Coded Orthogonal Frequency Division Multiple Access

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{Page added by Roger Marks}

(1) ABSTRACT

In this tutorial I shell discuss the Coded Orthogonal Frequency Division Multiple Access (COFDMA) technique. The tutorial will contain explanation on the OFDM basics and coverage options, including Single Frequency Network (SFN) and its possible application for fixed and mobile applications. I discuss several possible coding and multiplexing implementations, including scenarios for multiple access and bandwidth on demand allocations. I also present a newly innovative approach for multiple access allocation using Reed Solomon series, which allows a better Carrier Allocation.

(2) PERMISSION

Date: Fri, 12 May 2000 13:17:51 +0200
From: Tal Aharon <tal@runcom.co.il>
To: "'Roger B. Marks'" <marks@boulder.nist.gov>
Cc: Zion Hadad

Dear Roger,

The slides were presented for tutorial purpose only, I'm not able to remove the sentence since I have no idea who is going to receive the slides and what he intends to do with it.

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I hope this satisfies your needs.

Regards.

Tal

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Tal Aharon
V.P Operations

P-MP System Requirements

Customers and Mobility

- Fixed Users - Residential, Business
- Slow Mobility Users - Neighborhood (PC Cards, Set Top Boxes)

- Connection can be both Outdoor to Outdoor or Outdoor to Indoor (Base to Subscriber).

Capacity

- Use modulations with various Bit/Hz capabilities as Adaptive N-QAM.
- Use Adaptive ECC (Convolutional & Reed-Solomon or Turbo code)
- Maximal frequency reuse between cells/sectors (close to 1).
- Maximum sectors allocation.
- The use of statistical Multiplexing and concentration.
- Adaptive Carrier Allocations.

Bandwidth on Demand (BOD)

The capability to supply users needs upon demand

64Kbps – 24Mbps with small granularity steps

(for 6MHz MMDS bandwidth)

64Kbps – 48Mbps with small granularity steps

(for 12MHz MMDS bandwidth)

Large Scope of Services

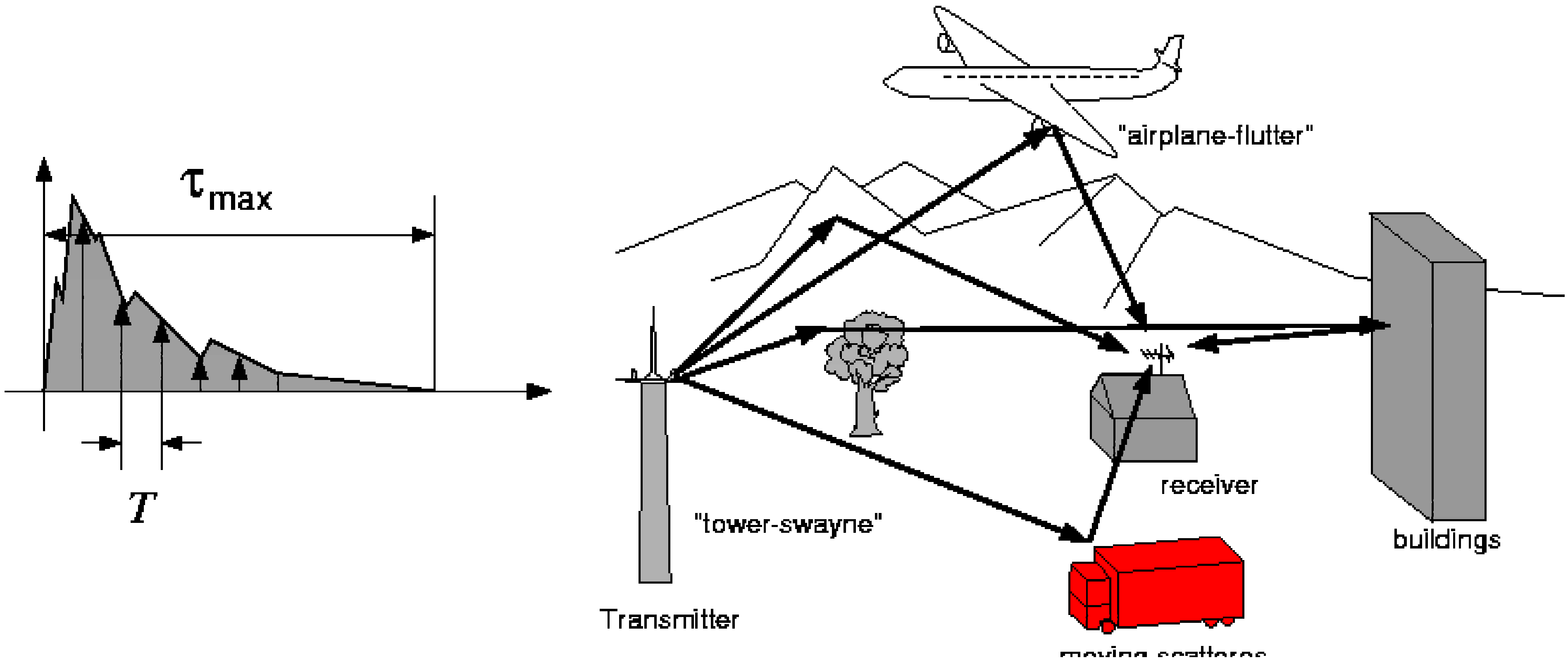
Supplying services for Video, Voice , Data interfacing to IP, ATM and other Packet Switching or Circuit switching data in the same access method while keeping the necessary QoS.

Coverage

- Urban, Semi Urban ,Rural
- NLOS conditions
- Ranges of up to 5Km in an urban environment, 10 Km in a semi urban environment and 20-30Km in a rural environment (Availability of 99.999%)
- Coverage of 99.9% of the area in the service zone
- High service reliability and connection survivability that should not be dependent on the terrain.
- Optimal usage of subscriber PA.

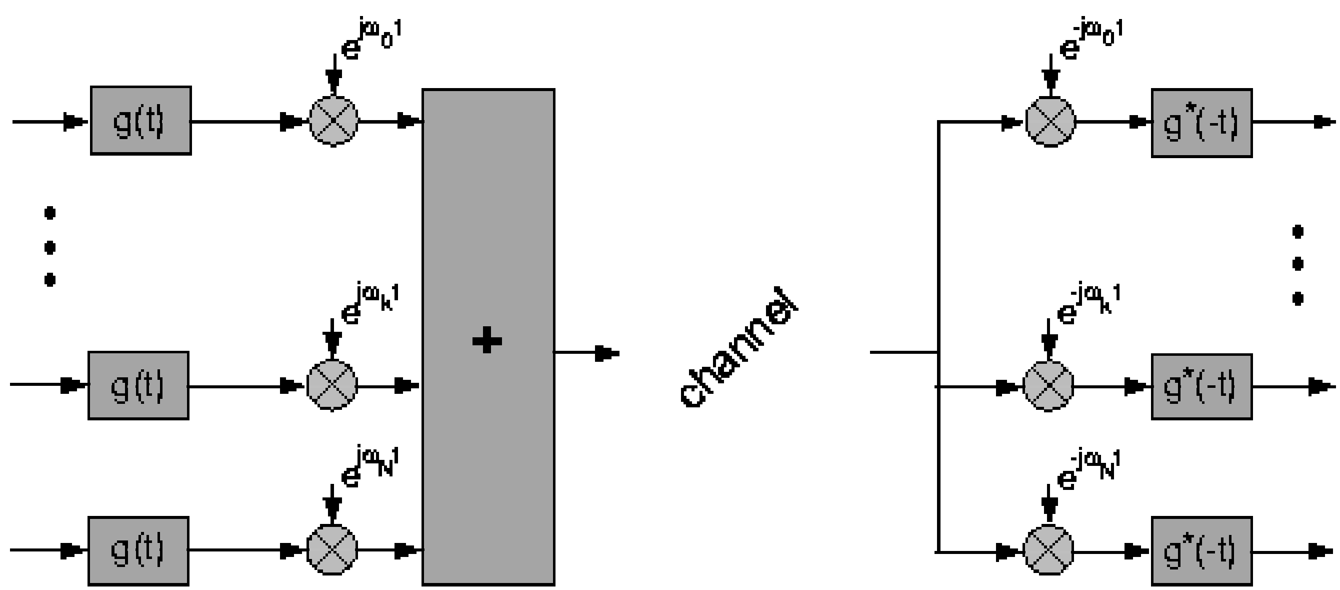
OFDM Overview

Basic Wireless Propagation

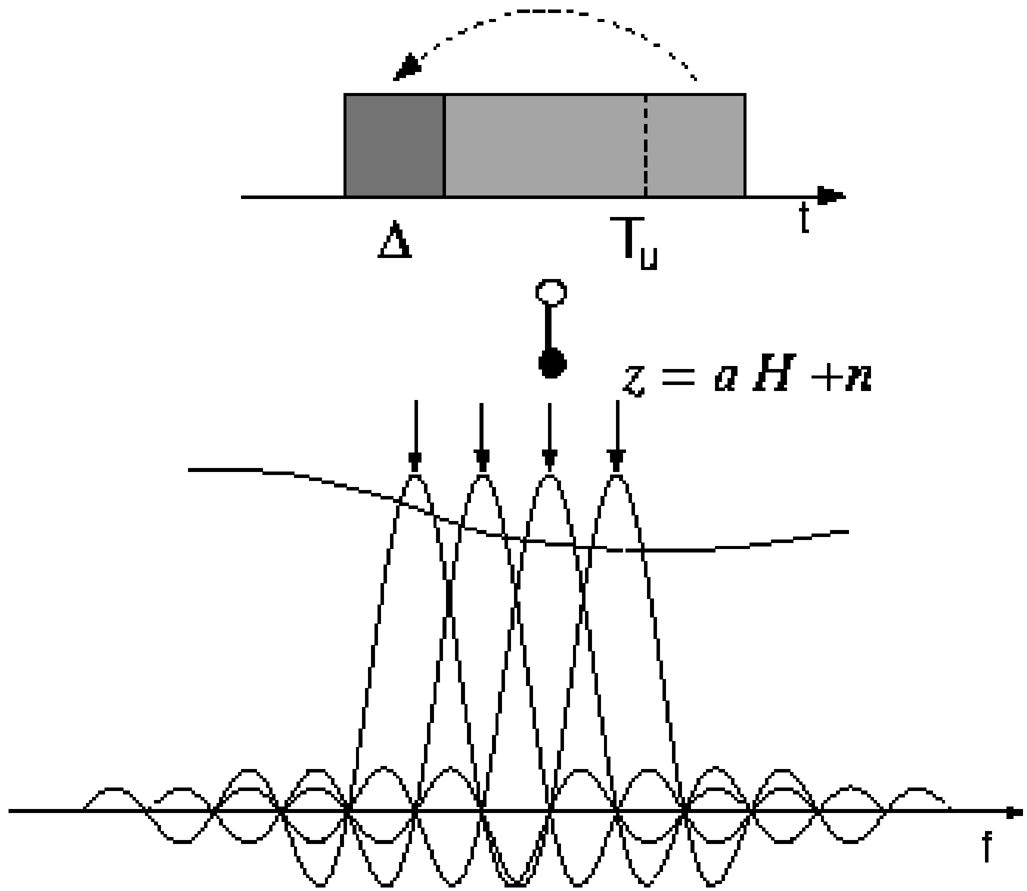


- For 2-3GHz, Delay Spread is 400ns-10μsec

Single Carrier and Multi Carrier



OFDM Spectrum



OFDM FFT Size Planning

The Basic assumption is: for less then 10% ISI there is no need for equalization, and a simple detection can be done.

For the 2-3GHz band, a 10μsec delay spread can be assumed, the basic carrier spacing should be approximately 4KHz (adding on top of that the Guard Interval).

OFDM FFT Size Planning

For a 6MHz channel approximately 1500 carriers should be used (for a 4KHz carrier spacing).

For a 12MHz channel approximately 3000 carriers should be used (for a 4KHz carrier spacing).

A good compromise is using a 2048 points FFT, which is best suited for the compromise between Multi-Path mitigation and Nomadity/Frequency accuracy considerations.

OFDMA System - Possible Architecture

Duplexing Technique

- FDD, TDD, FDD/TDD

Multiple Access Method

- TDMA/OFDMA

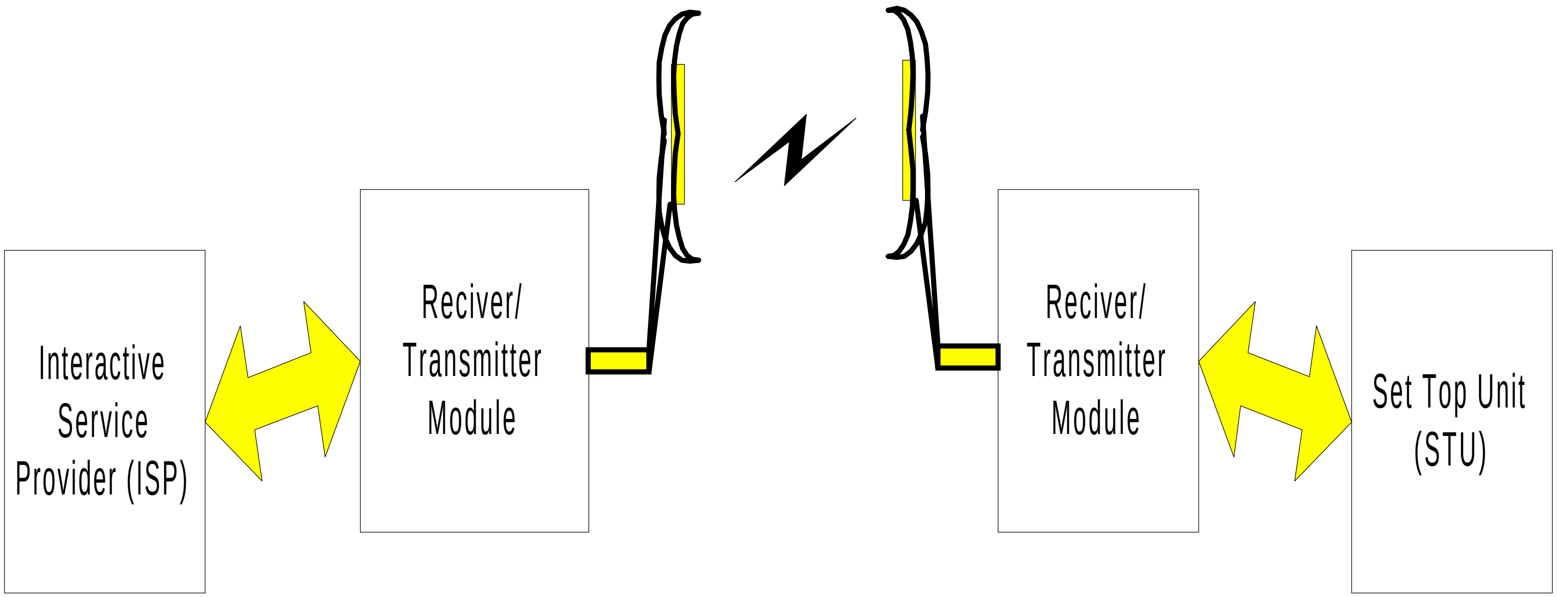
OFDM Symbols allocated by TDMA

Sub-Carriers within an OFDM Symbol allocated by OFDMA

Diversity

- Frequency, Time, Space, Code

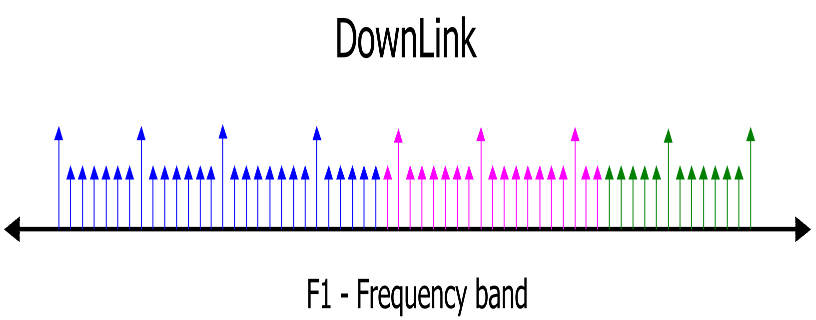
System Architecture - FDD or TDD

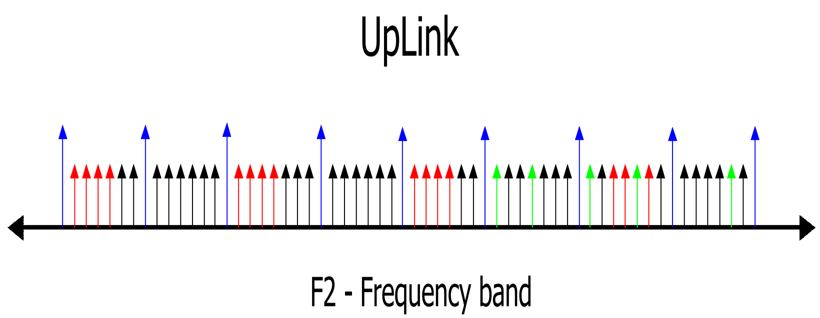


Frequency Division Duplexing (FDD) - Principles

One Frequency is Used for the DownLink, Using OFDM/TDM .

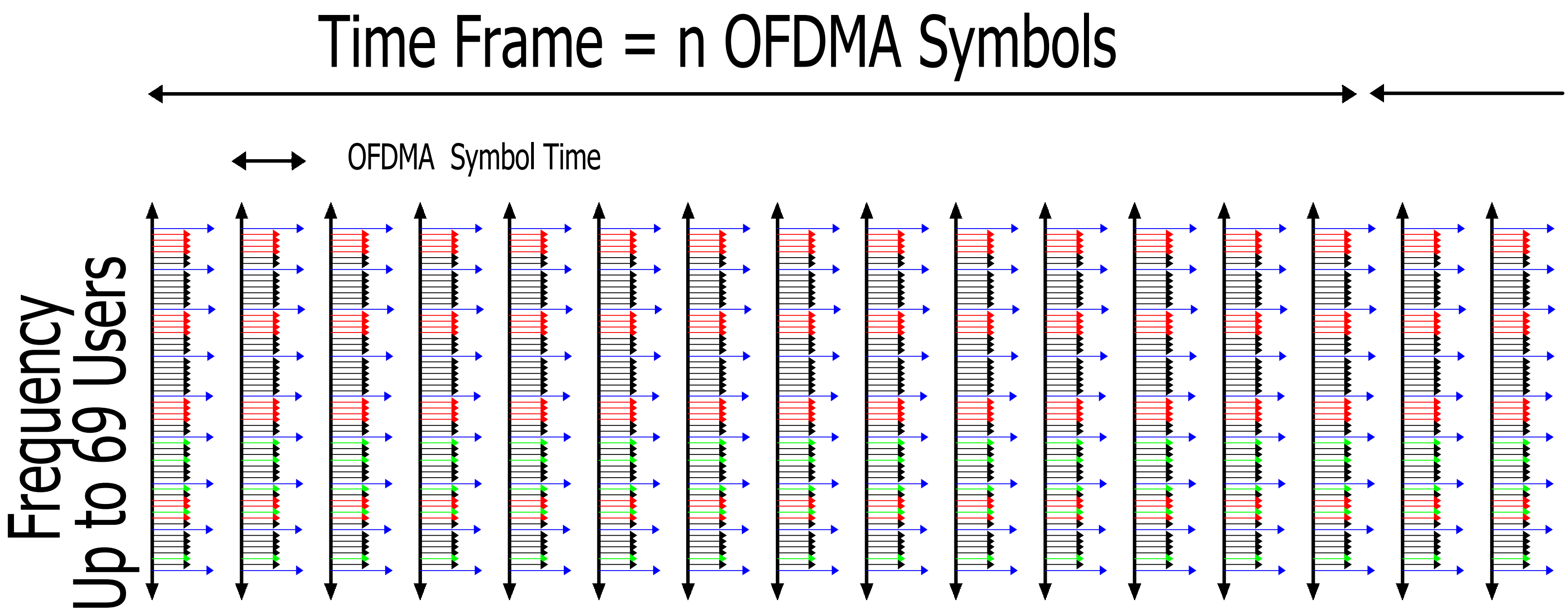
A Second Frequency is Used for the UpLink , Using OFDMA/TDMA .



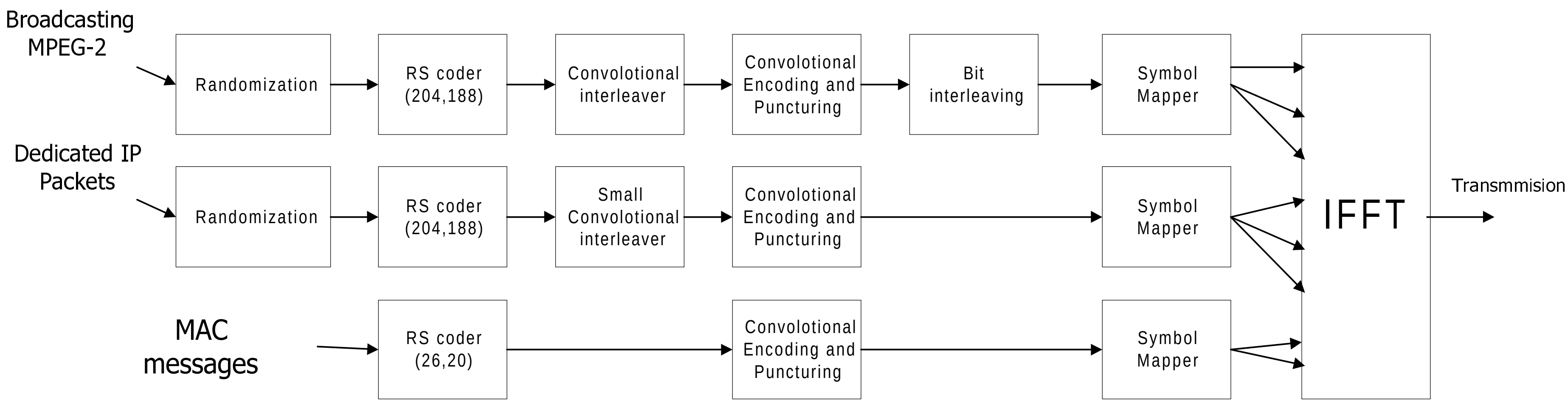


OFDMA/TDMA - Principles

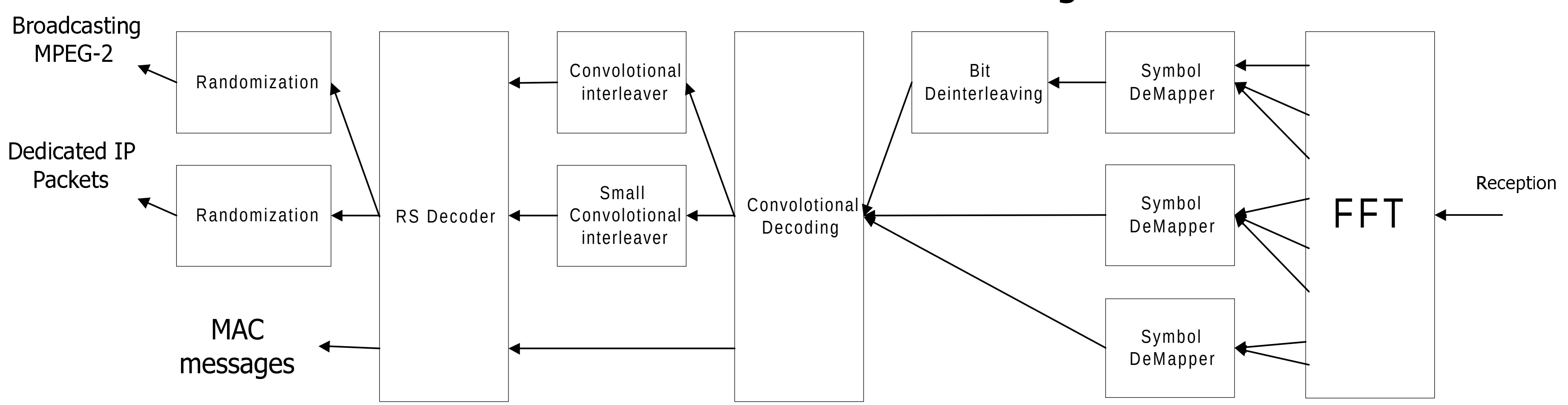
Using OFDMA/TDMA, Sub Channels are allocated in the Frequency Domain, and OFDM Symbols allocated in the Time Domain.



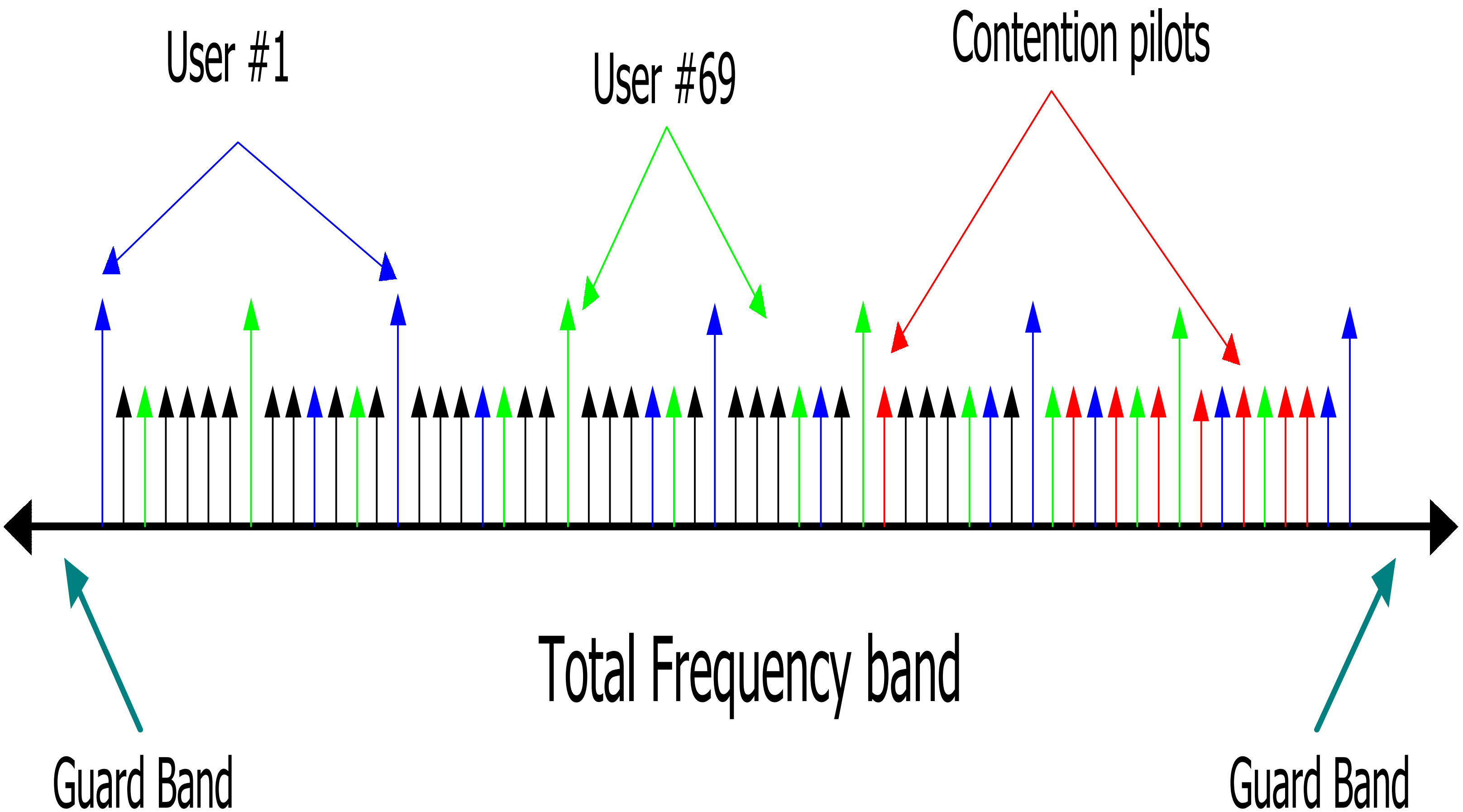
Down Stream Encoding and Modulation



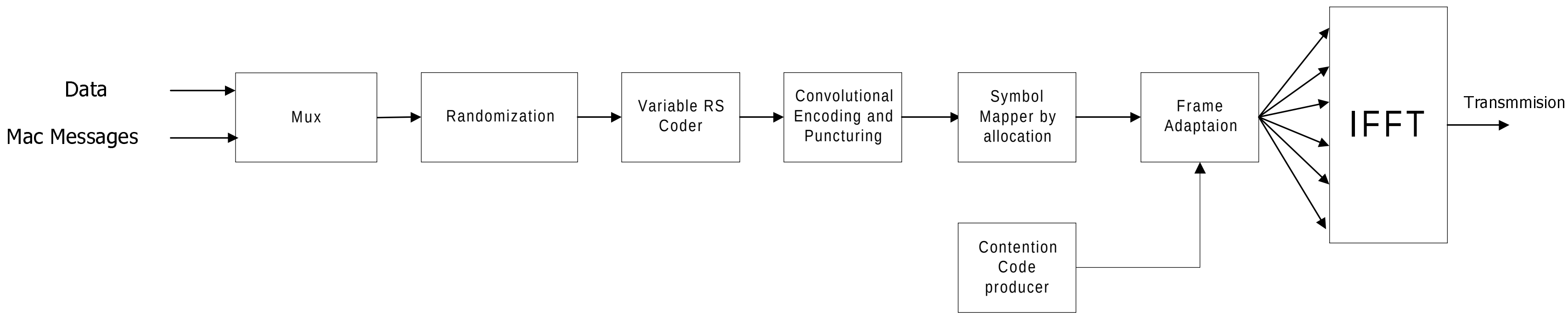
Down Stream Demodulation and Decoding



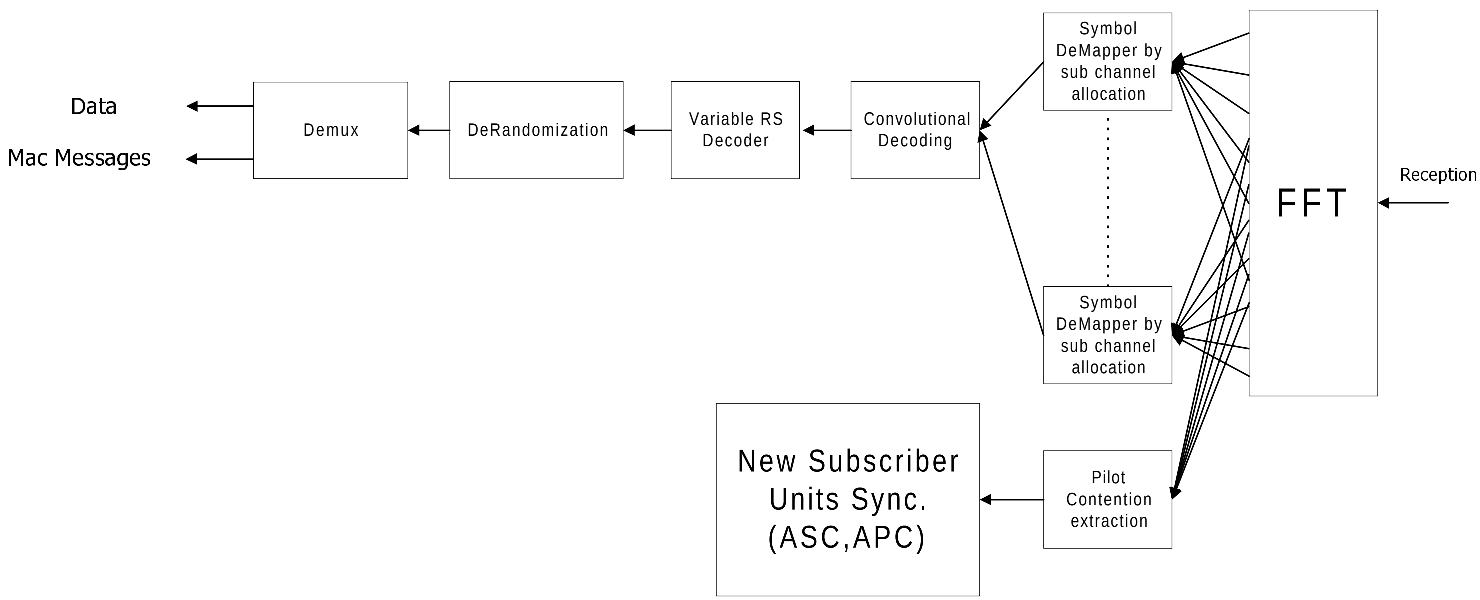
UpLink OFDMA Symbol



UpLink Encoding and Modulation

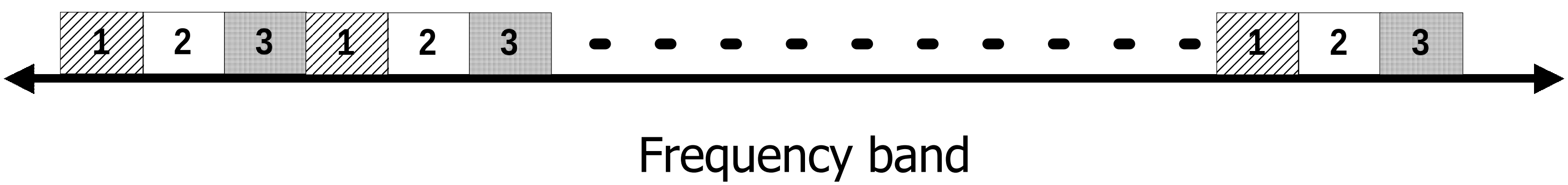


UpLink Demodulation and Decoding

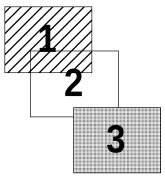


Using Special Permutations for Carrier Allocation

- All usable carriers are divided into 23 carrier groups named basic group, each main group contains 23 basic groups.
- There are 3 main groups.



each group contains 23 carriers

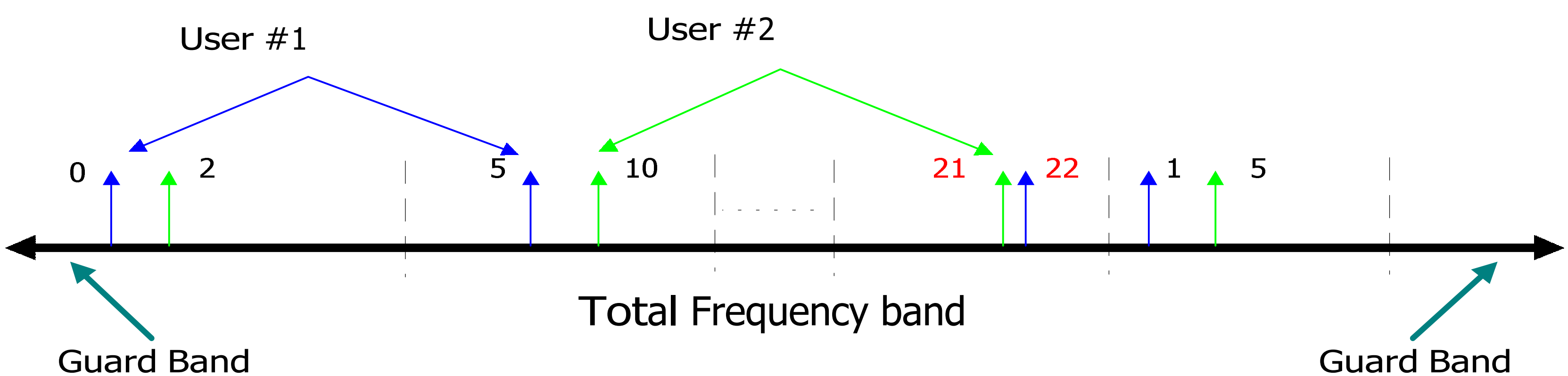


Using Special Permutations for Carrier Allocation

- Carriers are allocated by a basic series and it's cyclic permutations
- 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

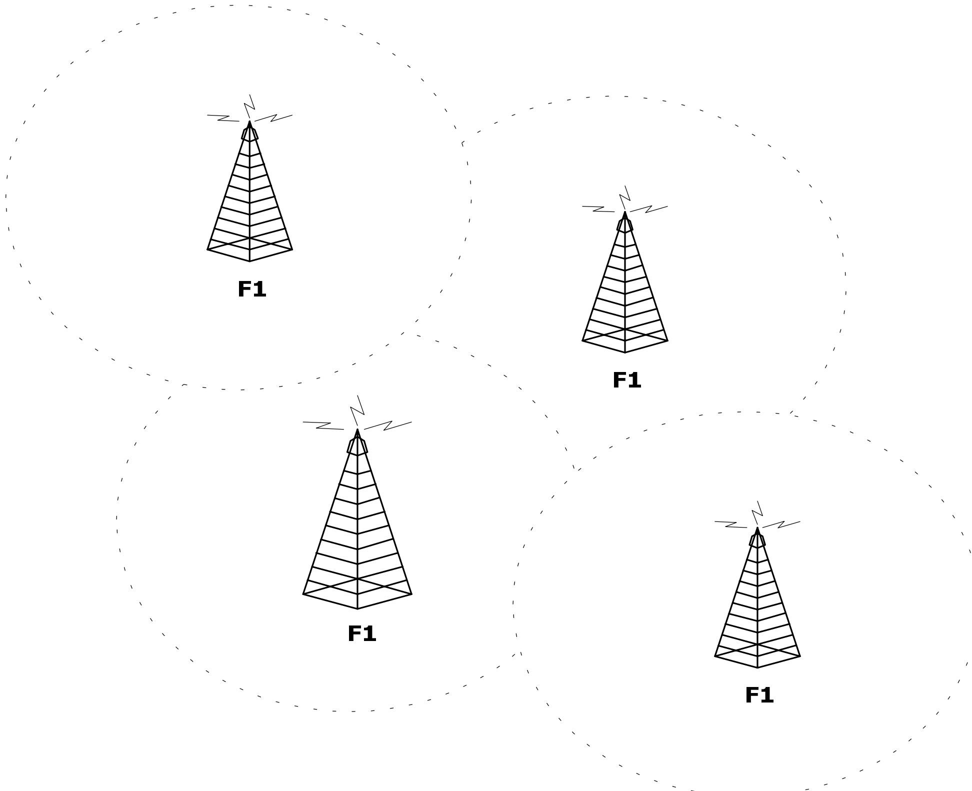


User 1 = 0,5,2,10,4,20,8,17,16,11,9,22,18,21,13,19,3,15,6,7,12,14,1
User 2 = 2,10,4,20,8,17,16,11,9,22,18,21,13,19,3,15,6,7,12,14,1,0,5

OFDMA System - Coverage and Capacity

Broadcasting SFN

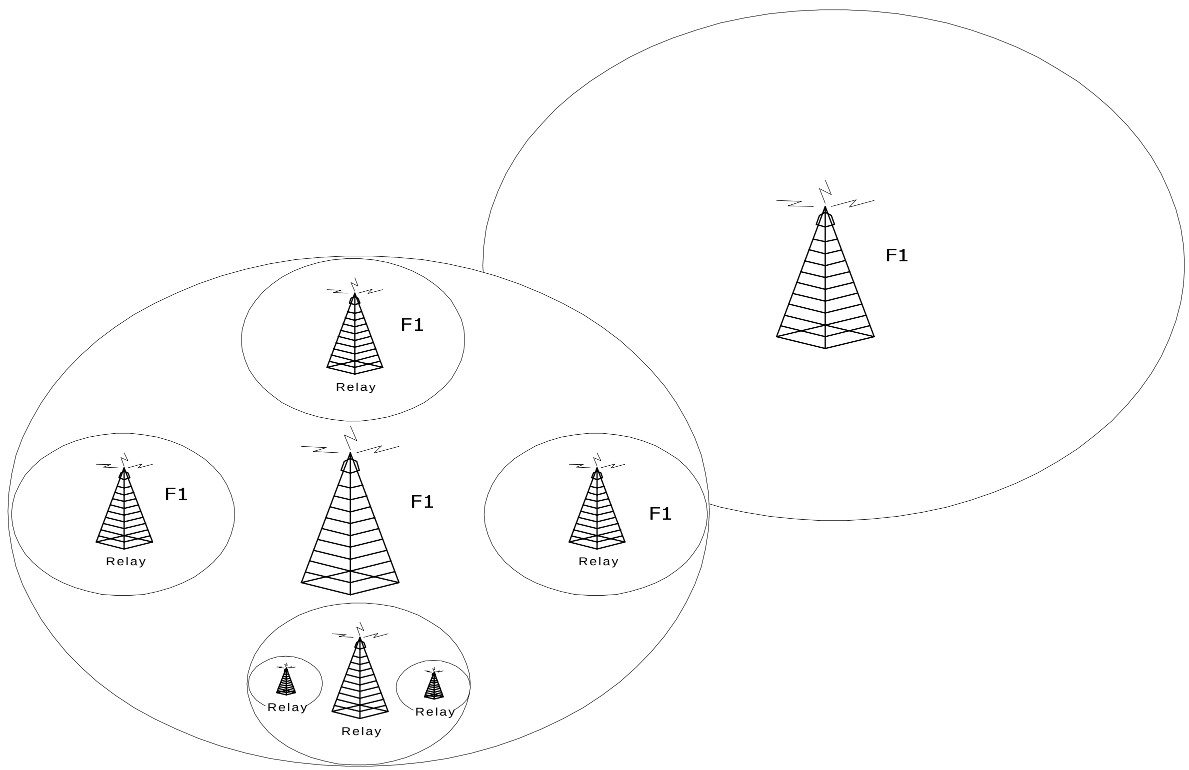
The Same Data for Mobile and Fixed Users



Broadcasting SFN, In-Door Antennas

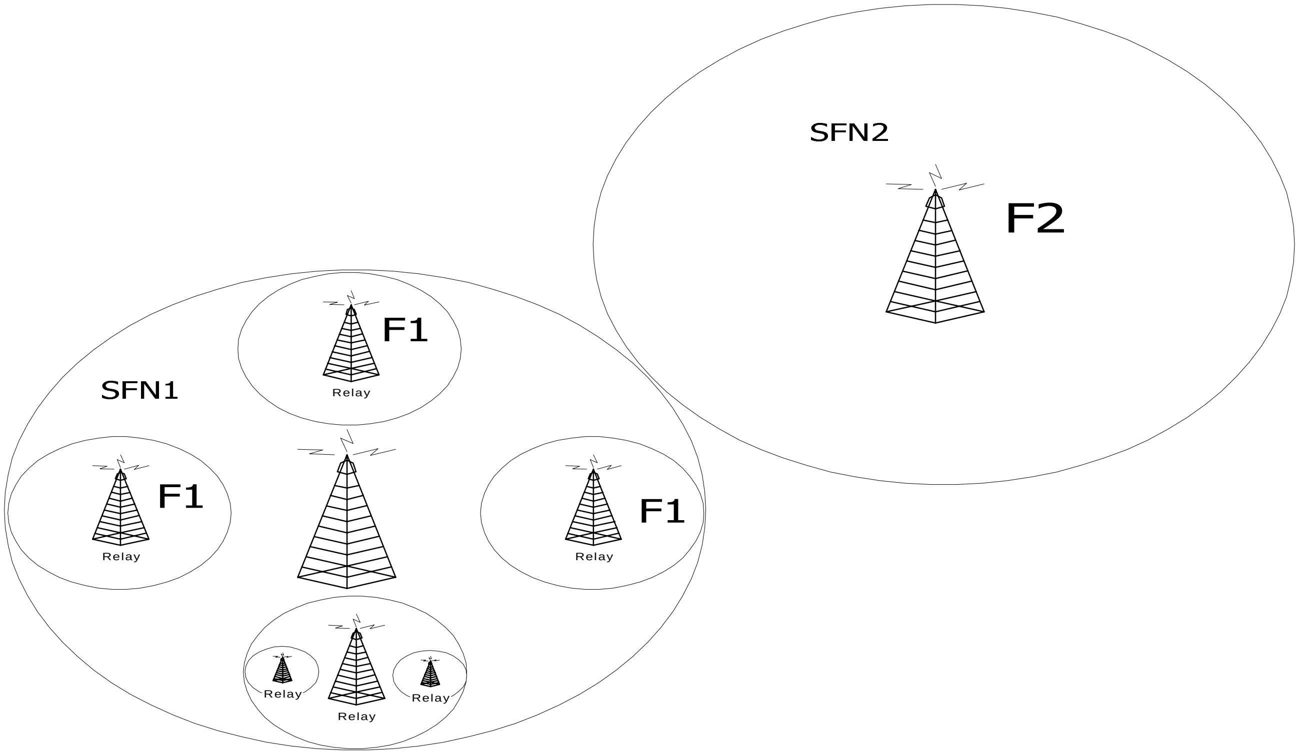
The Same Data for Mobile and Fixed Users

Where There is a Problem of Coverage, Smaller Cells are Used



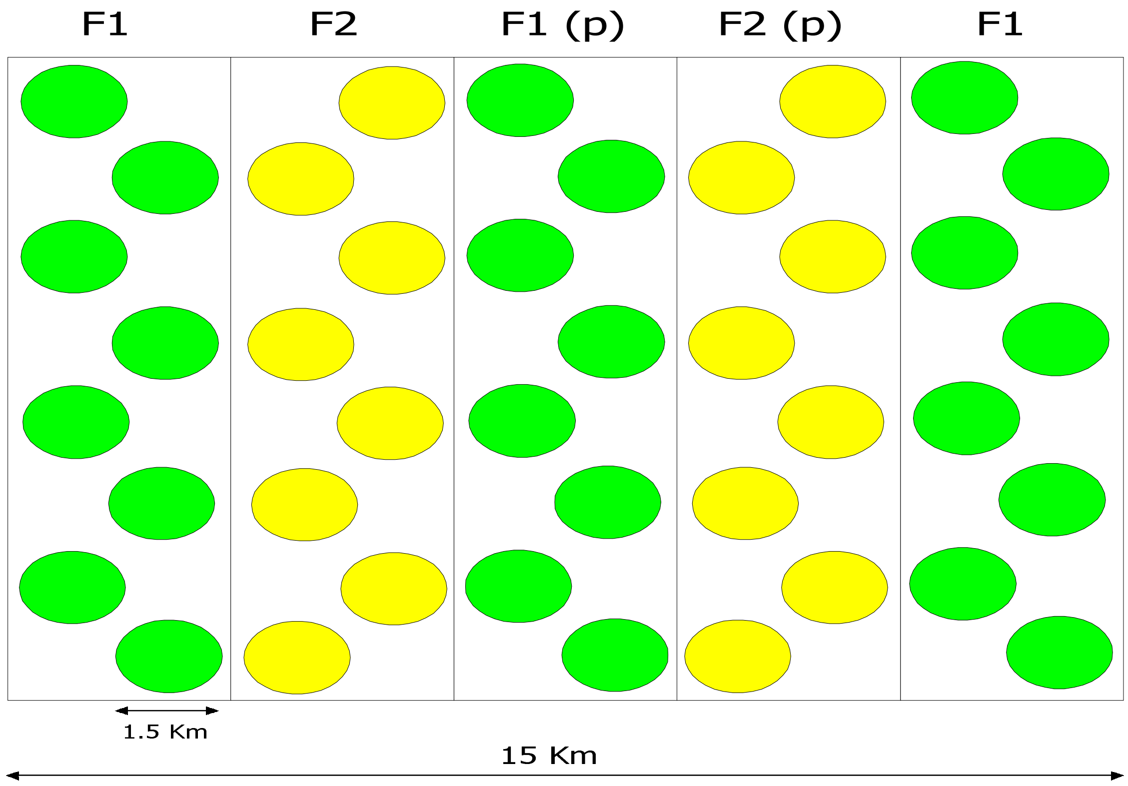
Local SFN - for Interactive Services

- Each SFN Enables the Users to Receive Transmissions From Any B.S.
- Users Transmission can be Received by some B.S., While the main B.S. can use MRC.

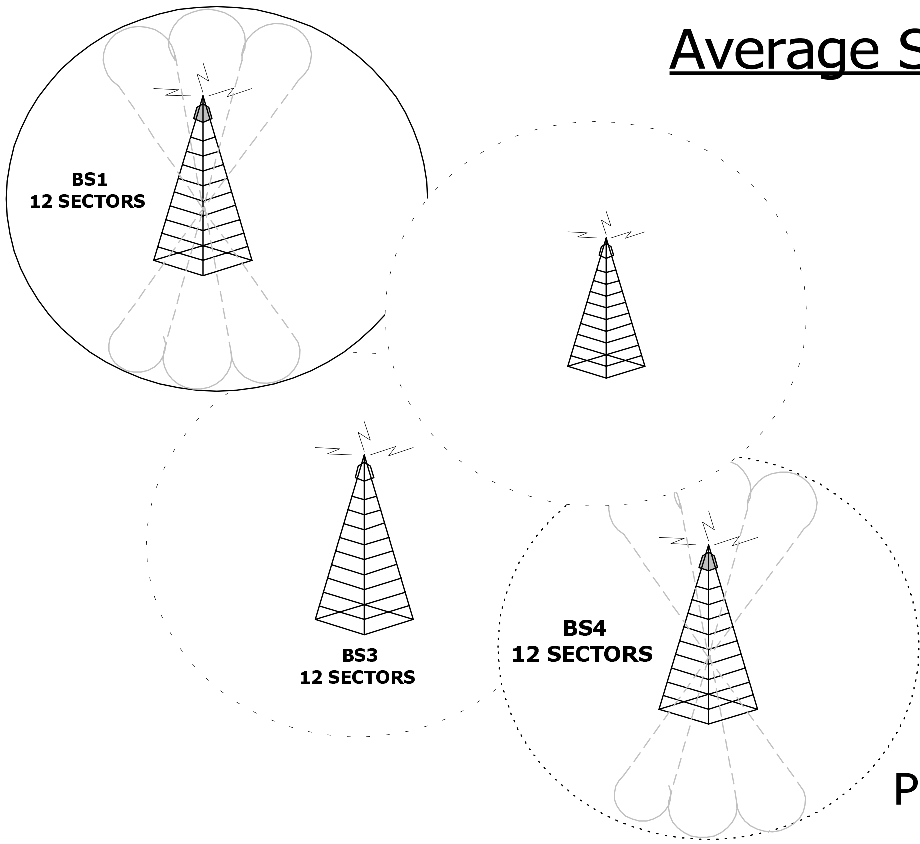


SFN Reuse for Slow Mobility or Indoor Antenna

This is an Example of a DVB-T interactive SFN with a Reuse Factor of 2



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

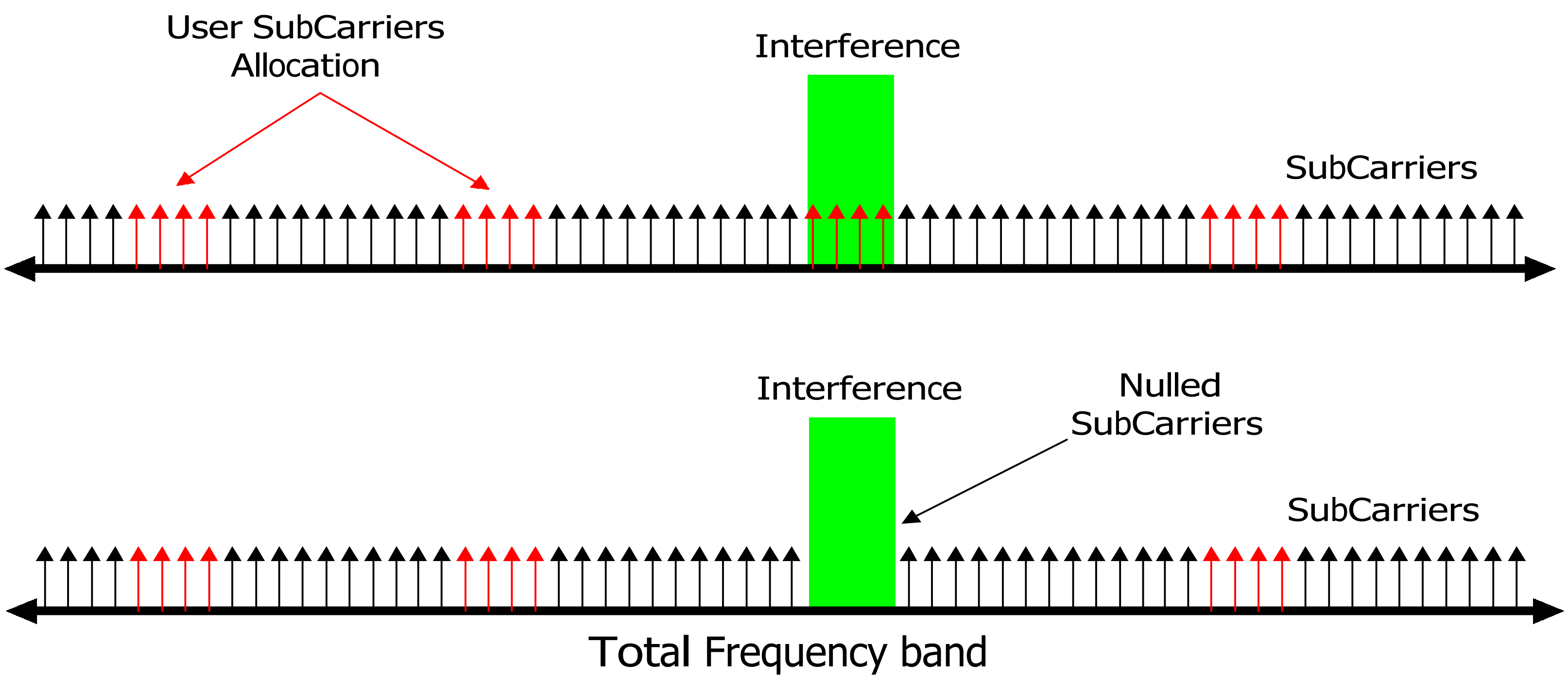
(Cross Polarization is Optional)

Peak Capacity for single sector = 24Mbps

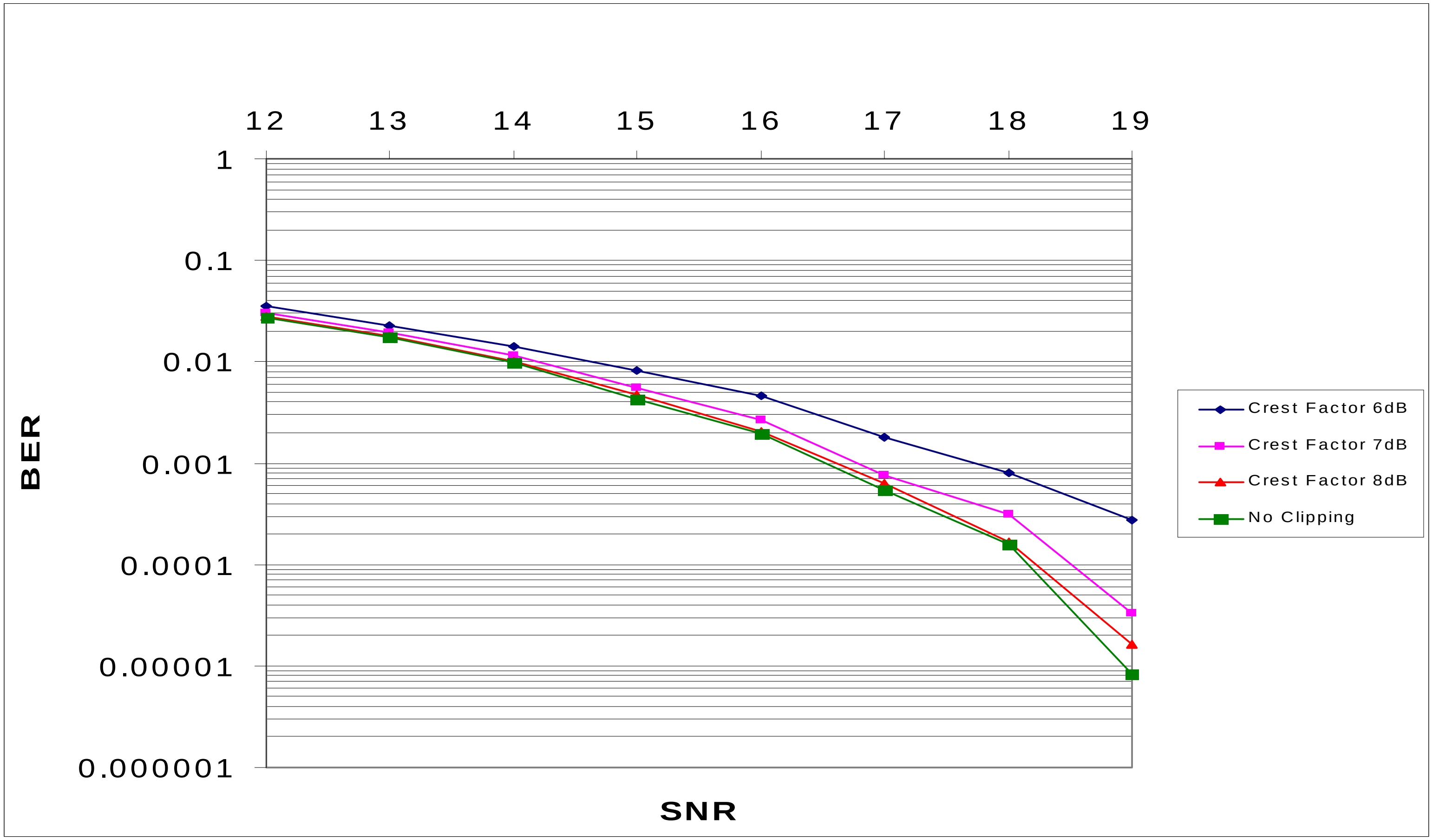
OFDMA System - Properties

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 .

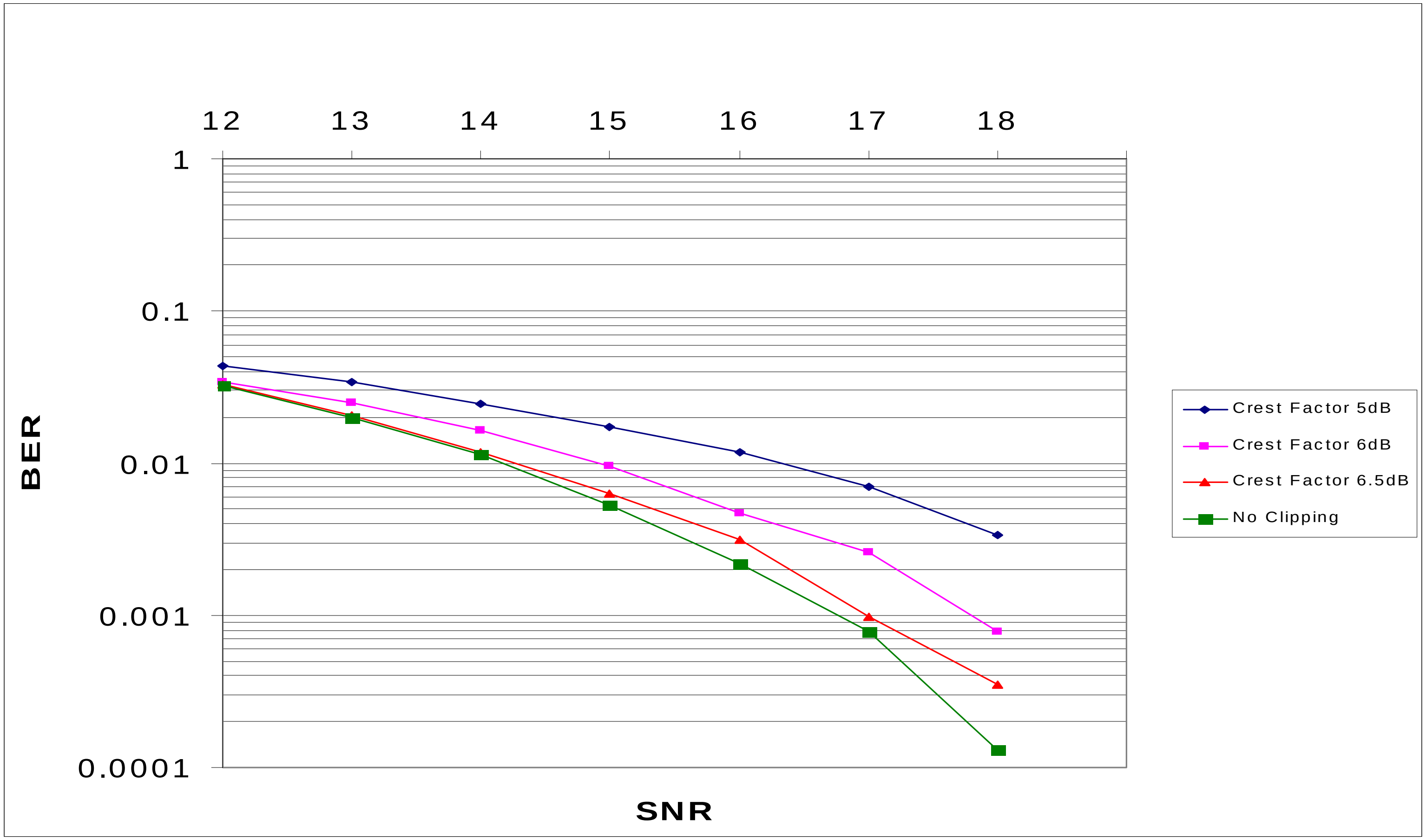


Crest Factor (Down Stream)



BER/SNR for different Crest Factor achieved by clipping

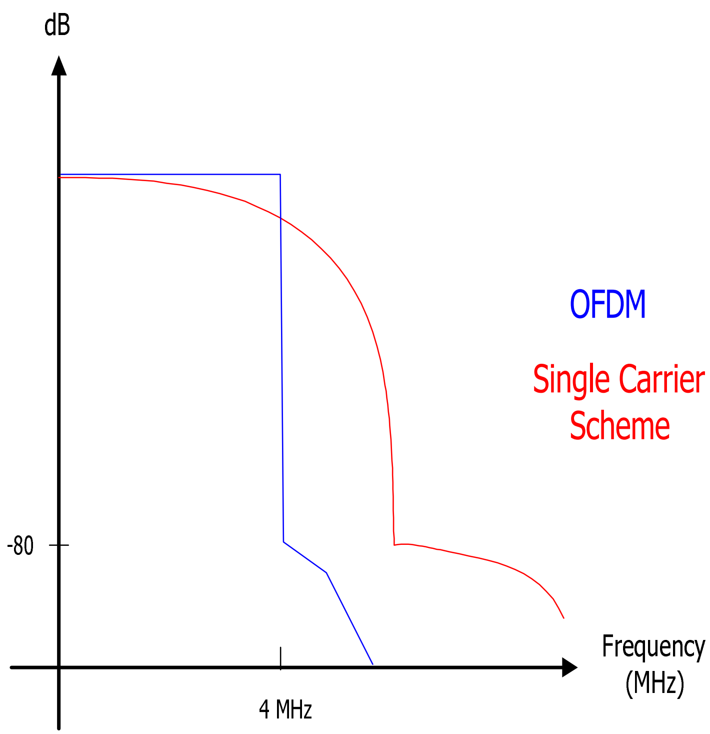
Crest Factor (Up Stream)

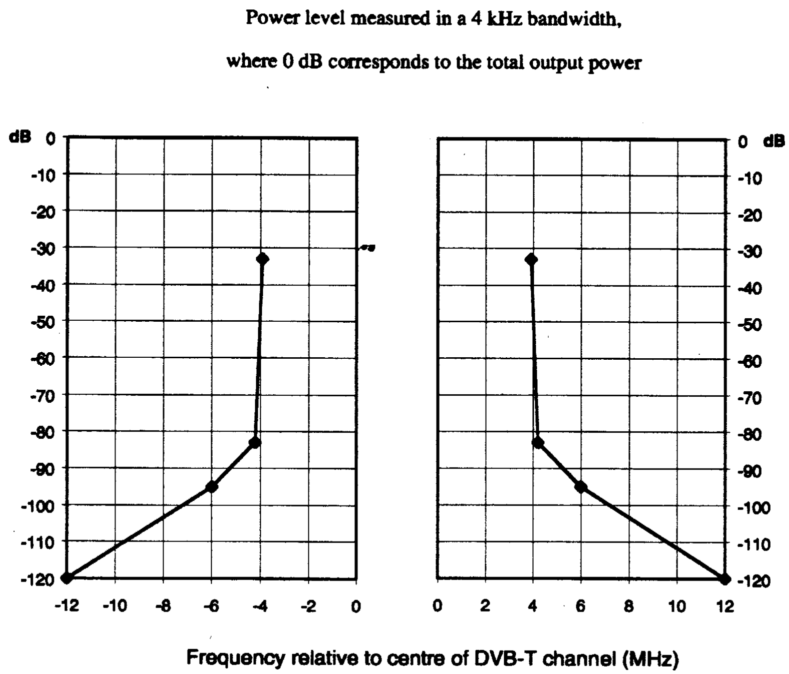


BER/SNR for different Crest Factor achieved by clipping for an Up Stream 16QAM OFDM Symbol

Spectrum Properties

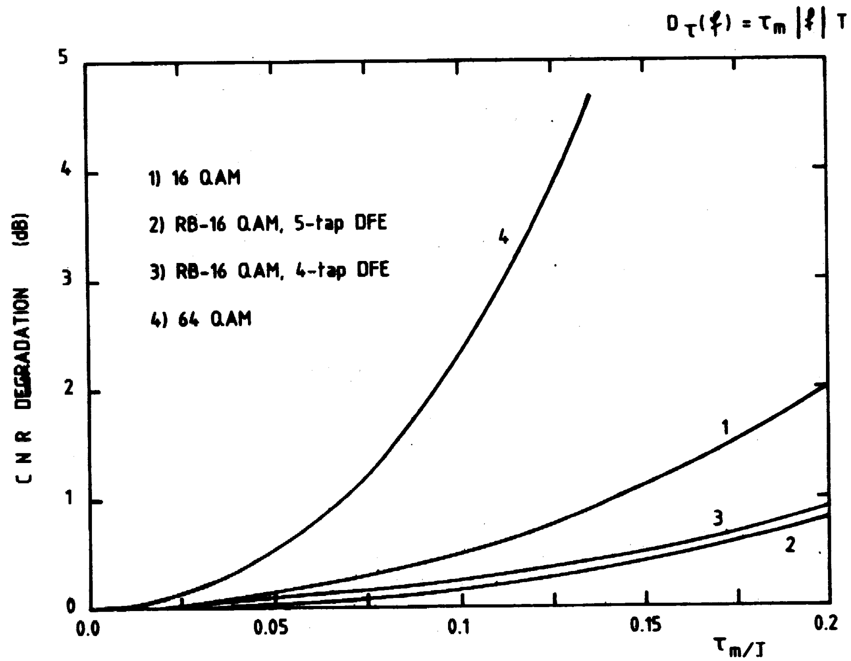
- Rectangular Spectrum Shape (Brick Wall)
- Small Frequency Guard band





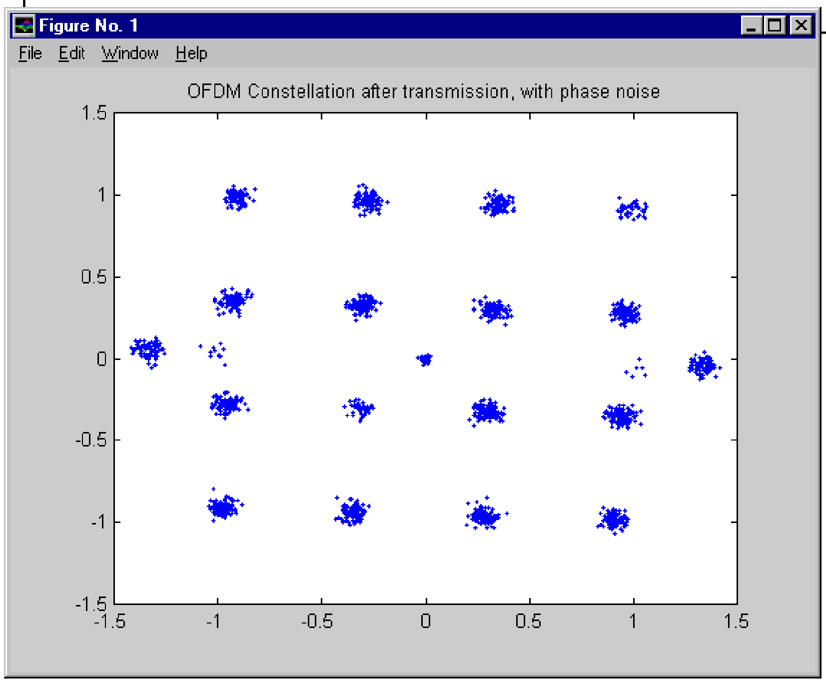
Group Delay

In OFDM Solved as channel impairment by phase and channel estimators, while in S.C. system degradation is performance occurs

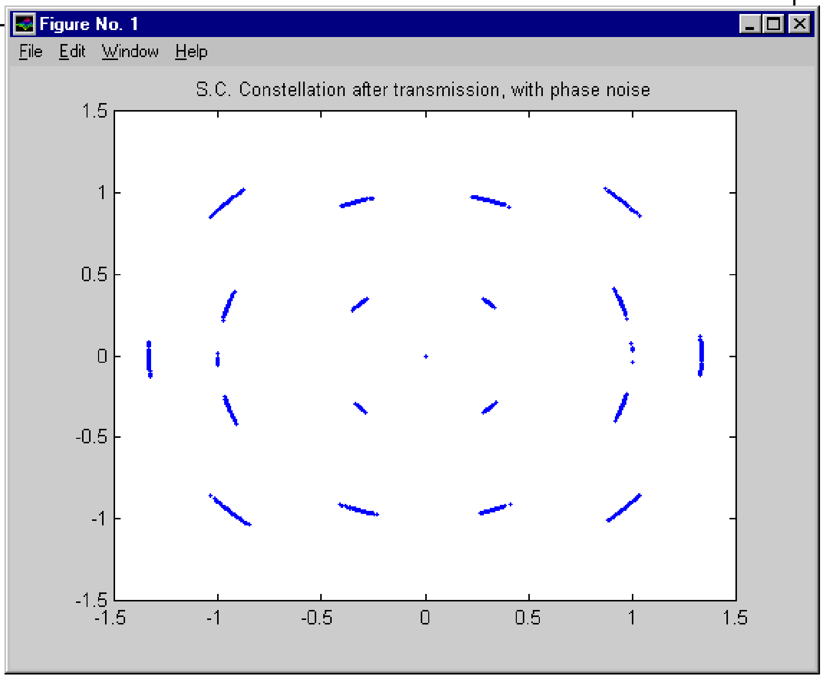


Influence of linear group-delay distortion on the performance of the three modulation schemes.

Phase Noise Effect

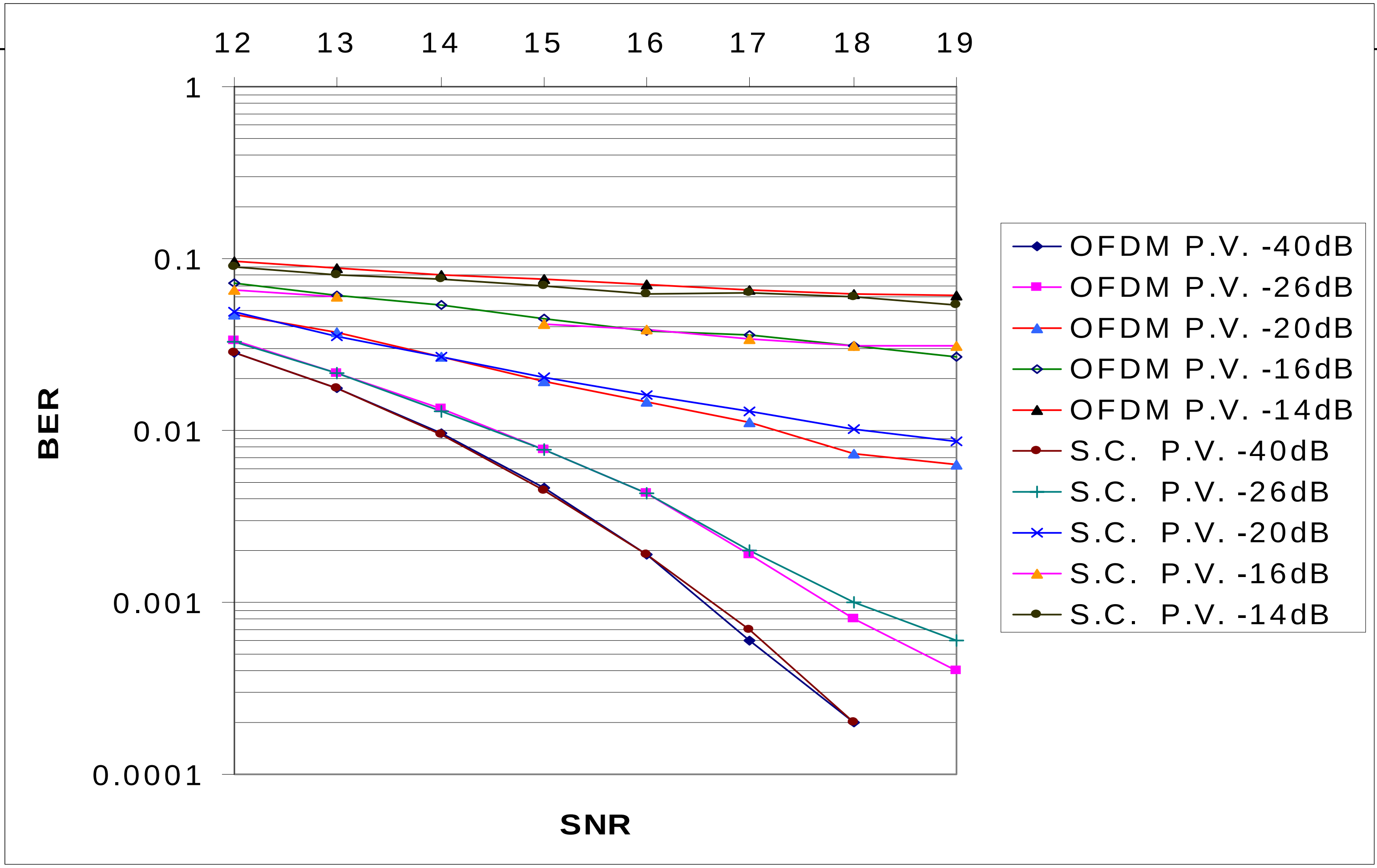


Phase Noise Effect on OFDM



Phase Noise Effect on S.C

Phase Noise BER Results



BER/SNR of the OFDM and S.C. systems for different Phase Variance (P.V.)

Power Amplifier Efficiency

- In the Up Stream due to Sub-Channel allocation (23 carriers from 1587 usable per OFDM symbol) a 18.4dB gain is achieved for one Sub-Channel allocation, an additional 1-2dB gain is achieved due to lower crest factor for the Up Stream.

- <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

MAC Principles

- Bandwidth allocation controlled by Base Station
- Bandwidth efficiency through support of variable-length packets
- Quality of Service including
  - Support for bandwidth and latency guarantees
  - Packet classification (VPI/VCI with ATM)
  - Dynamic service establishment
- Extension provided for security at the Data Link Layer
- Support for wide range of data rates
- Fragmentation - allows segmentation of large packets simplifying bandwidth allocation for CBR type services
- Concatenation - Allows bounding of multiple small packets to increase throughput

MAC - Principles

- Transparent Bi-Directional transfer of ATM cells and IP packets.
- Manages Adaptive FEC (Reed Solomon & Viterbi), one Up Stream Transmission contains an integer number of R.S. packets
- Manages Adaptive N-QAM UpLink Transmissions
- Manages APC/ASC Messages
- New Users are synchronized and granted access by CDMA techniques
- Uses Piggy-Back for continues data transmission
- Can Comply to DOCSIS 1.1 standard with wireless enhancements

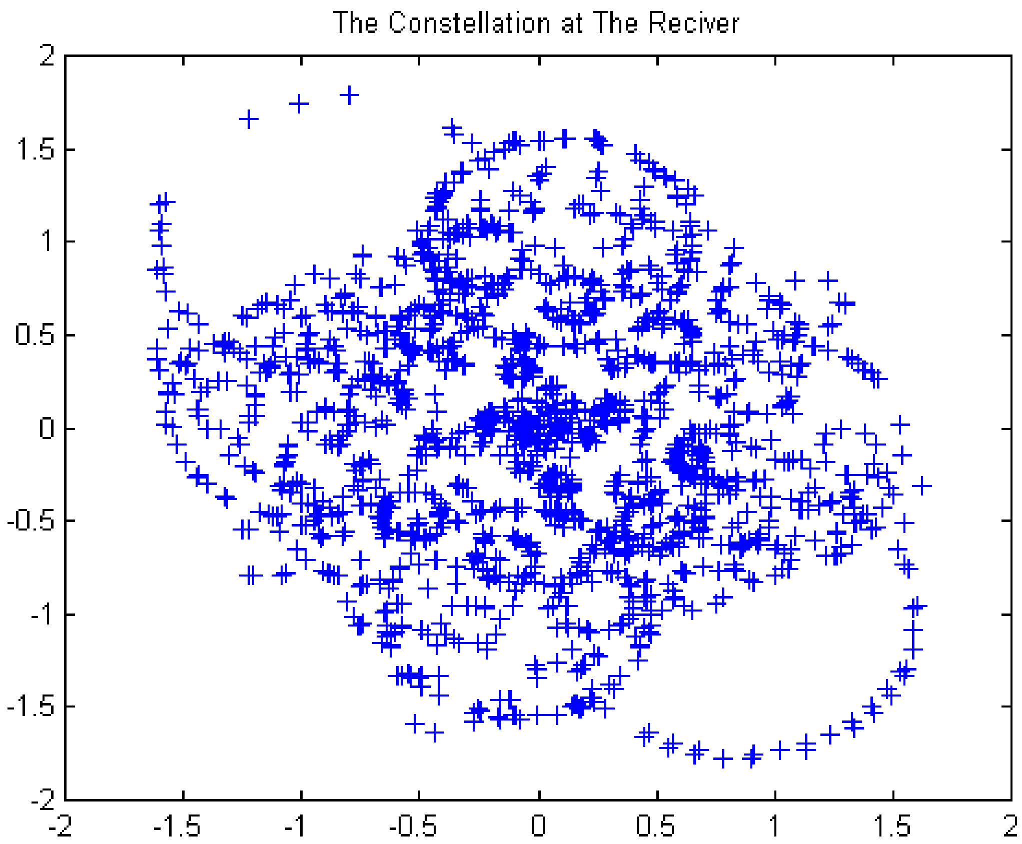
Return Channel Example

- 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

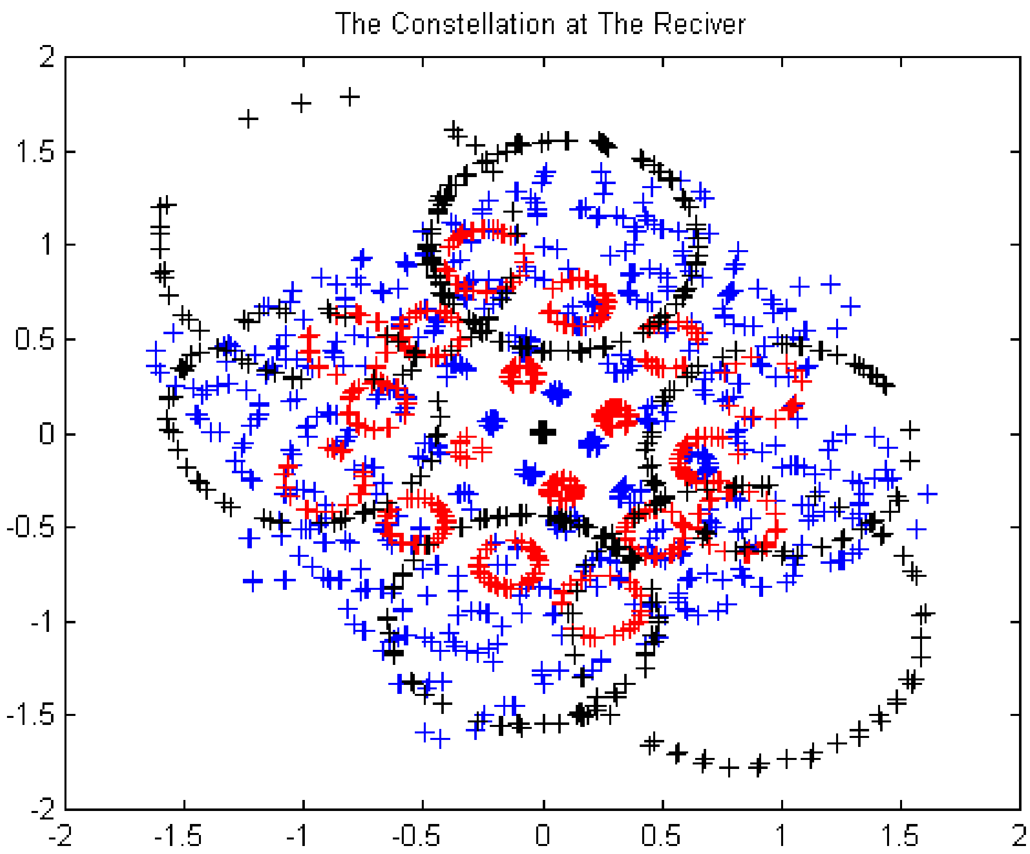
Results

- Constellation at the Base Station



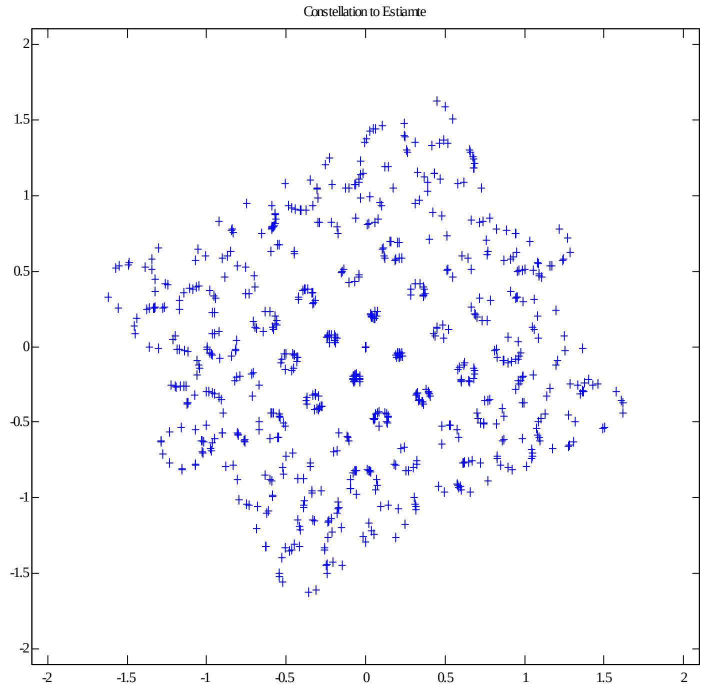
Results

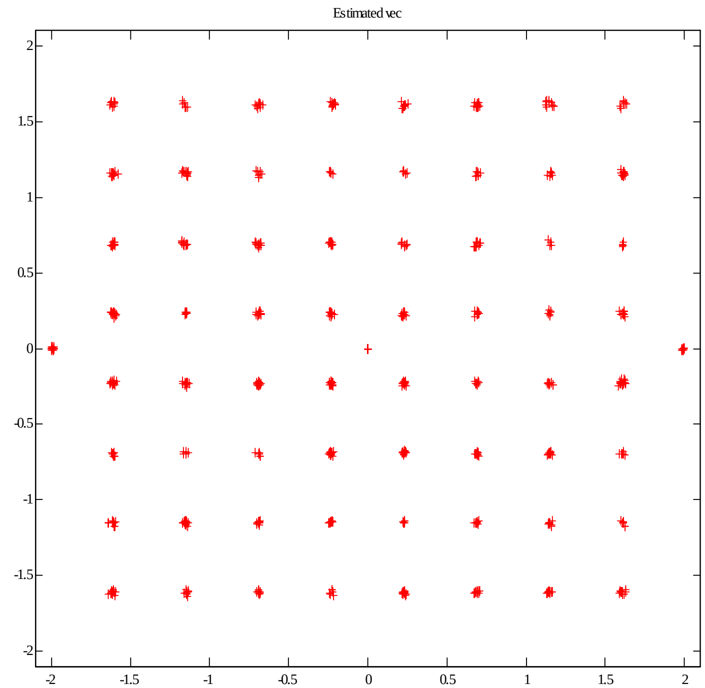
- Users Separation



Results

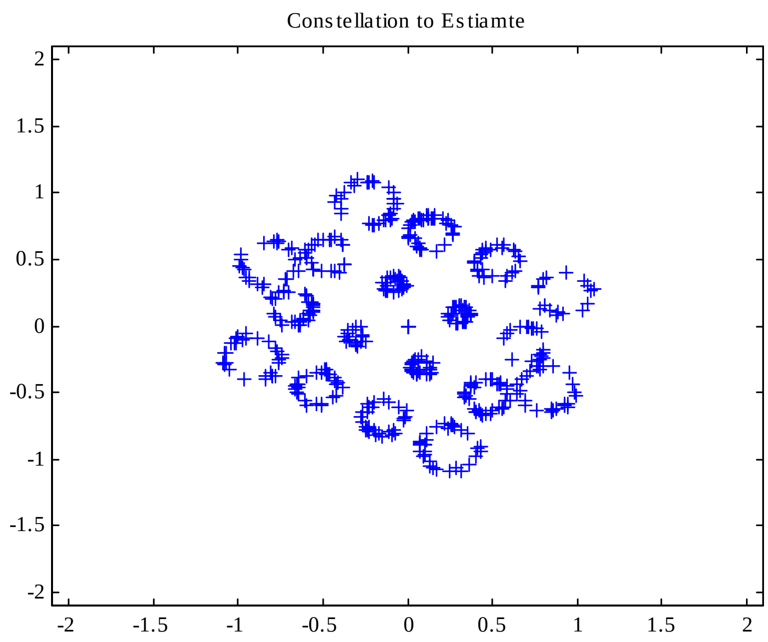
- User Estimation

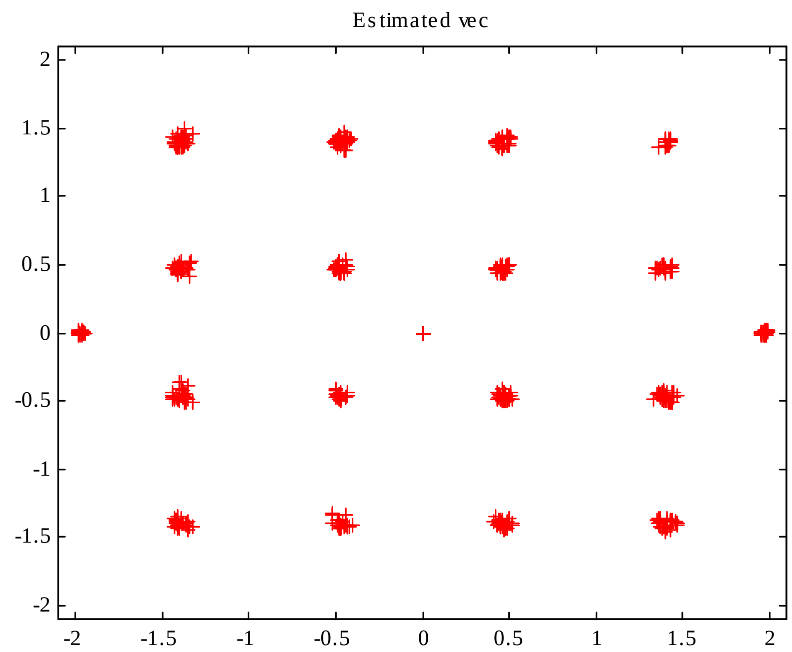




Results

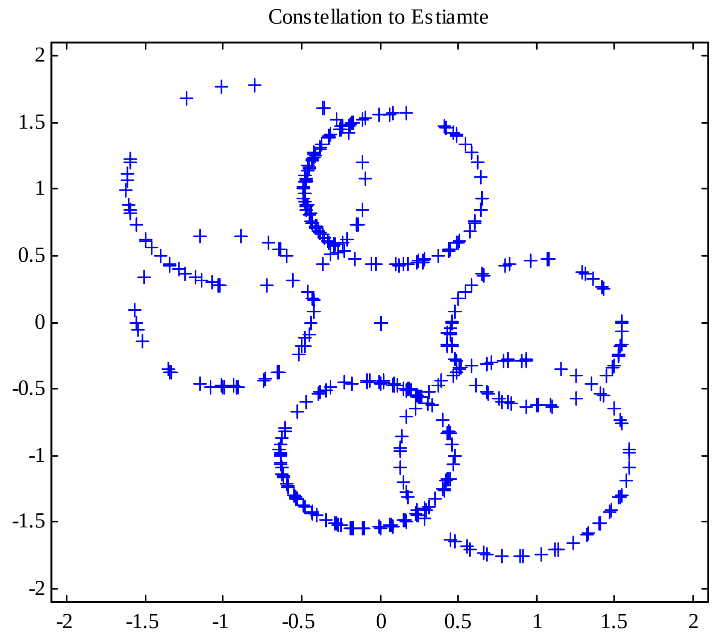
- User Estimation

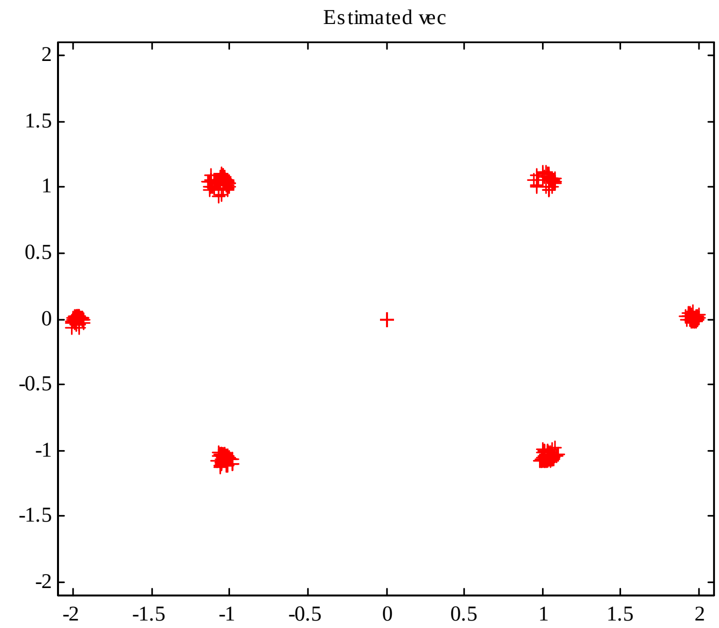




Results

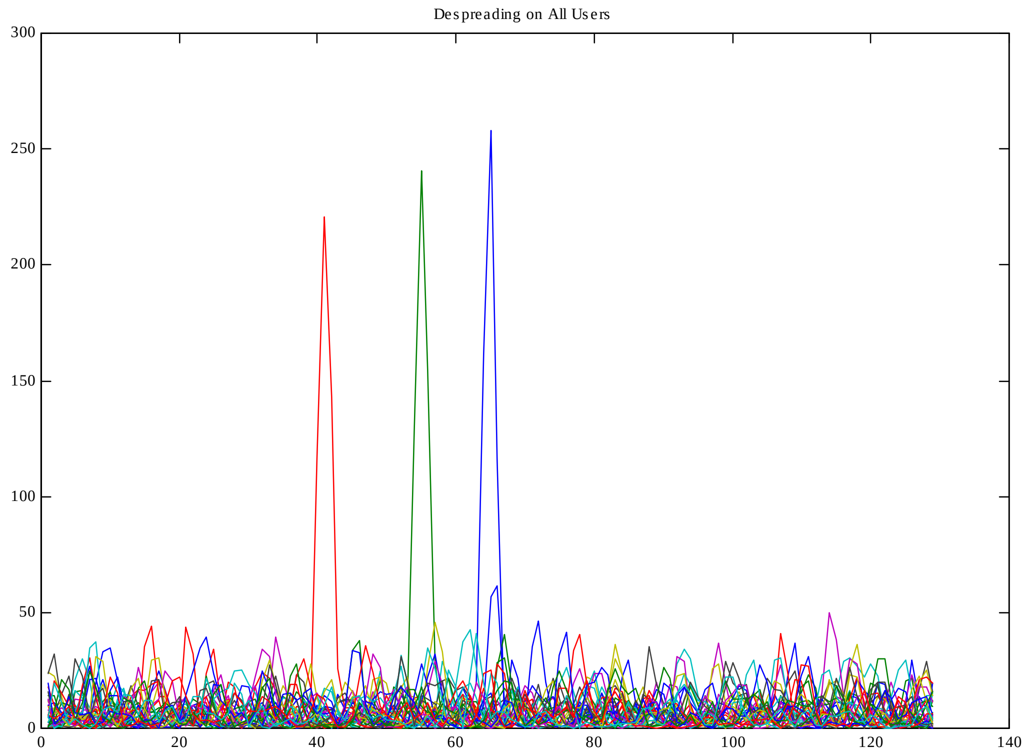
- User Estimation





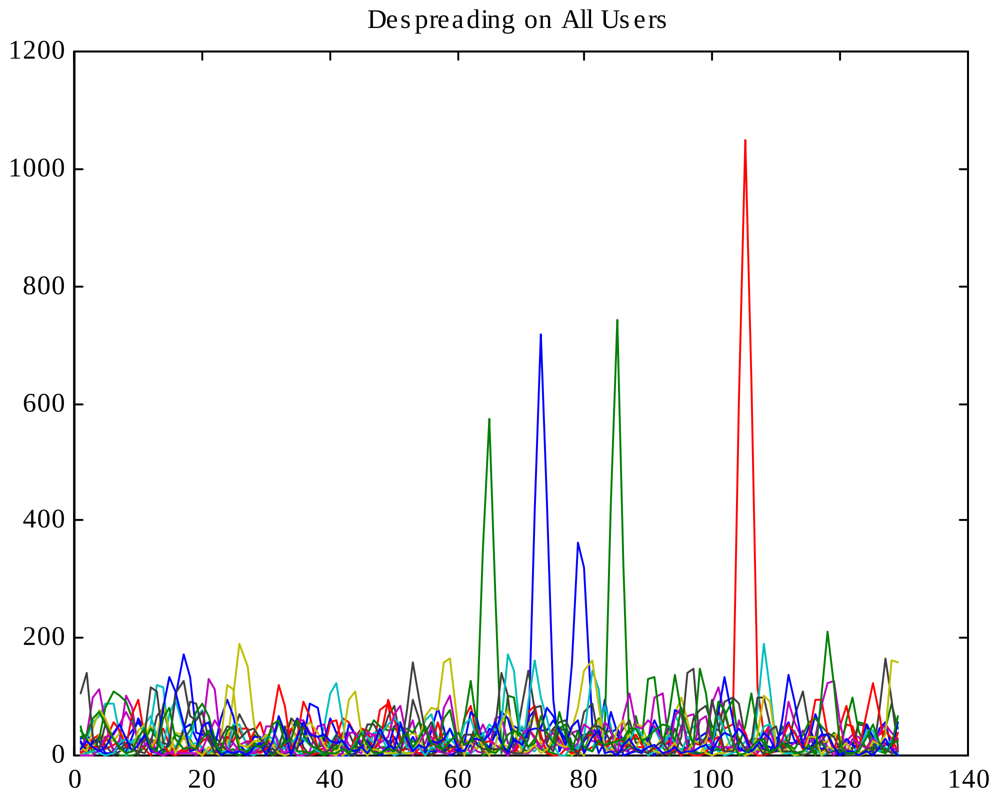
Results

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



Results

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



OFDMA 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.

OFDMA 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 23 carriers = nX23 carriers up to 1587 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.

OFDMA 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 (up to 18dB gain for 23 carrier allocation instead of 1587 carriers), 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.

OFDMA Advantages - Summary (4)

- Allocating carrier by OFDMA/TDMA strategy.
- Minimal delay per OFDMA symbol of 300μsec.
- Using Small burst per user of about 100 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.
- OFDM is a proven technology for transporting Hi data rates for NLOS, Long ranges with Multipath conditions like DVB-T, DAB etc.