Initial OFDMA proposal for the 802.16.4 PHY layer

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Purpose:
This proposal should be used as the baseline for the PHY specification of the TG4.

OFDMA PHY proposal for TG4

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Contents

PHY Planning Issues

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

Guidelines for PHY Planning

Remainder:

¥ Spectrum mask of 802.11a have been chosen

¥ 16MHz channel bandwidth

¥ Larger FFT s gives better multipath handling due to their longer GI

¥ Larger FFT s gives better spectral masks

¥ Less throughput overhead (GI) for larger FFT s

¥ OFDMA concept has many advantages

OFDM FFT Sizes Supported

Using a 16MHz bandwidth the next table shows the different GI for different FFT sizes

(*recommend modes)

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

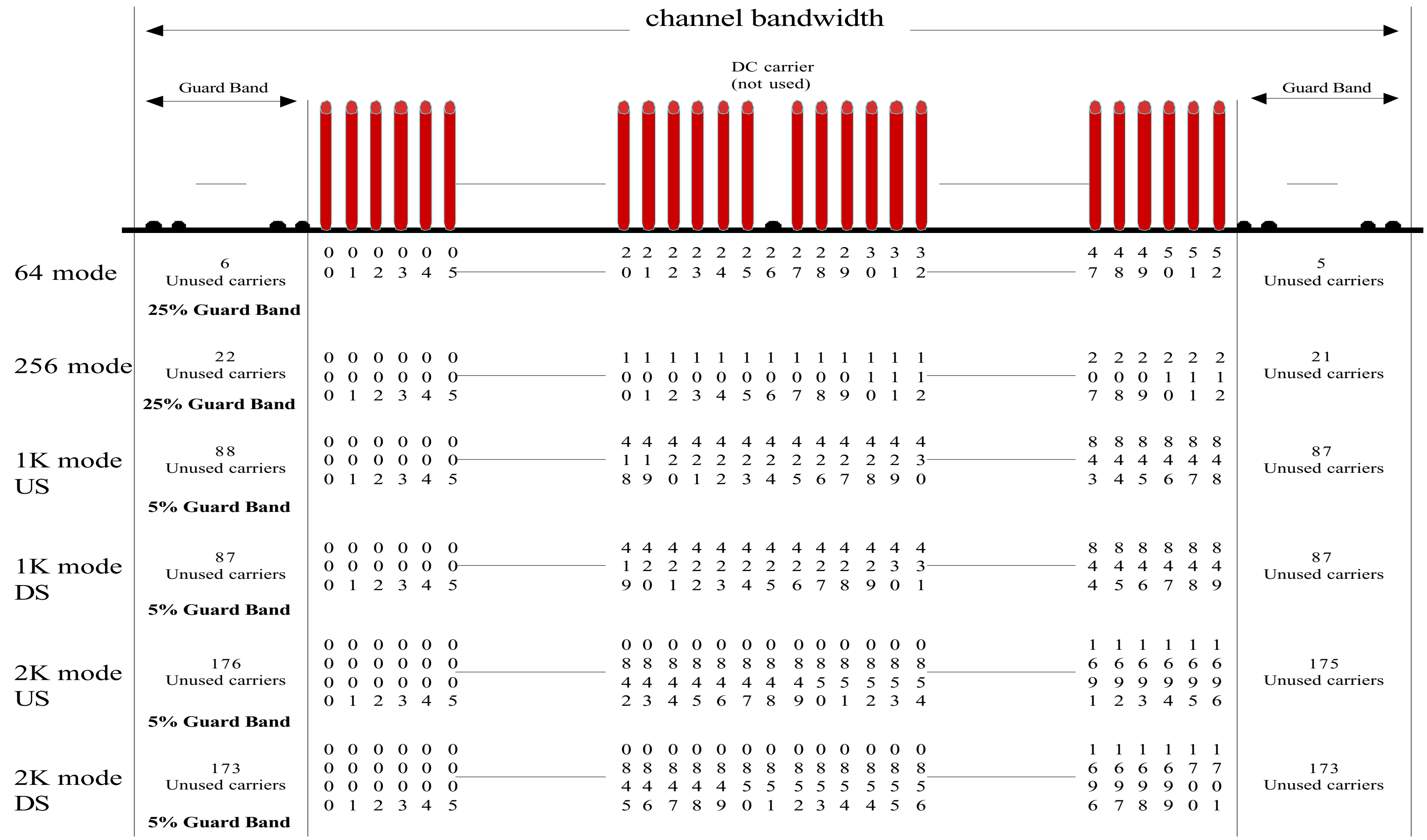
OFDM FFT Size Planning

- ¥ Remember, Larger FFT size give longer GI and better multipath handling !!!!
- ¥ Smaller granularity for each user, gives better throughput.
- ¥ Allocation of high data rates have better multiplexing gain

OFDMA Symbol Structure

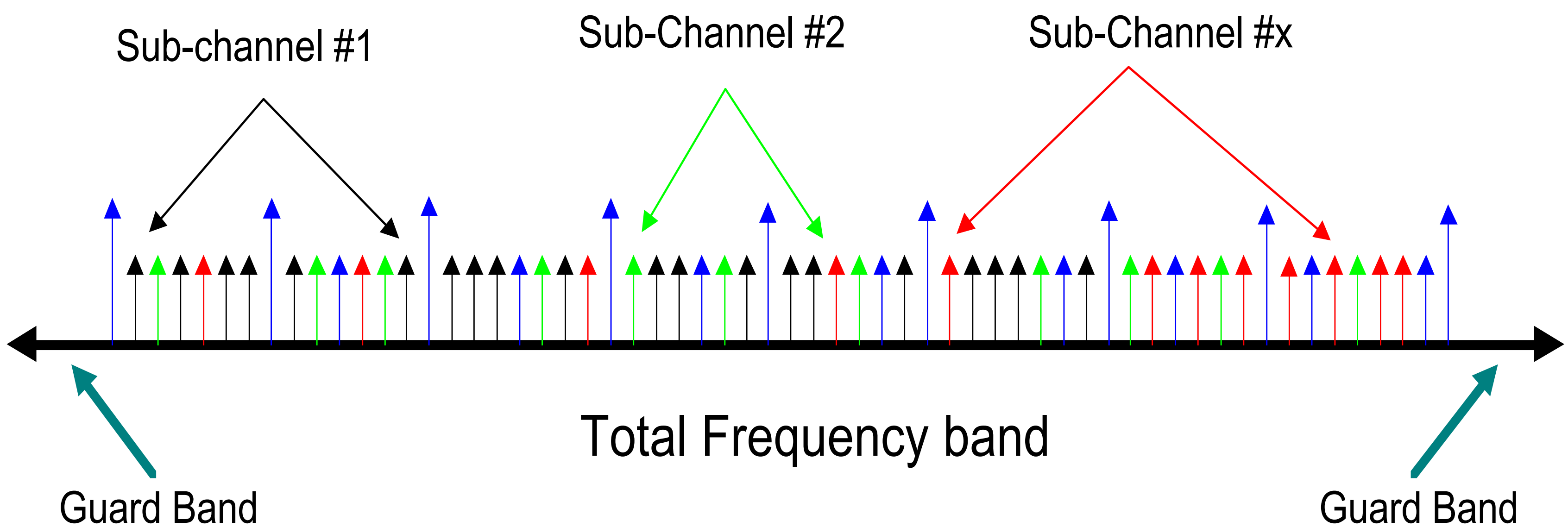
OFDMA symbol structure

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



OFDMA symbol structure

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



Using Special Permutations for Carrier Allocation

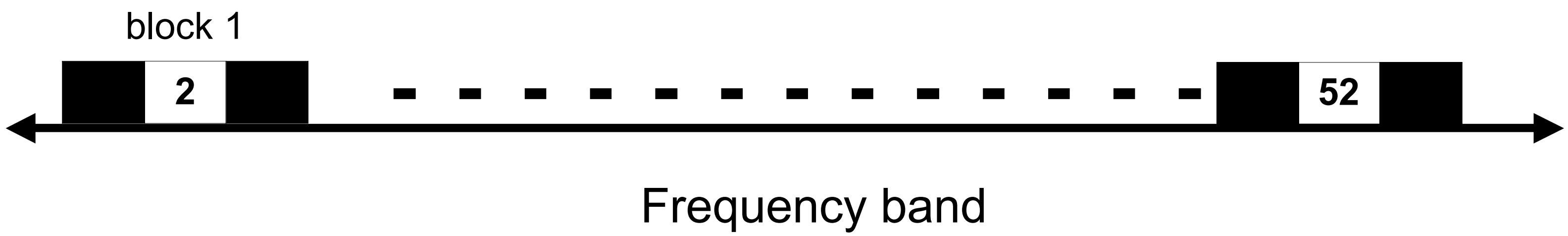
All usable carriers are divided into 53 carrier groups named basic group, each main group contains several carrier (depending on the mode used):

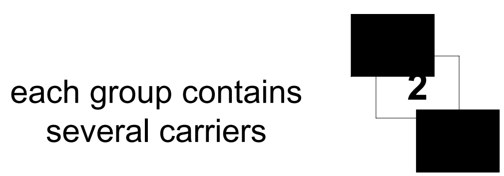
¥ 32 carriers for the 2k mode

¥ 16 carriers for the 1k mode

¥ 4 carriers for the 256 mode

¥ 1 carrier for the 64 mode (like 802.11a/Hiperlan2)





Using Special Permutations for Carrier Allocation

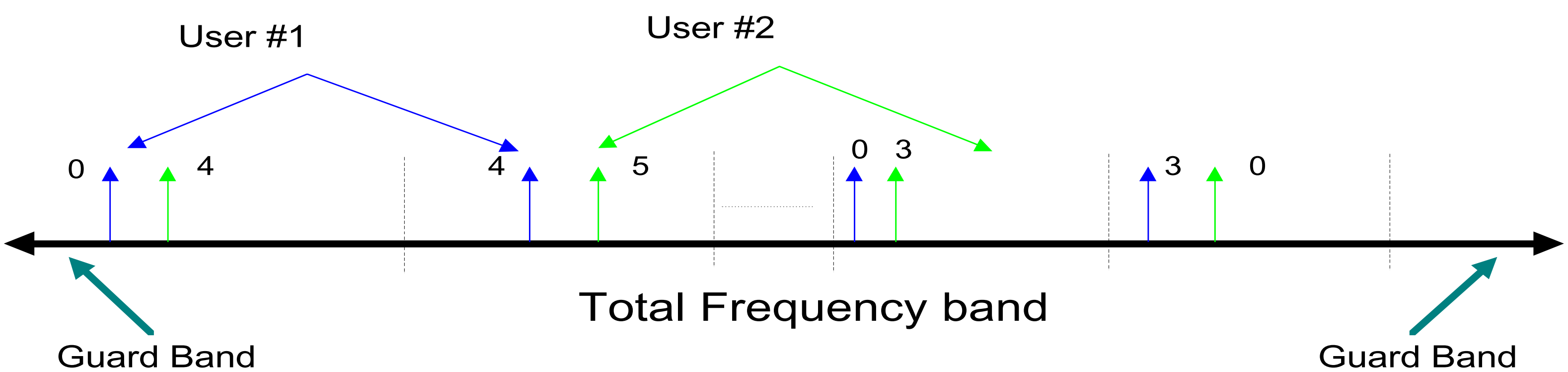
Carriers are allocated by concatenating a basic series, and cyclic permutations of it, for example (1k mode):

¥ 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



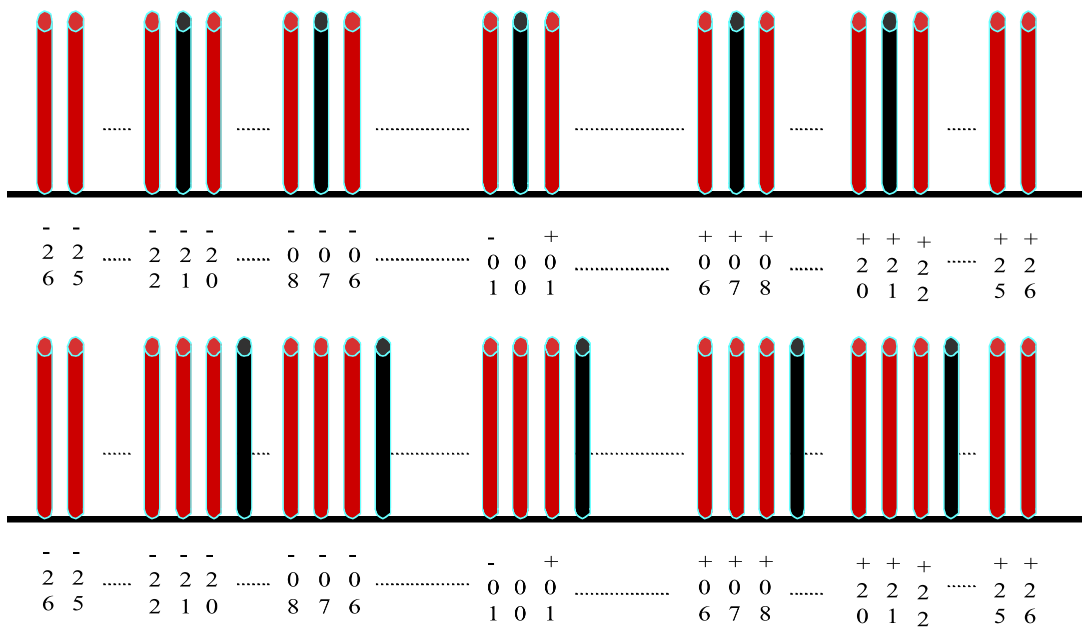
User 1 = 0 ,4 ,5 , 12, 10, 13, 1, 11, 3, 15, 14, 7, 9, 6 ....0, 3
User 2 = 4 ,5 , 12, 10, 13, 1, 11, 3, 15, 14, 7, 9, 6, 2....3, 0

Sub-Channel structure

Every Sub-Channel contains 53 carriers (5 pilot carriers and 48 data carriers)

Sub-Channel Illustration

Pilot s Location Rotated



Sub-Channel Details

The Sub-Channels are used for:

¥ Data transmission (DS and US)

¥ CDMA based Ranging and fast bandwidth request (US only)

Number of Sub-Channels for each FFT size:

¥ 2k mode — 32 Sub-Channels

¥ 1k mode — 16 Sub-Channels

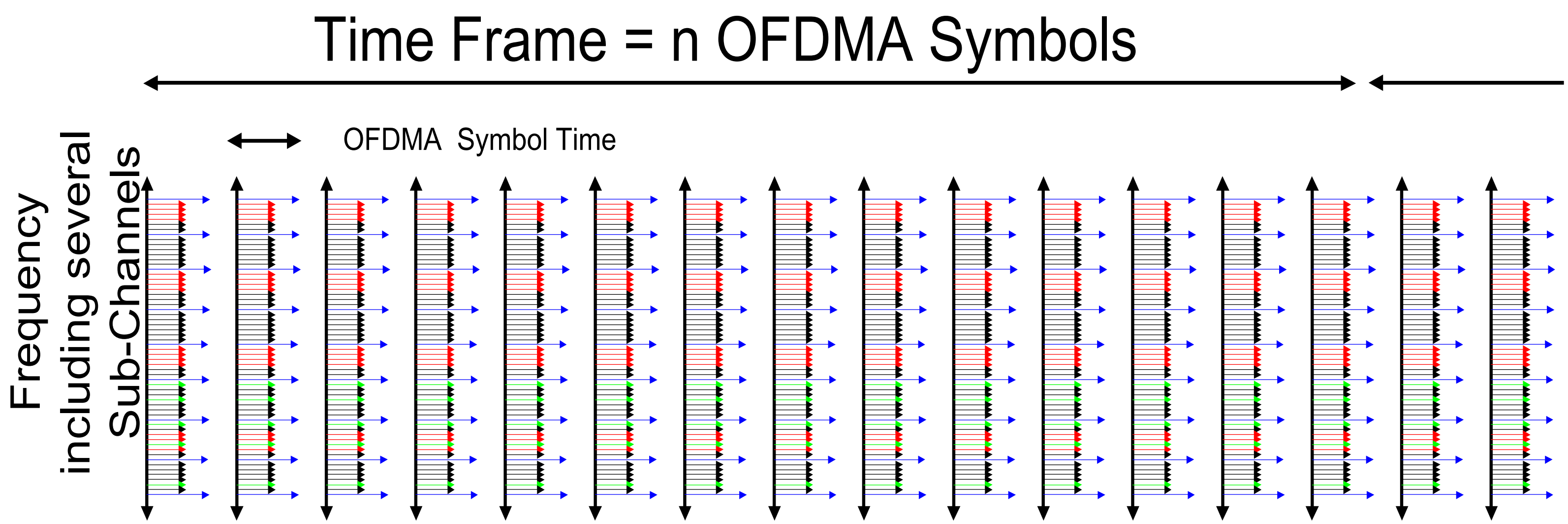
¥ 256 mode —4 Sub-Channels

¥ 64 mode — 1 Sub-Channel (IEEE802.**1**a, HiperLAN2 structure)

System Properties and Access Methods

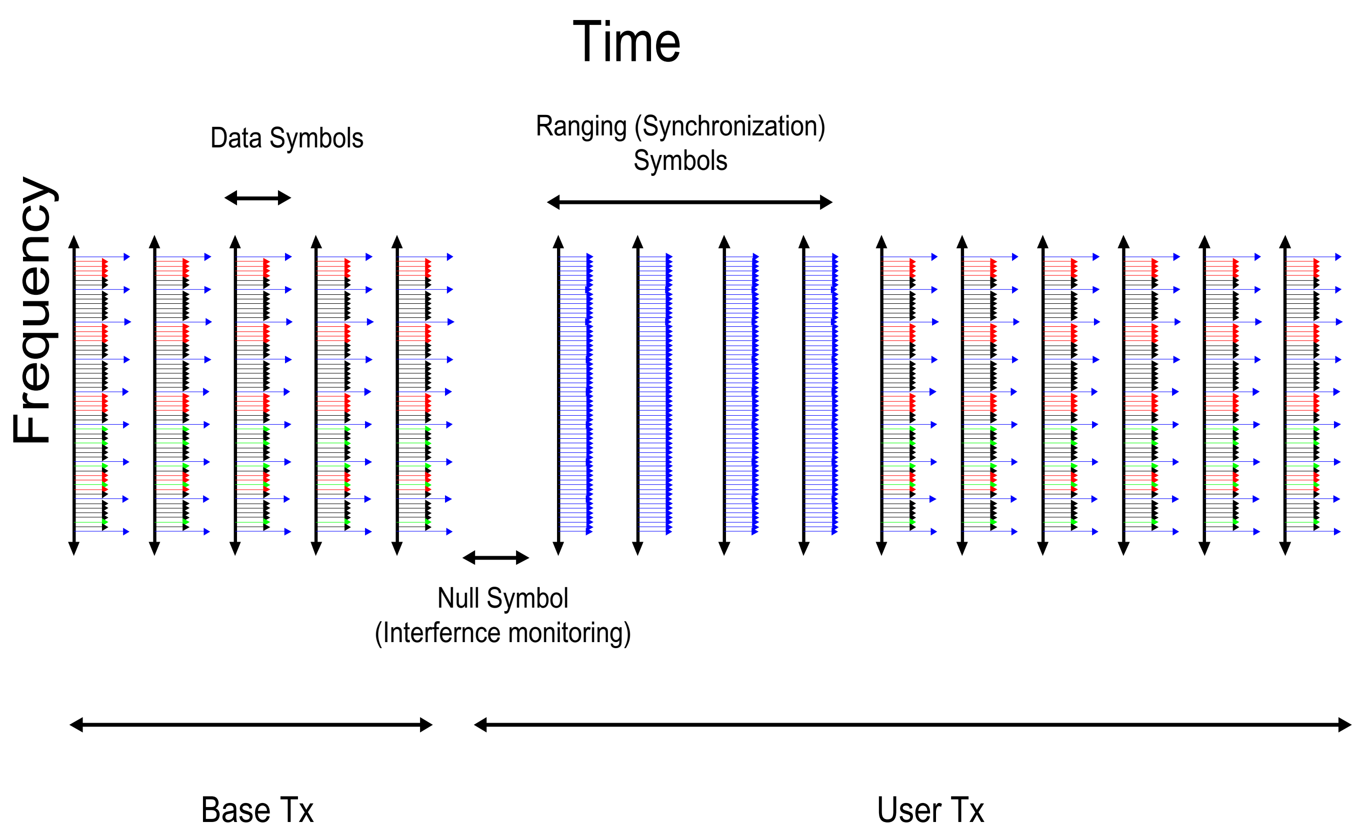
OFDMA/TDMA - Principles

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



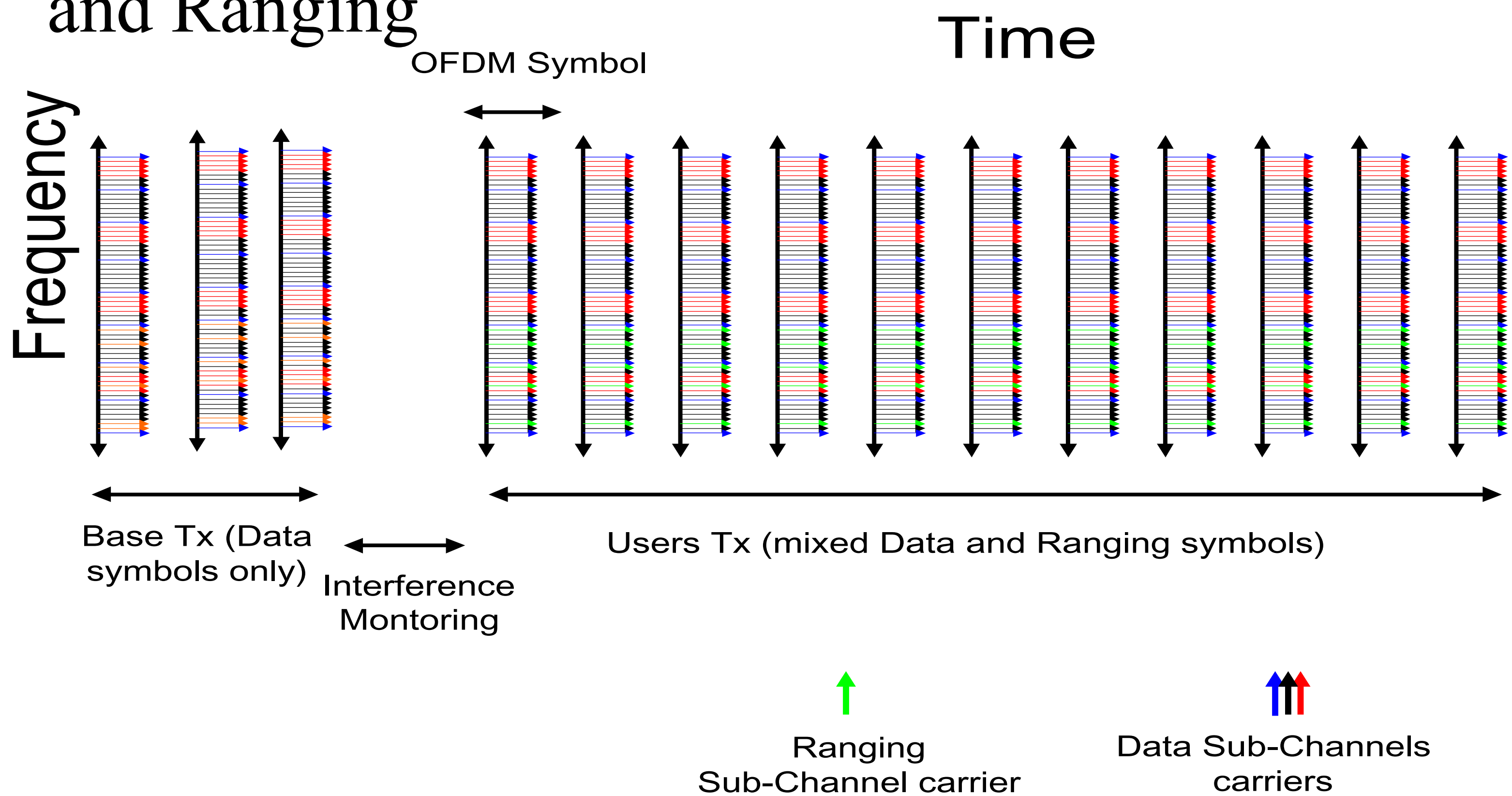
Access method for the 256, 64 modes

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

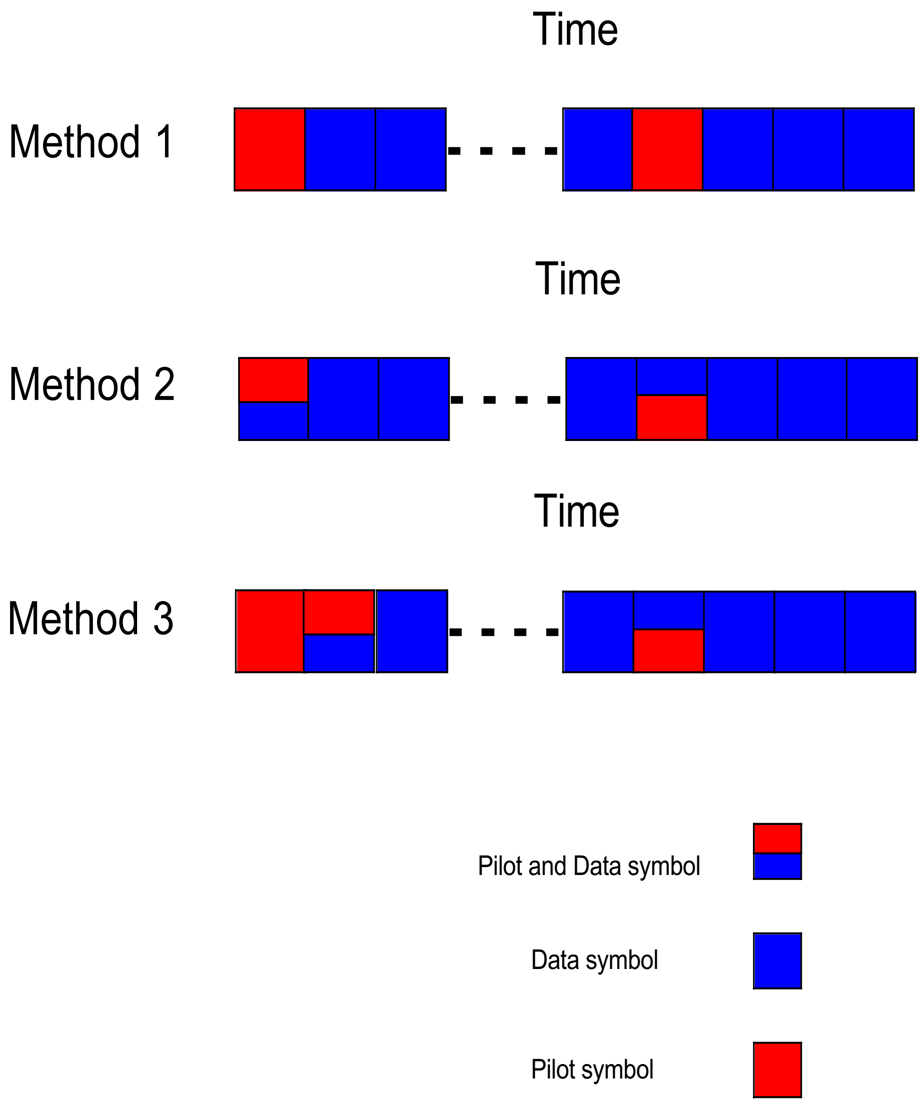


Access method for the 2k, 1k modes

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



Transmission Framing



There are 3 methods for transmission framing, each allows a different estimation method (using method 1 with the 64 mode is similar to the IEEE802.11a, HiperLAN2 framing)

Adaptive features

¥ FFT size setting

¥ Adaptive FEC

¥ Adaptive Modulation

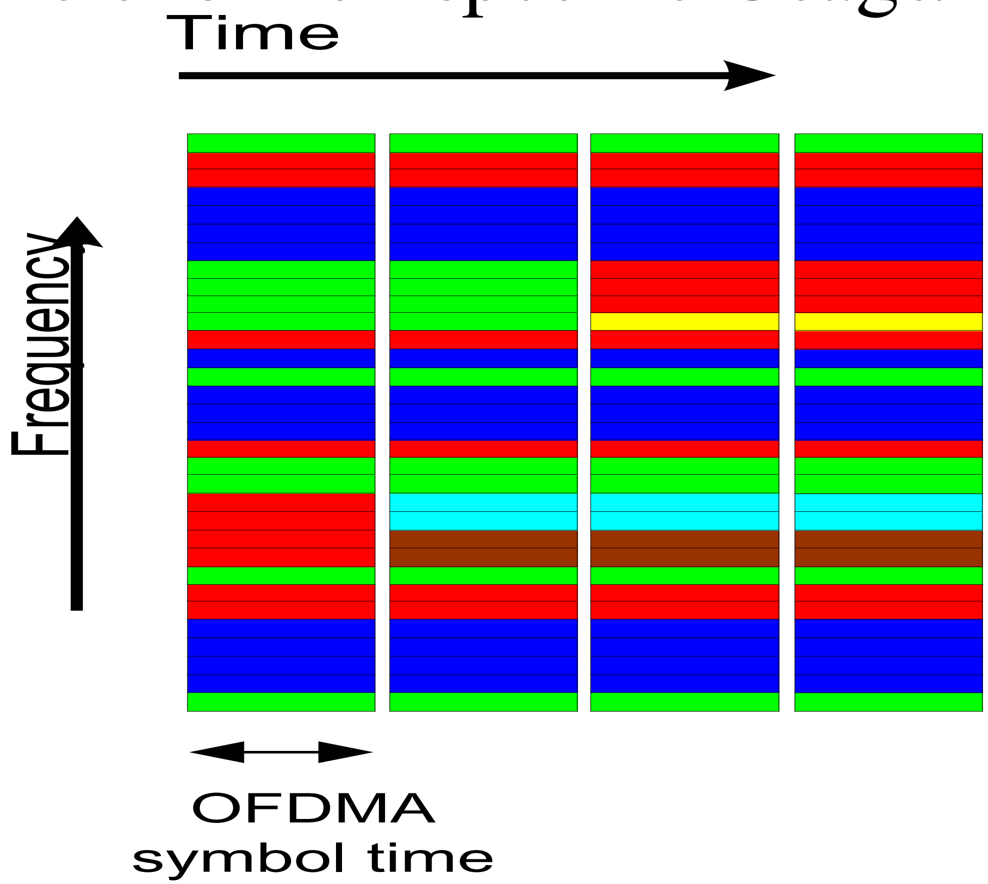
¥ Adaptive Bandwidth per Allocation (by using adaptive Sub-Channel Allocation)

¥ Power administration (FAPC)

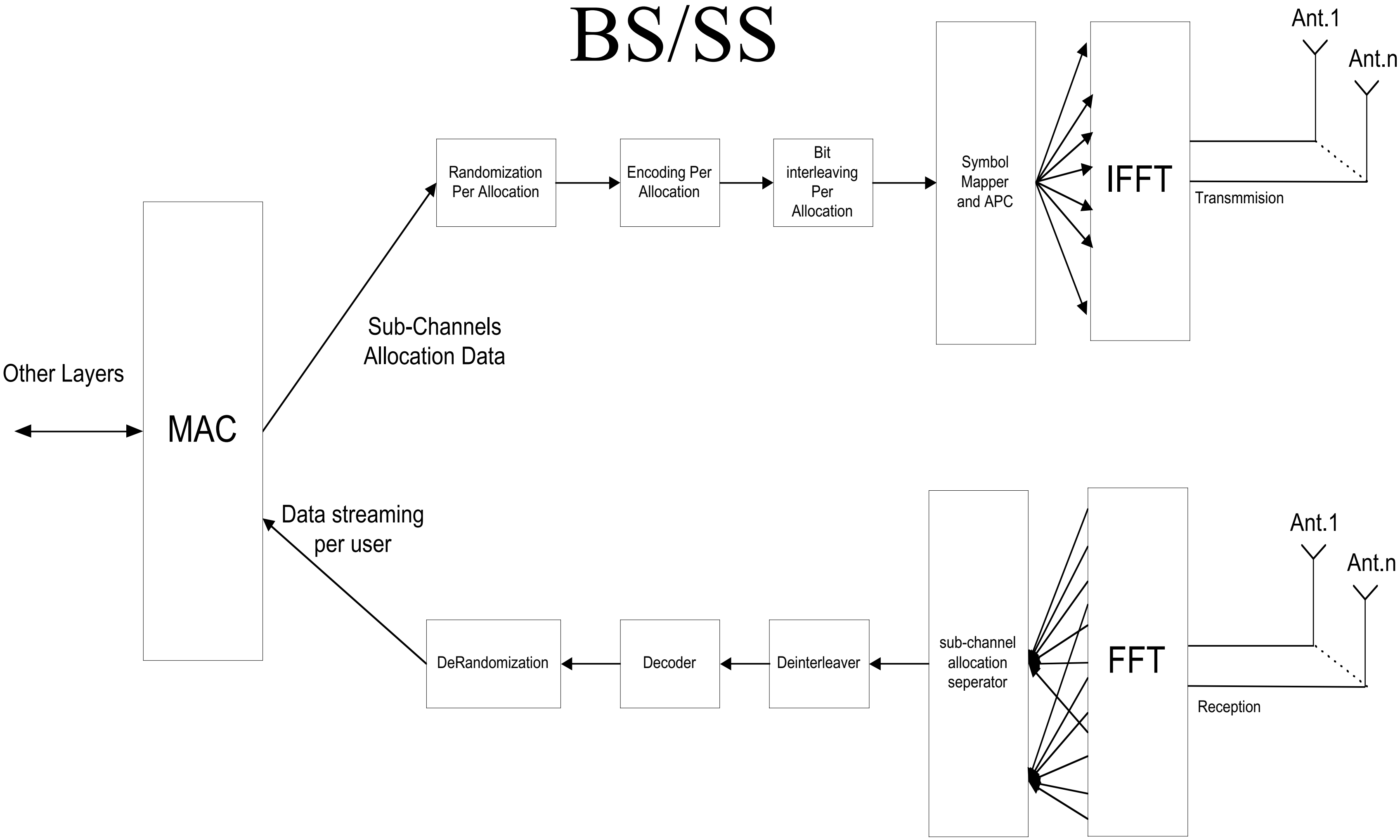
Down Stream Properties

Down Stream OFDMA/TDMA - Principles

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



OFDMA(*) Transceiver Block Diagram BS/SS

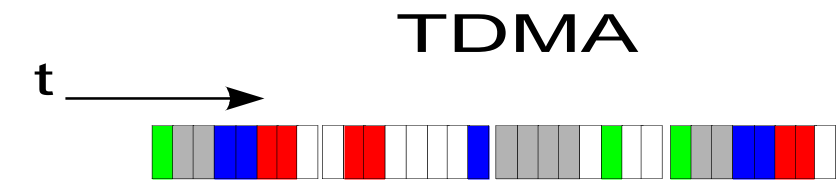


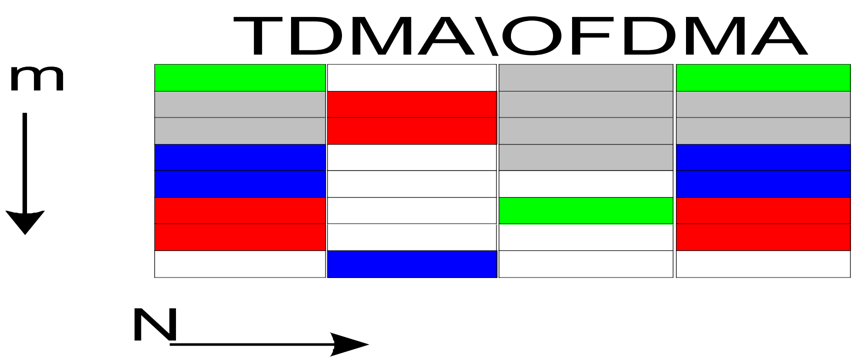
(*) If all Sub-Channels are allocated to one user then it is the case of regular OFDM

Up Stream Properties

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

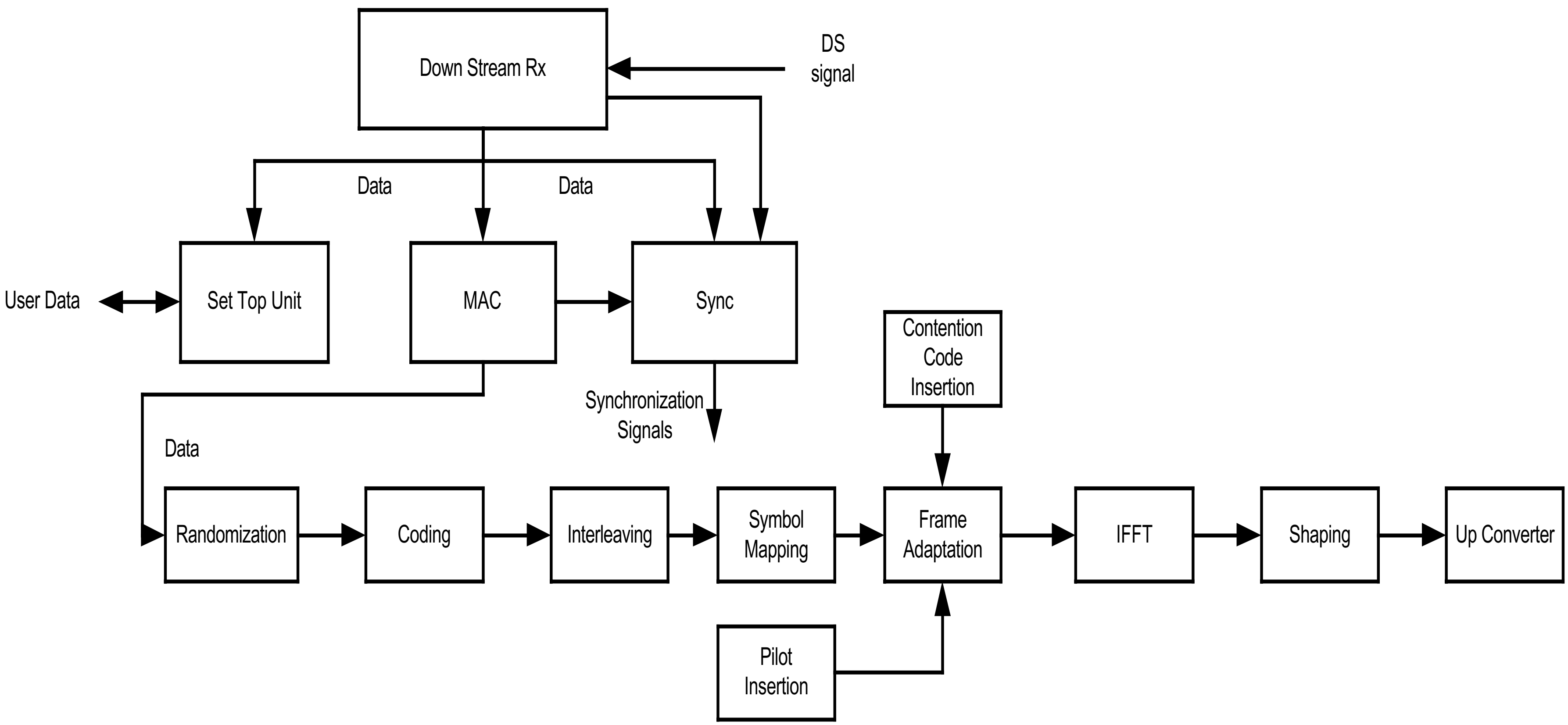
$t = 4 * N + m$ 256

$t = 1 * N$ 64

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

Up Stream Block Diagram



OFDMA System - Throughput

System Throughput

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

Power Concentration

Power Concentration

- 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

Power Concentration - Example

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

¥ 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

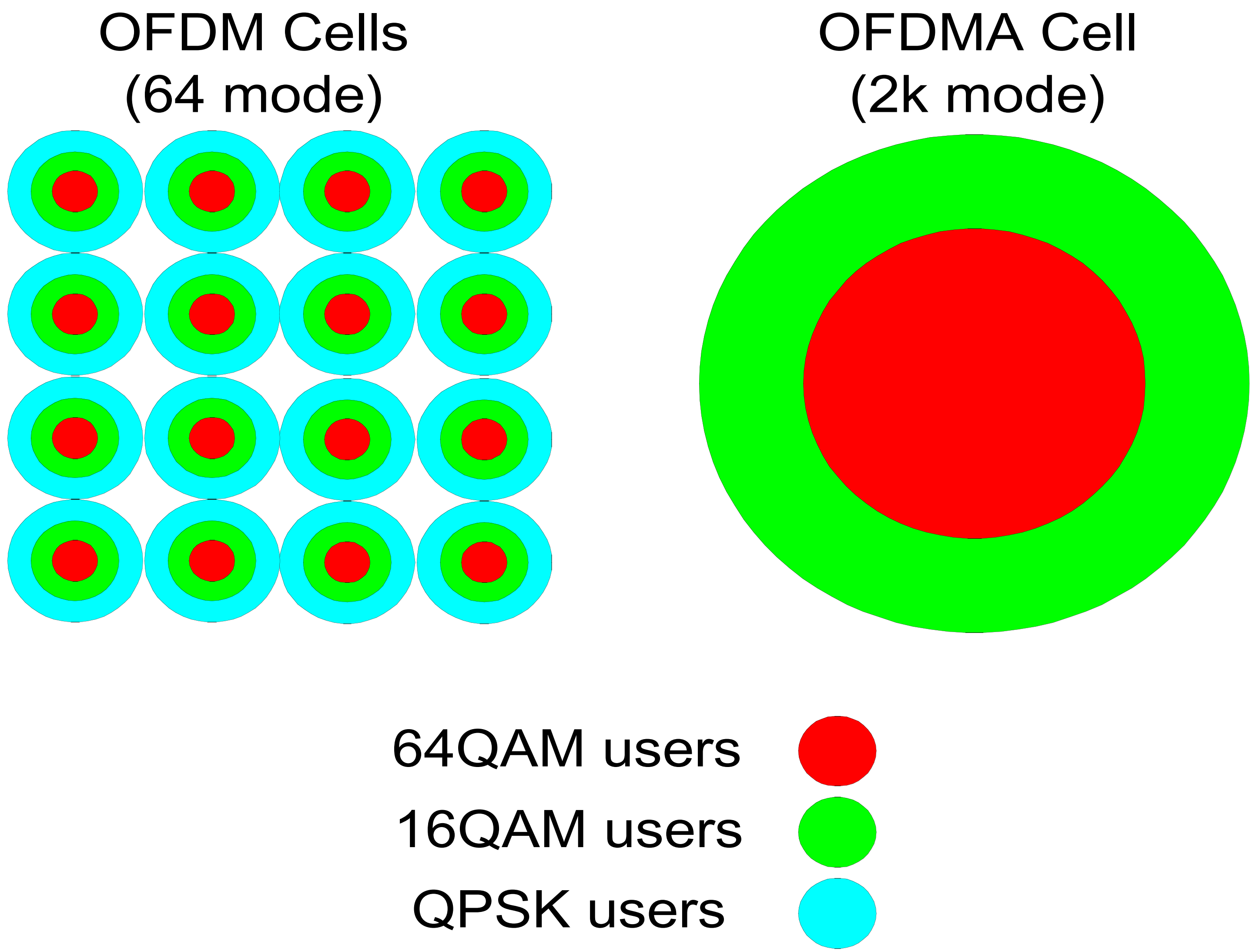
We get the following results:

64 OFDM: 2Km for LOS, 450m for NLOS

2k OFDMA: 11.6Km for LOS, 1.1km for NLOS

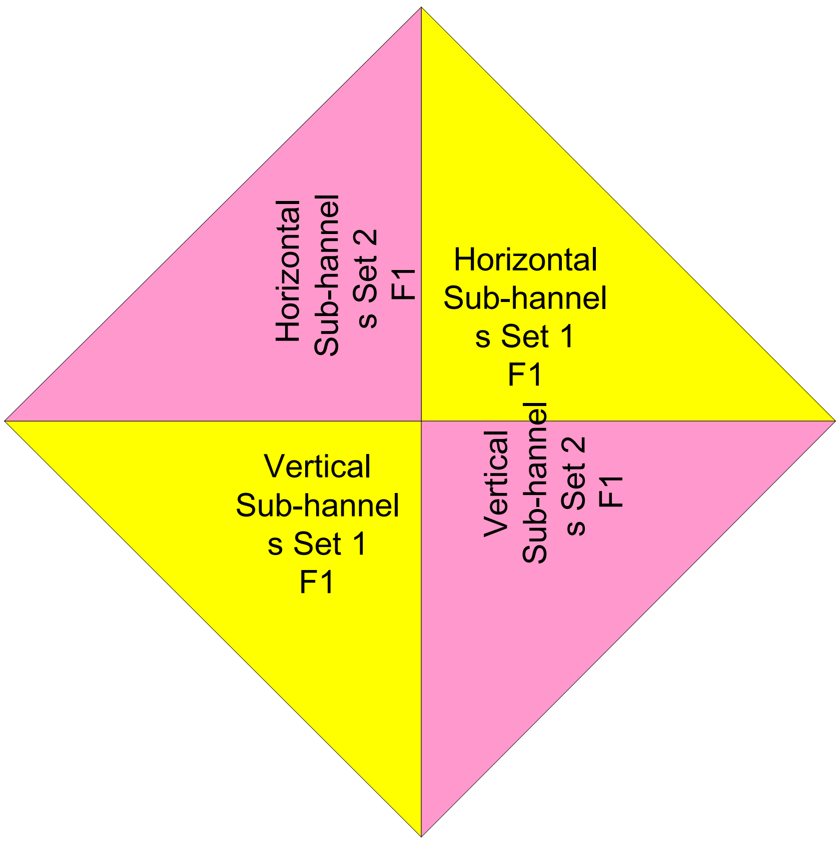
Cellular Deployment and Sectorization

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)



Operation in Presence of Interference in MAN Environment

Working with Different Interferers

Narrow Band Jamming —

¥ Using OFDM pulse shaping

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

Pulse Jamming —

¥ Using time interleaving over several OFDMA symbols pulse shaping, the Sub-Channels data capacity enables easy implementation of time interleaving

Working with Different Interferers

- OFDMA has inherited anti-jamming capability !!

Working with Different Interferers

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

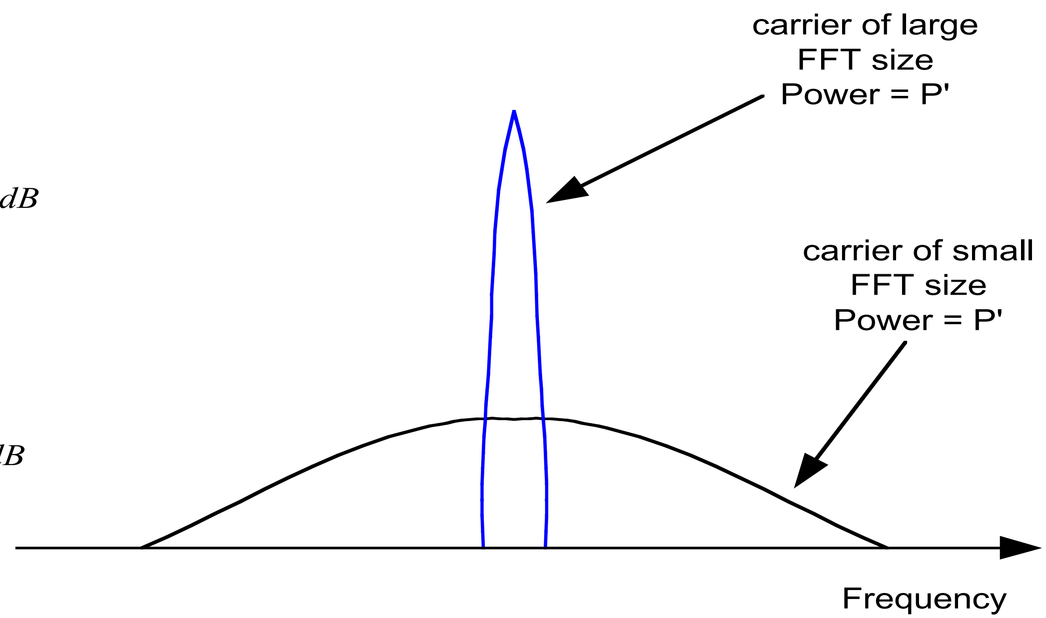
- ¥ Interference detection combined with smart ECC, enabling erasures on disturbed carriers
- ¥ The OFDMA (2k mode) has a 15dB processing gain against wide band Jammers or other 802.11a, HiperLAN2 interferers

for the large size FFT we get

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

for the Small size FFT we get

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



Working with Different Interferers

Additional features can include:

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

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

Additional Possible Features

Additional Possible features

¥ Time Space coding

¥ 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 BPSK, 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.

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

Advantages - Summary (5)

- Efficient Methods for PARP reduction
- DFS used by the Base Station
- Time Space Coding Can be added
- Antenna diversity can be added
- Antenna array could be supported