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Purpose:

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

# OFDMA/OFDMA PHY proposal

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# Contents

- FFT size planning
- Architecture
- Down Stream
- Up Stream
- Capacity
- OFDMA properties
- Simulation results
- Summary

# OFDM FFT Size Planning

Remainder:

- 2048 point FFT is a good solution (and should be taken for the worst case scenario, let’s plan for the worst !!)
- Less points FFT could be compromised for a bigger waste of throughput (GI)
- Less points FFT could be compromised for smaller cells and smaller delay spread for the same overhead (GI)
- Large number of FFT allows easily SFN, for better coverage

# OFDM FFT Size Planning

Using a 3.5MHz bandwidth the next table shows the different GI for different FFT sizes in order to mitigate 20usec delay spread

| FFT size | GI in usec | GI (%) |
|---|---|---|
| 512 | 20 | 16% |
| 1024 | 20 | 8% |
| 2048 | 20 | 4% |

# OFDM FFT Size Planning

Using a 14MHz bandwidth the next table shows the different GI for different FFT sizes in order to mitigate 20usec access delay spread

| FFT size | GI in usec | GI (%) |
|---|---|---|
| 512 | 20 | 64% |
| 1024 | 20 | 32% |
| 2048 | 20 | 16% |

# OFDM FFT Size Planning

- Remember, the range decreases as the bandwidth increases. We have to do something about it !!!!

- Smaller granularity for each user, gives better throughput.

- The higher the data rate users are allocated the better the multiplexing gain is

# Power Concentration Clarification

Estimating the path loss for 50Km, for 2.6GHz band we get (roughly from the AT&T results)

- LOS = 135dB
- NLOS = 160dB

Considering a channel of 3MHz with NF=4dB, we have a floor noise of: -105dBm.

Assuming power emission of 33dBm and 43dBm for SS and BS (by ETSI regulation, using a 30° antenna at the SS and 60° at the BS)

When using power concentration we get the same link budget for the uplink and downlink, satisfying the range requirements

# OFDMA System - Possible Architecture

## Duplexing Technique

- FDD, TDD

## Multiple Access Method

- OFDMA/ TDMA

OFDM Symbols allocated by TDMA

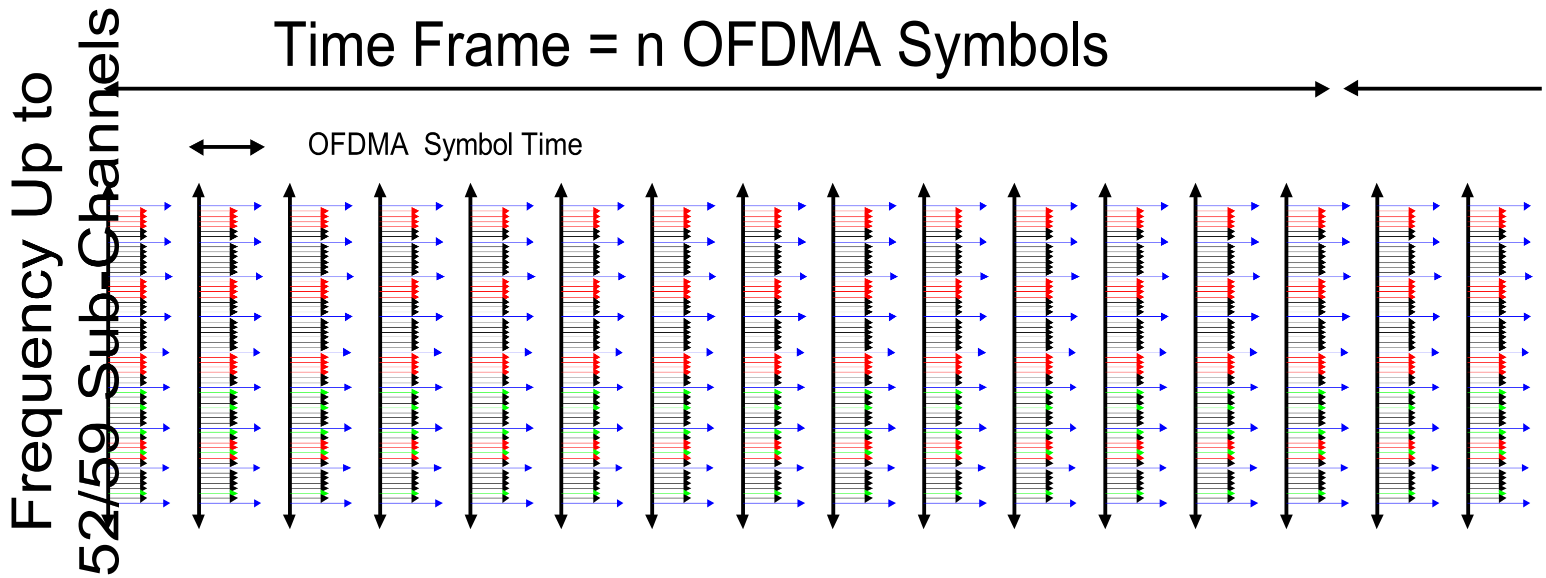
Sub-Carriers within an OFDM Symbol allocated by OFDMA

## Diversity

- Frequency, Time, Space, Code

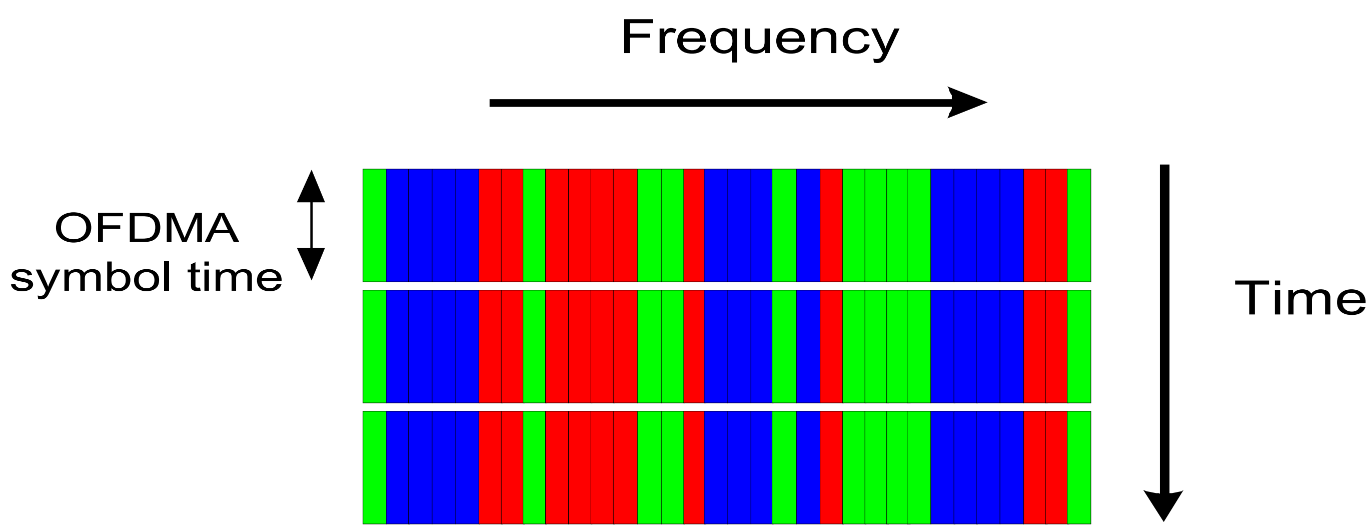
# OFDMA/TDMA - Principles

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



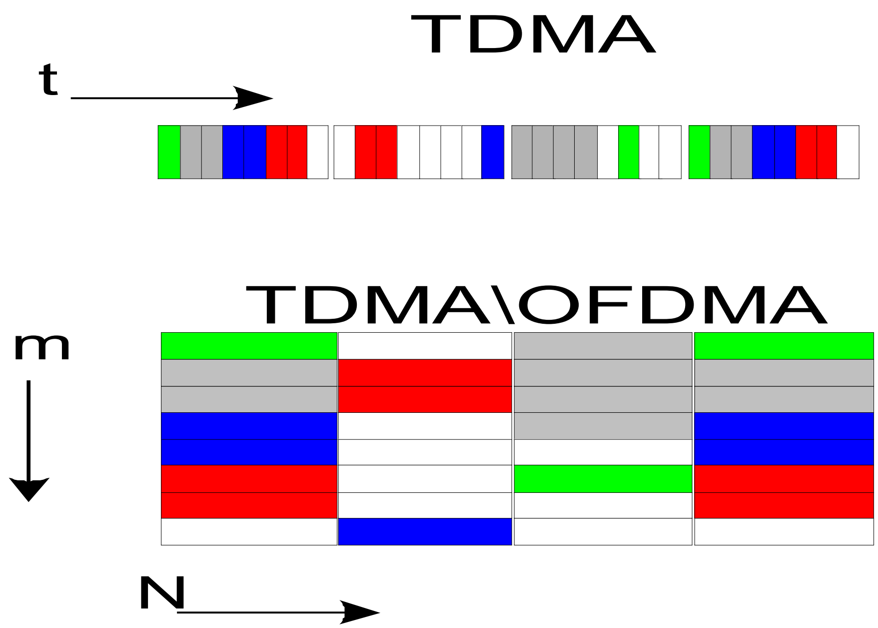
# Down Stream OFDMA/TDMA - Principles

MAC Mapping maps the down stream Sub-Channels to their specific usage (Broadcast, Unicast, Fast MAC route) .



# 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.

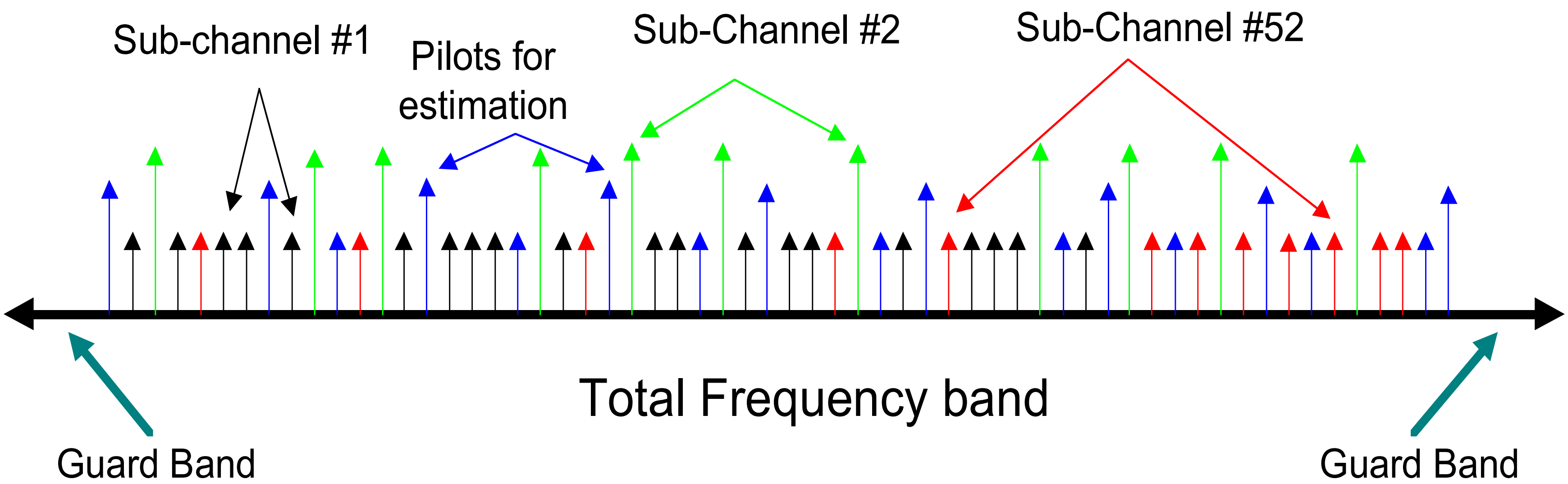



$$t = 59 * N + m$$

# Down Stream properties

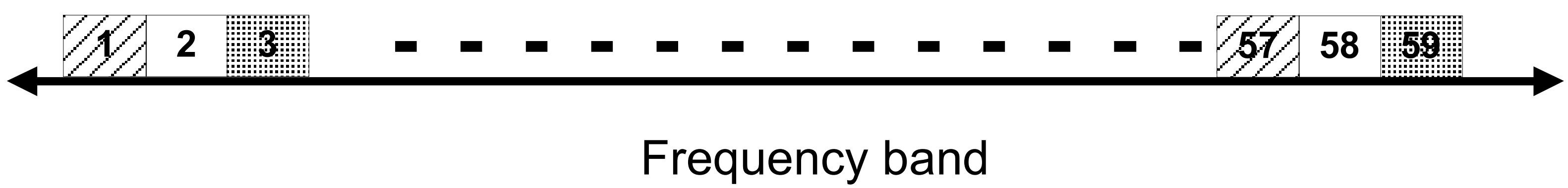
# Down Stream OFDMA symbol Structure

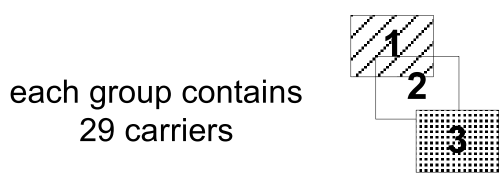
Up to 52 Sub-Channels in one OFDMA symbol



# Using Special Permutations for Carrier Allocation (DVB-RCT Based)

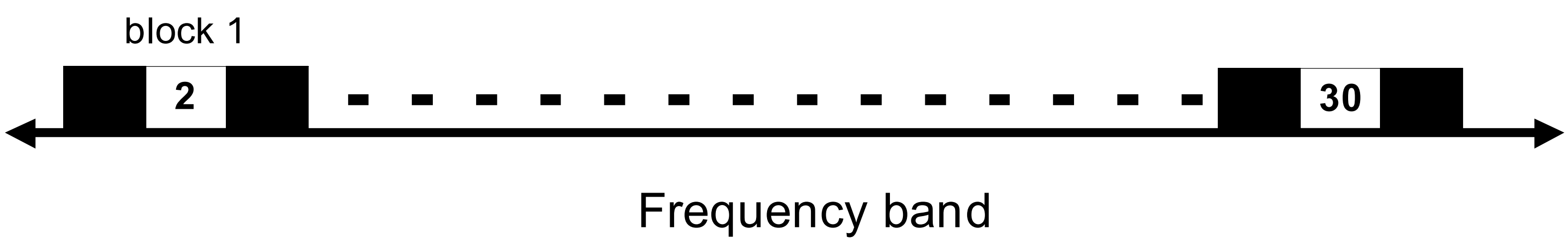
- All usable carriers are divided into 52 carrier groups named basic group, each main group contains 29 basic groups.

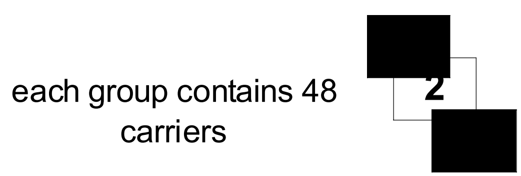


# Using Special Permutations for Carrier Allocation based on 802.11a

- Another strategy will be to split the band into 31 Sub-Channels of 48 carriers each. This allocation of usable carriers is in line with the IEEE802.11a carrier allocation.



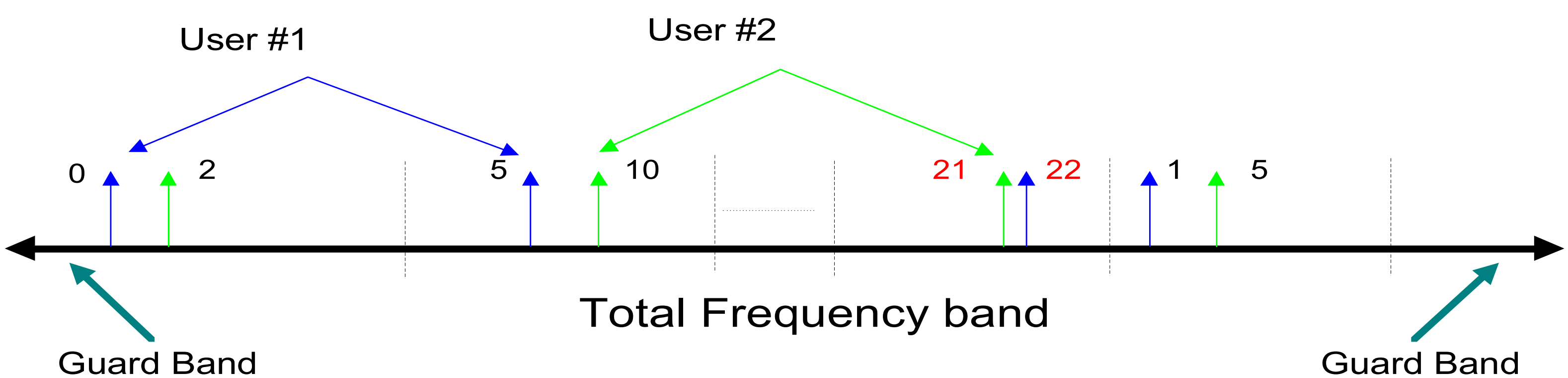



# Using Special Permutations for Carrier Allocation

- Carriers are allocated by a basic series and it's cyclic permutations for example:
- Basic Series:

  0,5,2,10,4,20,8,17,16,11,9,22,18,21,13,19,3,15,6,7,12,14,1
- After two cyclic permutations we get:

  2,10,4,20,8,17,16,11,9,22,18,21,13,19,3,15,6,7,12,14,1,0,5




User 1 = 0,5,2,10,4,20,8,17,16,11,9,22,18,21,13,19,3,15,6,7,12,14,1
User 2 = 2,10,4,20,8,17,16,11,9,22,18,21,13,19,3,15,6,7,12,14,1,0,5

# Down Stream based on

- FFT size : 2048, 1024, 512
- Guard Intervals : _, 1/8, 1/16, 1/32
- Coding :
  - concatenated RS(n,k,8) and Convolutional coding (k=7,G1=171,G2=133,Puncture Rate = _, 2/3, _, 5/6, 7/8) with and without Convolutional Interleaver
  - Turbo Block Code
- QPSK, 16QAM, 64QAM, optional 256QAM
- Down Stream Mapping sets the Sub-Channel allocation and parameters (modulation, coding and power)
- 52 Sub-Channels enabling throughput administration based upon Sub-Channel allocation
- Sub-Channels Power Manipulation (Forward Automatic Power Control – FAPC)

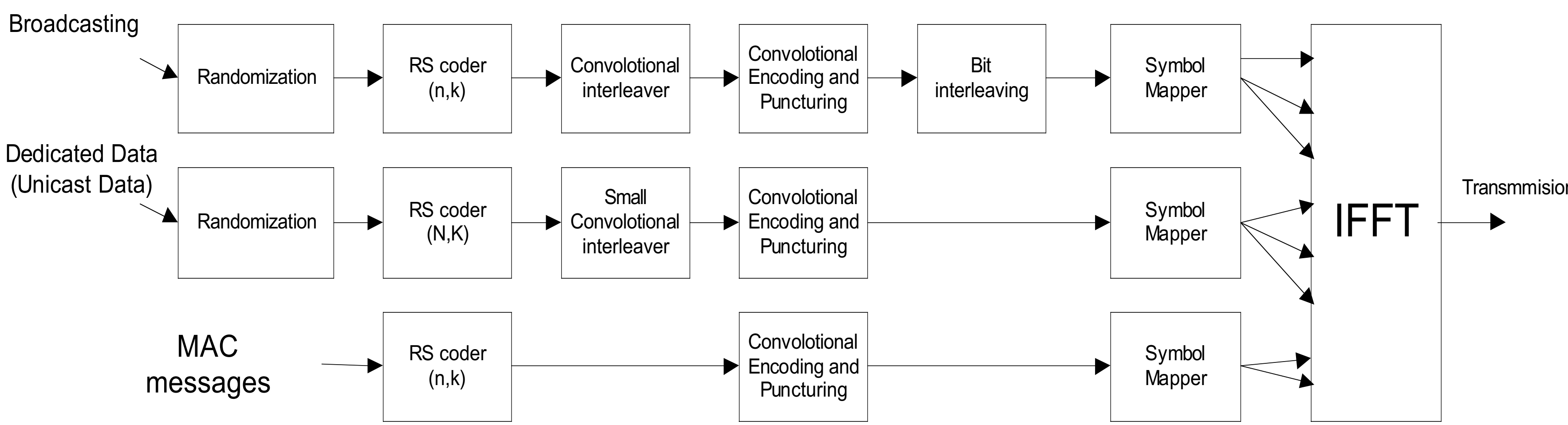
# Down Stream Throughput (8MHz Channel)

| 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 | _ | 4.98 | 5.53 | 5.85 | 6.03 |
| | 2 | 2/3 | 6.64 | 7.37 | 7.81 | 8.04 |
| | 2 | _ | 7.46 | 8.29 | 8.78 | 9.05 |
| | 2 | 5/6 | 8.29 | 9.22 | 9.76 | 10.05 |
| | 2 | 7/8 | 8.71 | 9.68 | 10.25 | 10.56 |
| 16-QAM | 4 | _ | 9.95 | 11.06 | 11.71 | 12.06 |
| | 4 | 2/3 | 13.27 | 14.75 | 15.61 | 16.09 |
| | 4 | _ | 14.93 | 16.59 | 17.56 | 18.10 |
| | 4 | 5/6 | 16.59 | 18.43 | 19.52 | 20.11 |
| | 4 | 7/8 | 17.42 | 19.35 | 20.49 | 21.11 |
| 64-QAM | 6 | _ | 14.93 | 16.59 | 17.56 | 18.10 |
| | 6 | 2/3 | 19.91 | 22.12 | 23.42 | 24.13 |
| | 6 | _ | 22.39 | 24.88 | 26.35 | 27.14 |
| | 6 | 5/6 | 24.88 | 27.65 | 29.27 | 30.16 |
| | 6 | 7/8 | 26.13 | 29.03 | 30.74 | 31.67 |

# Down Stream Block Diagram

Three routes of transmission:

- Broadcasting/Multicasting
- Dedicating/Unicast
- MAC Messages

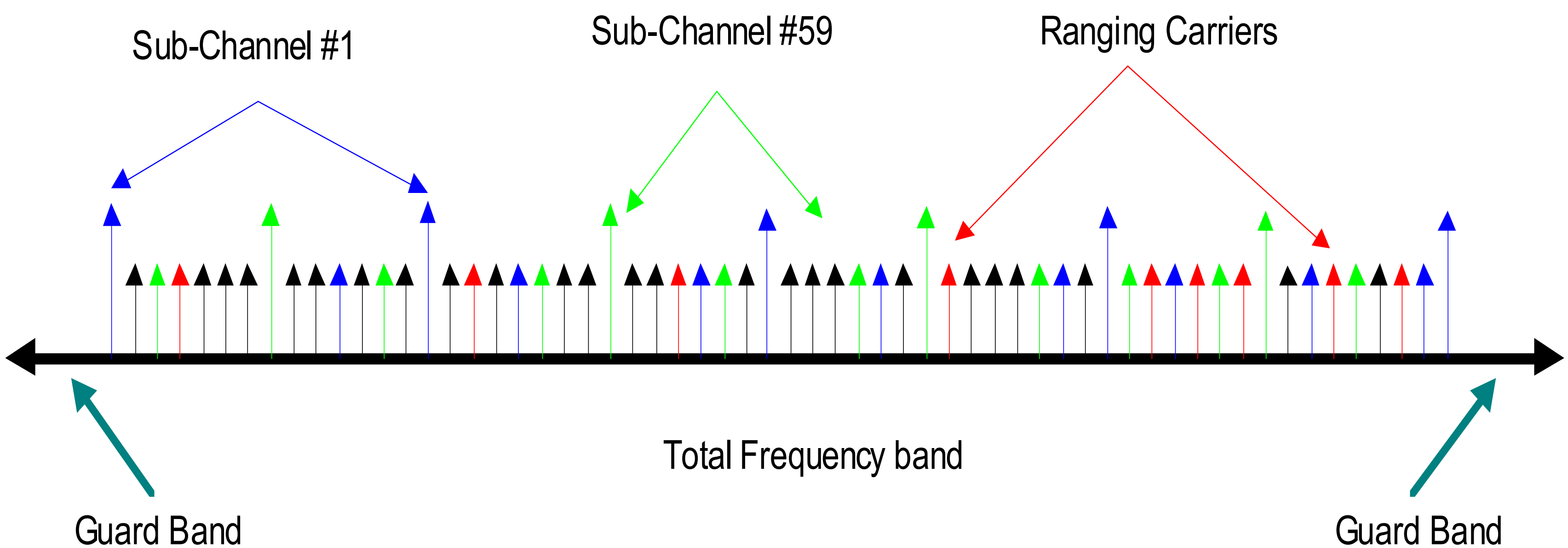


# Down Stream Adaptive features

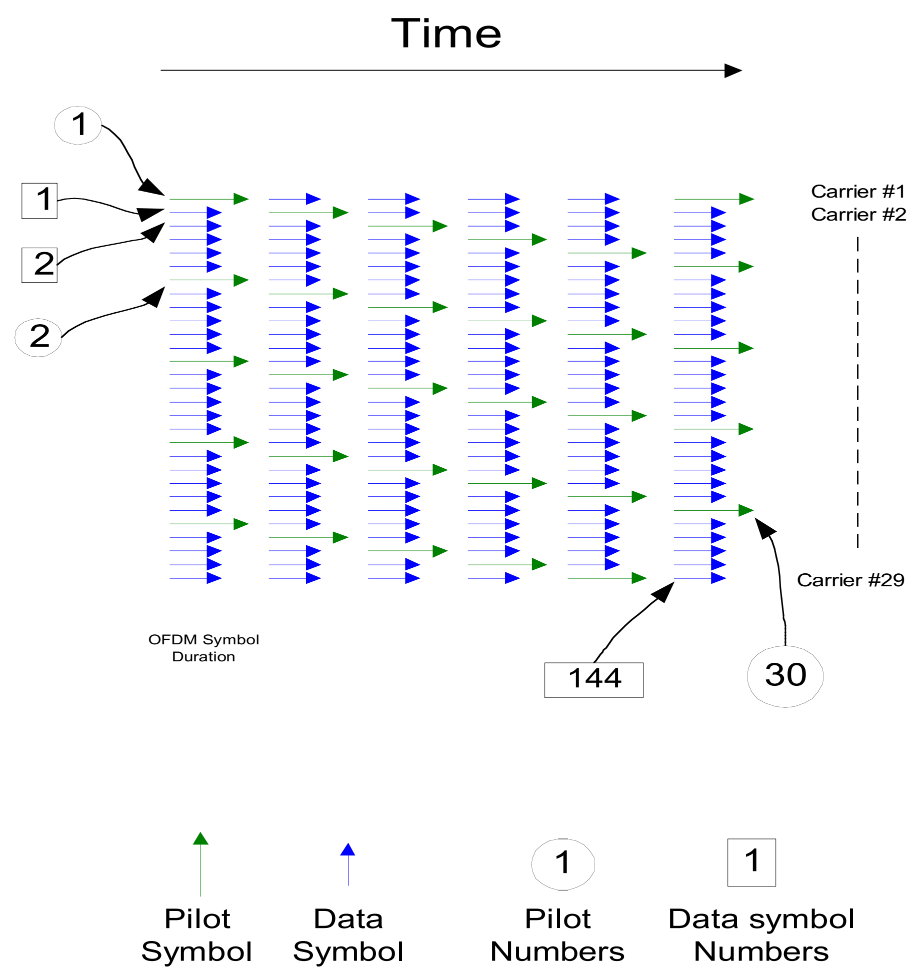
- Adaptive FEC
- Adaptive Modulation
- Adaptive Bandwidth per transmission route (by using adaptive Sub-Channel Allocation)
- Power administration (FAPC)

# Up Stream properties based on the DVB-RCT

# Up Stream OFDMA Symbol



# Up Stream Burst Structure




**the Sub-Channel is composed of 29 Carriers spread all over the usable frequency band. carriers are allocated by Reed-Solomon permutaion**

# Using CDMA like Synchronization

- The CDMA like synchronization is achieved by allocating several of the usable carriers to the Ranging Sub-Channel.
- Onto the Ranging Sub-Channel 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

# Ranging Carrier Allocation

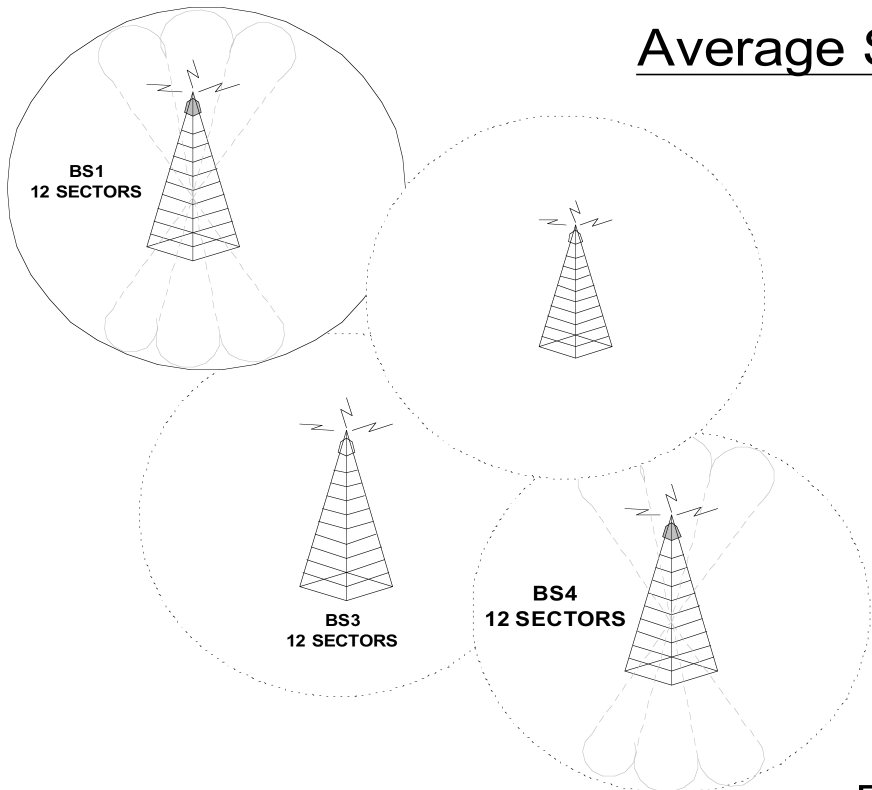
- Ranging Carriers are allocated by allocating several Sub-Channels for this purpose, the carriers are spread all over the bandwidth, and used with the CDMA approach

# Coding schemes

- Based on the Concatenated RS(n,k,4) and convolutional coding (k=9,G1=561,G2=753)
- Turbo Convolutional coding, showing no error floor, or Turbo Product Code

# OFDMA System - Capacity

# Deployment for Interactive Services for Fixed Users




Average SYSTEM CAPACITY (Each BS)

DOWNLINK = 144Mbps

UPLINK = 144Mbps

Reuse Factor = 1

Average QAM Efficency = 3 bps/Hz

Average FEC Rate = 2/3

B.W = 12MHz (Using Variable number of Sub-Channels)

Sectors = 12

Number Of Freq. = 1

(Cross Polarization is Optional)

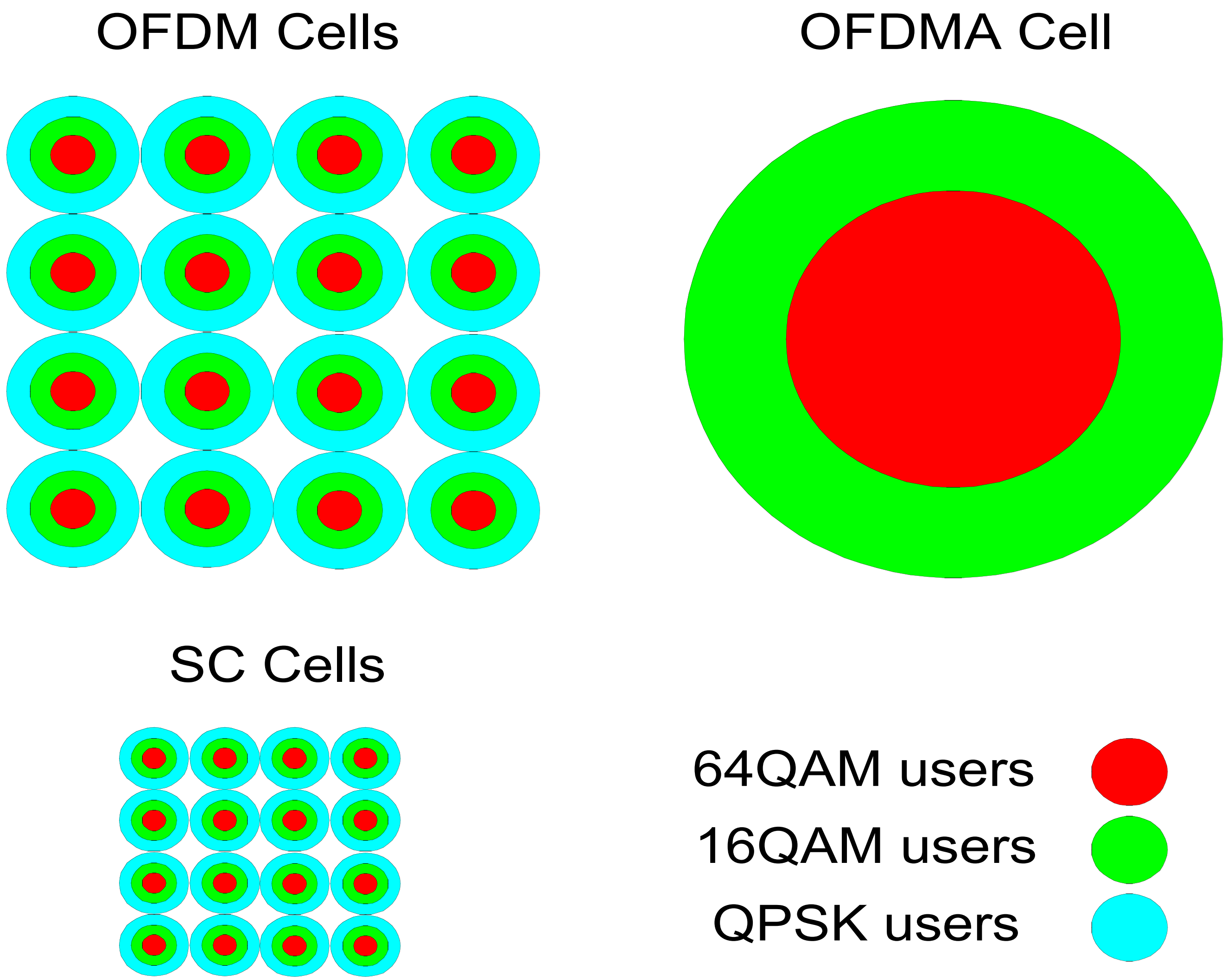
Peak Capacity for single sector = 24Mbps

# OFDMA System - Properties

# Power Concentration

- In the Up Stream due to Sub-Channel allocation (29 carriers per Sub-Channel) a **18dB** gain is achieved for one Sub-Channel allocation.
- In the Down Stream due to Sub-Channel allocation (29 carriers per Sub-Channel) a **10dB** gain can be achieved for one Sub-Channel busted (FAPC).
- This additional power gain enables communication up to 50Km or penetration into buildings at the uplink, and a better coverage on the down stream.
- This additional gain could be used for:
  - Bigger cell radius (up to 8 times in LOS)
  - Better coverage and availability
  - Better capacity
  - Chipper and smaller power amplifiers
  - Simpler antennas

# LOS/NLOS Conditions - Coverage limited



- <u>Timing Sensitivity</u>

Low timing sensitivity is needed, and simple phase and channel estimators solve timing problems.

- <u>Frequency Sensitivity</u>

solved by locking onto the Base-Station transmission and deriving the Subscriber Unit's clocks from it.

- <u>Equalization</u>

No Equalizers are needed, channel impairment and timing problems are both solved with simple phase and channel estimators

# Additional Possible features

- Time Space coding
- Antenna array (beam forming)
- Antenna Diversity (Base Station and Where needed Subscriber Station)

# Advantages - Summary (1)

- 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, 64QAM and 256QAM.
- Enables adaptive carrier allocation in multiplication of 29 carriers = nX29 carriers up to 1711 carriers (all data carriers).
- Gives Frequency diversity by spreading the carriers all over the used spectrum.
- Gives Time diversity by optional interleaving of carrier groups 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 (**18dB** gain for 29 carrier allocation), 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 - 3 times the distance for $R^4$ and 8 time for $R^2$ for LOS conditions.
- 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.
- Minimal delay per OFDMA symbol of 300μsec.
- Using Small burst per user of about 150 symbols for better statistical multiplexing and smaller jitter.
- User symbol is several times longer then for TDMA systems.
- Using the FEC to the outmost by error detection of disturbed frequencies.
- Based on a Proven technology for wireless environment even under 1GHz
- Many ASIC manufactures already have OFDM implementation

# Advantages - Summary (5)

- Time Space Coding Can be added
- Antenna diversity can be added
- Antenna array could be supported

# 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 14. to summarize the system supports adaptive modulation of QPSK, 16QAM and 64QAM and different coding rates (differ in the uplink and downlink), this will enable the system to gain the highest throughput possible fro a certain scenario. The maximum Net throughput for the down stream is 32Mbps and for the upstream 25Mbps (for a 8MHz channel). 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. |

# Comparison Matrix (2)

| | | |
|---|---|---|
| 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.<br>The DVB-T which is proposed for the down stream is a well known technology, where today there are about 8 ASIC manufacturers producing chip s. The DVB-RCT, which is based on the DVB-T receiver chip, will be manufactured after its standardization by several large ASIC manufactures therefore achieving a single system chip.<br>The DVB-T which is proposed for the down stream is a well known technology, where today ASIC manufacturers produces these chips.<br>The RF ends for the subscriber unit can be built with off the shelf RF ends or components.<br><br>The large production of Base station will enable cost reduction and simple interfaces to the base station enables it's cost reduction.<br><br>The installation cost will be very cheep due to the fact that wider antennas are considered for the OFDM/OFDMA system. Therefore there will be no need for a sophisticated installation, the end goal is a plug and play feature without expert installation involved. |

# Comparison Matrix (3)

| | | |
|---|---|---|
| 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 can be 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 and 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 6bps/Hz (using 256QAM), within a cell structure when averaging the throughput of cells 5bps/Hz/Cell (using 256QAM) 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. Excellent coding gain is achieved for the upstream due to power concentration, which can give up to 18,26dB additional gain. Furthermore the adaptive modulation can trade off another 20dB, and therefore adjust the performance of the cell to the optimum. |

# Comparison Matrix (4)

| | | |
|---|---|---|
| 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:<br>· Directional antennas where it is appropriate (to reduce interference to other users)<br>· Directional antennas at the user side<br>· Diversity antennas at the BS and at the SS (where appropriate).<br>· Space/Time Coding are fitted very well to OFDM/OFDMA technology |

# Comparison Matrix (5)

| | | |
|---|---|---|
| 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 OFDM/OFDMA symbol because of fading is about 40dB, giving excellent recovery opportunity, the OFDM/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.<br>other features as:<br>· Diversity antennas at the BS and at the SS (where appropriate).<br>· Space/Time Coding<br>· Time Diversity of the signal<br>· Adaptively of Code and Modulation<br>Are also combined to get the maximum out of the channel. |
| 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, and the defined DVB-T has inherent features to help and estimate the phase noise. 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 introduces. Power amplifiers Non-Linearity can be solved in the digital level although it has small effect in OFDM systems [1],[2]. |

# Comparison Matrix (6)

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