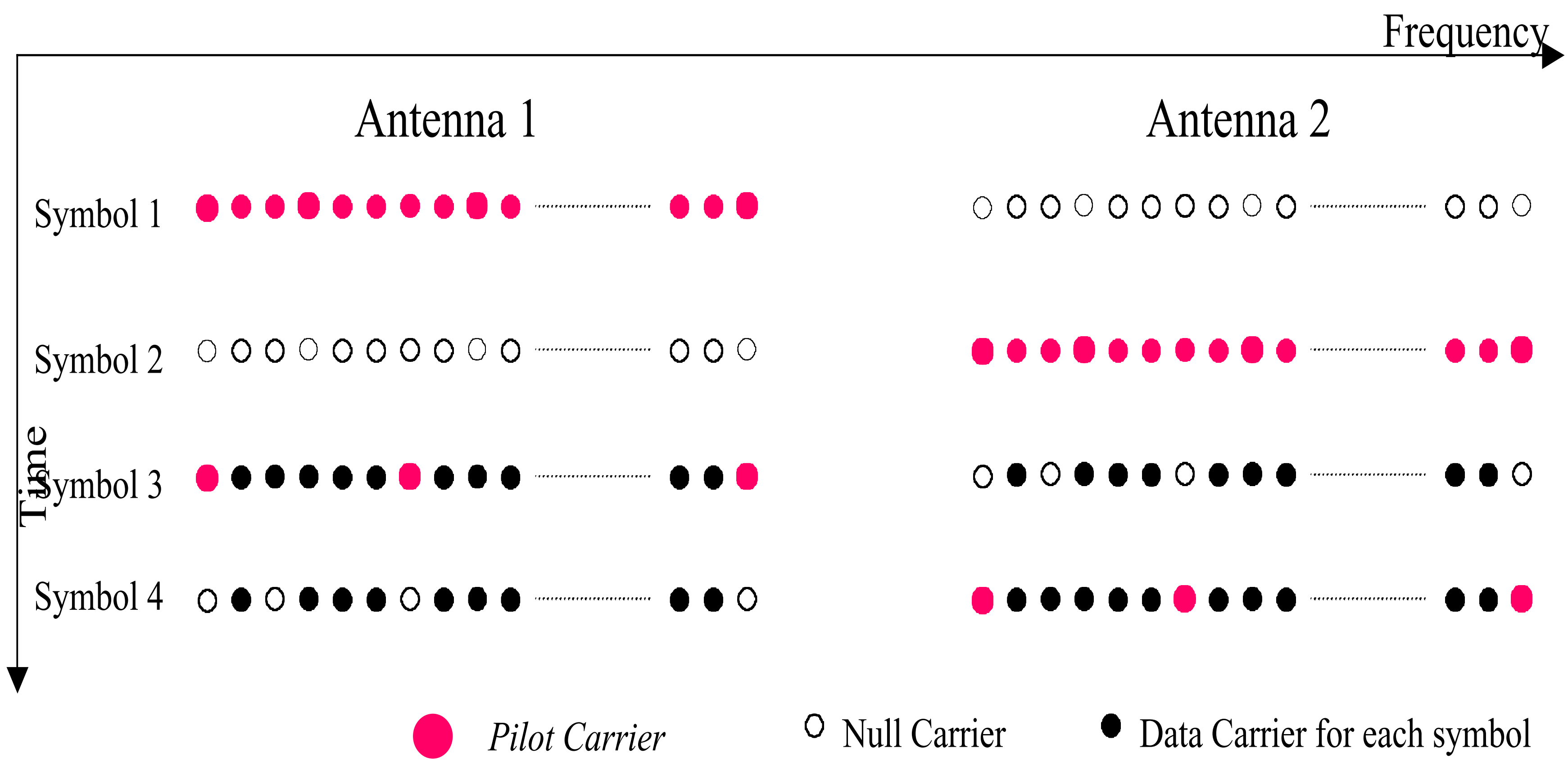
Sub-Channel Illustration



Space Time Coding (2k, 1k modes)

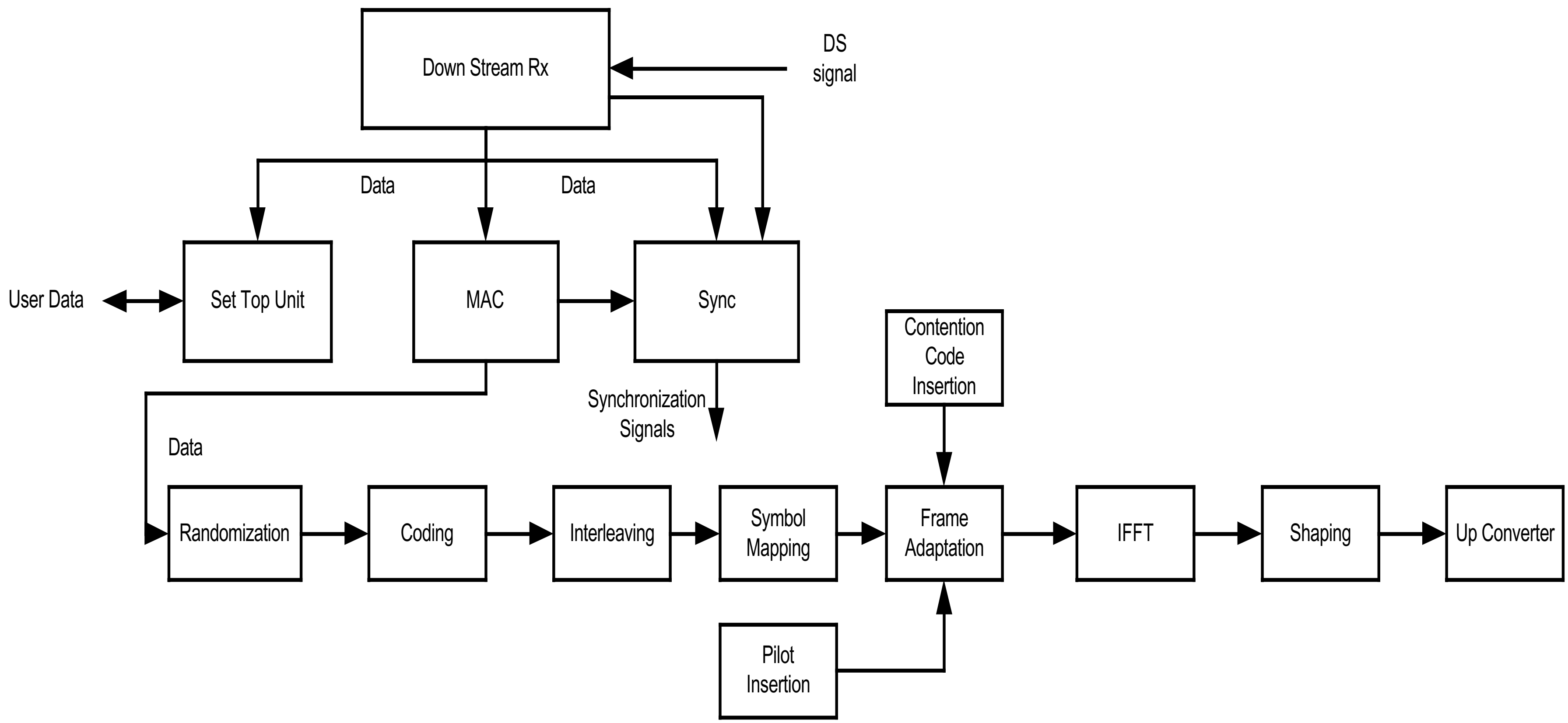


Space Time Coding (256, 64 modes)



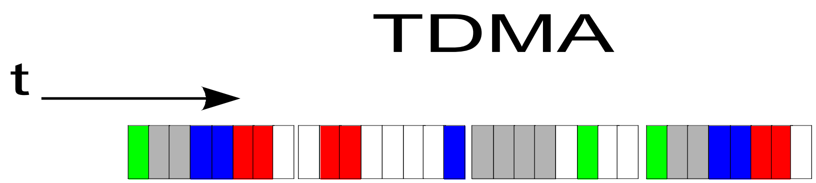
Up Stream Properties

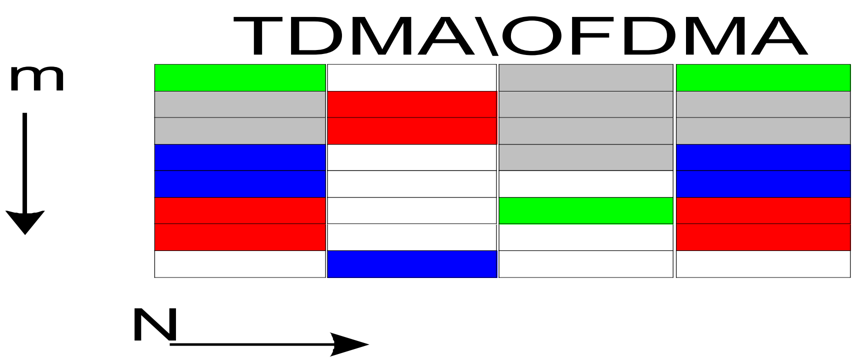
Tx Upstream Block Diagram



Up Stream OFDMA/TDMA - Principles

MAC Mapping stays in the same complexity level as for ordinary TDMA schemes. Elements of two dimensional mapping can be introduced for better performance.





$t = 32 * N + m$	2K
$t = 16 * N + m$	1K
$t = 4 * N + m$	256
$t = 1 * N$	64

Sub-Channel Details

The Sub-Channels are used for:

¥ Data transmission

¥ Maybe used for channel estimation

Number of Sub-Channels for each FFT size:

¥ 2k mode — 32 Sub-Channels→ 15 dB improvement

¥ 1k mode — 16 Sub-Channels→ 12 dB improvement

¥ 256 mode —4 Sub-Channels → 6 dB improvement

¥ 64 mode — 1 Sub-Channel (IEEE802.**1**a, HiperLAN2 structure) → 0 dB no improvement

Using CDMA like Synchronization

¥ The CDMA like synchronization is achieved by allocating one or several Sub-Channels for Ranging or fast bandwidth request purposes.

¥ Onto the Ranging Sub-Channels users modulate a Pseudo Noise (PN) sequence using BPSK modulation

¥ The Base Station detects the different sequences and uses the CIR that he derives from the sequences for:

—Time and power synchronization

—Decide on the user modulation and coding

—Bandwidth allocation

¥ Throughput —more the 85% (slotted ALOHA is 34%)

OFDMA System - Throughput

System Net Data Rates

The table was calculated for 3MHz channel, using the 2k mode.

Modulati on	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

Power Concentration and Anti-Jamming Processing Gain

Power Concentration and AJ

¥ In the Up Stream due to Sub-Channel allocation (53 carriers per Sub-Channel) a **15dB** gain for the 2k mode is achieved for one Sub-Channel allocation.

¥ In the Down Stream due to Sub-Channel allocation (53 carriers per Sub-Channel) a **10dB** gain can be achieved for one Sub-Channel busted (FAPC).

¥ This additional power gain enables better communication range, penetration into buildings, and a better coverage.

¥ This additional gain could be used for:

— Bigger cell radius

— Better coverage and availability

— Better capacity

— Chipper and smaller power amplifiers

— Simpler antennas

¥ OFDMA gives 15 dB anti-jamming processing gain against NB and BB

Power Concentration — Range Example

Estimating the cell radius for the system with the following parameters:

¥ 3MHZ channel Bandwidth

¥ 64QAM modulation

¥ One Sub-Channel transmission

¥ Receiver NF=4dB

¥ Assuming power emission of 30dBm

¥ using a 30¡ antenna at the SS and 60¡ at the BS

¥ Simple propagation model for LOS and NLOS

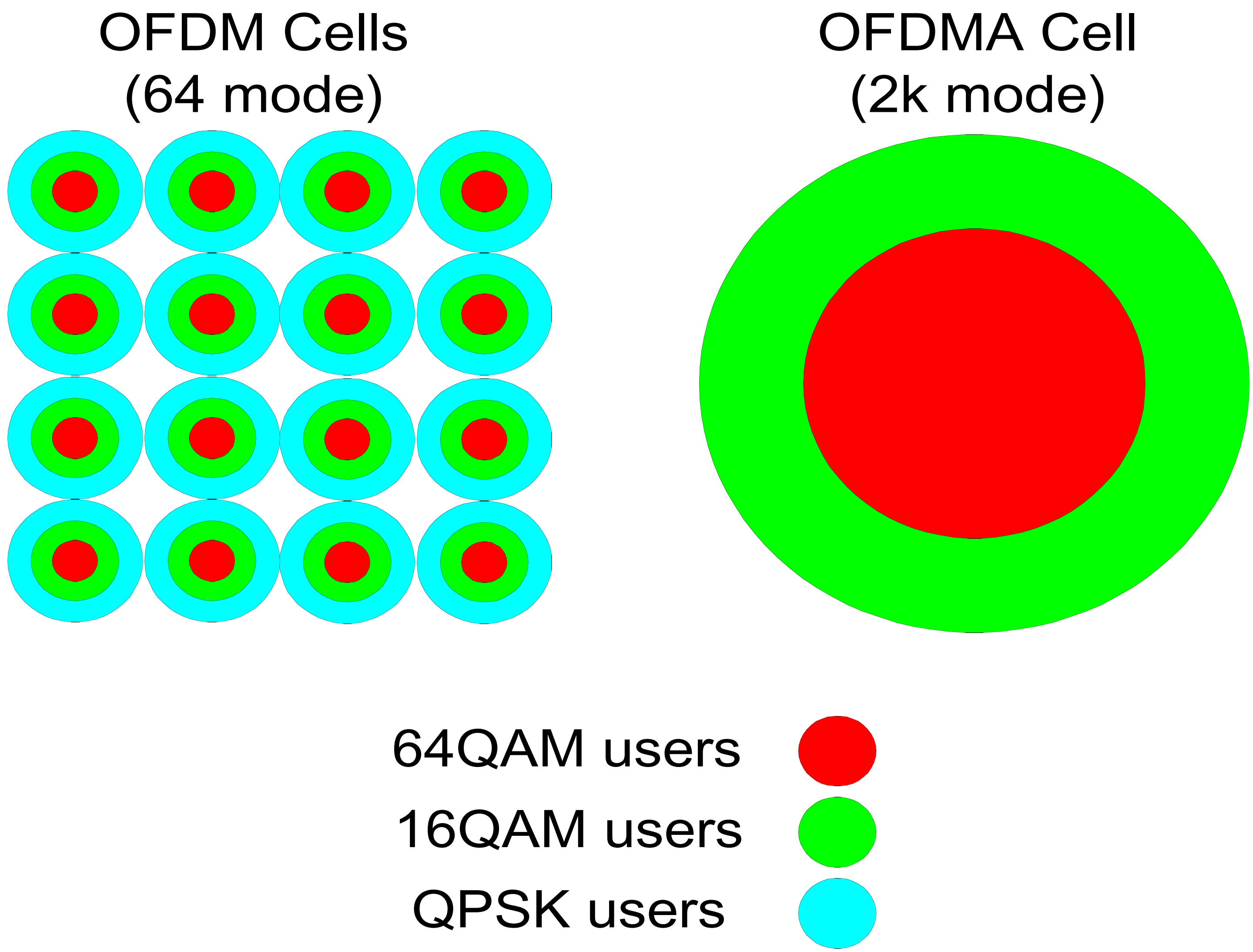
We get the following results:

64 OFDM: 4.8Km for LOS, 690m for NLOS

2k OFDMA: 26.9Km for LOS, 1.64km for NLOS

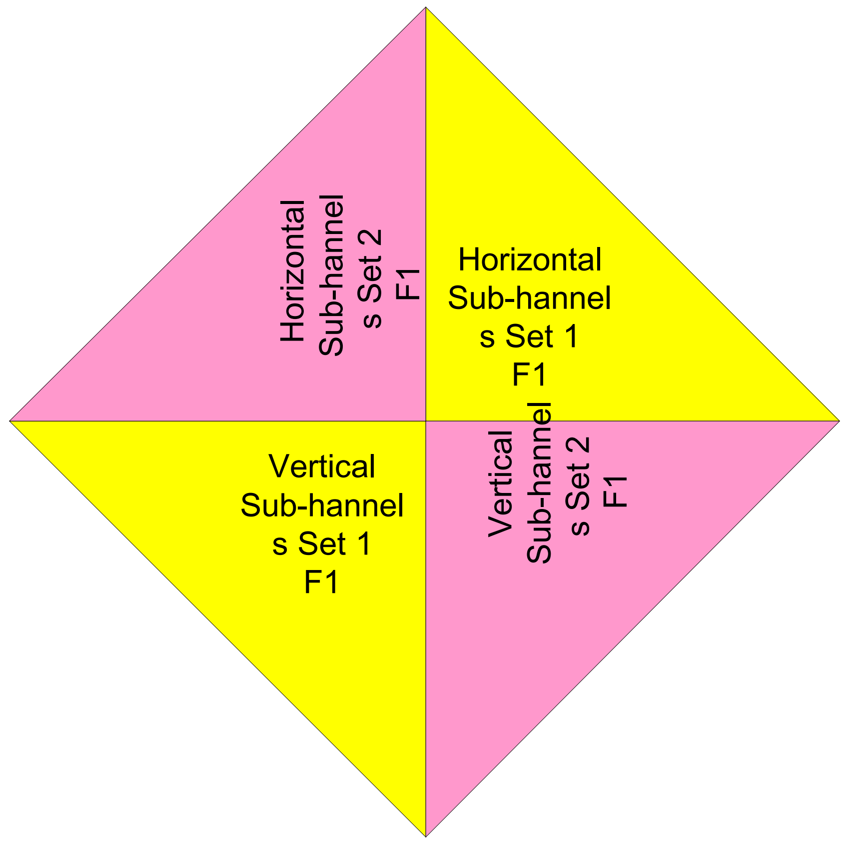
Cellular Deployment and Sectorization

LOS/NLOS Conditions - Coverage limited



Using a Reuse Factor of 1

By allocating different Sub-Channels to different sectors we can reach reuse factor of 1 with up to 12 sectors (changing the polarity enhances the performance)



Working with Different Interferers

¥ OFDMA has inherited anti-jamming capability !!

Working with Different Interferers

Partial Band Jamming and Coexistence with IEEE802.11a, HiperLAN2 systems —

¥ Interference detection combined with smart ECC, enabling erasures on disturbed carriers

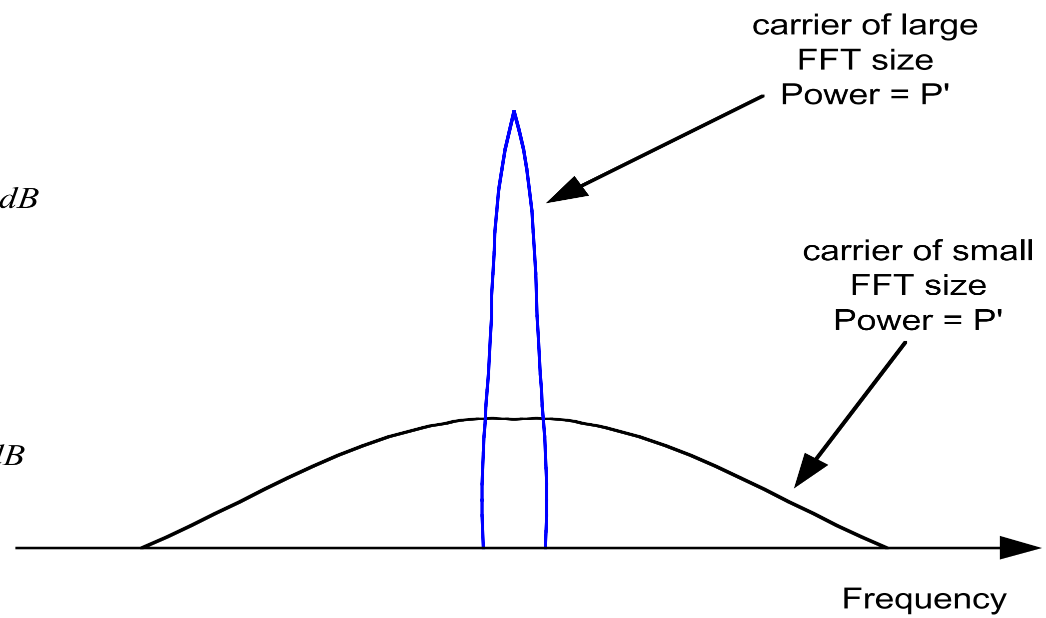
¥ The OFDMA (2k mode) has a 15dB processing gain against wide band Jammers or other 802.11a, HiperLAN2 interferers

for the large size FFT we get

$$\frac{S}{N} = OFDMA / 802.11a - Jammer = 15dB$$

for the Small size FFT we get

$$\frac{S}{N} = 802.11a / OFDMA - Jammer = 0dB$$



PAPR Reduction

PAPR Reduction

¥ Using shaping on the signal peaks

¥ Limiting the PAPR to a constant value by vector reduction

¥ Possibility to use some pilot carrier for PARP reduction

¥ Using two randomization sequence and switch between them in the transmitter if necessary

Other Enabled Features

Other Enabled features

¥ Antenna array (beam forming)

¥ Antenna Diversity (Base Station and Where needed Subscriber Station)

OFDMA System Summary

Advantages - Summary (1)

¥ 15 dB anti-jamming/interference processing gain

¥ Averaging interference's from neighboring cells, by using different basic carrier permutations between users in different cells.

¥ Interference s within the cell are averaged by using allocation with cyclic permutations.

¥ Enables orthogonality in the uplink by synchronizing users in time and frequency.

¥ Enables Multipath mitigation without using Equalizers and training sequences.

¥ Enables Single Frequency Network (SFN) coverage, where coverage problem exists and gives excellent coverage.

Advantages - Summary (2)

- Enables spatial diversity by using antenna diversity at the Base Station and possible at the Subscriber Unit.
- Enables adaptive modulation for every user QPSK, 16QAM and 64QAM
- Enables adaptive carrier allocation in multiplication of 53 carriers (one Sub-Channel) up to full Symbol capacity
- Gives Frequency diversity by spreading the Sub-Channel carriers all over the used spectrum.
- Gives Time diversity by optional interleaving of Sub-Channels in time.
- Time Space Coding for better performance and channel handling

Advantages - Summary (3)

- Using the cell capacity to the outmost by adaptively using the highest modulation a user can use for the uplink, this is allowed by the gain added when less carriers are allocated (**15dB** gain for the 2k mode), therefore gaining in overall cell capacity.
- Reaching users with higher modulation and capacity in the down Stream by power concentration on specific Sub-Channels at the down Stream (up to **10dB** more gain on a Sub-Channel) using FAPC.
- The power gain can be translated to distance 2.5 times the distance for R^4 (NLOS) and 5.5 time for R^2 (LOS).
- Enabling the usage of Indoor Omni Directional antennas for the users.
- MAC complexity is the same as for TDMA systems.

Advantages - Summary (4)

¥ Allocating carrier by OFDMA/TDMA strategy.

¥ Using Small burst per user with granularity of 48 symbols for better statistical multiplexing and smaller jitter.

¥ User OFDM symbol with large FFT size gives better immunity to channel multipath.

¥ Using sophisticated ECC schemes to the outmost by error detection of disturbed frequencies.

¥ Gives a reuse factor of 1(reuse the frequency in every cell and sector)

Advantages - Summary (5)

¥ Efficient Methods for PARP reduction

¥ DFS used by the Base Station

¥ Antenna diversity

¥ Antenna array could be supported

Comparison Matrix

Comparison Matrix (1)

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.

Comparison Matrix (2)

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.

Comparison Matrix (3)

9	Robustness to interference	OFDMA has inherent anti-jamming capability. he 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. 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: Æ Directional antennas where it is appropriate (to reduce interference to other users) Æ Directional antennas at the user side Æ Diversity antennas at the BS and at the SS (where appropriate). Æ Space/Time Coding are fitted very well to OFDMA/OFDMA technology

Comparison Matrix (4)

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: Æ Diversity antennas at the BS and at the SS (where appropriate). Æ Space/Time Coding Æ Time Diversity of the signal Æ 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.

Comparison Matrix (4)

12	Support of advanced antenna technique	The OFDMA technique supports all the advanced coding and antenna techniques as: ° Æ Directional antennas where it is appropriate (to reduce interference to other users) Æ Diversity antennas at the BS and at the SS (where appropriate). Æ Space/Time Coding are fitted very well to OFDM/OFDMA technology Æ 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).