4G Technologies
Myths and Realities

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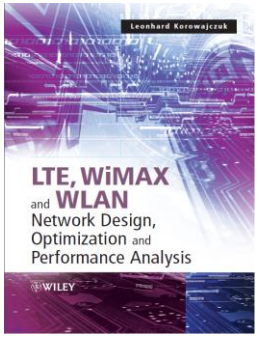
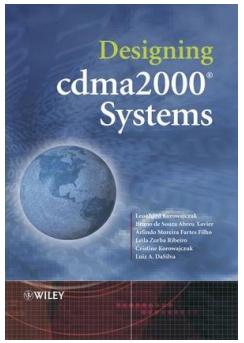
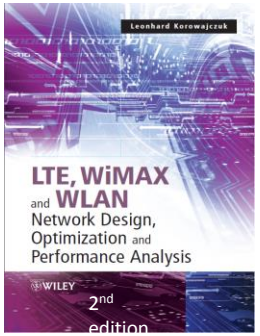
Caribbean Association of National
Telecommunications Organizations

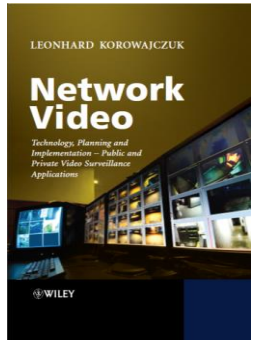
Presenter

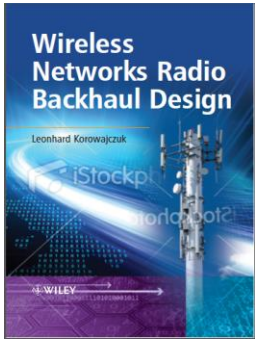
- **Leonhard Korowajczuk**
  - CEO/CTO CelPlan International
  - 45 years of experience in the telecom field (R&D, manufacturing and services areas)
  - Holds13 patents
  - Published books
    - "Designing cdma2000 Systems"
      - published by Wiley in 2006- 963 pages, available in hard cover, e-book and Kindle
    - "LTE , WiMAX and WLAN Network Design, Optimization and Performance Analysis "
      - published by Wiley in June 2011- 750 pages, available in hard cover, e-book and Kindle
  - Books in Preparation:
    - LTE , WiMAX and WLAN Network Design, Optimization and Performance Analysis
      - second edition (2012) LTE-A and WiMAX 2.1(1,000+ pages)
    - Network Video: Private and Public Safety Applications (2013)
    - Backhaul Network Design (2013)
    - Multi-Technology Networks: from GSM to LTE (2014)
    - Smart Grids Network Design (2014)

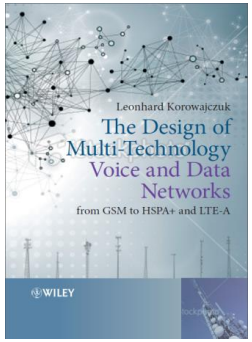












CelPlan International

- Employee owned enterprise with international presence
  - Headquarters in USA
  - 450 plus employees
  - Revenues of US$ 40M
  - Twenty (20) years in business
- Subsidiaries in 6 countries with worldwide operation
- Vendor Independent
- Network Design Software (CelPlanner Suite)
- Network Design Services
- Network Optimization Services
- Network Performance Evaluation
- Services are provided to equipment vendors, operators and consultants
- High Level Consulting
  - RFP preparation
  - Vendor interface
  - Technical Audit
  - Business Plan Preparation
  - Specialized (Smart Grids, Aeronautical, Windmill, …)
- Network Managed Services
- 2G, 3G, 4G, 5G Technologies
- Multi-technology / Multi-band Networks
- Backhaul, Small cells, Indoor, HetNet

Marketing Claims

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Some Marketing Claims

- What is said
  - What is not said
- UMTS sites can be co-located with GSM sites
  - Yes, but you need to deploy additional sites in between GSM sites to get high speed data
- LTE systems can use a frequency reuse of 1
  - Yes, but your cell capacity will be reduced to 1/10 of its original capacity
- LTE-A achieves a spectrum density of 30 bits/Hz (300 Mbps/10MHz)
  - Yes, in the lab with cables instead of antennas
  - In real life LTE-A and WiMAX 2.1 have an average spectrum density of 2 bit/Hz (20Mbps/10MHz) or less
  - A practical result is 0.05 bit/Hz/cell/user (250 kbit/cell/user for a 5 MHz channel) or less

4G Technologies Myths and Realities

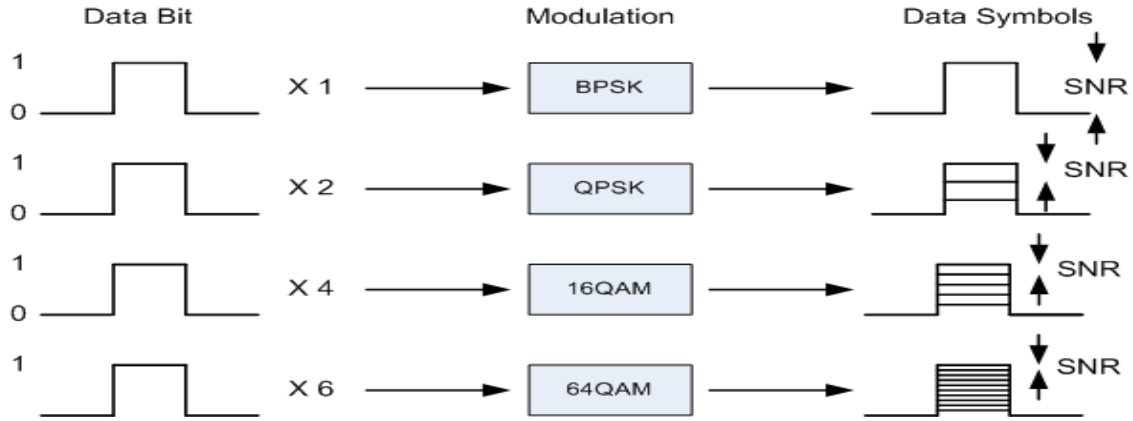
Topics

1. UMTS-HSPA (WCDMA) x WiMAX/LTE (OFDM)
2. Average Throughput per user
3. Throughput Claims and Real Capacity
4. Interference in Cellular Systems and Reuse Factor
5. The next Generation: 5G

UMTS-HSPA (WCDMA)
x
WiMAX/LTE (OFDM)

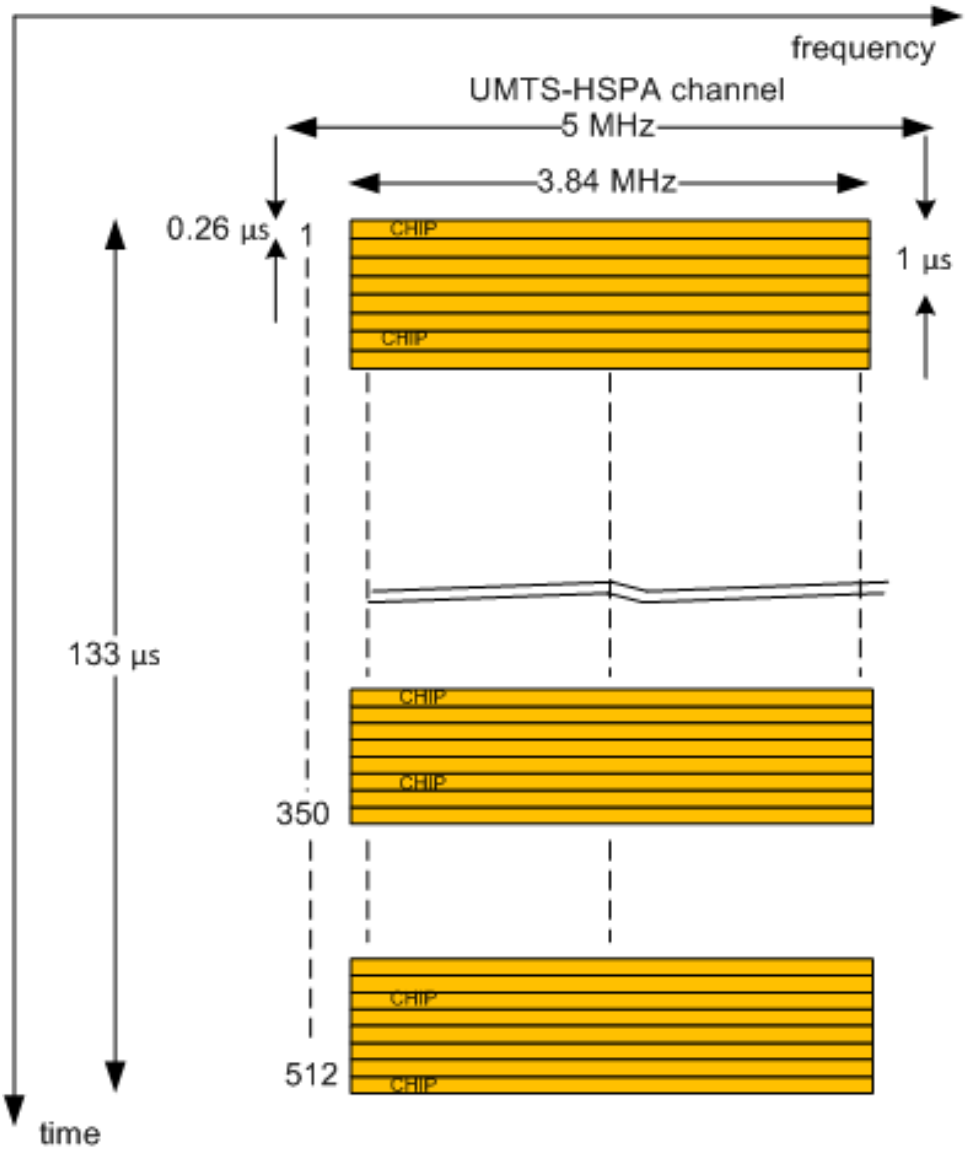
Data Bits and Data Symbols

- User data is represented in bits
  - Each bit represent a 1 or 0
- User data is added additional overhead before it is sent through the wireless channel
  - Overhead is used for error correction and can have the same amount of bits as the data
  - Forward Error Correction (FEC) is sent with the data, so it can be used if an error occurs
  - FEC overhead can be from 20% (5/6) to 100% (1/2)
- User data is mapped to symbols, according to the modulations scheme used
  - BPSK modulation has 2 states, higher modulation schemes have more states
  - Modulation states are separated by a threshold
  - One symbol can represent the information from 1 to 6 user data bits, depending on the modulation used
- Noise (and interference) should be smaller than the distance between thresholds
  - It is expressed by SNR (Signal to Noise Ratio)
- The highest possible modulation scheme allowed by the SNR is always used
- Data symbols are sent over the air



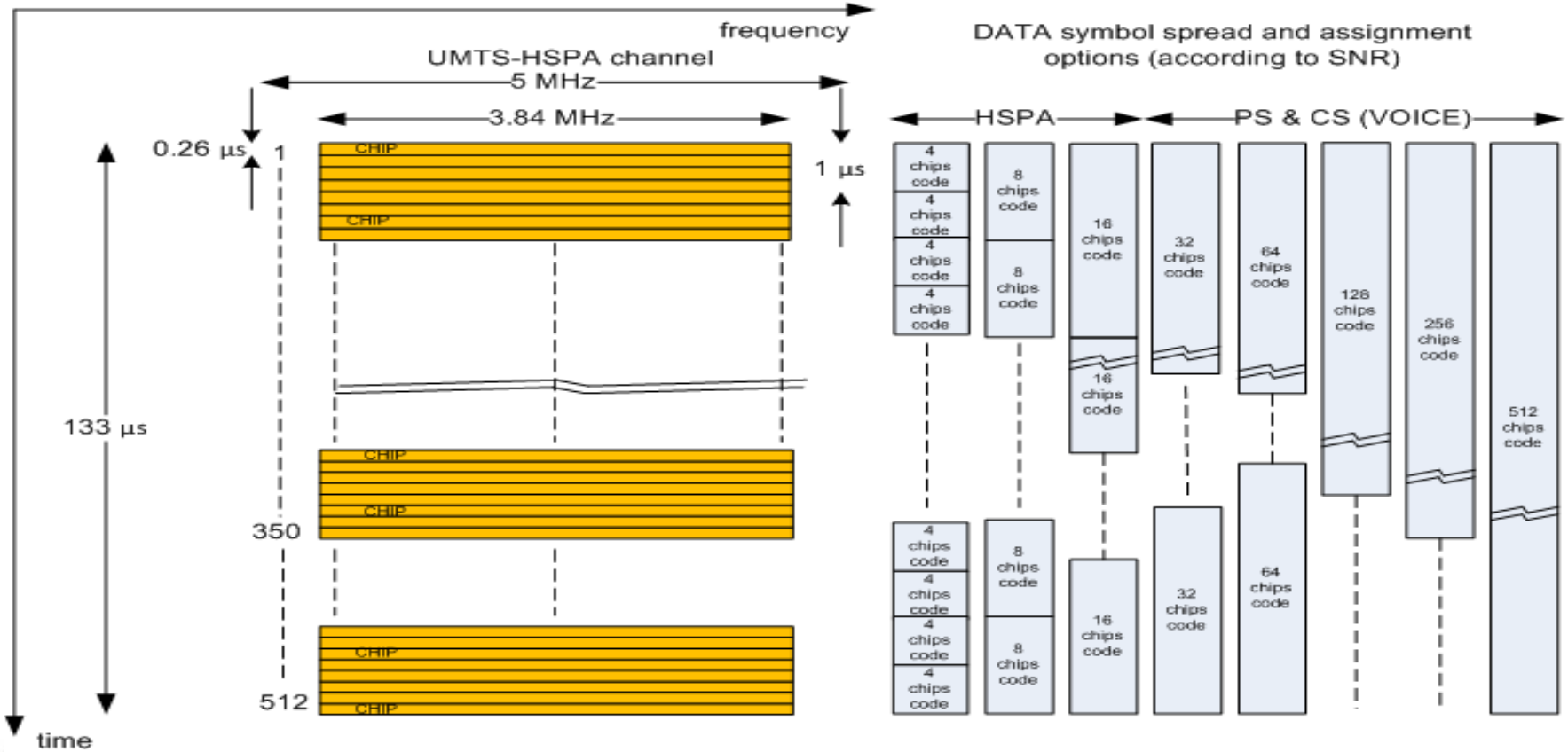
UMTS-HSPA (WCDMA) channel

- WCDMA channel has 5 MHz
- UMTS signal occupies 3.84 MHz
- WCDMA RF symbols are 1/3.84 MHz long= 0.26 µs
  - An UMTS RF symbols is called a *chip*
- UMTS symbols carry orthogonal codes
  - UMTS codes are measured in chips, to differentiate them from data bits
  - The main codes are 512 bits long
- User data is assigned over a set of codes



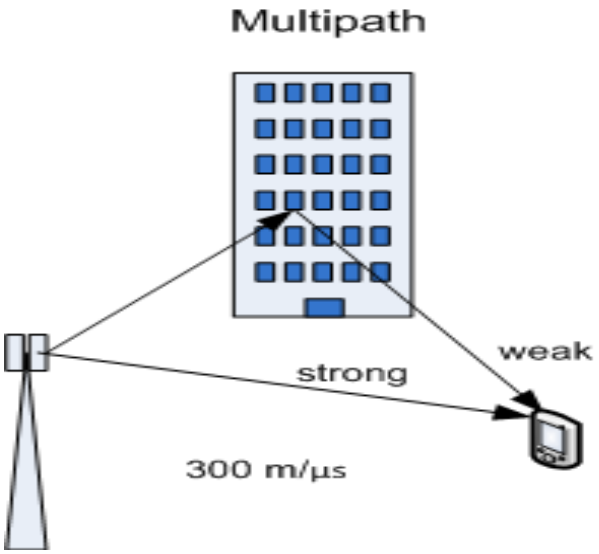
UMTS-HSPA (WCDMA) channel

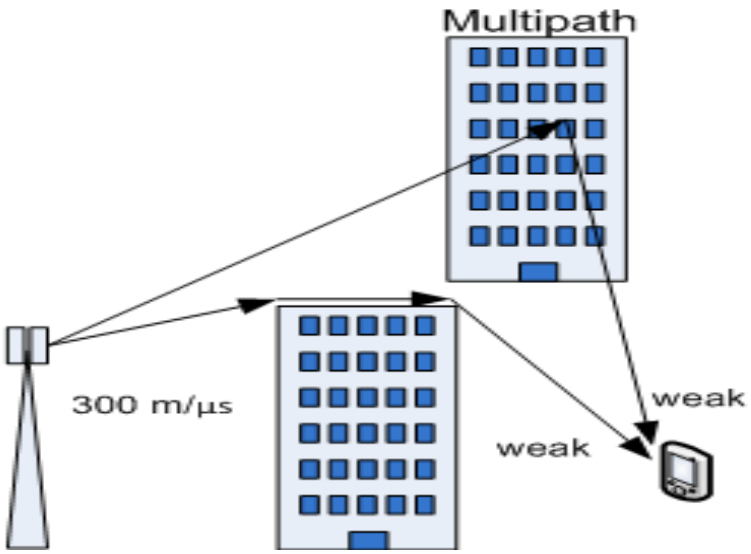
- User data is spread over several chips
- Larger the spread more energy the signal will have
- Larger the spread smaller the throughput
- The network selects the best spread based on the user SNR and type of data being sent (circuit switched voice, packet data or high speed packet data)

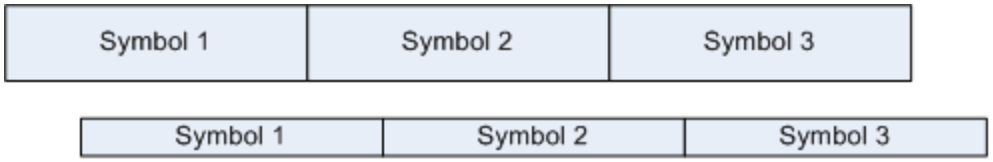


Multipath or Self Interference
(The Villain)

- Delayed coded symbols overlap the next symbols, causing errors in its detection
- A symbol should not overlap more than half of the next symbol
- NLOS multipath can be as strong as NLOS signals

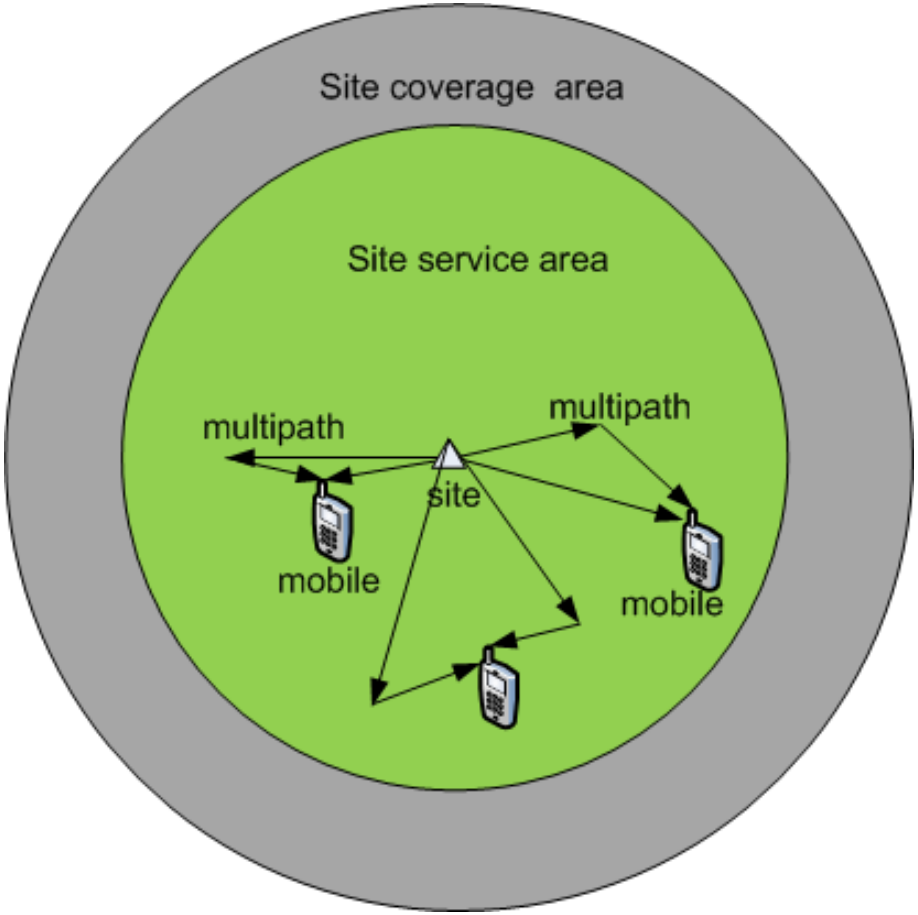






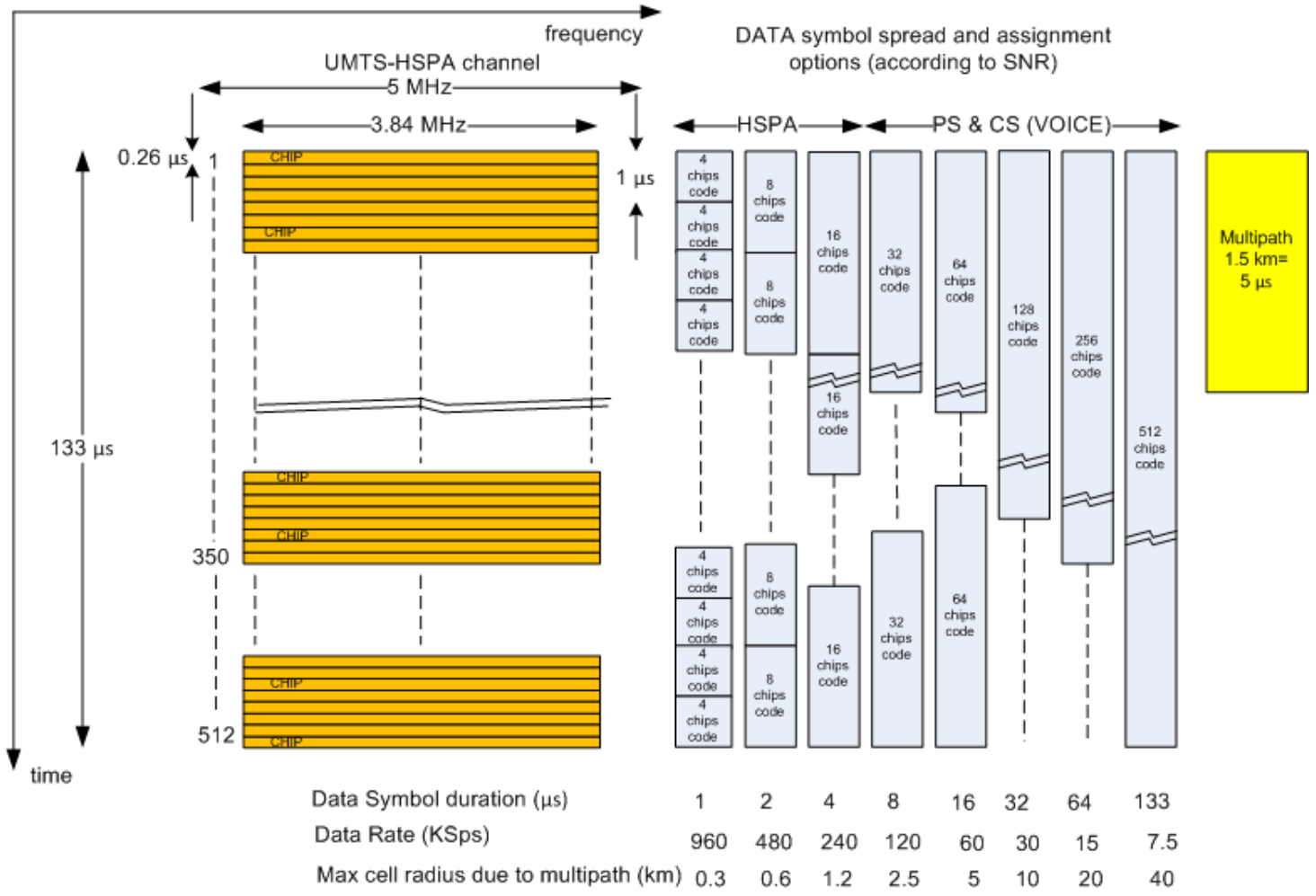
Multipath Delay Spread

- Multipath is difficult to characterize as it is time variant
- A reasonable assumption is to estimate its probability based on the cell coverage area
- The worst case multipath delay spread in this case will be equivalent to about half the cell radius



UMTS-HSPA Data Allocation

- Coded data Symbols are spread (multiplied) over several chips
- Spreading varies between 4 (1 µs) and 512 (133 µs) chips

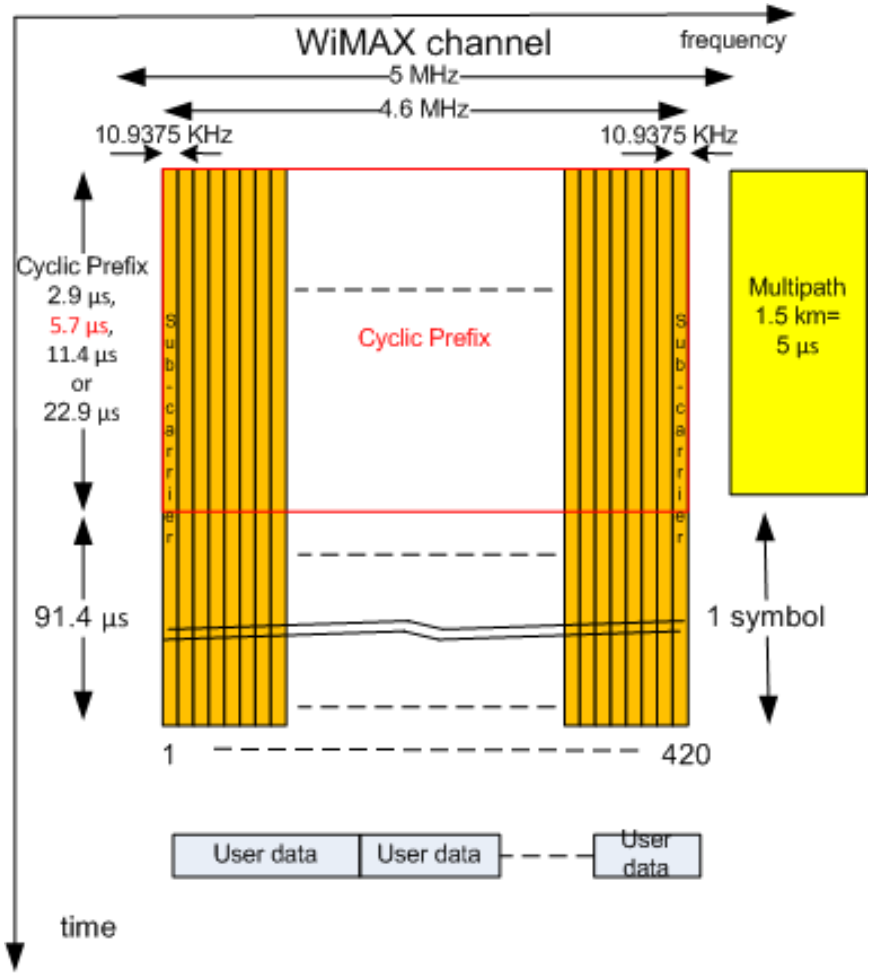


WCDMA

- Equalization
  - Compensates RF channel variation in frequency selective and time dispersive channels
    - Transversal filter
    - Lattice
- Rake Receiver
  - An UMTS Rake receiver has 4 correlators. One correlator is used to scan for shifted versions. Remaining correlator detects a time shifted version of the transmission, delayed at least one chip from the previous correlator
  - The Rake receiver harvests the energy of multipath to increase the energy of the symbols

WiMAX Channel

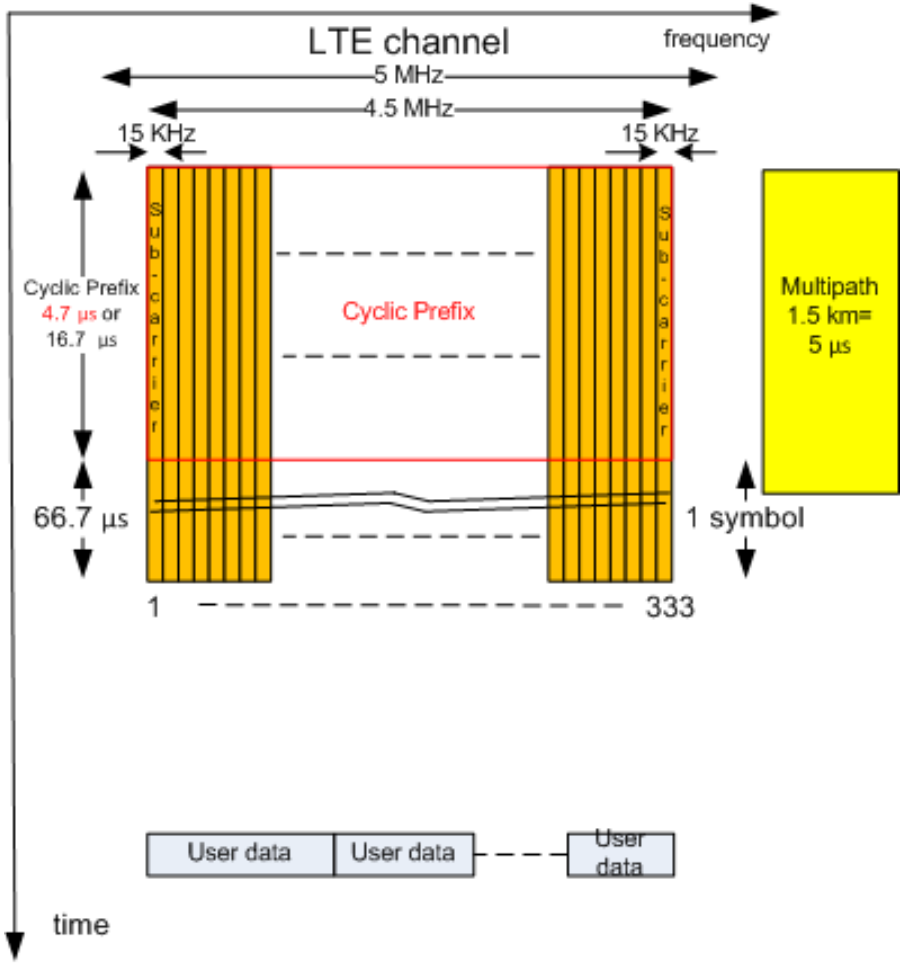
- A 5 MHz FDD WiMAX channel occupies 4.6 MHz
- This WiMAX channels has 420 sub-carriers
- A WIMAX symbols has 91.4 µs
- Cyclic prefix options are: 2.9 µs (0.8 km), 5.7 µs (1.7 km), 11.4 µs (3.4 km) and 22.9 µs (6.8 km)
- User data is assigned along the sub-carriers



Symbol duration (µs)	91.4
Data Rate (KSps)	4,200
Max cell radius due to multipath (km)	3.4 / 6.6

LTE Channel

- A 5 MHz FDD LTE channel occupies 4.5 MHz
- This LTE channels has 333 sub-carriers
- An LTE symbols has 66.7 µs
- Cyclic prefix options are: 4.7 µs (1.4 km), or 16.7 µs (5 km)
- User data is assigned along the sub-carriers

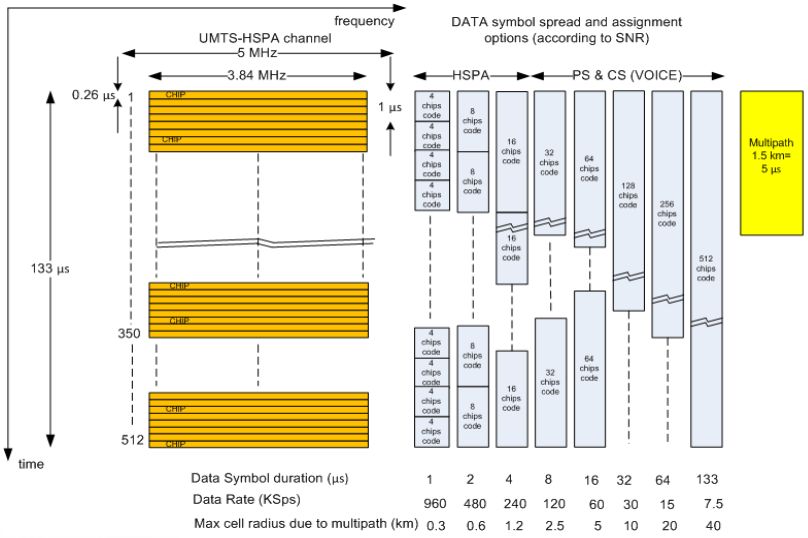


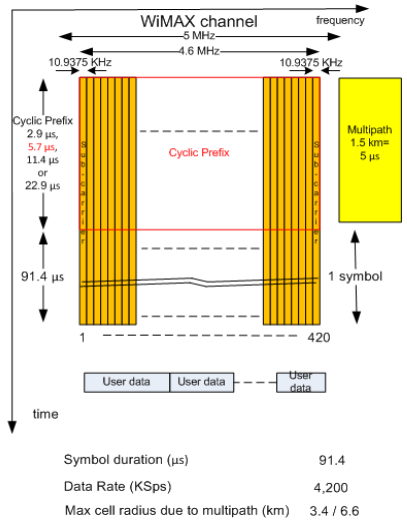
Symbol duration (µs)	133.3
Data Rate (KSps)	4,200
Max cell radius due to multipath (km)	1.4 / 5

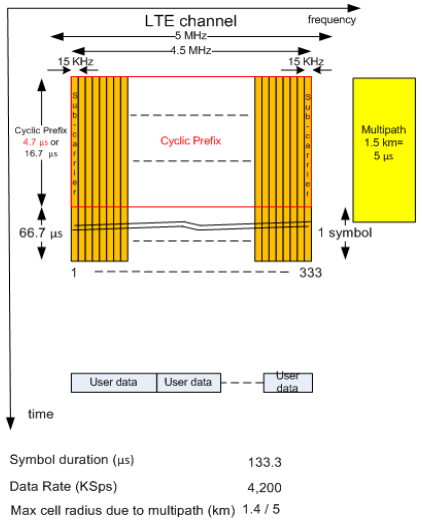
UMTS x WiMAX x LTE channel

- UMTS throughput is limited by self interference (ISI) at high rates
  - HSPA is mainly affected
  - Larger the cell, lower the throughput
  - A 300 m cell radius is required for a spread of 4 (960 kSps)
- WiMAX performance
  - Cyclic prefix allows multipath up to 6.6 km
  - Maximum rate is 4,200 kSps
  - Actual rate (removing overhead) is 2.2 MSps
- LTE performance
  - Cyclic prefix allows multipath of 5 km
  - Maximum rate is 4,200 kSps
  - Actual rate (removing overhead) is 2.00 MSps

Raw Througput (5 MHz)								
	WiMAX				LTE		UMTS	
Sub-carriers /chips	420				333		4	512
Data Symbol (µs)	91.4				66.7		1.0	133.3
Cyclic Prefix (µs)	2.9	5.7	11.4	22.9	4.7	16.7	-	-
RF Symbol (µs)	94.3	97.1	102.8	114.3	71.4	83.4	1.0	133.3
Maximum Multipath (km)	0.9	1.7	3.4	6.9	1.4	5.0	0.2	20.0
Throughput (MSps)	4.5	4.3	4.1	3.7	4.7	4.0	0.96	0.01





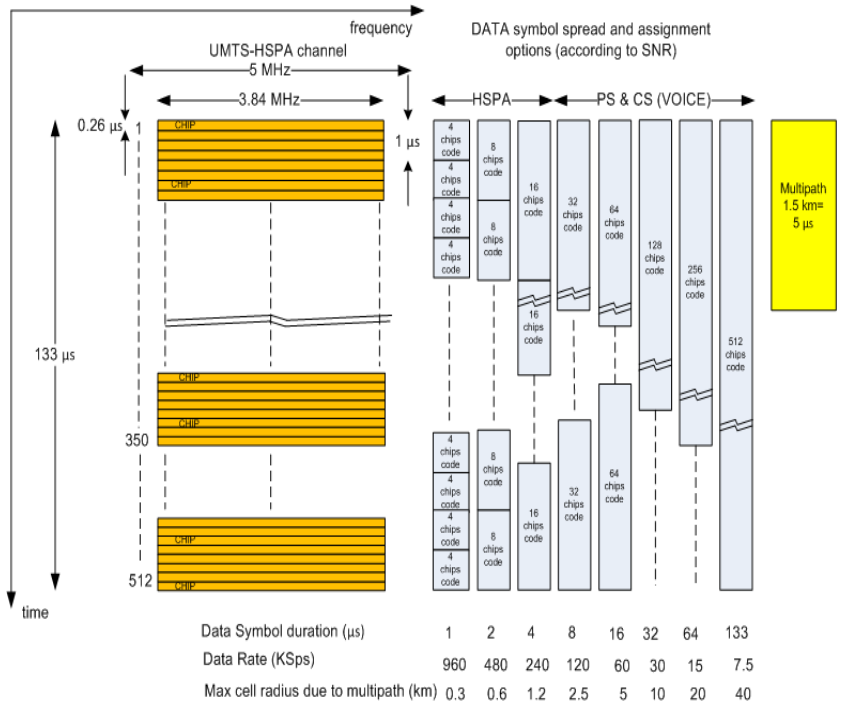


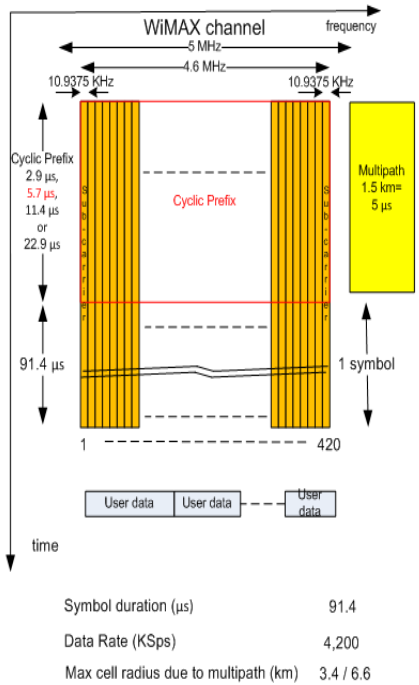
Multipath Delay

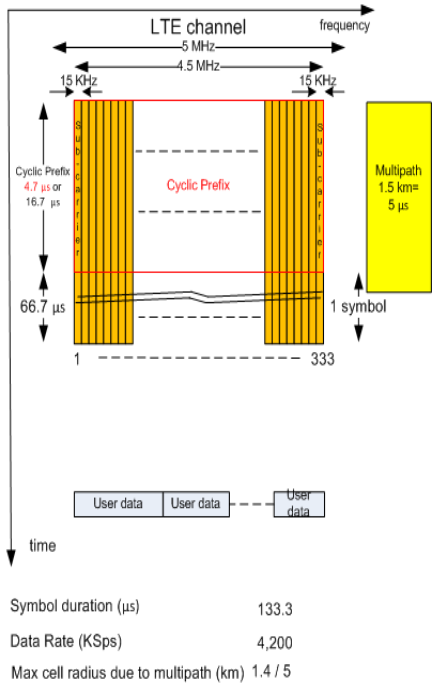
Cell Radius (km)	Multipath spread (km)	Multipath delay (µs)
0.5	0.25	0.83
1	0.5	1.67
1.5	0.75	2.50
2	1	3.33
2.5	1.25	4.17
3	1.5	5.00
3.5	1.75	5.83
4	2	6.67
4.5	2.25	7.50
5	2.5	8.33
5.5	2.75	9.17
6	3	10.00
6.5	3.25	10.83
7	3.5	11.67
7.5	3.75	12.50
8	4	13.33

UMTS-HSPA (WCDMA) x WiMAX/LTE (OFDM)

	UMTS								WiMAX	LTE
Parameter\ spread	512	256	128	64	32	16	8	4		
Data Symbol Duration (µs)	133	66	32	16	8	4	2	1	92	66.7
Maximum Data Rate (kSps)	7.5	15	30	600	120	240	480	960	4,200	4,200
Maximum cell radius due to multipath (km)	40	20	10	5	2.5	1.25	0.625	0.312	13.2	10.0







WiMAX x LTE

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WiMAX x LTE

- **WiMAX**
  - Conceived as TDD
  - More mature technology
  - Internet compatible technology
  - More economical
  - Better specifications
- **LTE**
  - Conceived as FDD
  - Better marketing
  - Supported by 2G European vendors
  - 2G compatible technology
  - More expensive
  - Flawed specifications being fixed
  - Should prevail with traditional operators

WiMAX x LTE - Interference Control

- **WiMAX**
  - Common channels use different locations in each cell
  - Pilots use different locations in each cell
  - Permutation scheme (PUSC) is responsible for interference averaging
  - Many different cyclic prefixes
  - Reduced overhead
- **LTE**
  - Common channels use same location in all cells
  - Pilots use same locations in all cells
  - No permutation scheme to control interference
    - ICIC (Inter-Channel Interference Control) scheme left to vendors
  - Two cyclic prefixes only
  - Large overhead

Average Throughput per User

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Average throughput per user

- Market is moving towards GB subscriptions (pre and post paid)
- Monthly packages of 2 to 10 GB are common
  - Packages should increase 5 fold in the next 5 years
- Instantaneous RF user throughput is limited by the modulation schemes used only
  - Data is always sent at maximum speed on the RF link
- Operator can slow down user data using:
  - Data throttling
    - Works by limiting (throttling) the rate at which a bandwidth intensive device (a server) accepts data
  - Data capping
    - Standard cap limits the bitrate or speed of data transfer on a broadband internet connection. It is used to prevent individuals from consuming the entire transmission capacity of the medium.
    - Lowered cap reduces an individual user's bandwidth cap as a defensive measure and/or as a punishment for heavy use of the medium's bandwidth.
- A regular user that spends 1 GB a month will have a peak hour tonnage of only 16 kbps

User Data Dimensioning

Service	Daily usage	Data used by device		Monthly Tonnage (MB/mo)	Service Type	Priority	Delay (ms)	BER	Down	Up
Number of text-only emails sent/received	20	10	KB	5.86	UGS	1	150	1.E-03	1200	1200
Number of web pages visited	20	1	MB	600.00	BE	5	1000	1.E-04	1300	350
Minutes streaming audio	5	60	MB/hr	150.00	rtPS	3	150	1.E-03	70	70
Minutes streaming video (standard def)	1	650	MB/hr	325.00	rtPS	3	150	1.E-03	1200	120
Minutes streaming video (high def)	0.5	10	GB/hr	2560.00	rtPS	3	150	1.E-03	1500	120
Number of photos uploaded/downloaded	3	5	MB	450.00	BE	5	1000	1.E-04	1500	500
Minutes using GPS navigation	0	5	MB/hr	0.00	rtPS	3	150	1.E-03	300	150
Minutes using VoIP applications	0	30	MB/hr	0.00	UGS	1	150	1.E-03	70	70
Minutes using VoIP applications with video	0	425	MB/hr	0.00	UGS	1	150	1.E-03	1200	1200
Minutes using online games	3	5	MB/hr	7.50	rtPS	3	150	1.E-03	300	300
		TOTAL GB/mo		4.00	Average:	4	150.0	1.0E-04	1,392.0	195.4

Average Quality of Service		
Subscriber Monthly Plan Allowance (GB/month):	4.00	
Average Subscriber Monthly Tonnage Usage (GB/month):	3.00	
Offered Traffic Ratio (Downstream/Total):	0.80	
Oversubscription:	12	
	Downstream	Upstream
Guaranteed Bit Rate (kbps):	8	5
Mean Packet Size (bytes):	1392.0	195.4
Peak Hour Traffic to Daily Traffic Ratio:	0.3	0.3
Target Delay (s):	0.15	0.15
Allocation Inefficiency	5.0%	10%
MAC Overhead	8.4%	40%
Data overhead factor:	13.4%	50%
Required Bit Error Rate - BER:	1.E-04	1.E-04

Throughput Claims and Capacity

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Throughput claims and capacity

- Claims of 30 bit/s/Hz have been made (150 Mbit/s for 5 MHz channel and 3 Gbit/s for an 100 MHz channel)
  - Yes, replacing the wireless connection by cables with channel simulators
- Throughput of 3 Gbit/s claim has been made
  - Yes, using 100 MHz of spectrum, single user, single cell
- Operators are mislead with marketing promises and pay a high price in the end
- User get bad service and keep changing operators
- Digging into ITU standard we can find more realistic claims, but still very optimistic

3GPP TR 36.913 v11.0.0

3GPP TR 25.912.v.8.0.0; ITU-R M.2134

- The peak spectrum efficiency is the highest data rate normalised by overall cell bandwidth assuming error-free conditions, when all available radio resources for the corresponding link direction are assigned to a single UE.

- Average spectrum efficiency is defined as the aggregate throughput of all users (the number of correctly received bits over a certain period of time) normalized by the overall cell bandwidth divided by the number of cells. The average spectrum efficiency is measured in bps/Hz/cell

- The cell edge user throughput is defined as the 5% point of CDF of the user throughput normalized with the overall cell bandwidth. The calculations are done for 10 users randomly distributed.

3GPP TR 36.913 v11.0.0

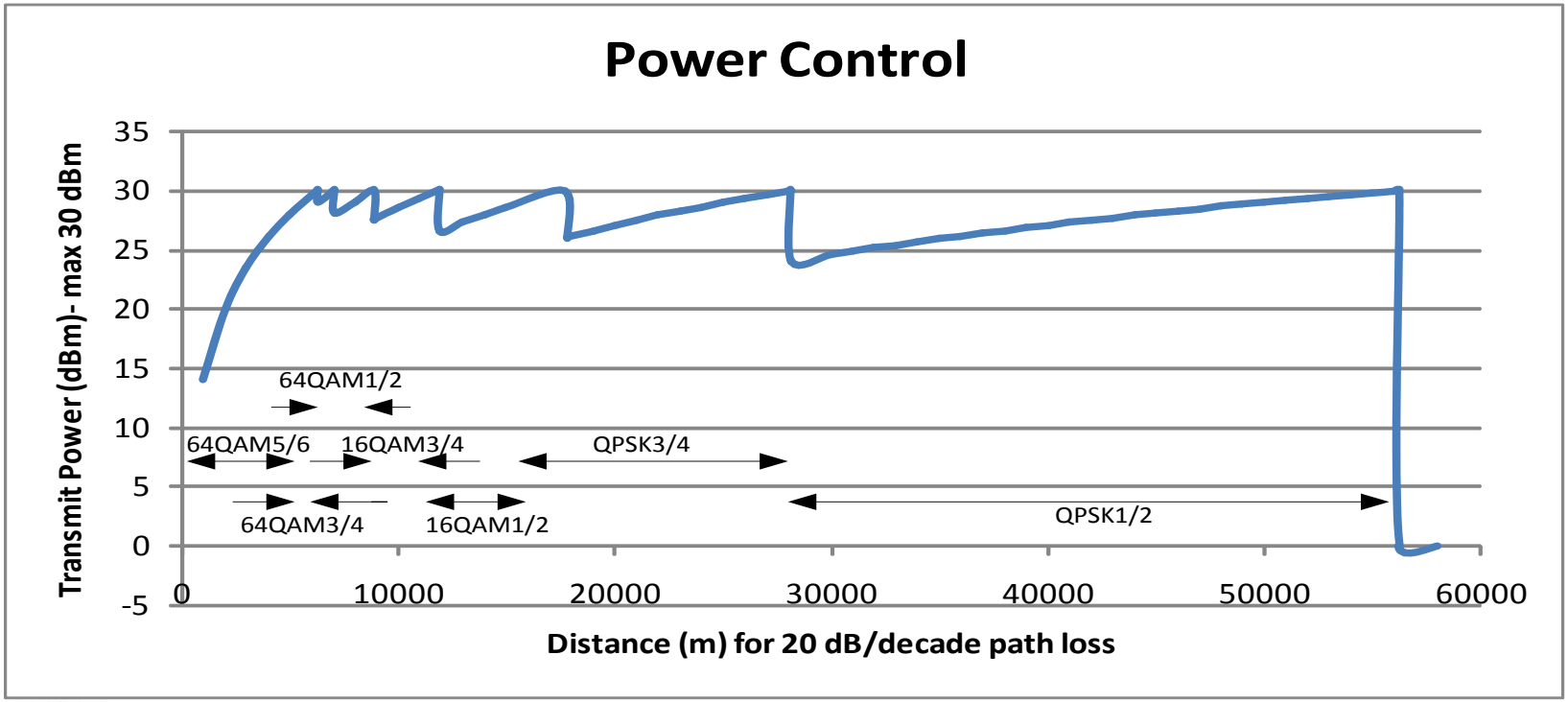
3GPP TR 25.912.v.8.0.0; ITU-R M.2134

LTE FDD ITU (Release 8) Spectral Efficiency Objectives (bit/s/Hz)									
				Downlink			Uplink		
Scenario	Antennas	Inter-Site Distance (m)	Penetration Loss (dB)	Peak (bps/Hz)	Average (bps/Hz/cell)	Cell Edge 10 users per cell (bps/Hz/cell/user)	Peak (bps/Hz)	Average (bps/Hz/cell)	Cell Edge 10 users per cell (bps/Hz/cell/user)
3GPP Case 1 Carrier: 2 GHz Bandwidth: 10 MHz	1x2	500	20				3.75	0.86	0.028
	2x2			7.5	1.63	0.05			
	4x2			15	1.93	0.06			
	4x4				2.87	0.11			

LTE-A ITU Spectral Efficiency Objectives (bit/s/Hz)									
				Downlink			Uplink		
Scenario	Antennas	Inter-Site Distance (m)	Penetration Loss (dB)	Peak (bps/Hz)	Average (bps/Hz/cell)	Cell Edge 10 users per cell (bps/Hz/cell/user)	Peak (bps/Hz)	Average (bps/Hz/cell)	Cell Edge 10 users per cell (bps/Hz/cell/user)
ITU Indoor Hot Spot	4x2	60			3	0.1		2.25	0.07
	2x4								
ITU Urban Micro	4x2	200			2.6	0.075		1.8	0.05
	2x4								
ITU Urban Macro	4x2	500			2.2	0.06		1.4	0.03
	2x4								
ITU Rural Macro	4x2	1732			1.1	0.04		0.7	0.015
	2x4								
3GPP Case 1 Carrier: 2 GHz Bandwidth: 10 MHz	1x2	500	20					1.2	0.04
	2x4							2	0.07
	2x2				2.4	0.07			
	4x2				2.6	0.09			
	4x4				3.7	0.12	15		
	8x8			30					

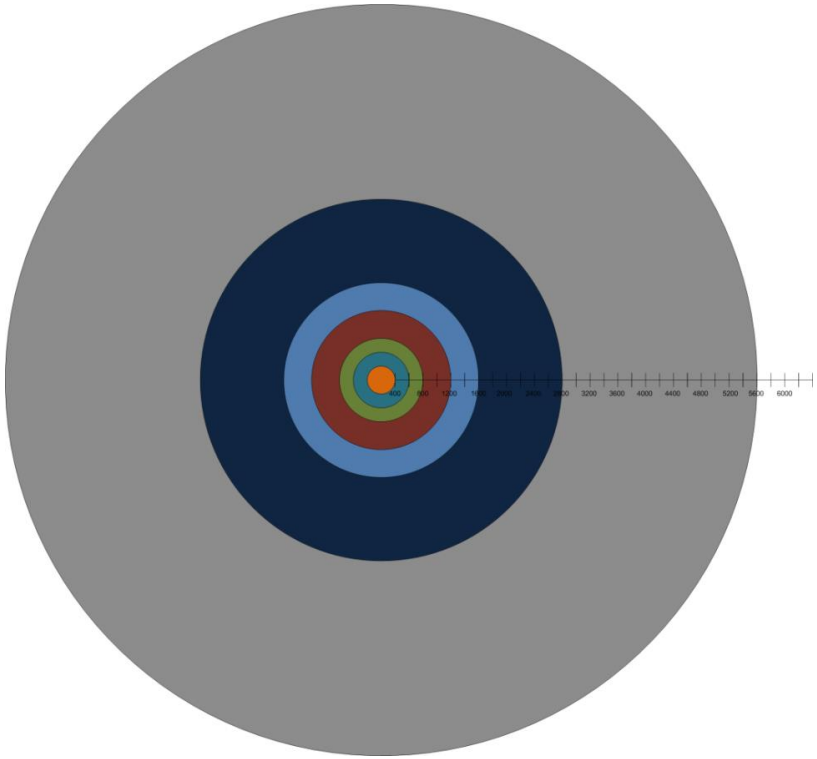
Planning Aspects
Adaptive Modulation Scheme

- You can have a throughput of 200 Mbps over a 10 MHz channel
  - Not really, even the 3GPP in its best estimates targets 4 bits/s/Hz (40 Mbps/10 MHz)
  - Real system do average less that 1 bit/s/Hz

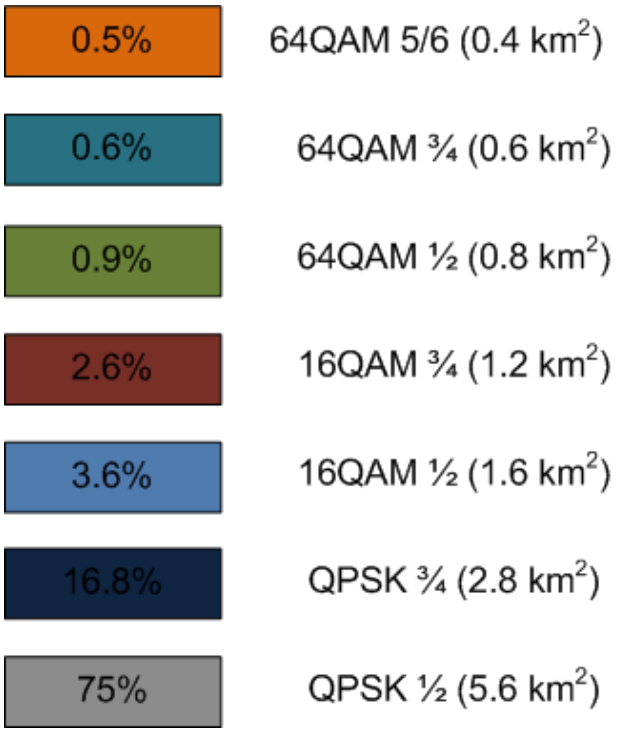


Adaptive Modulation Relative Areas

- Unrestricted cell
- Propagation in free space: 20dB/decade
- Percentages will change if cells are closer to each other and lower modulation schemes are not used
- Cell capacity drops with the increase in cell size
- Larger the cell smaller the capacity

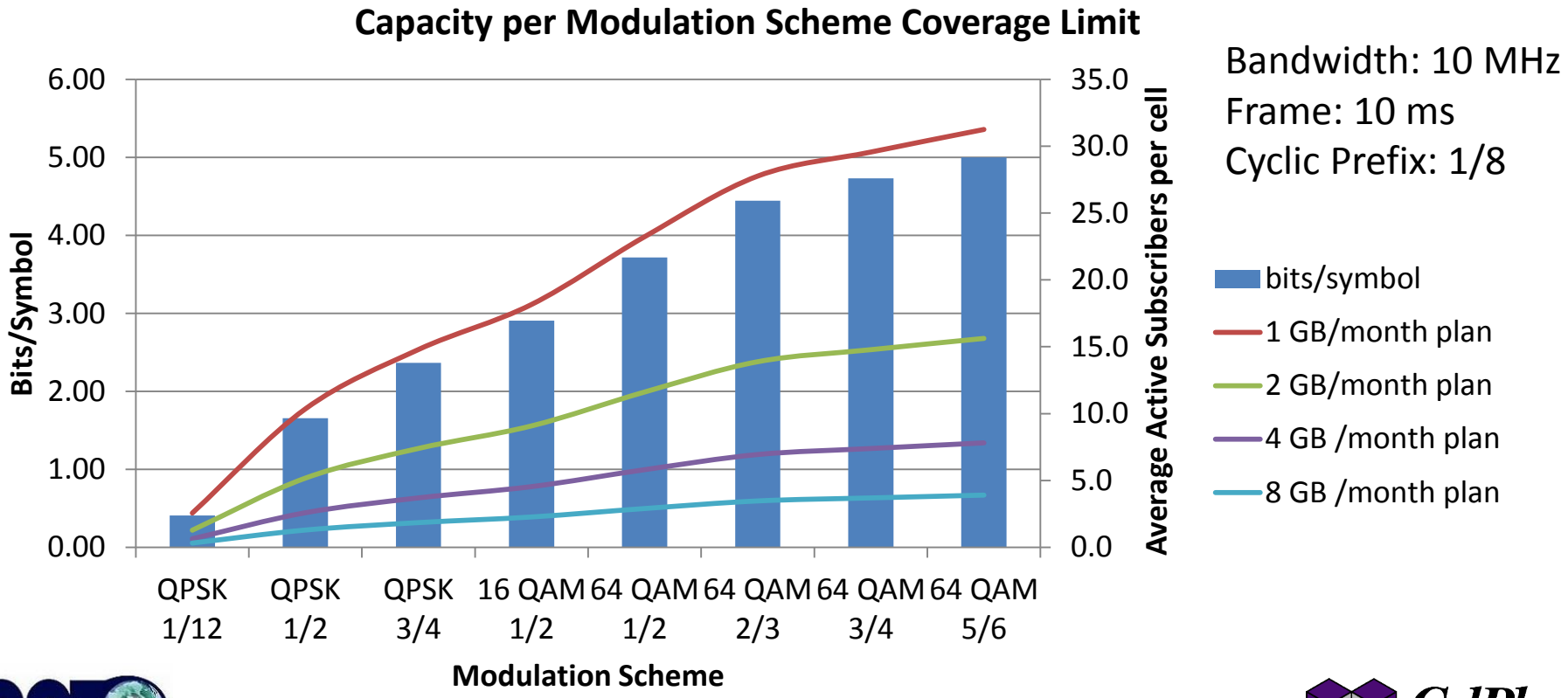


Bits / Symbol	
64QAM 5/6	5
64QAM 3/4	4.5
64QAM 1/2	3
16QAM 3/4	3
16QAM 1/2	2
QPSK 3/4	1.5
QPSK 1/2	1.5



Adaptive Modulation Capacity

- On the bottom are the modulation schemes
- On the right are the average bits per symbol achieved by each modulation scheme (blue bars)
- On the left are the average active users that can be accommodated by each modulation scheme
  - The curves represent monthly user tonnage plan



Interference in Cellular Systems

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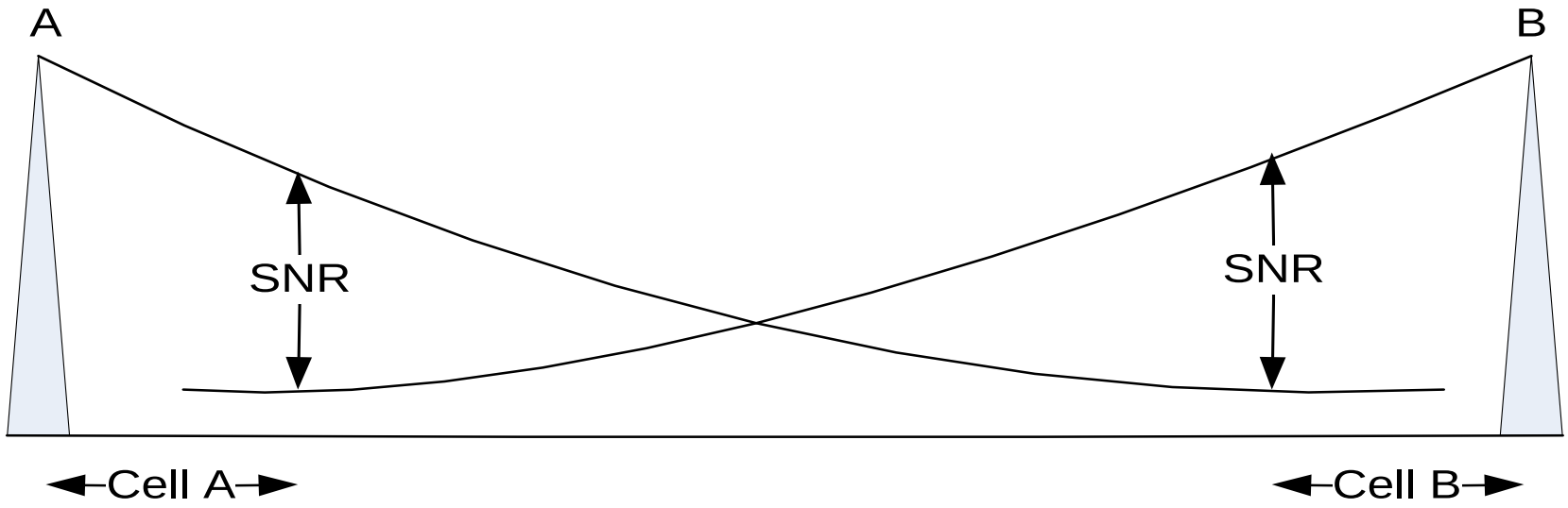
Interference in Cellular Systems

- Regular Wi-Fi has only 3 channels
- How does it work in a trade show, with hundreds of hotspots?
- What is frequency reuse?
- Is frequency the only resource that can be considered for reuse?

Interference in Cellular Systems

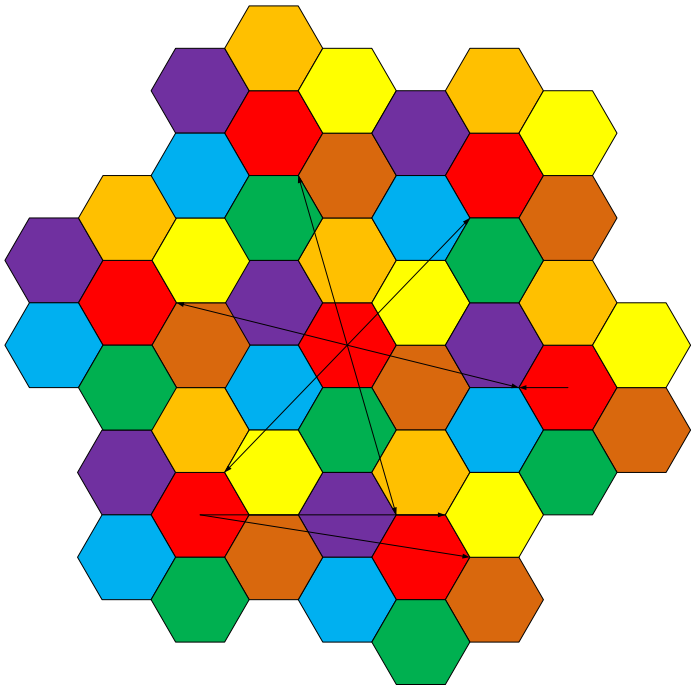
- Each cell requires an SNR (Signal to noise Ratio) to operate
- There is a gap between two cell that use the same resources
- A resource reuse results in a SNR value, that should be compatible with the desired modulation requirement



Required SNR (dB)			
	QPSK	16QAM	64 QAM
Gaussian	2.5	8.2	12.1
Rayleigh	15.7	21.3	25

Omni (reuse 7)

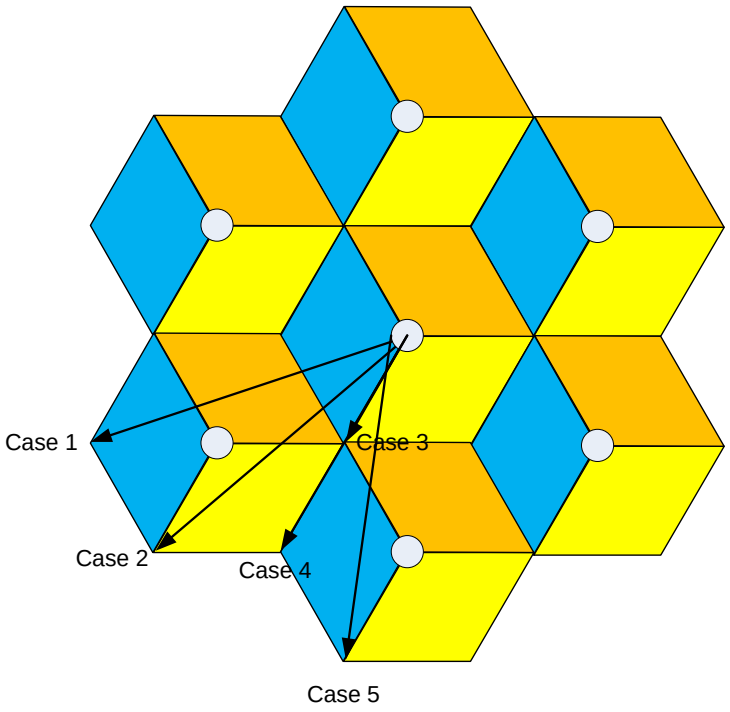
distance
path loss
SNR



Reuse	7	omni	20 db/dec		
	distance		path loss		SNR
	signal	interference	signal	interference	
case 1	1	2.6	0.0	8.5	8.5

Reuse	7	omni	40 dB/dec		
	distance		path loss		SNR
	signal	interference	signal	interference	
case 1	1	2.6	0.0	16.9	16.9

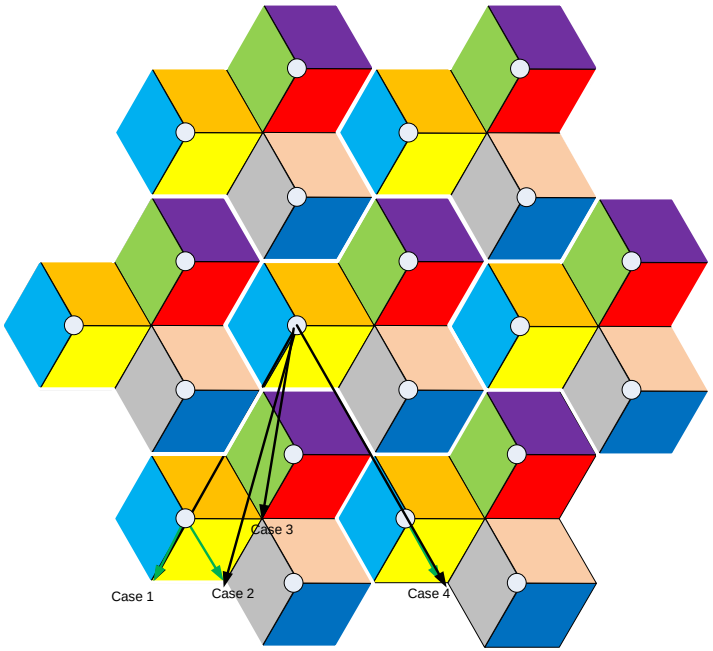
Sector (reuse 3)



Reuse	3	sector	20 dB/dec		
	distance		path loss		SNR
	signal	interference	signal	interference	
case 1	1	2.6	0.0	8.5	8.5
case 2	1	2.6	0.0	8.5	8.5
case 3	1	1.0	0.0	0.0	0.0
case 4	1	2	0.0	6.0	6.0
case 5	1	2.6	0.0	8.5	8.5
average					7.8

Reuse	3	sector	40 dB/dec		
	distance		path loss		SNR
	signal	interference	signal	interference	
case 1	1	2.6	0.0	16.9	16.9
case 2	1	2.6	0.0	16.9	16.9
case 3	1	1.0	0.0	0.0	0.0
case 4	1	2	0.0	12.0	12.0
case 5	1	2.6	0.0	16.9	16.9
average					15.7

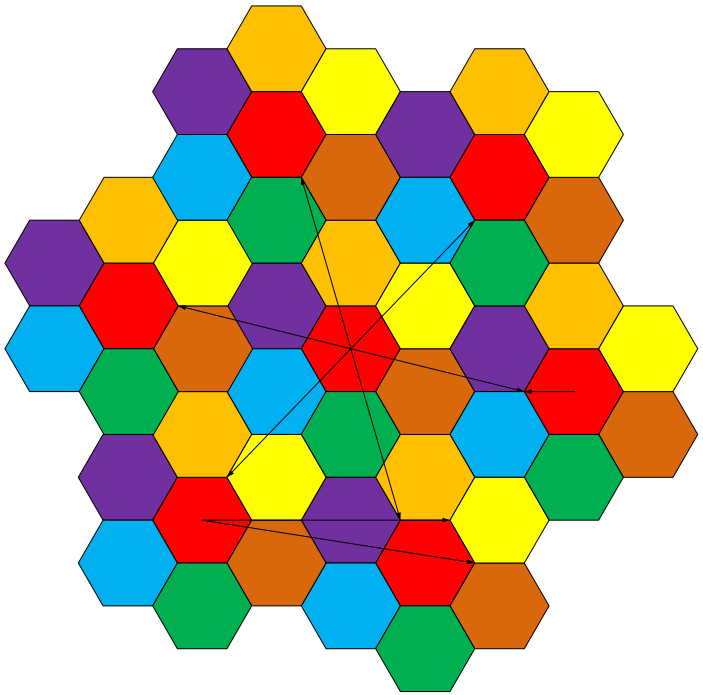
Sector (reuse 9)



Reuse	9	sector	20 dB/dec		
	distance (cell radius)		path loss		SNR
	signal	interference	signal	interference	
case 1	1	4	0.0	12.0	12.0
case 2	1	3.6	0.0	11.1	11.1
case 3	1	2.6	0.0	8.5	8.5
case 4	1	4.0	0.0	12.0	12.0
average					10.9

Reuse	9	sector	40 dB/dec		
	distance (cell radius)		path loss		SNR
	signal	interference	signal	interference	
case 1	1	4	0.0	24.1	24.1
case 2	1	3.6	0.0	22.3	22.3
case 3	1	2.6	0.0	16.9	16.9
case 4	1	4.0	0.0	24.1	24.1
average					21.8

Sector (reuse 21)

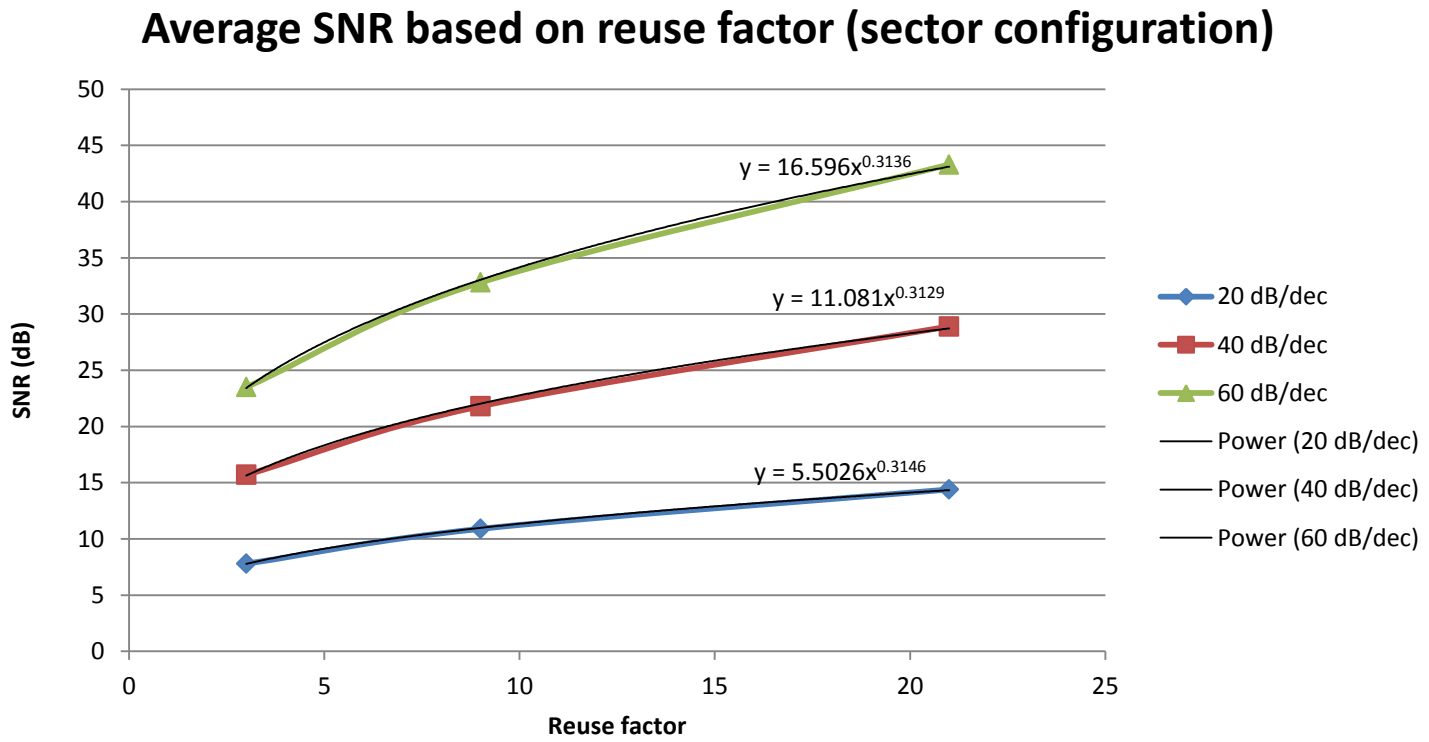


Reuse	21	sector		20 dB/dec	
	distance		path loss		SNR
	signal	interference	signal	interference	
case 1	1	5.0	0.0	14.0	14.0
case 2	1	5.6	0.0	14.9	14.9
average					14.4

Reuse	21	sector		40 dB/dec	
	distance		path loss		SNR
	signal	interference	signal	interference	
case 1	1	5.0	0.0	28.0	28.0
case 2	1	5.6	0.0	29.8	29.8
average					28.9

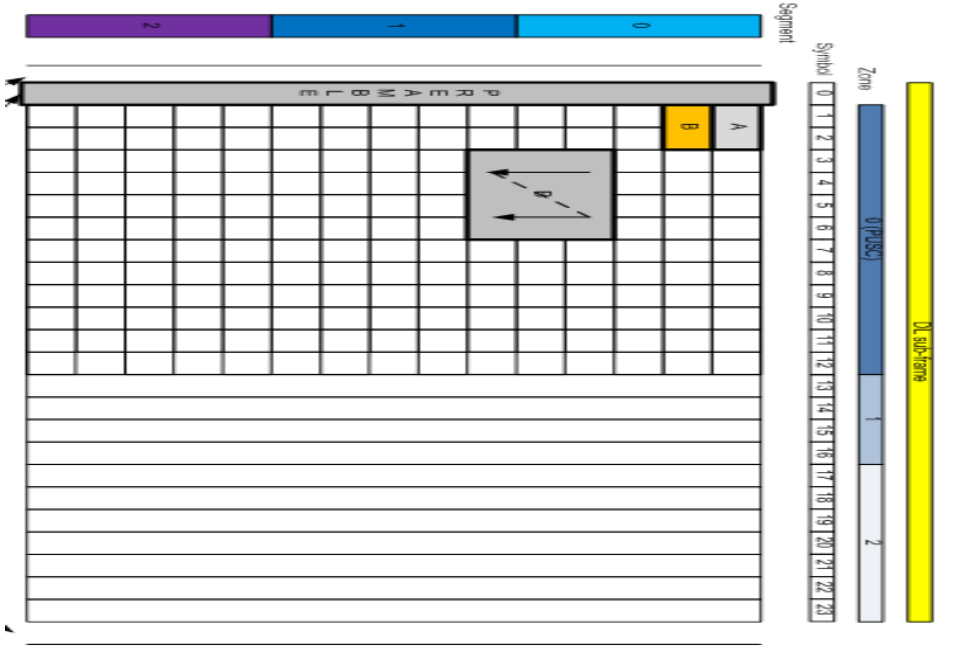
Average SNR according to reuse factor

- The equations to find the reuse from the target SNR are:
- For 20 dB/dec: $x = \left(\frac{SNR}{5.5026}\right)^{3.18877551}$
- For 40 dB/dec: $x = \left(\frac{SNR}{11.081}\right)^{3.195909}$
- For 60 dB/dec: $x = \left(\frac{SNR}{16.596}\right)^{3.17864}$



Resources and Interference Mitigation

- **WiMAX**
  - Resources
    - RF Channels
    - Sub-Channels : 48 Data Symbols
    - Segments: up to six
    - Zones: up to eight
  - Interference Avoidance
    - Resource Planning
    - Permutation Schemes (PUSC and other)
- **LTE**
  - Resources
    - RF Channels
    - Resource Blocks: (84/78 Data Symbols)
  - Interference Avoidance
    - No Permutation
    - Resource Planning
    - ICIC (Inter-Cell Interference Coordination)
    - eICIC (enhanced ICIC)



The next Generation: 5 G

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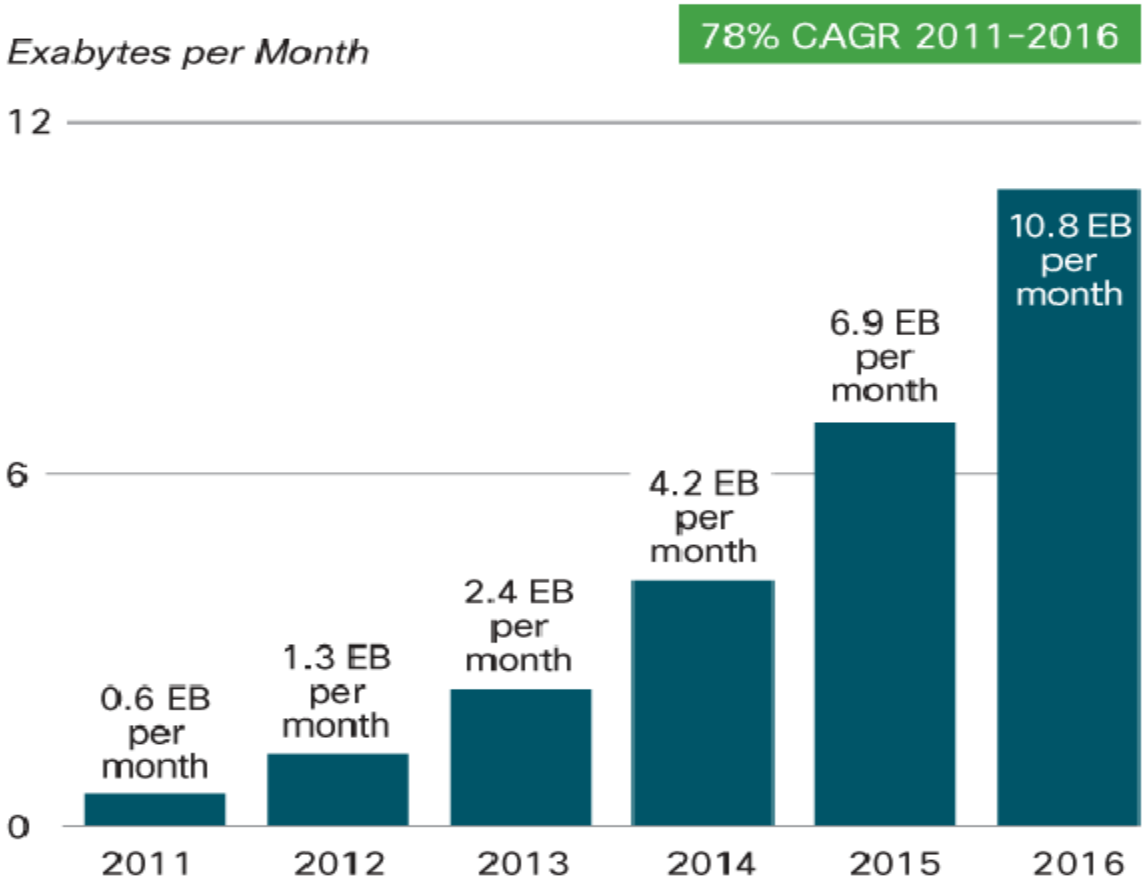
Expected Data Growth

- Cisco Visual Networking Index



Source: Cisco VNI Mobile, 2012

The next Generation: 5 G

- Data traffic will be offloaded to professional grade Wi-Fi hotspots (600 MHz available)
  - Dual connection path (private and public)
  - Authentication
  - Better security
  - Seamless connection
  - Use of public and private hotspots
- A new generation of scheduled Wi-Fi may arise
- Operators will only manage hotspot traffic
- Operators will still provide mobile data connections
- Operator will provide hotspot backhaul (when cable is not available)

Thank You!

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Questions?