# [Insert Document Title Here]

**IEEE 802.16 Presentation Submission Template (Rev. 8)**

Document Number:

IEEE 802.16.3p-00/33

Date Submitted:

2000-11-13

Source:

Yossi Segal
RunCom Technologies LTD.
Rishon Lezion, Moshe Levi 14 st.
Israel

Voice: 972-3-9528440
Fax: 972-3-9528805
E-mail: yossis@runcom.co.il

Venue:

Tampa, Florida

Base Document:

IEEE 802.16.3c-00/33

Purpose:

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

Notice:



Release:



IEEE 802.16 Patent Policy:

# OFDM/OFDMA PHY proposal

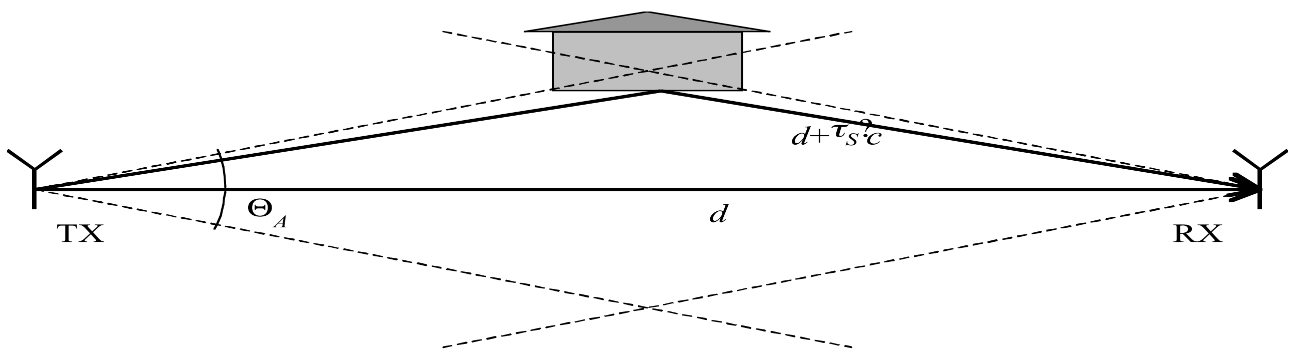
Yossi Segal
Runcom Technologies LTD.

# Contents

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

# OFDM FFT Size Planning

In order to calculate the access delay spread let us use the 2 ray model for different distances and antenna angles.



# OFDM FFT Size Planning

| BS–SU distance | Maximum excess delay spread $\tau_S$ *for* $\Theta_A = 60°$ |
|---|---|
| 5Km | 2.58 usec |
| 10Km | 5.16 usec |
| 20Km | 10.31 usec |
| 30Km | 15.47 usec |
| 50Km | 30.94 usec |

This table gives us the excess delay spread for a ***60°*** antenna and different distances. As we can see delay spreads of 30usec are possible.

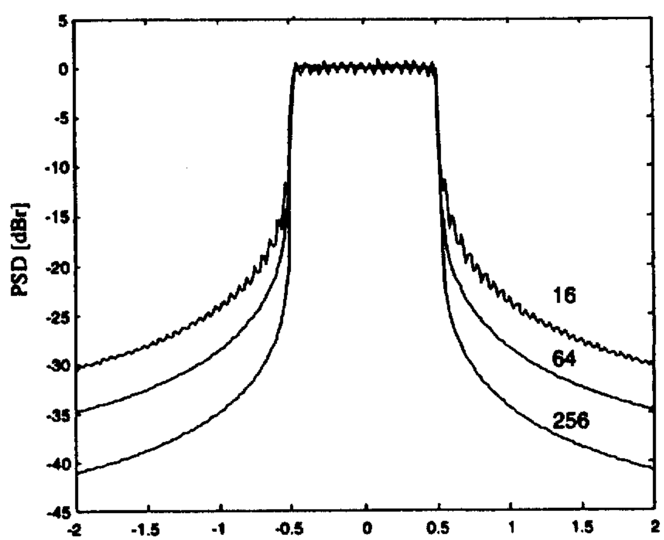
# OFDM FFT Size Planning

In order to loss small amount of the data rate a GI of 1/16 (~6%) should be used. The next table summarizes the FFT sized that should be used in order to deal with such excess delay spread.

| Channel Bandwidth | 3MHz | 6MHz | 12MHz |
|---|---|---|---|
| Distance | | | |
| 5Km | 128 FFT points | 256 FFT points | 512 FFT points |
| 10Km | 256 FFT points | 512 FFT points | 1024 FFT points |
| 20Km | 512 FFT points | 1024 FFT points | 2048 FFT points |
| 40Km | 1024 FFT points | 2048 FFT points | 4096 FFT points |
| 50Km | 1024 FFT points | 2048 FFT points | 4096 FFT points |

# OFDM FFT Size Planning

A good compromise is using a 2048 points FFT, which is best suited for the compromise between Multi-Path mitigation, Frequency accuracy considerations and the spectral shaping (as shown in the next figure)



# OFDMA System - Possible Architecture

## Duplexing Technique

- FDD, TDD

## Multiple Access Method

- TDMA/OFDMA

OFDM Symbols allocated by TDMA

Sub-Carriers within an OFDM Symbol allocated by OFDMA

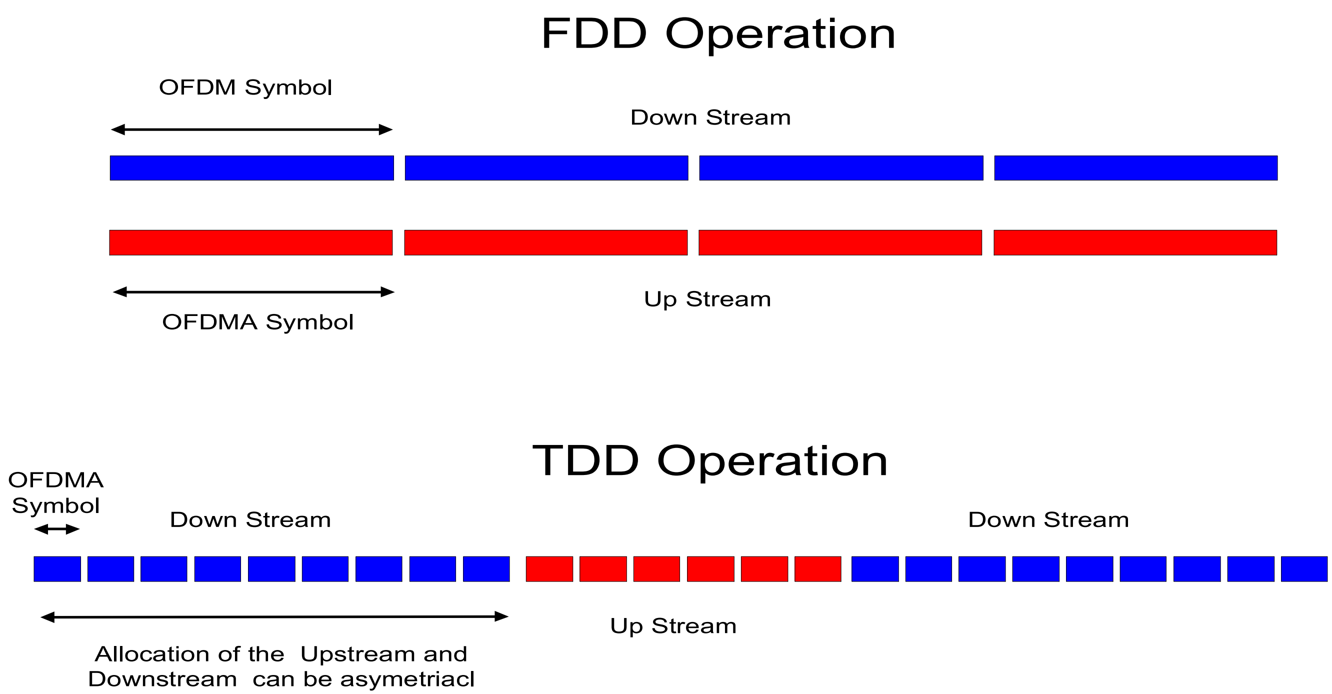
## Diversity

- Frequency, Time, Space, Code

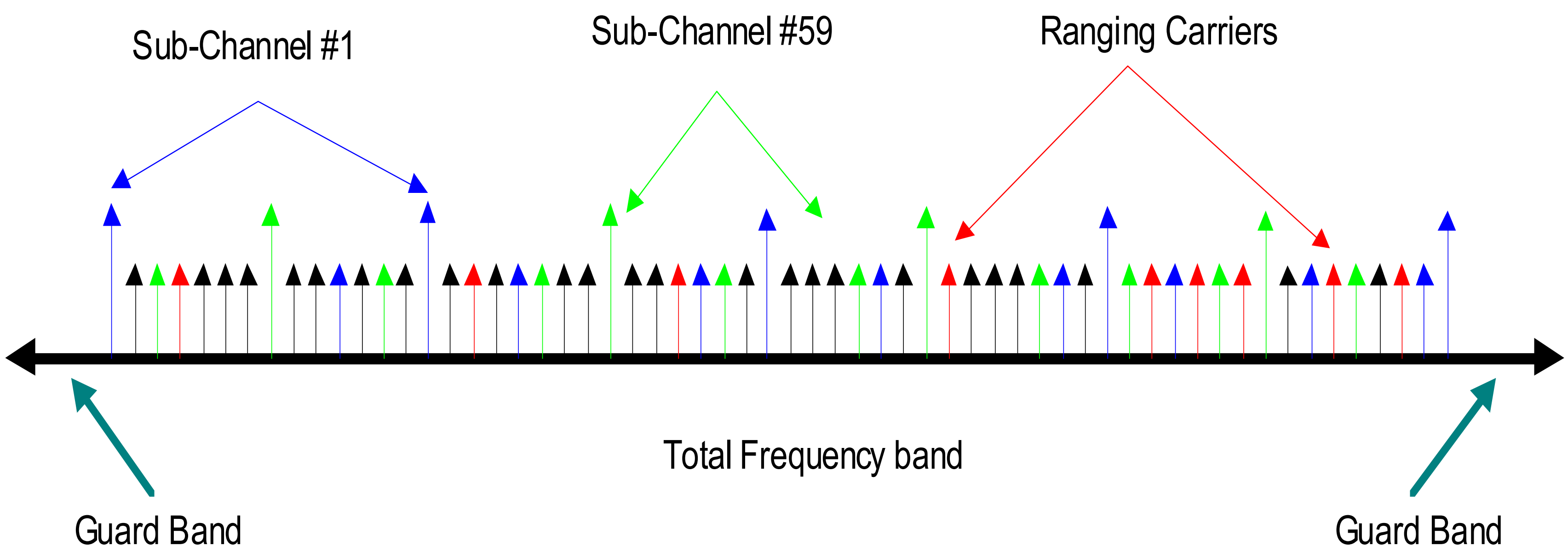
# Duplexing Techniques

Down Stream using OFDM/TDM

Up Stream using OFDMA/TDMA .

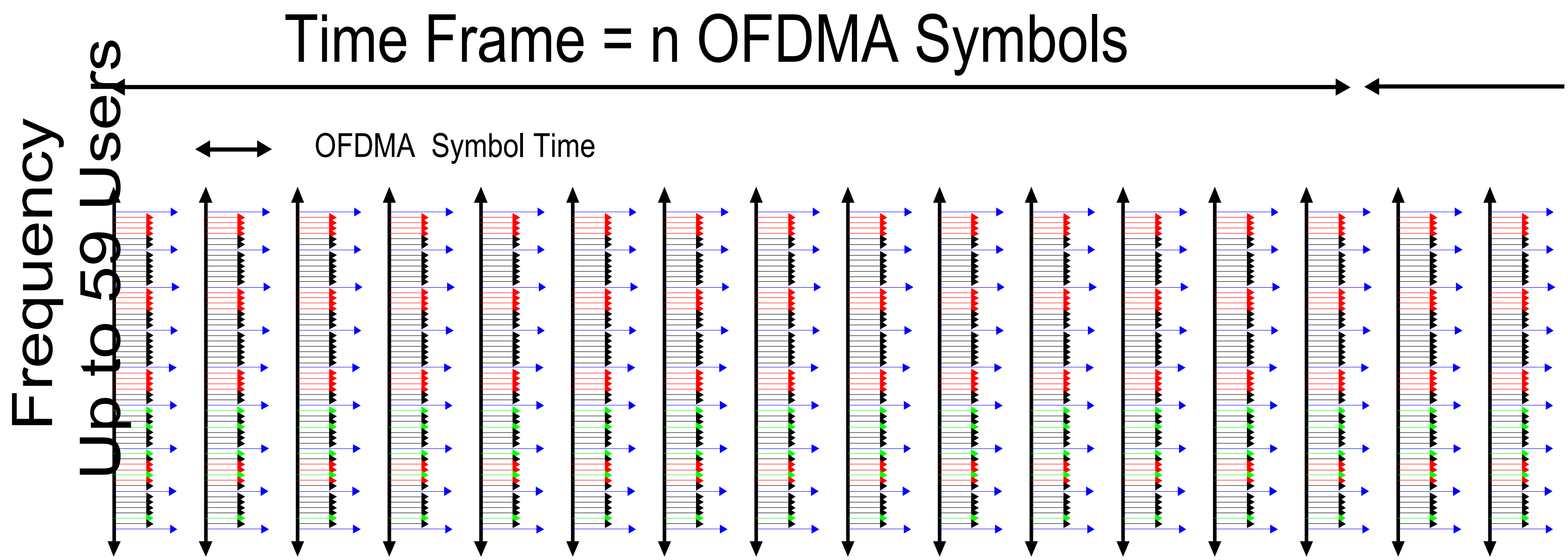


# Up Stream OFDMA Symbol



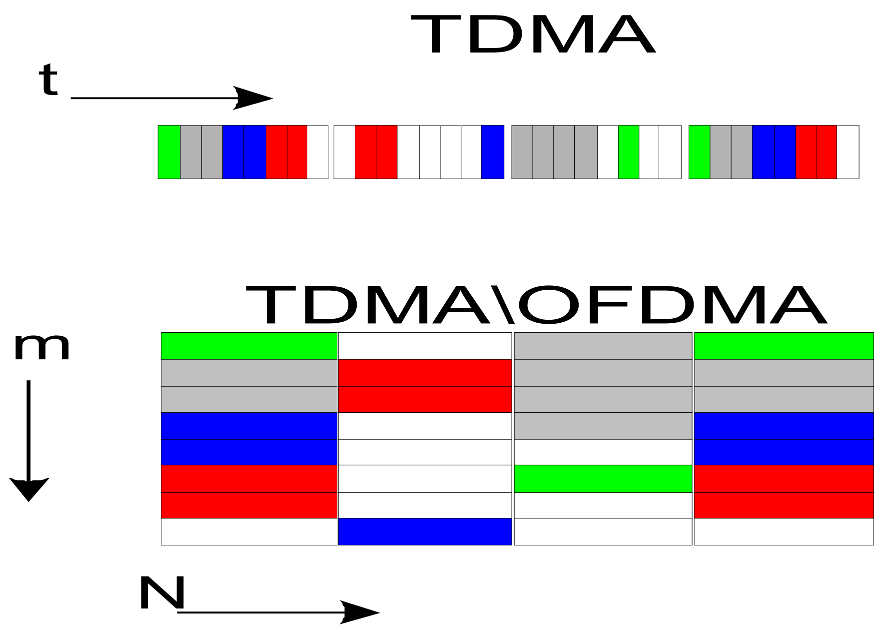
# Up Stream OFDMA/TDMA - Principles

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



# 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

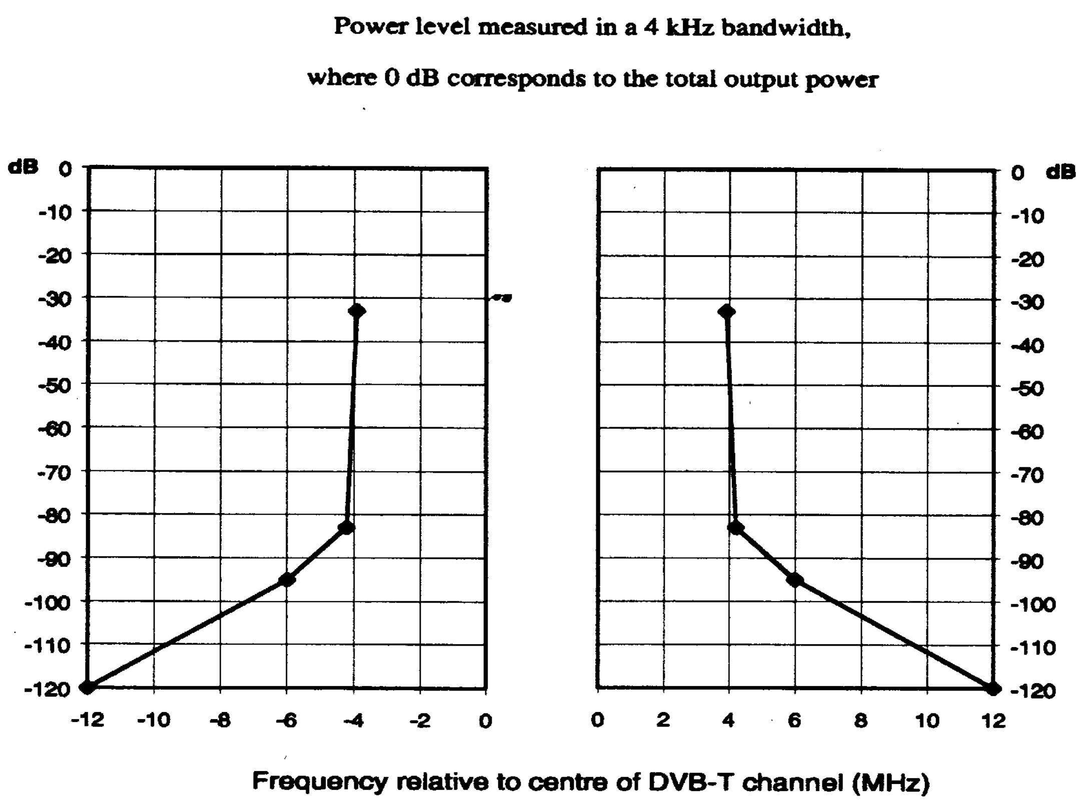
# Down Stream based on some of the DVB-T modes

- FFT size : 2048
- Guard Intervals : _, 1/8, 1/16, 1/32
- Coding : concatenated RS(204,188,8) and Convolutional coding (k=7,G1=171,G2=133,Puncture Rate = _, 2/3, _, 5/6, 7/8) with Convolutional Interleaver
- In band parameter exchange using TPS carriers
- QPSK, 16QAM, 64QAM modulation
- MPEG-2 Transport Stream

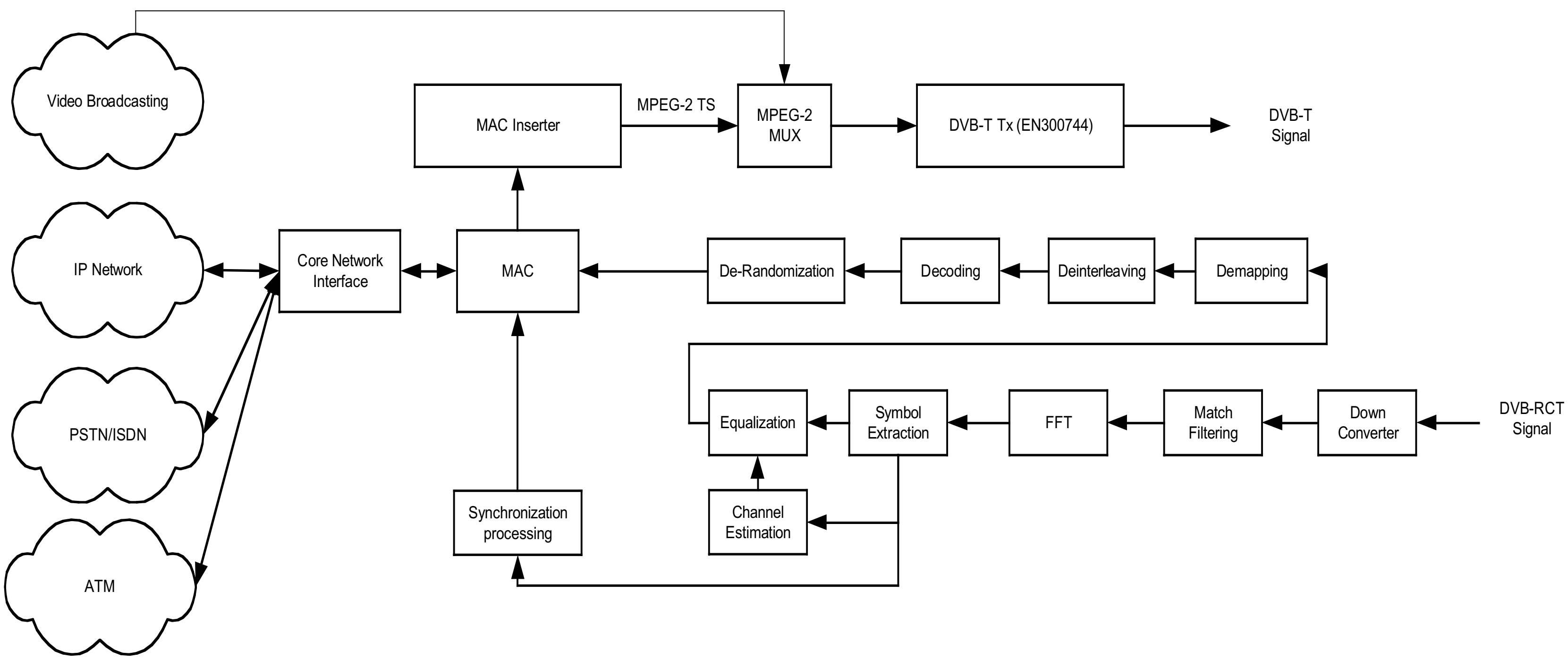
# Down Stream Throughput (8MHz Channel)

| Modulation | Bits per sub-carrier | Inner 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 Spectral Mask (8MHz Channel)

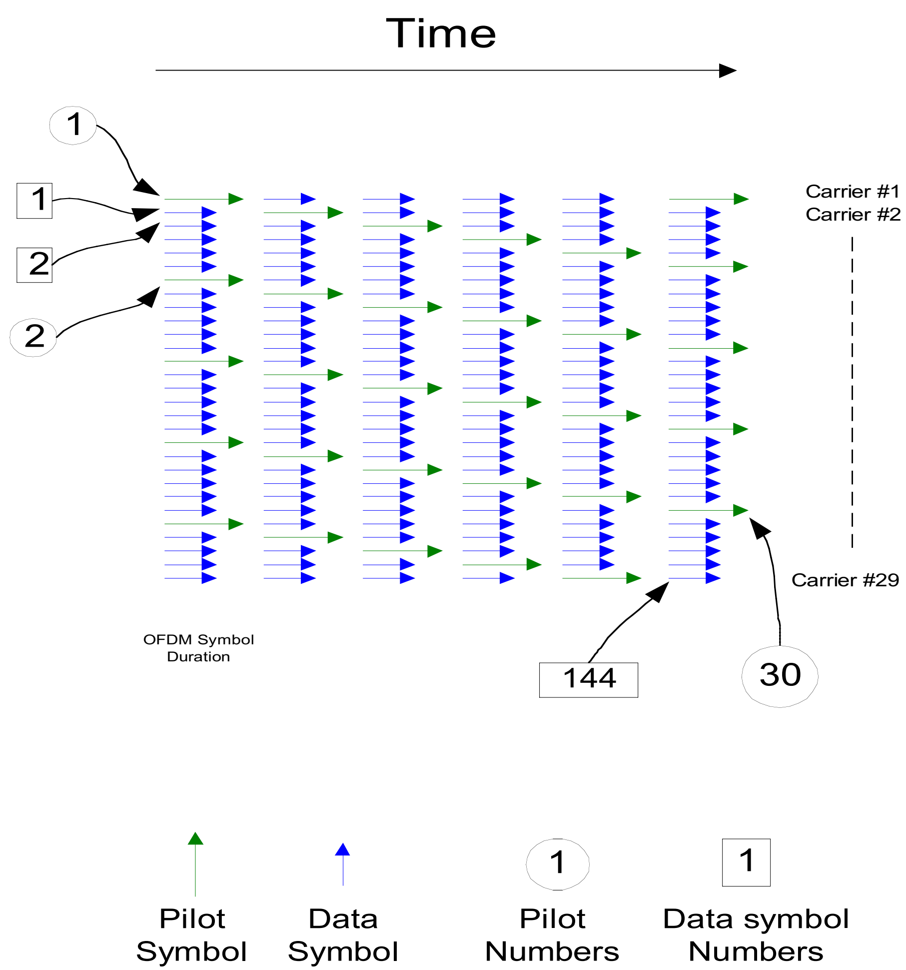


# Down Stream Block Diagram



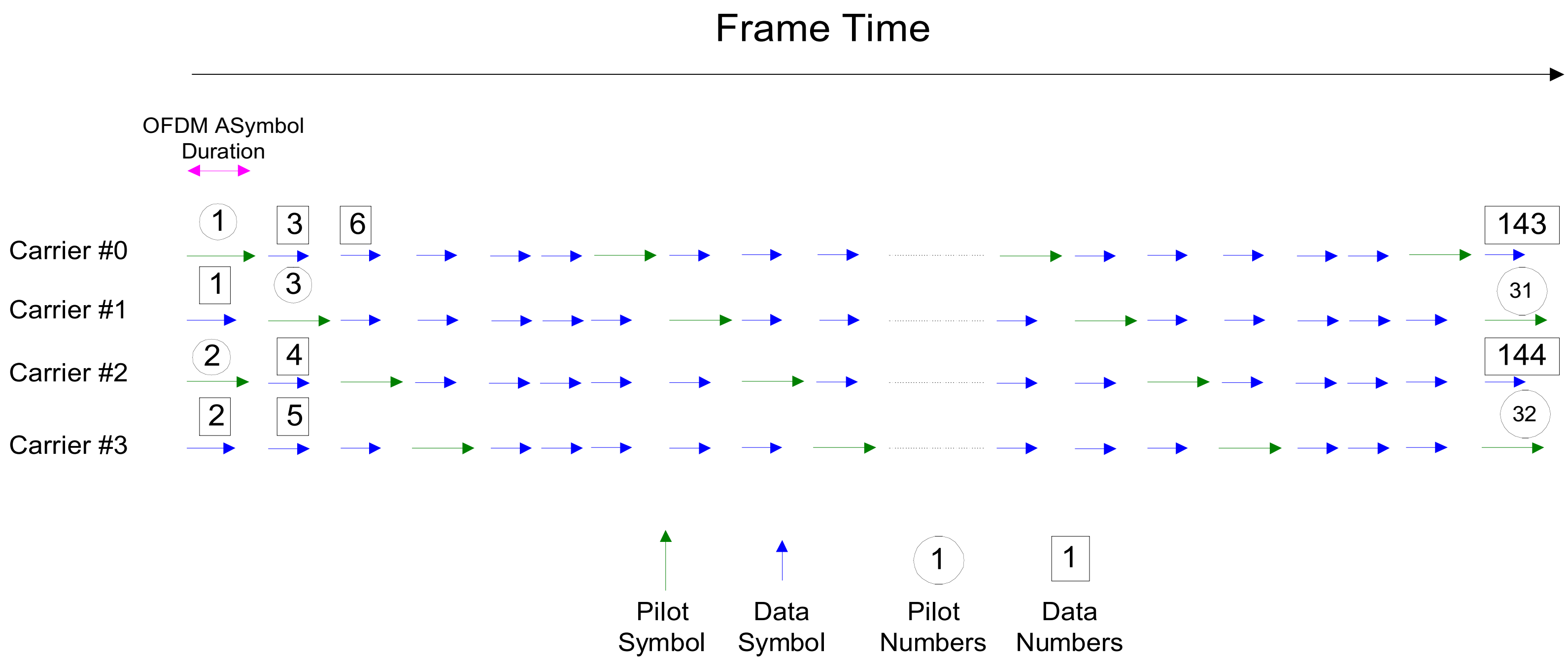
# Up Stream properties based on the DVB-RCT

# 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**

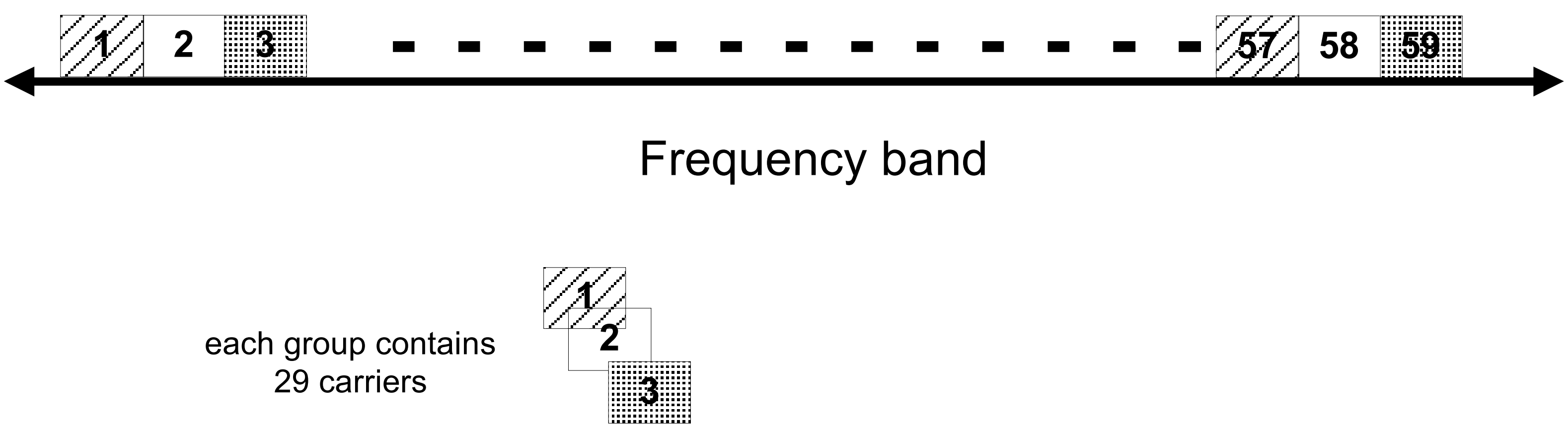
# Up Stream Burst Structure




- For the different Burst Structure, a constant 144 usable symbols are transmitted per Sub-Channel (using Time Interleaving)

# Using Special Permutations for Carrier Allocation

- All usable carriers are divided into 59 carrier groups named basic group, each main group contains 29 basic groups.

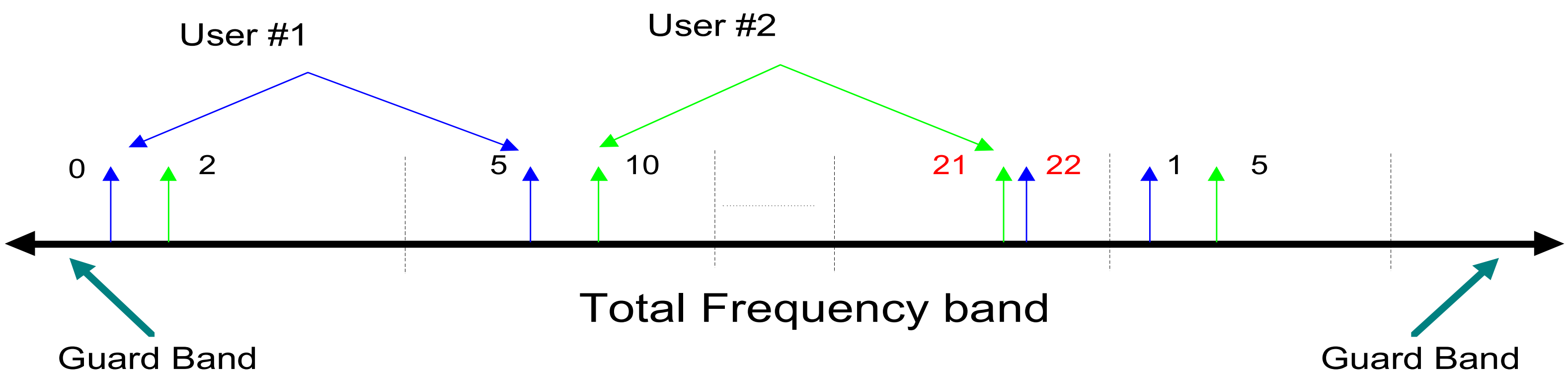


# Using Special Permutations for Carrier Allocation

- 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

# Using Special Permutations for Carrier Allocation

- The Carriers of each Sub-Channel are spread all over the usable frequency for best frequency diversity

- The allocation by permutation give an excellent Reuse factor almost 1.

- The allocation by permutation give an excellent interference spreading and averaging.

# 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

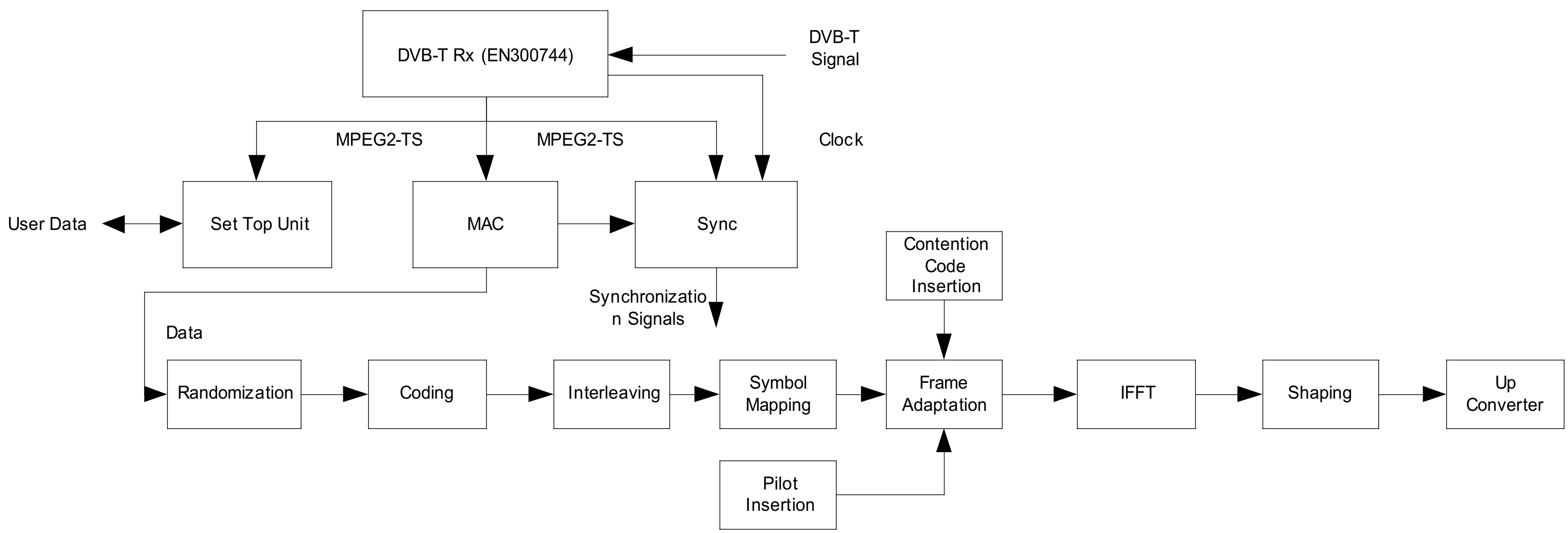
# Ranging Carrier Allocation

- 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

# Adaptive Coding schemes

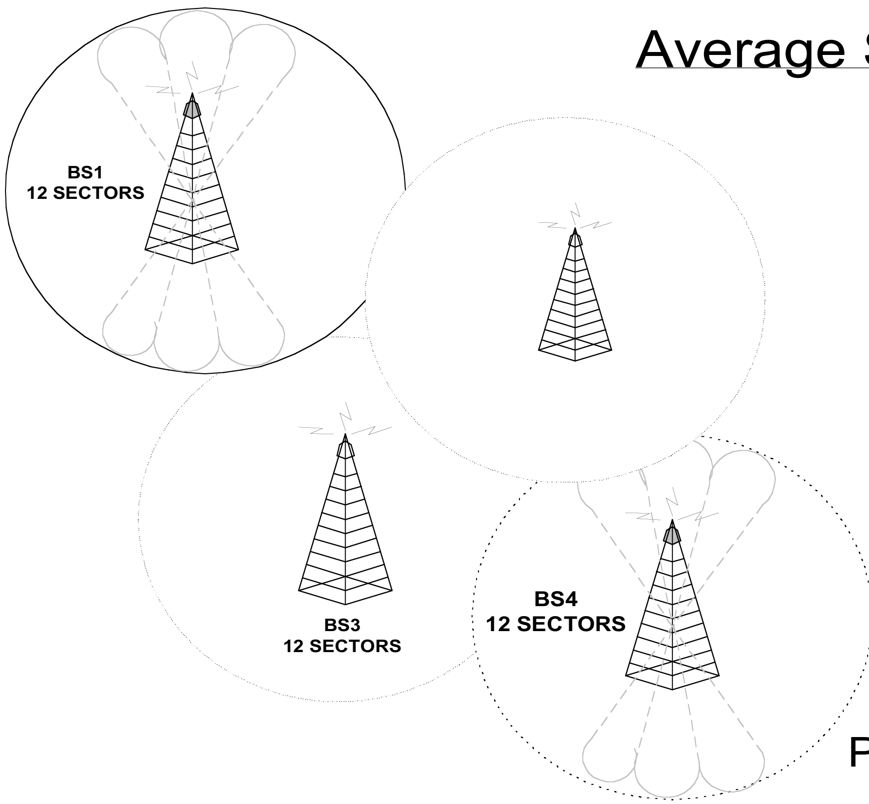
- Based on the Concatenated RS(63,55,4) and convolutional coding (k=9,G1=561,G2=753)
- Turbo Convolutional coding, showing no error floor or Turbo Product Code

# Up Stream Block Diagram



# OFDMA System - Capacity

# Deployment for Interactive Services for Fixed Users




Average SYSTEM CAPACITY (Each BS)

DOWNLINK = 144Mbps

UPLINK = 144Mbps

Reuse Factor = 1/2

Average QAM Efficency = 3 bps/Hz

Average FEC Rate = 2/3

B.W = 6MHz

Sectors = 12

Number Of Freq. = 2

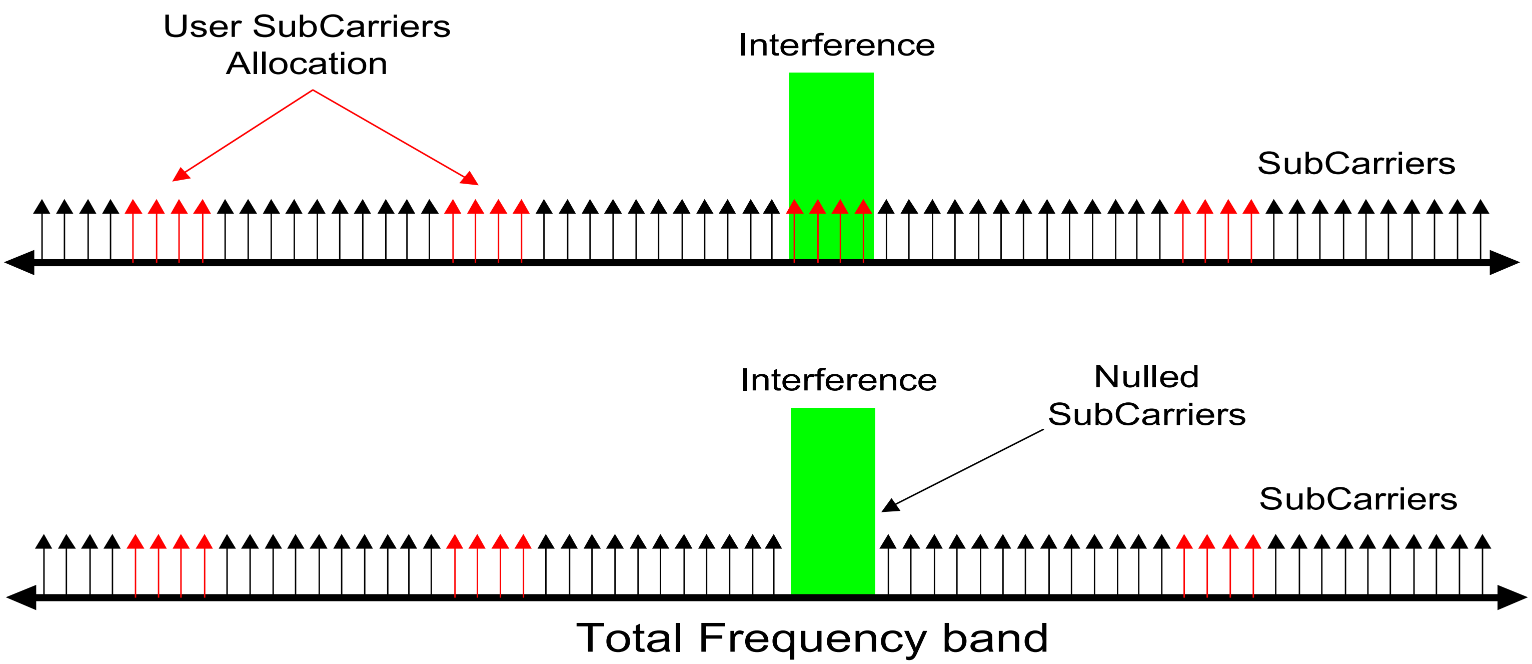
(Cross Polarization is Optional)

Peak Capacity for single sector = 24Mbps

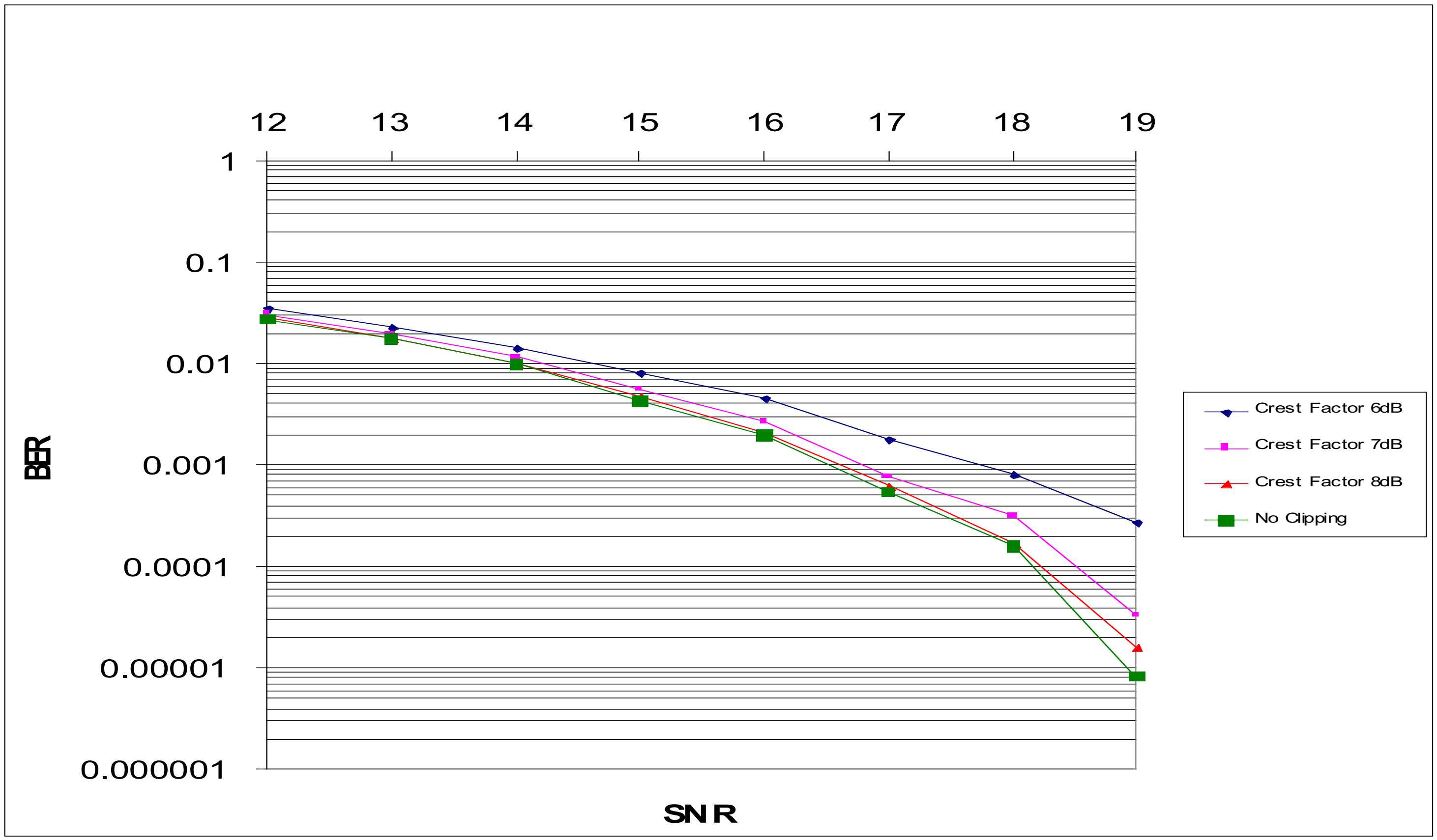
# OFDMA System - Properties

# Interference Rejection/Avoidance

- Narrowband Interference Rejection
  - User SubCarriers Blocks are Allocated by IFFT & FFT .
  - Easy to Avoid/Reject Narrowband Dominant Interference .
  - Less Interfered Part of the Carrier Can Still Be Used .

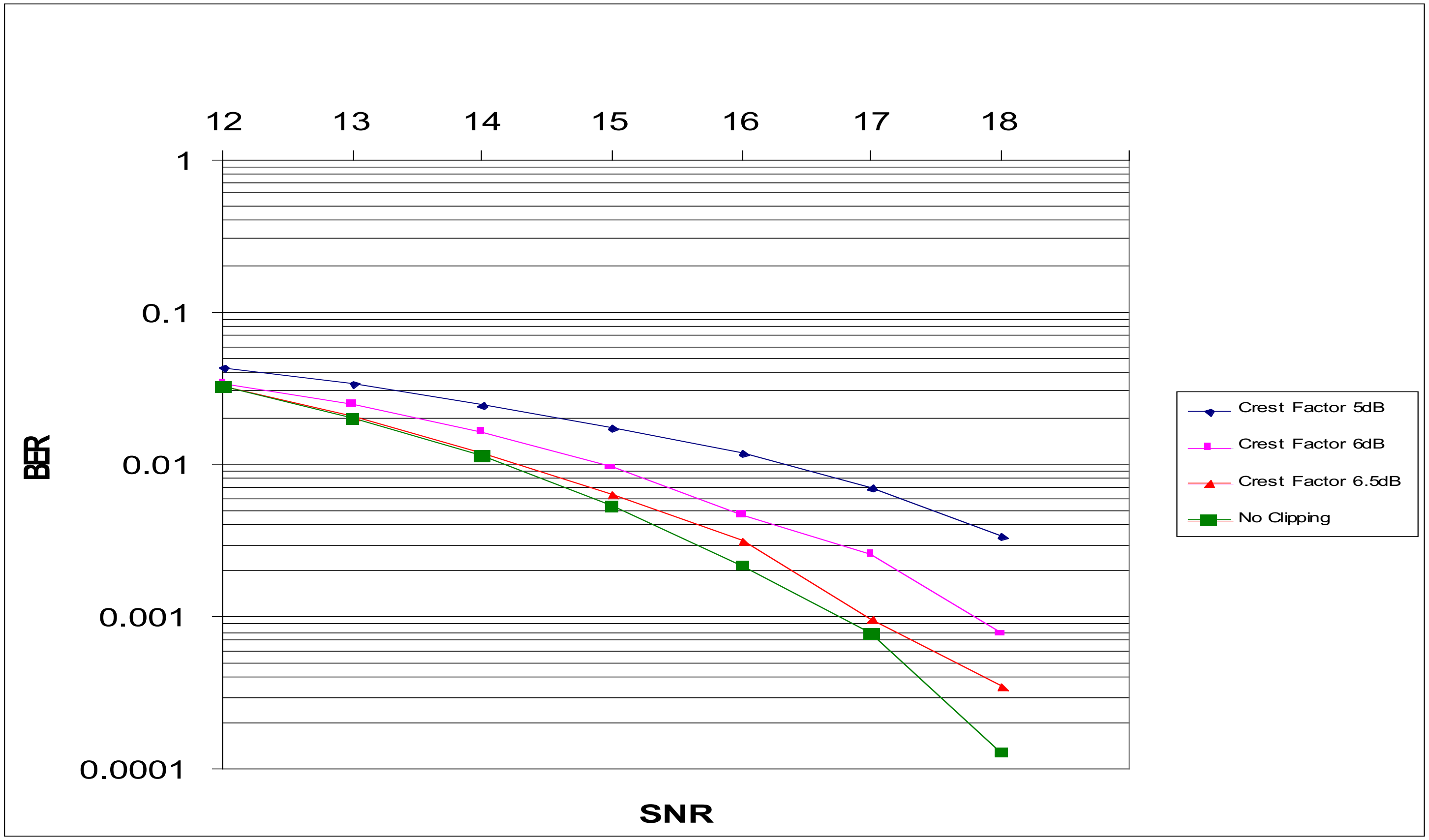


# Crest Factor (Down Stream)




BER/SNR for different Crest Factor achieved by clipping

# Crest Factor (Up Stream)




BER/SNR for different Crest Factor achieved by clipping for an Up Stream 16QAM OFDM Symbol

# Power Concentration

- In the Up Stream due to Sub-Channel allocation (29 carriers or 4 carriers per Sub-Channel) a **18dB** or **26dB** gain is achieved for one Sub-Channel allocation, Compared to a full OFDM symbol.
- This additional power gain enables communication up to 50Km, and a link budget without competition.
- This additional power 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

# 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

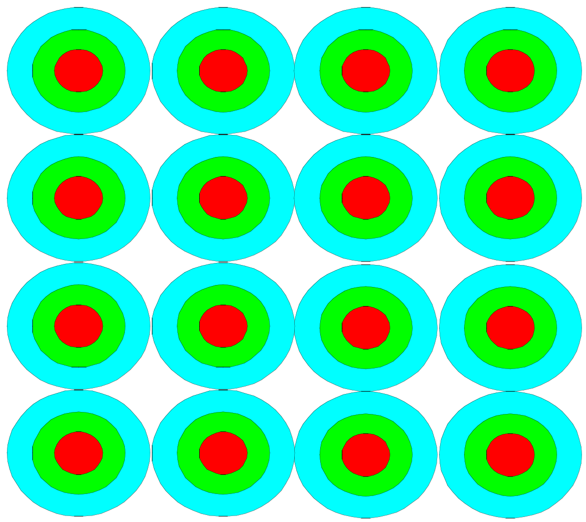
Considering a channel of 3MHz with NF=4dB, we have a floor noise of: -105dBm.

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)

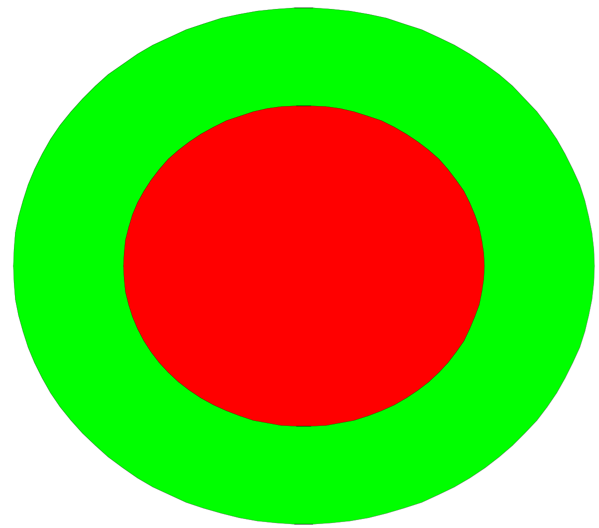
When using power concentration we get the same link budget for the uplink and downlink, satisfying the range requirements

# LOS/NLOS Conditions - Coverage limited

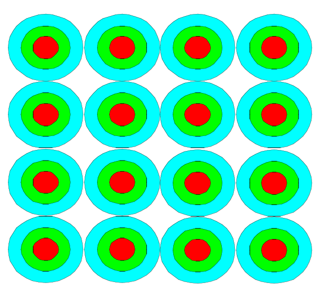
OFDM Cells



OFDMA Cell



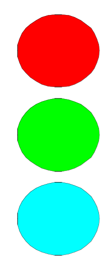
SC Cells



64QAM users

16QAM users

QPSK users



- Timing Sensitivity

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

- Frequency Sensitivity

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

- Equalization

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)

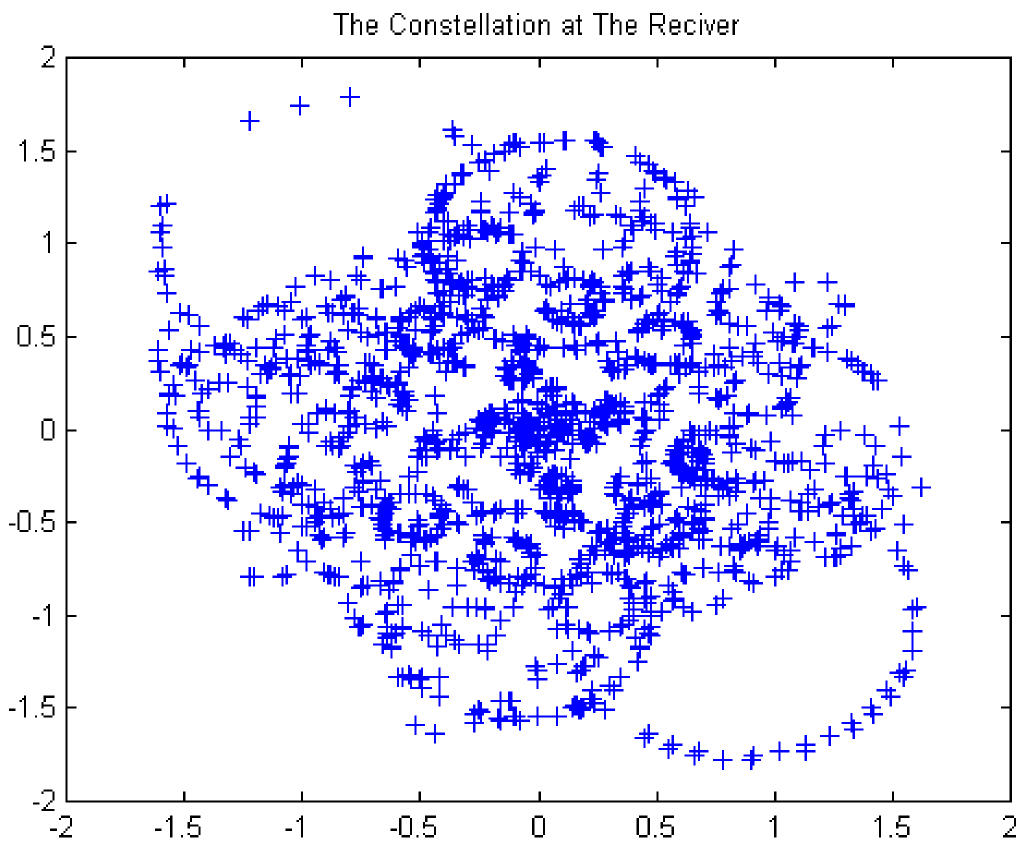
# Up Stream Channel Example

- Subscriber Units at the Current OFDMA Symbol = 3
- Pilot Carriers for channel estimation per Subscriber Unit
- Sub-Channels Allocated to Subscriber-Unit #1 = 30
- Sub-Channels Allocated to Subscriber-Unit #2 = 22
- Sub-Channels Allocated to Subscriber-Unit #3 = 17
- Number Of New Subscriber-Units Requesting Services = 3

**All Subscriber-Units Suffer Different Multi-Paths and different Attenuation's**

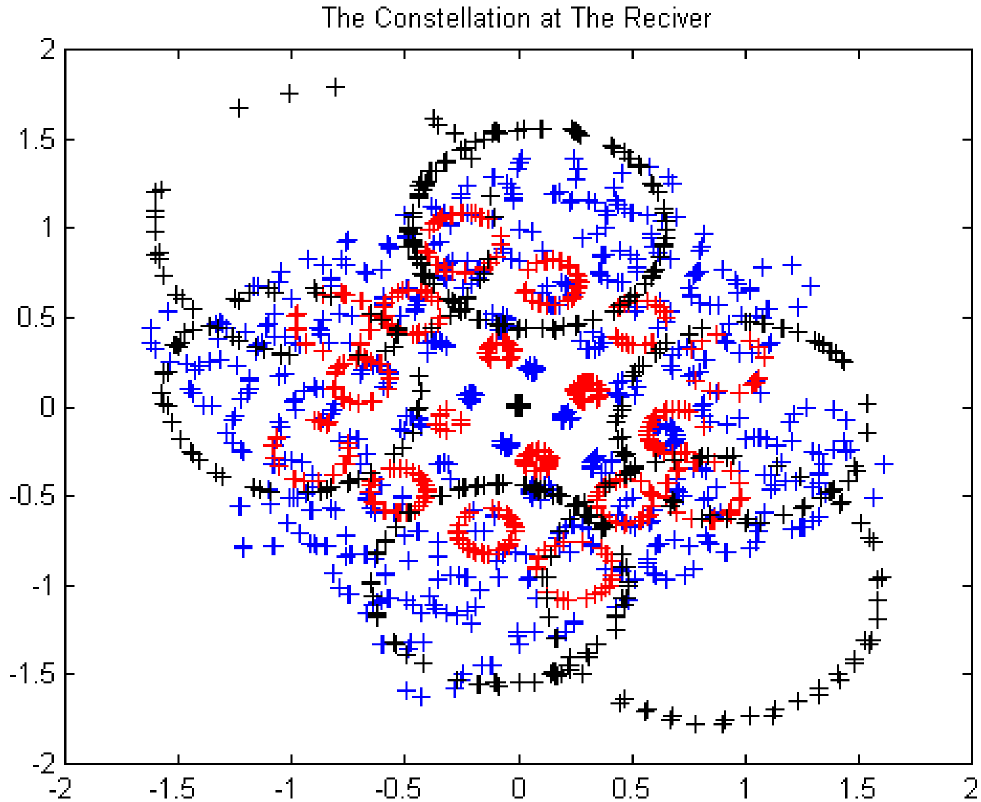
# Results

- Constellation at the Base Station



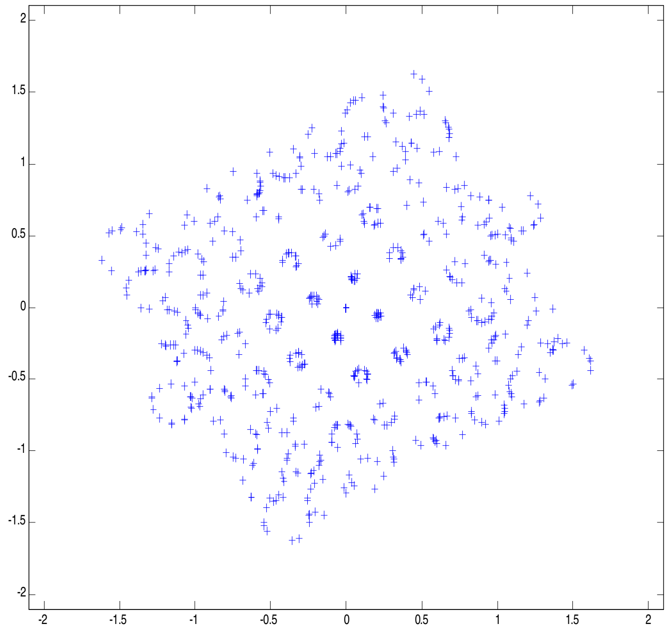
# Results

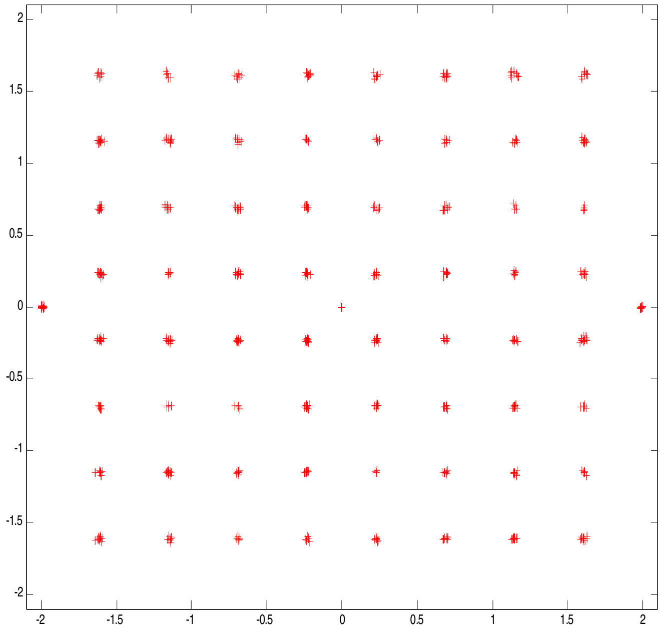
- Users Separation



# Results

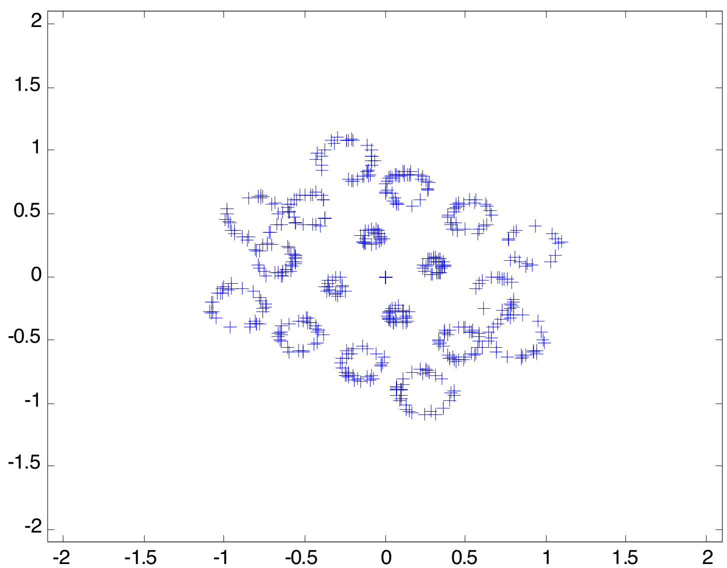
- User Estimation

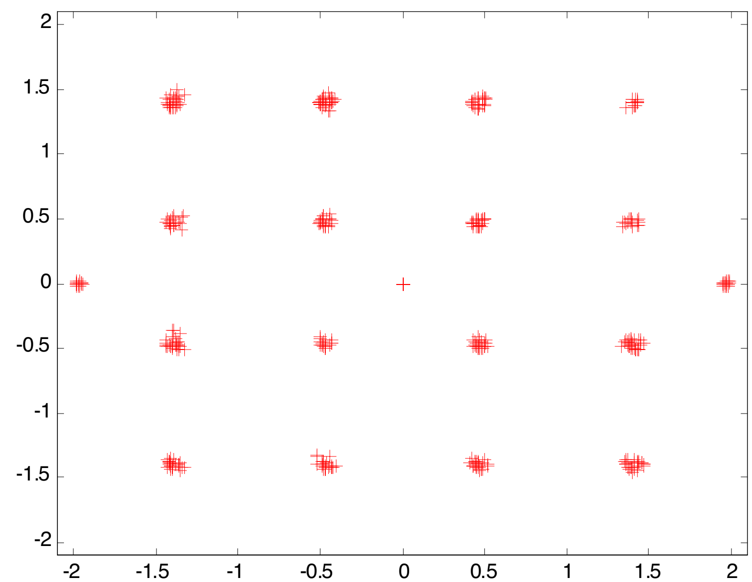


# Results

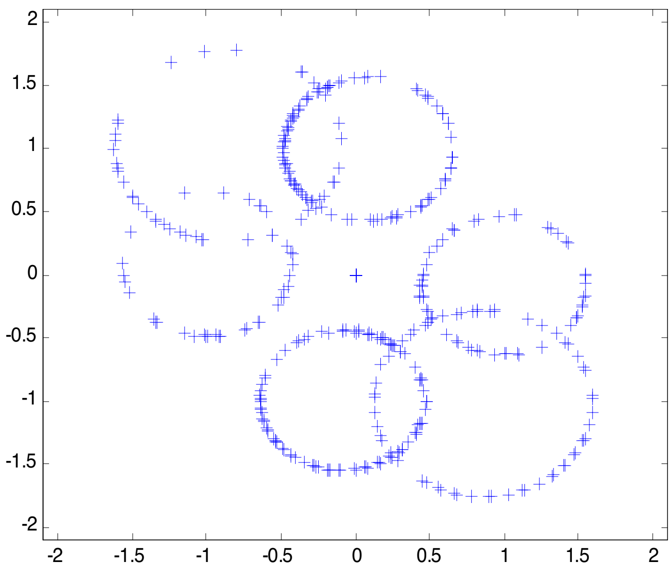
- User Estimation

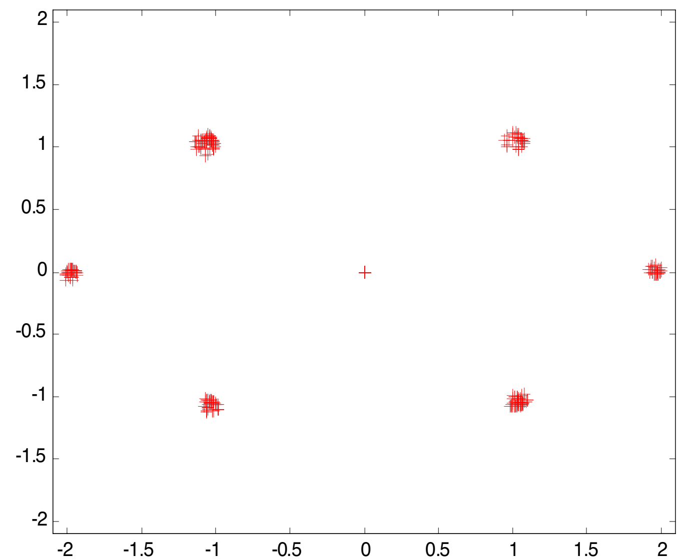


# Results

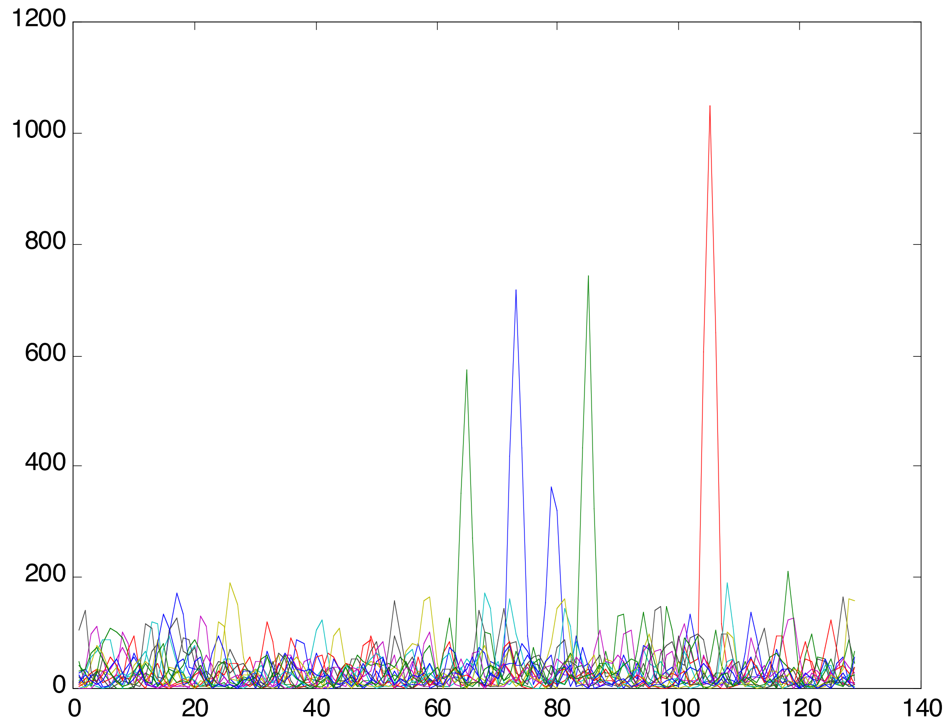
- User Estimation



# Results

- Finding New Subscriber-Units Requesting Services, Using the Contention Pilots (CDMA/OFDM Techniques), results with Multipath



# 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 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 optionally 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, this is allowed by the gain added when less carriers are allocated (18dB gain for 29 carrier allocation, 26dB Gain for 4 carrier allocation), therefore gaining in overall cell capacity.
- 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 144 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.
- DVB-T is a Proven technology for wireless environment even under 1GHz
- Many ASIC manufactures
- Low cost of DVB-T receivers ASICs

# 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><br>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>Today ASIC manufacturers produce chips in the same technology. The RF ends for the subscriber unit can<br>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. |

# 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 DVB-T is a well known and proven standard in Europe, Asia, Australia, India etc. it has already shown the capability to work very well under extreme conditions and regulations. The DVB-RCT is the return channel for the DVB-T and is following its footsteps. |