UNIK4230: Mobile Communications

Spring Semester, 2013

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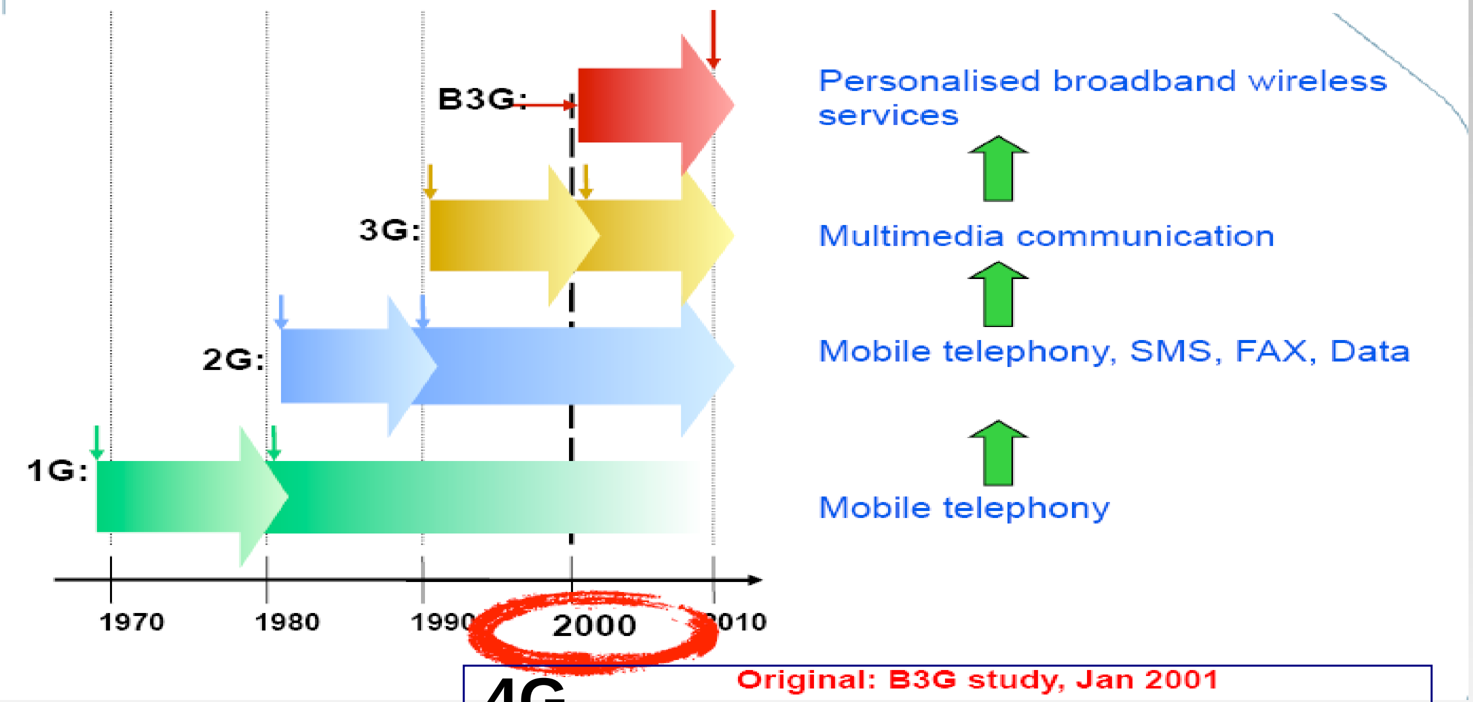
Tentative lecture schedule

- 24. Jan. 2012 Introduction
- 31. Jan. 2012 Network Architecture and Functionality
- 07. Feb. 2012 Propagation Characteristics of Wireless Channel-I
- 14. Feb. 2012 Propagation Characteristics of Wireless Channel-II
- 21. Feb. 2012 Winter break
- 28. Feb. 2012 Combating the effect of Fading in Mobile Systems
- 07. Mar. 2012 Cell and Cellular Traffic-I
- 14. Mar. 2012 Cell and Cellular Traffic-II
- 21. Mar. 2012 Multiple Access
- 28. Mar. 2012 Easter holiday
- 04. April. 2012 Students Seminar on selected topics (All)
- 11. April. 2012 Mobile Broadband-I (Market Trends, Evolution, LTE)
- 18. April. 2012 Mobile Broadband-II (LTE, SON, QoS, LTE-A)
- 25. April. 2012 Refarming and the challenges of Mobile Communications, 700 MHz - 2.6 GHz as well as technology focus with LTE, 3G (HSPA)
- 02. May. l2012 Small Cell and Heterogeneous Network (HetNet)
- 16. May 2012 Repetition and walk through on the course including Exam guidance

Lecture-1: Introduction

- What is mobile communication?
- History and trends
- Elements in mobile communication systems
- Basic functionality

Generations in Mobile communication



1G

Analog communication

Only voice

e.g NMT-450, AMPS

2G

Digital communication

Mostly voice service, data service limited and low speed

e.g. GSM

3G

Simultaneous voice and data

peak data rate at least 200 kbps (IMT-2000 specs.)

Latest UMTS release HSPA+ (Evolved HSPS): upto 84Mbit/s (DL), upto 22 Mbit/s (UL) -> 3.75G?

4G

100 Mbit/s for high mobility communication

1 Gbit/s low mobility communication

LTE wont fulfill ITU-R requirements

Candidate: LTE-A

Service e.g. Mobile broadband

Frequency band, technologies & operators

	Frekvens-bånd	Total mengde tilgjengelig	Bruk i Norge (forventet bruk)	Aktører i Norge
450 MHz	453-457 463-467	2*4 MHz	CDMA	"ICE"
DD (800 MHz)	790-820 832-862	2*30 MHz	(LTE)	(frekvenser ikke delt ut)
900 MHz	880-915 925-960	2*35 MHz	GSM	Netcom/ Telenor
1800 MHz	1710-1805 1805-1880	2*75 MHz	GSM	Netcom/ Telenor/ Network Norway
2100 MHz	1920-1980 2110-2190	2*60 MHz	UMTS	Netcom/ Telenor
2600 MHz	2500-2570 2620-2690	2*70 MHz	LTE	Netcom

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History- NMT

- In 1984 NMT started facing capacity problem
- In 1986 NMT-450 had 87000 subscription in Norway
- To increase capacity, NMT later rolled out NMT 900 MHz band
- In 1995, two years after the start of GSM, NMT subcriber number peaked and there were 488 000 NMT subscribers in Norway
- Finally NMT were laid down in 2005, a month after 3G network was opened in Norway

History- GSM

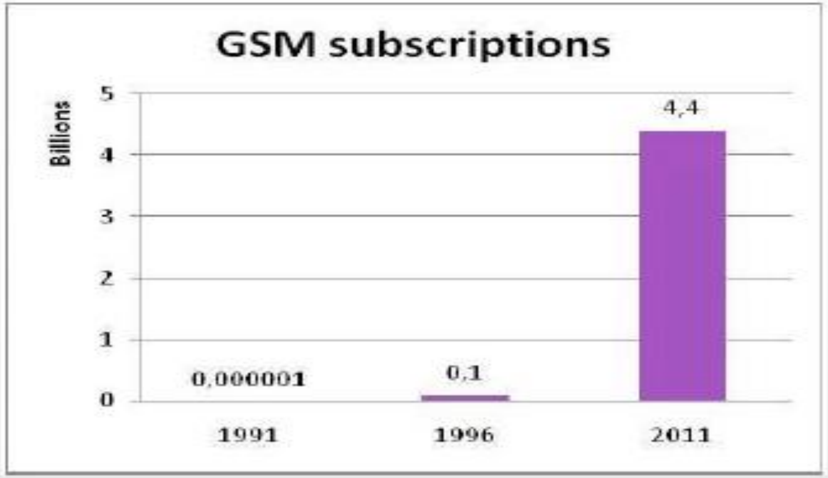
1993: Tele-Mobil (Telenor Mobil) and NetCom GSM opens their networks in Norway

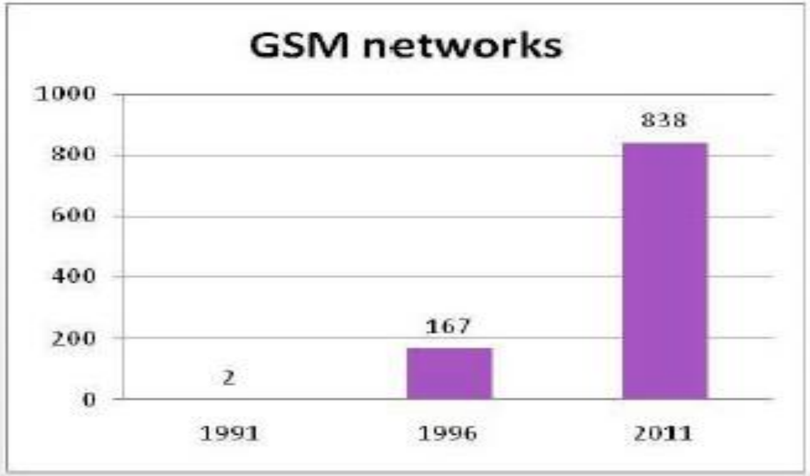
1998: GSM 1800 starts operation to increase the network capacity in cities in Norway

2001: GPRS service started by Telenor Mobil

2004: EDGE Service started in Norway

2003: First 3G service in Europe





Regulation & standardization

National & International regulators decide to use different frequency band for different applications. The most important regulatory bodies are:

- Post & Telecommunication Authority, regulatory authority in Norway
- CEPT (Conference of European Post and Telecommunications Administrations)
- ITU-R (International Telecommunication Union – Radio Communication), international regulatory authority arrange WRC (World Radio Communication Conference)

Standard organizations develop and adopt international standards for telecommunication systems, most important bodies are:

- ETSI (European Telecommunication Standard Institute), developed GSM standards
- ITU-T (International Telecommunication Union Standardization Sector), part of the ITU standardization
- 3GPP (3rd Generation Partnership Project), cooperation between regional standardization body of Europe, North America and Asia; responsible for all standardization of 3G and GSM development

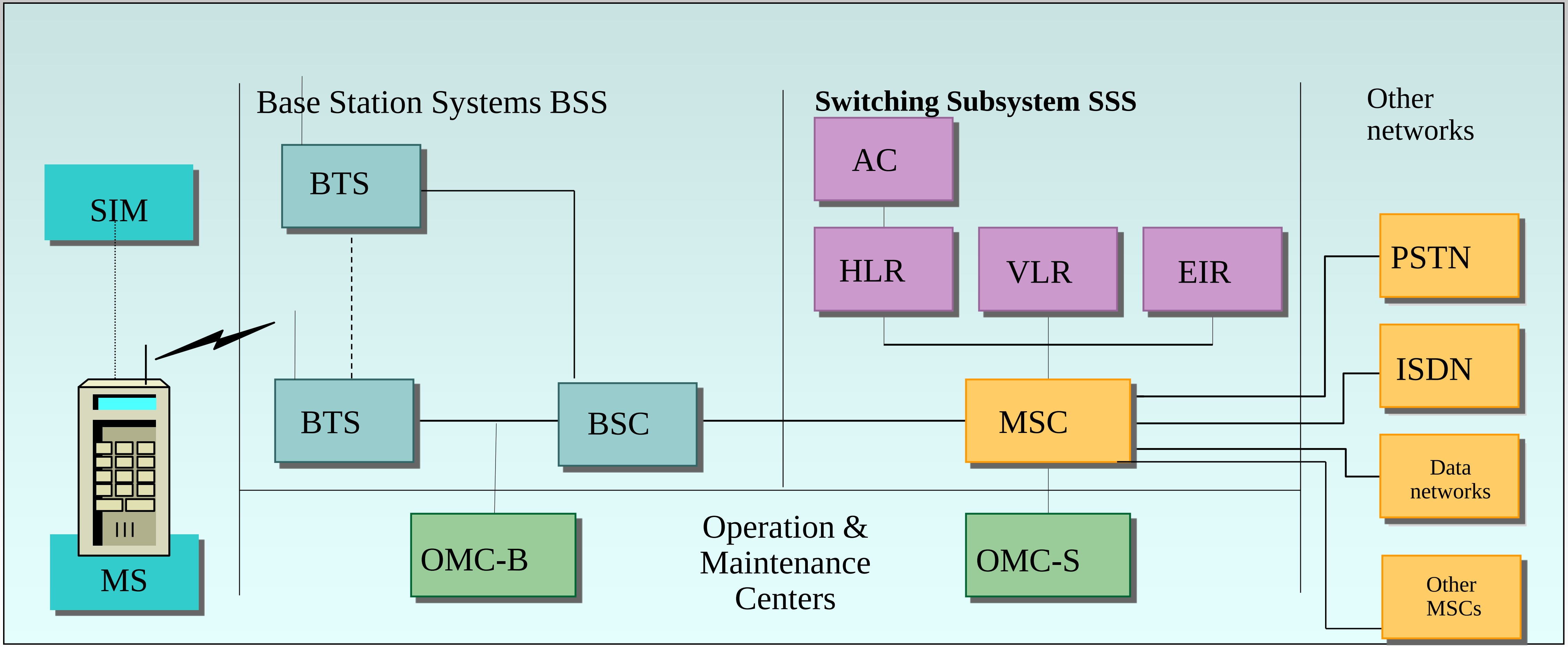
Challenges of building future mobile networks

Some of the challenges include

- Provide mobile subscriptions to the low income segment
- Build network capacity to meet the data traffic explosion while revenue growth is minimal
- Limited spectrum
- Invest in new technology (e.g. HSPA+, LTE) while need to keep legacy network (e.g. GSM, CDMA) for many more years
- Main revenue sources of Operators like voice, SMS is increasingly being commoditized by internet players
- Prediction of huge Machine to Machine subscription which will have low ARPU*.

*ARPU: Average Revenue per User

Architecture of GSM Network



Basic elements in mobile communication systems

SIM – A smart card stores identification (IMSI) of a subscriber, holds Auth. Key that identifies SIM on the mobile network

ME/MU/MS – the mobile device

BTS – Facilitate wirlesss communication between UE/ME and the network

BSC – Allocates radio channel to ME, several BTS under the control of one BSC

MSC – carries out call switiching (ME-ME, ME-phones of other network)

VLR – linked to MSc, temporary DB of subscriber who roamed into a specific MSC

HLR – a central DB of ME

AuC – to authenticate each SIM

EIR – keeps lists of ME which are to be banned or monitored

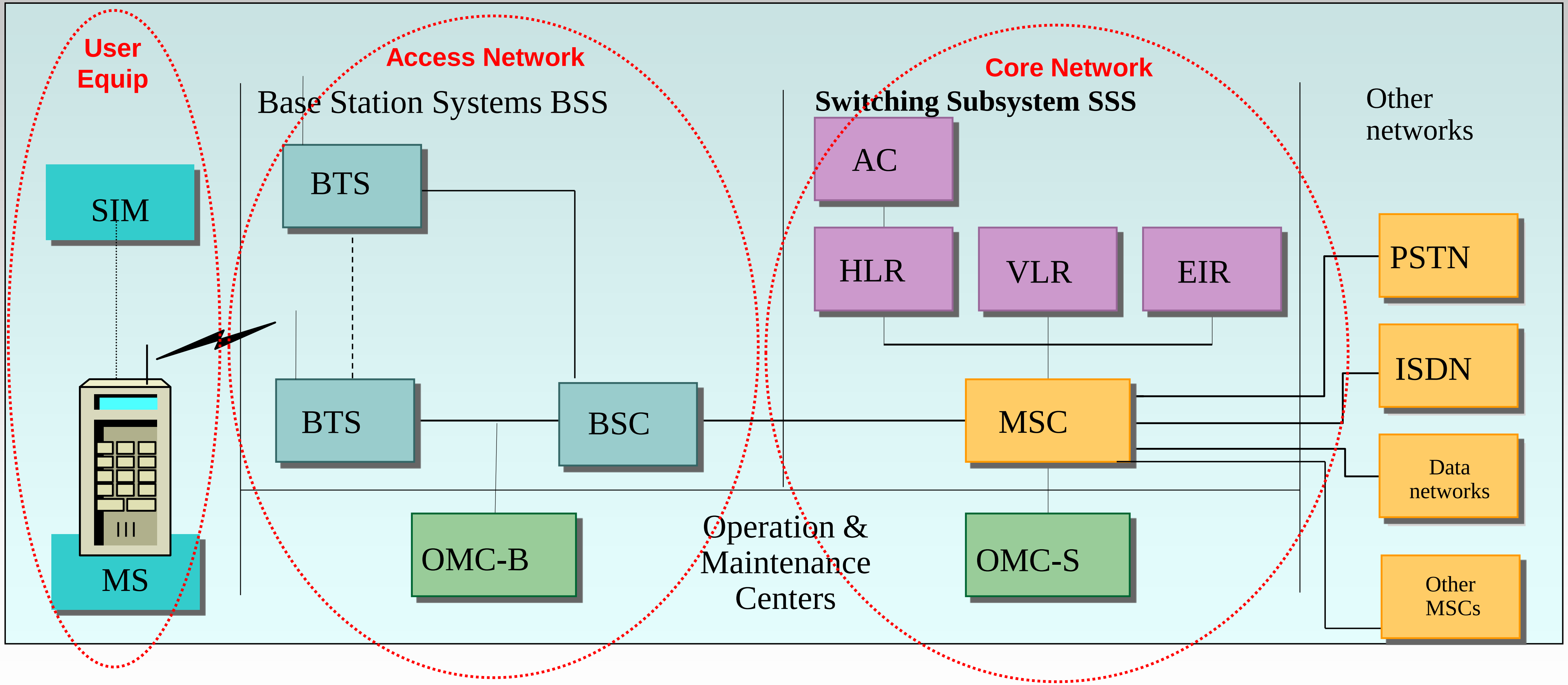
Some concepts in mobile communications

- **Cell** – A limited geographic area covered by a BTS (e.g. max. Cell size of GSM cell 35km, typically several km)
- **Control channel** – Radio channel used for all control info. e.g. call request, call set up etc.
- **Information channel** – Radio channel used for user info. e.g. data or voice
- **Downlink (forward channel)** – communication from BTS till ME
- **Uplink (reverse channel)** – communication from ME till BTS
- **Handover (handoff)** – transferring an ongoing communication from one BTS to another BTS typically due to movement
- **Full duplex/half duplex/simplex** –
  - Both direction simultaneously/ both direction but only one direction at a time/Only one way communication

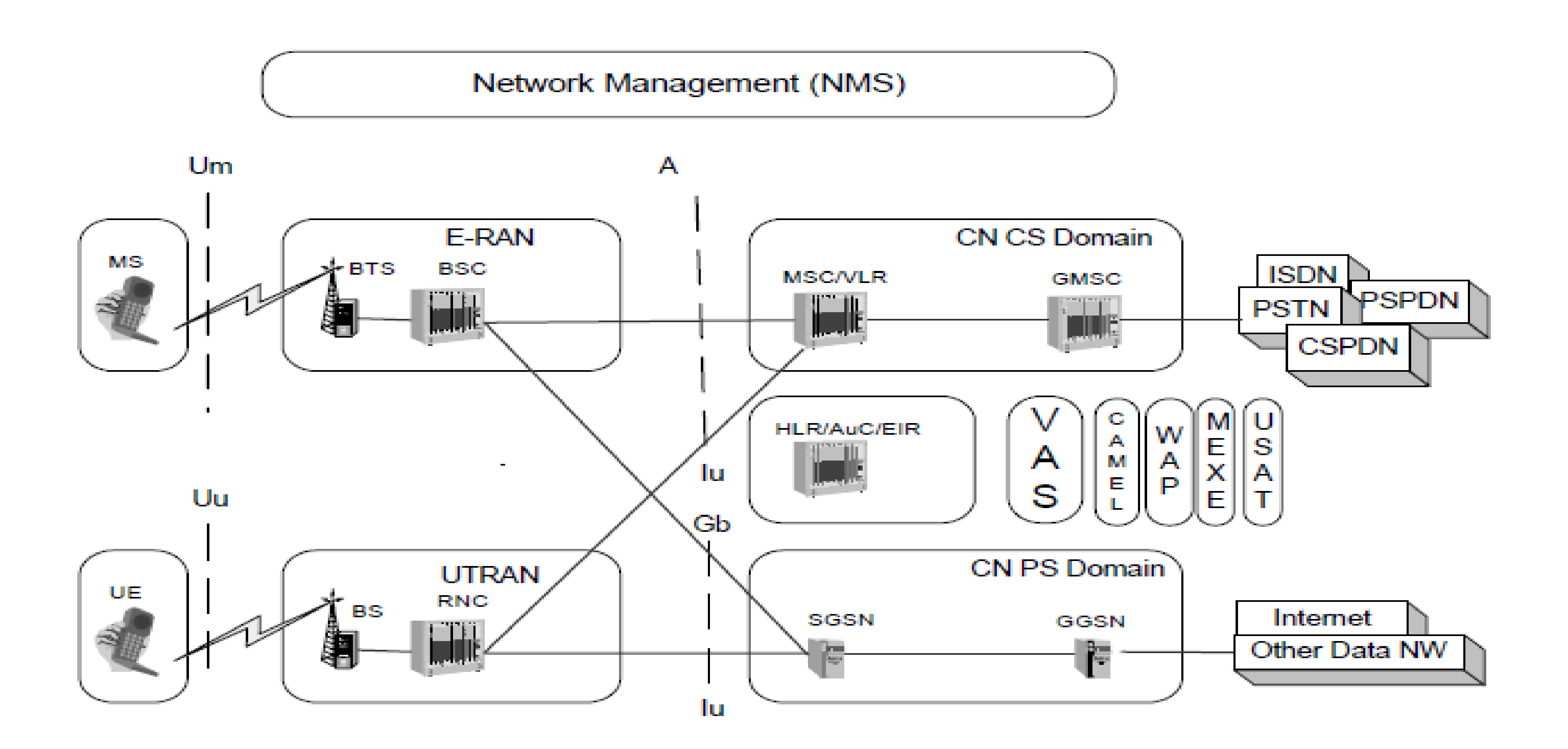
Lecture-2: Network Architecture and Functionality

- Network Architecture
- Protocol stacks
- Air Interface
- System Capacity

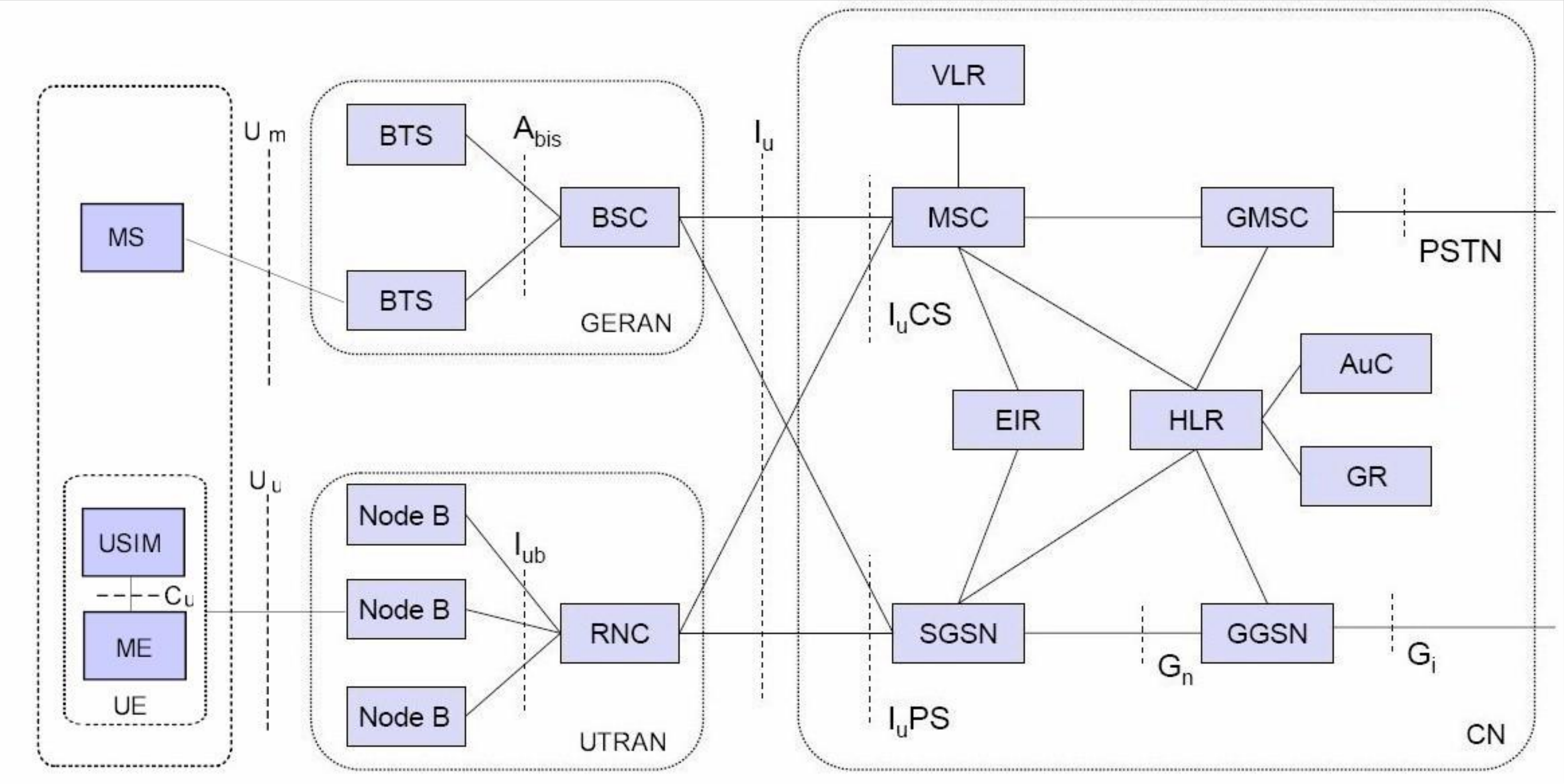
Architecture of GSM Network



Release 99: Introduction of 3G Network



GSM and UMTS Network Layout



Protocol Stack structure of GSM

U_m

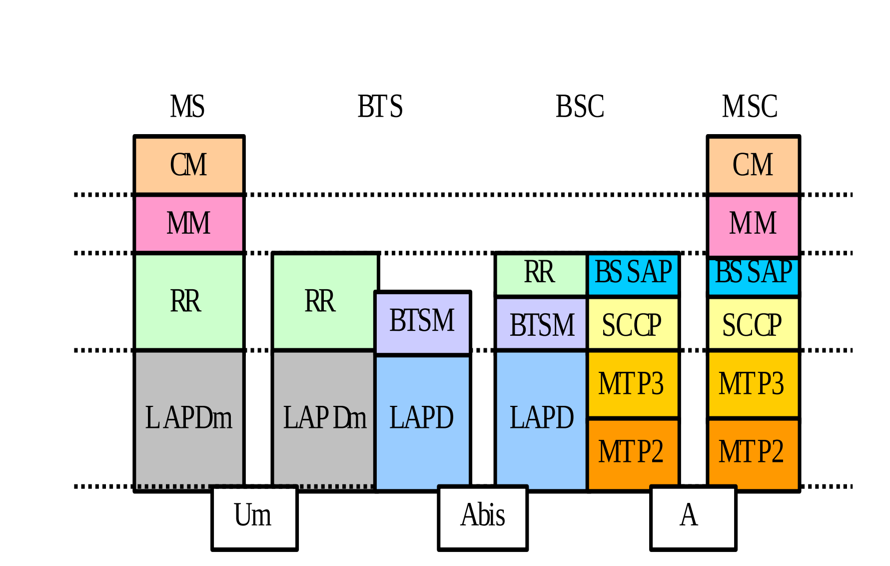
- Radio interface between MS and BTS
- each physical channel supports a number of logical channels

A_{bis}

- between BTS and BSC
- primary functions: traffic channel transmission, terrestrial channel management, and radio channel management

A

- between BSC and MSC
- primary functions: message transfer between different BSCs to the MSC



- The data link layer (layer 2) over the radio link is based on a modified LAPD (Link Access Protocol for the D channel) referred to as LAPDm (m like mobile).
- The Message Transfer Protocol (MTP) level 2 of the SS7 protocol is used at the A interface.

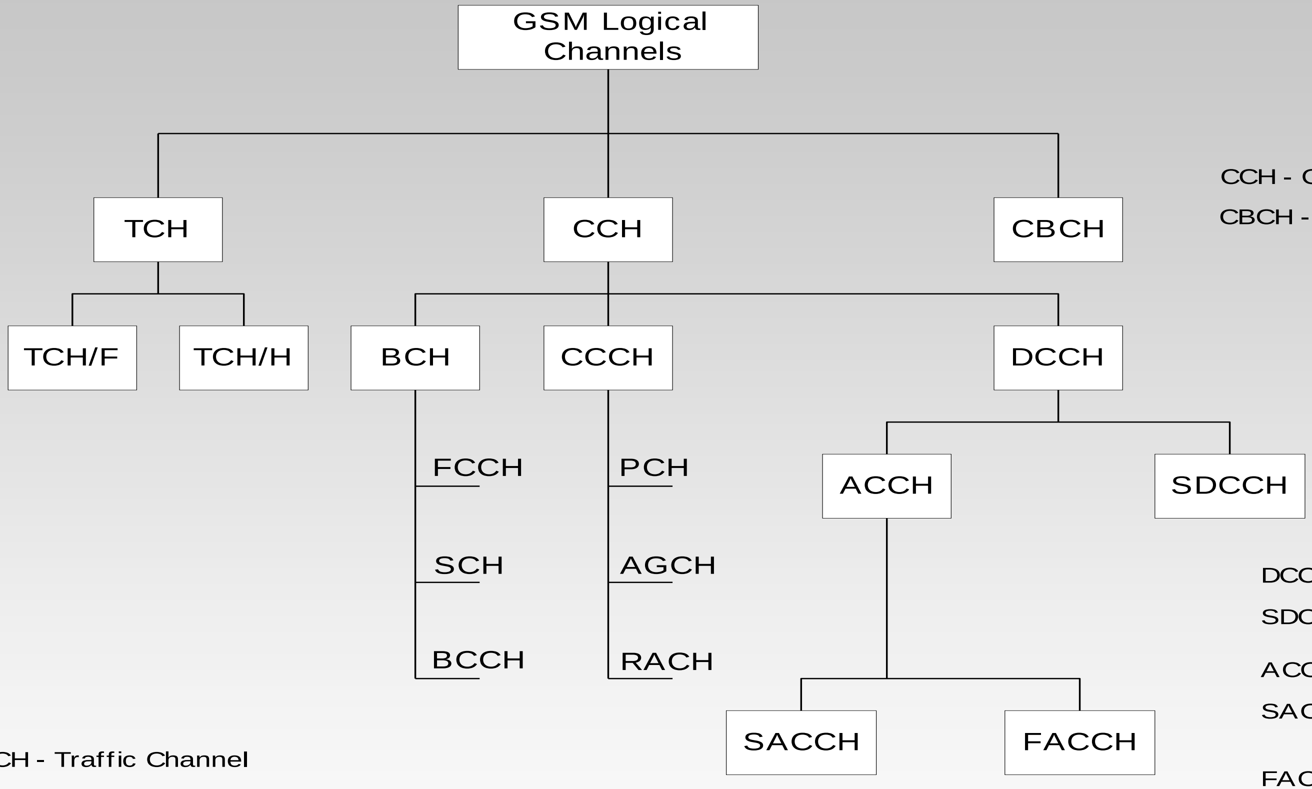
Frequency Resource

GSM900 :
up: 890~915MHz
down: 935~960MHz
duplex interval: 45MHz
bandwidth: 25MHz，
frequency interval: 200KHz

GSM1800 :
up: 1710-1785MHz
down: 1805-1880MHz
duplex interval: 95MHz，
working bandwidth: 75MHz，
frequency interval: 200KHz

GSM1900MHz:
up:1850~1910MHz
down:1930~1990MHz
duplex interval: 80MHz，
working bandwidth: 60MHz，
frequency interval: 200KHz

GSM Logical Channels



CCH - Control Channel

CBCH - Cell Broadcast Channel

DCCH - Dedicated Control Channels

SDCCH - Stand-alone Dedicated Control Channel

ACCH - Associated Control Channels

SACCH - Slow Associated Control Channel

FACCH - Fast Associated Control Channel

TCH - Traffic Channel

TCH/F - Traffic Channel (Full Rate)

TCH/H - Traffic Channel (Half Rate)

BCH - Broadcast Channels

FCCH - Frequency Correction Channel

SCH - Synchronization Channel

BCCH - Broadcast Control Channel

CCCH - Common Control Channels

PCH - Paging Channel

AGCH - Access Grant Channel

RACH - Random Access Channel

Logical Channels- Summary

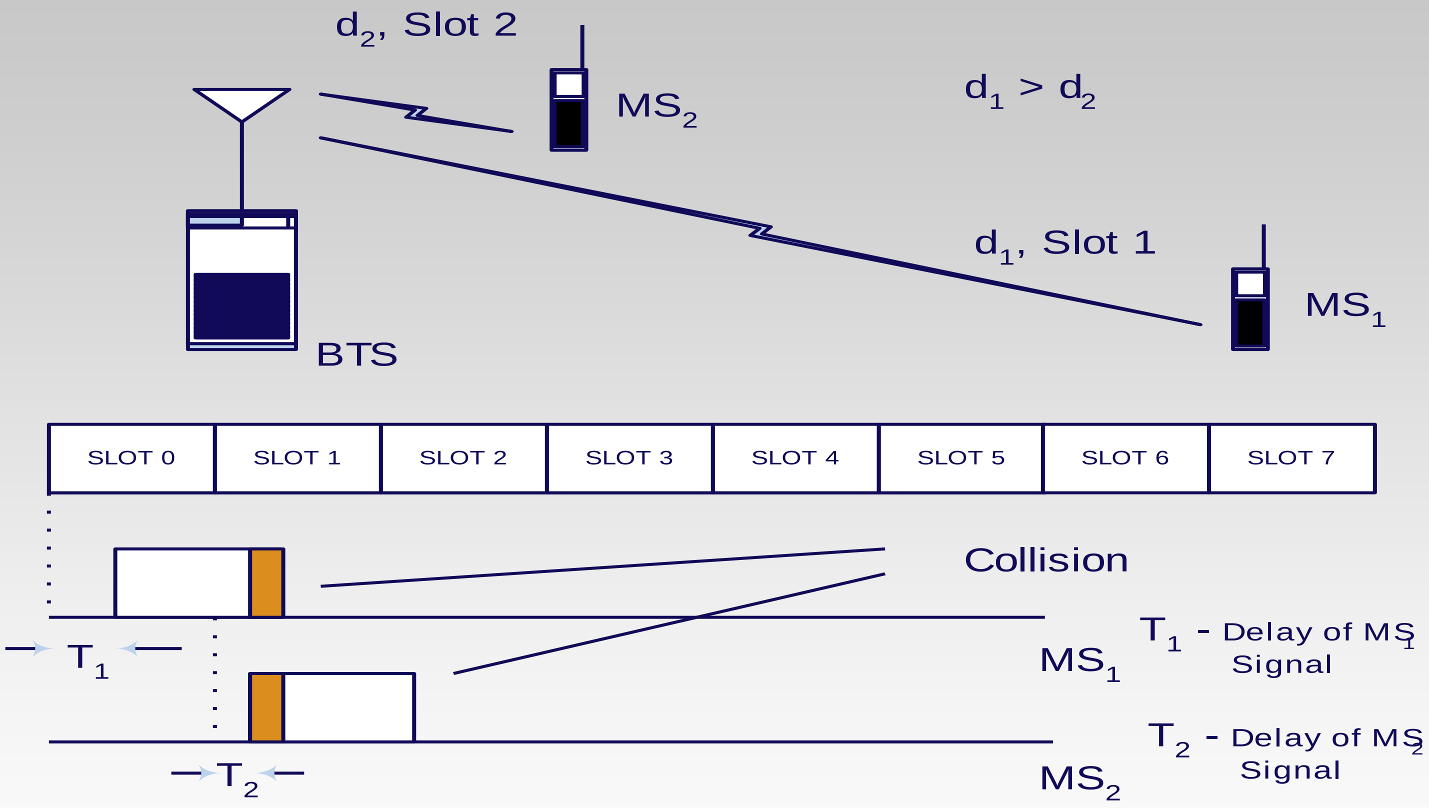
Channel	UL only	DL only	UL/DL	Point to point	Broadcast	Dedicated	Shared
BCCH		X			X		X
FCCH		X			X		X
SCH		X			X		X
RACH	X			X			X
PCH		X		X			X
AGCH		X		X			X
SDDCH			X	X		X	
SACCH			X	X		X	
FACCH			X	X		X	
TCH			X	X		X	

UL - Uplink

DL - Downlink

Timing Advance

- Mobiles randomly distributed in space
- Timing advance prevents burst collision on the reverse link
- Maximum advancement is 63 bits



$$D\max = \frac{1}{2}\left(3\times10^{8}\,\frac{\text{m}}{\text{s}}\cdot 63\text{bit}\cdot 3.693\times10^{-6}\,\frac{\text{s}}{\text{bit}}\right)\approx 35\text{km}$$

System Capacity

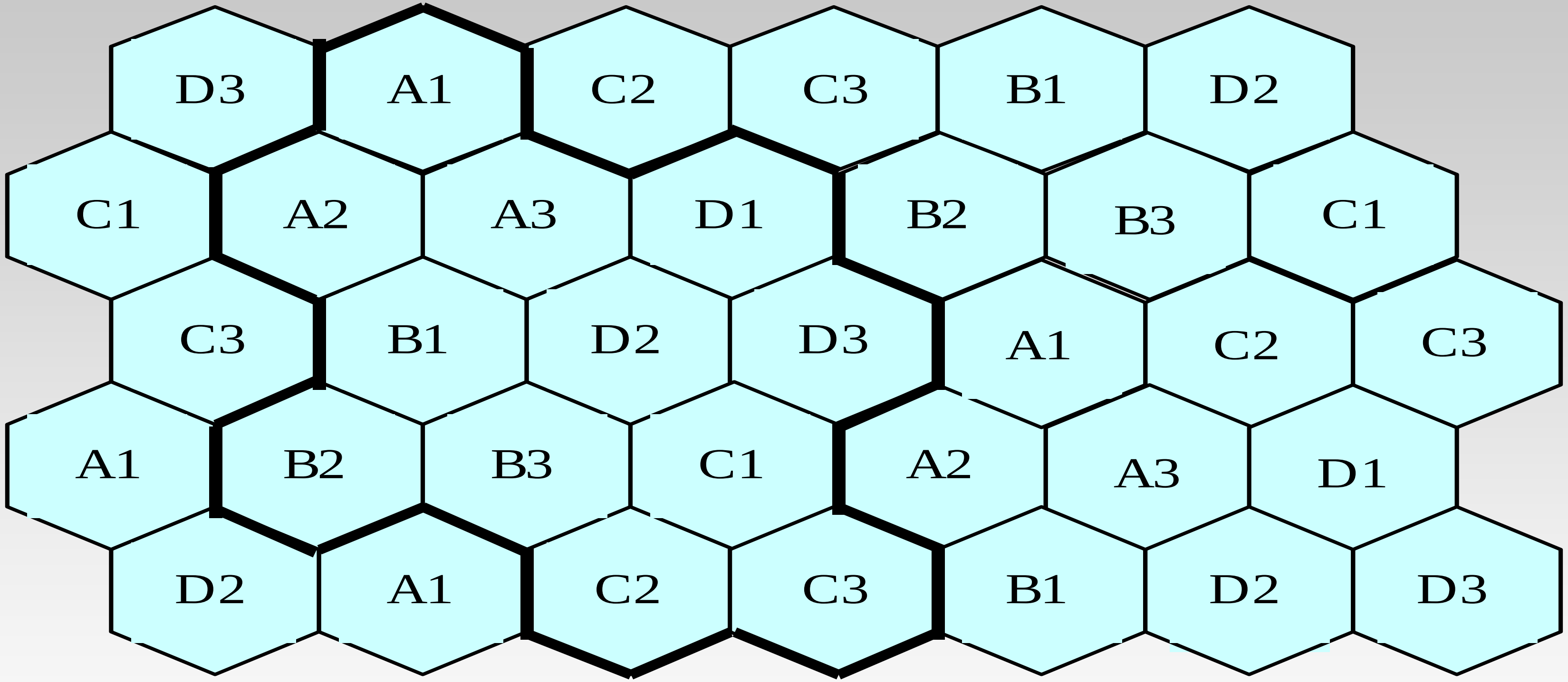
Erlang :

the traffic intensity of a totally occupied channel (i.e. the call hour of a unit hour or the call minute of a unit minute). For example, the traffic of a channel occupied for 30 minutes in an hour is 0.5 Erlang)

GOS:

defined as the probability of call blocking or the probability when the call delay time is longer than a given queuing time.

Frequency Reuse



"4 ´ 3" reuse mode:

one group includes 3 sectors /site ,12 frequency which are distributed to 4 sites. Every site owns 3 frequency.

Lecture-3,4: Propagation characteristic of wireless channel

Radio wave propagation phenomena

- Reflection
- Refraction
- Diffraction
- Scattering

Signal attenuation

- Attenuation and fading
- Path loss
- Hata model

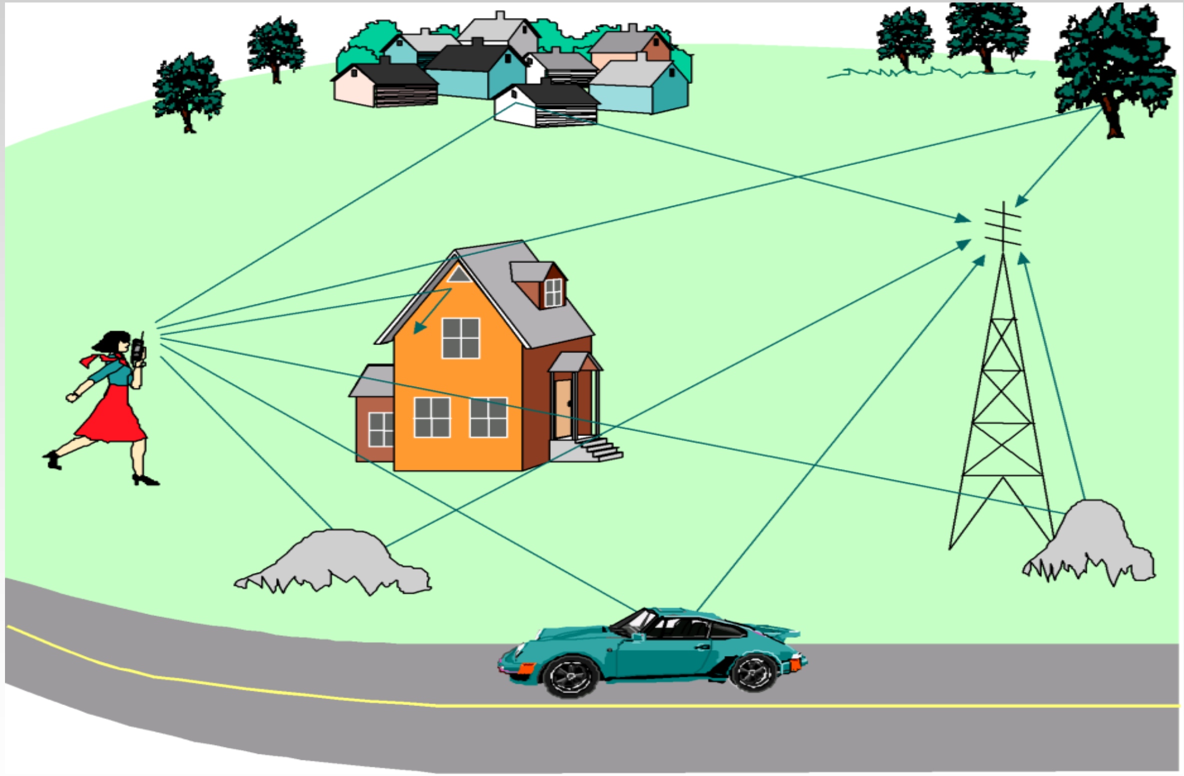
Indoor propagation

More on fading

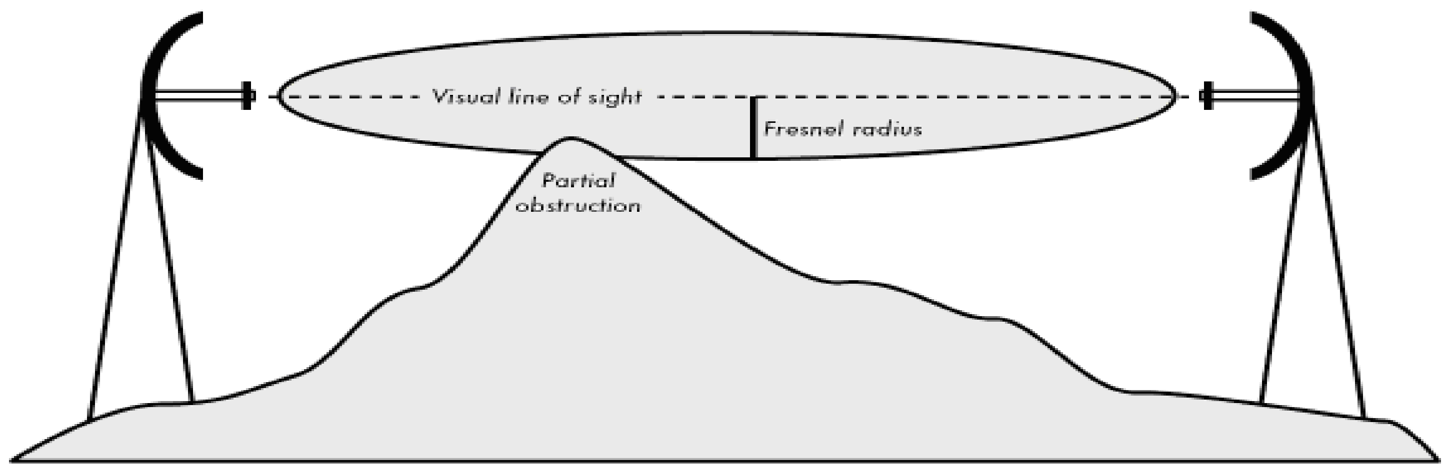
Radio channel

The transmitted signal arrives at the receiver from different directions at different times over a number of ways

- Line of sight (LOS) or
- Non-line of sight (NLOS)



Fresnel zones



The Fresnel zone is partially blocked on this link, although the visual line of sight appears clear..

$$F_n = \sqrt{\frac{n\lambda d_1 d_2}{d_1 + d_2}}$$

All units are meter

1st Fresnel zone while D in Km and f in GHz

$$r = 8.657\sqrt{\frac{D}{f}}$$

Fresnel zones determine whether a given obstacle will cause a constructive or desctructive interference at the receiver due to reflection

- Reflection can enhance received signal if reflected and direct signals arrive in-phase
- Its important to clear obstruction from first Fresnel zone

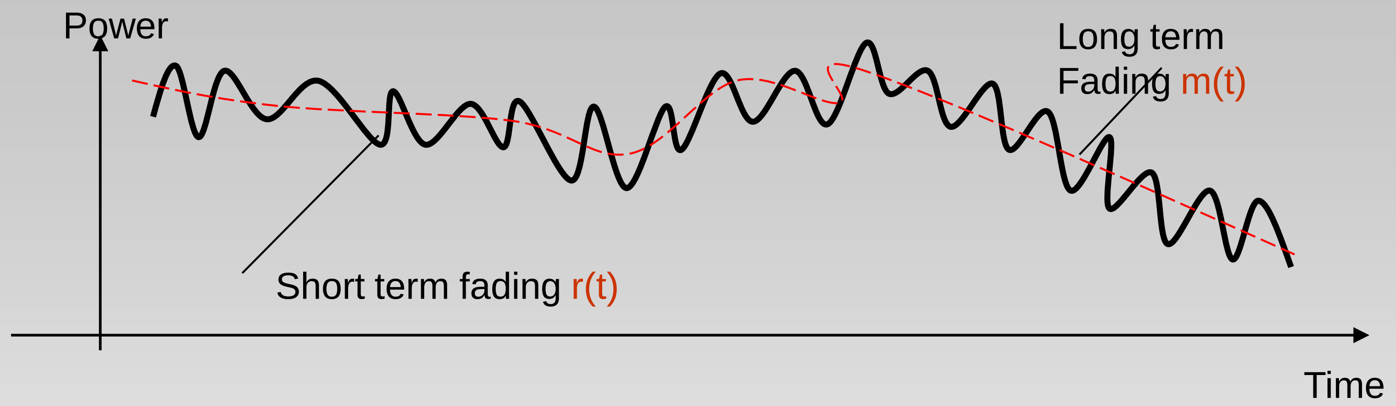
The radius of first Fresnel zone, r = 17.31 * sqrt(N(d1*d2)/(f*d)) ...where r is the radius of the zone in meters, N is the zone to calculate, d1 and d2 are distances from obstacle to the link end points in meters, d is the total link distance in meters, and f is the frequency in MHz.

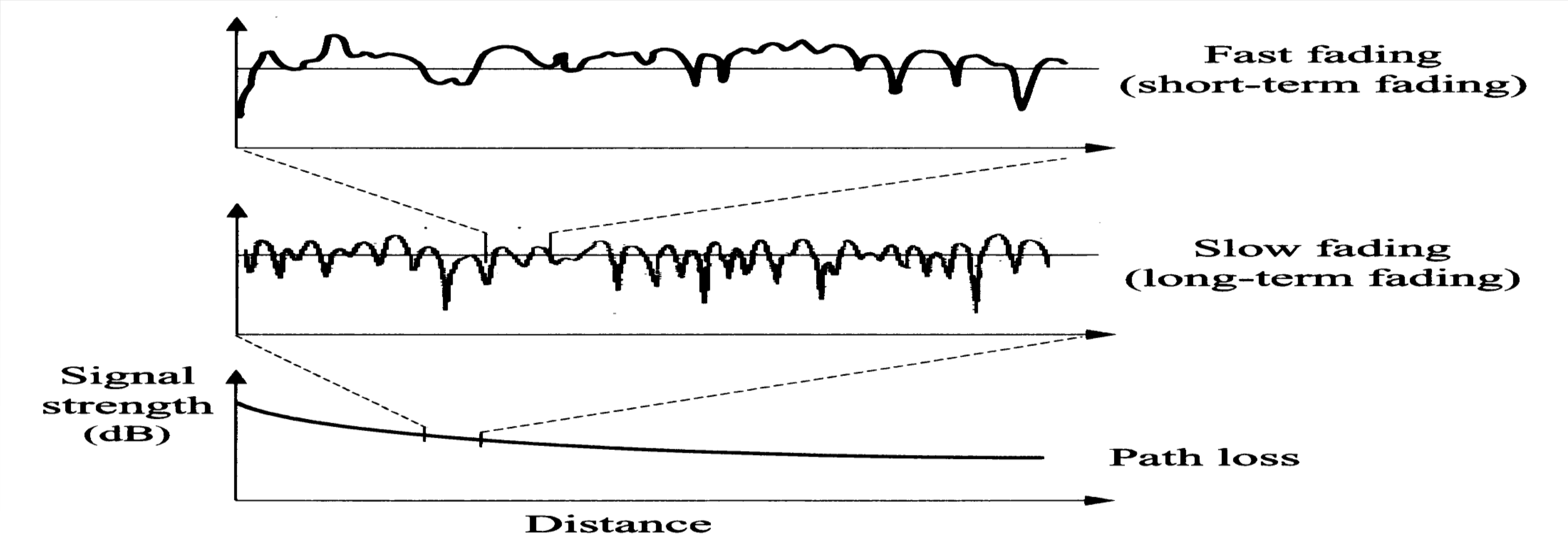
Attenuation and fading

Fading is deviation of attenuation a radio wave experience over certain propagation media.

- Distance dependent attenuation
- Fast fading: Rapid fluctuation of signal over a small areas. Fast fading occurs due to multipath propagation
  - Fast fading is characterized by Rayleigh and Rician distribution.
  - Rayleigh distribution: It assumes infinite reflected path with all possible attenuation and no direct path. E.g. It is used to characterize worst case urban or indoor communications
  - Rician distribution: It assumes a direct path from TX to RX as well as infinite reflected paths. E.g. Used to characterize satellite communication channels
- Slow fading: It is long-term fading effect caused by large obstruction (shadowing) such as large building or hills
  - Shadowing is modeled using log-normal distribution.

Attenuation and fading





About the term dB

Widely used to measure e.g. gain, attenuation, signal to noise ratio (SNR) etc.

The ratio of power value P_a to another power value P_b is calculated as:

$$X_{dB} = 10\log_{10}\left(\frac{P_a}{P_b}\right) \quad dB$$

Example:

Ratio = 0.1 = -10 dB

= 1 = 0 dB

= 10 = 10 dB

= 100 = 20 dB

Decibel (dB) is a dimensionless Unit

$$P_a = 10^{\frac{X_{dB}}{10}} P_b \; watt \; given \; P_b \; in \; watt$$

About the term dBm

dBm (decibel-milliwatt) is the power unit in dB referenced to 1 mW.

It measures absolute power in radio, microwave and fiber option network.

- dBm can measure both very small and very large values in short form

To measure an arbitrary power P_a as x dBm:

$$x = 10\log_{10}\left(\frac{P_a(mW)}{1mW}\right) \quad dBm$$

Example:

P_a = 1 mW, x = o dBm

P_a = 1 W, x = 30 dBm, maximum outout power of GSM 1800 mobile phone

x = 33 dBm, P_a = 2 W

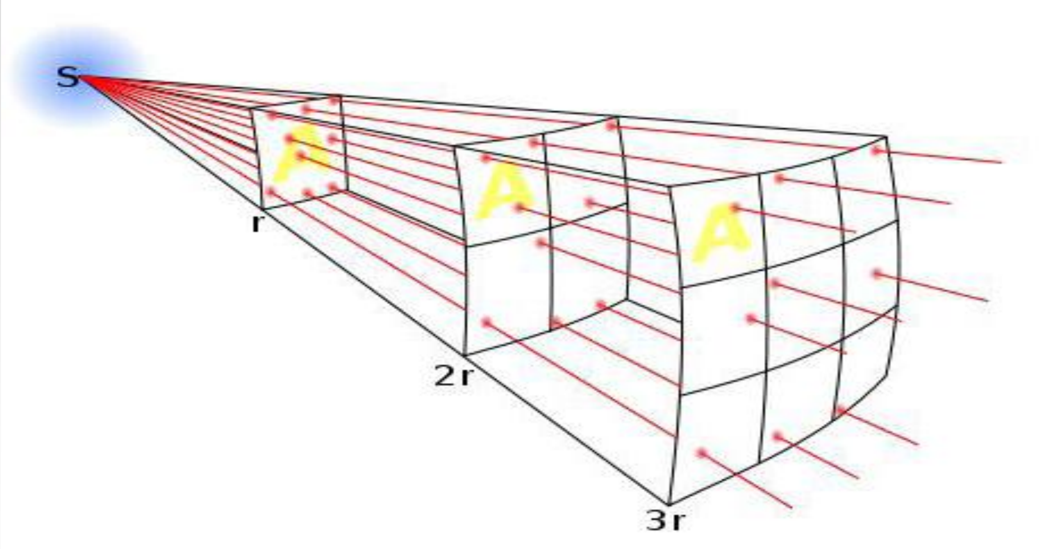
x = 80 dBm, P_a = 100 KW, P_{tx} of FM radio transmitter with 50km range

dBm is an absolute measure of power in mW

Attenuation in free space

When there is line of sight between transmitter and receiver, received power follows inverse square law:

$$P_r \propto d^{-2}$$



Path loss

If transmitted and received power are known, path loss can be calculated:

$$L(dB) = 10\log_{10}\left(\frac{P_t}{P_r}\right)$$

if both transmitter and receiver has no gain, its identical to free space loss

From the above equation, we can also write:

Path Loss (dB) = Transmit Power (dBm) – Received Power (dBm)

Attenuation factor

In real case attenuation is much higher because signal propagation path is not really free space.

With attenuation factor, received power:

$$P_r \propto d^{-\nu}$$

v=2 for free space

Typical values for urban areas are 3-5

With reference distance one can write:

$$P_r(d)[dBm] = 10\log_{10}(P_r(d_{ref})) + 10.\nu.\log_{10}\left(\frac{d_{ref}}{d}\right)$$

Okumura model

Combining all these causes (reflection, scattering, and diffraction), Okumura et al. (1968) proposed channel model

The model includes correction factor to account for terrain.

But correction factors have to be incorporated for every scenario

- Hata (1980) proposed a model to overcome the problem

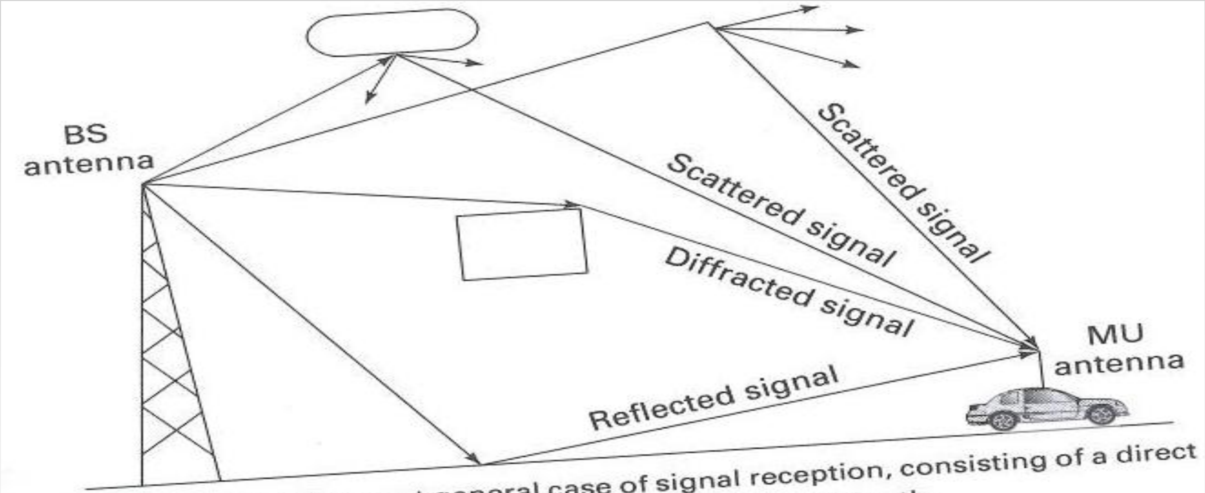


FIGURE 2.10 The most general case of signal reception, consisting of a direct path, a reflected path, a scattered path, and a diffracted path.

Hata model

- In Hata model, path loss in urban areas is given by:

$$L_p(dB) = 69.55 + 26.16\log_{10}(f_0) + (44.9 - 6.55\log_{10} h_b)\log_{10} d - 13.82\log_{10} h_b - a(h_{mu})$$

$$where$$

$$f_0 = carrier\ \ frequency\ (MHz)$$

$$d = separation\ between\ BTS\ and\ MU\ (km);\ d \geq 1\, km$$

$$h_b = height\ of\ the\ BTS\ antenna\ (m)$$

$$h_{mu} = height\ of\ the\ MU\ antenna\ (m)$$

$$a(h_{mu}) = correction\ \ factor\ \ for\ MU\ antenna\ height$$

- For large cities, the correction factor $a(h_{mu})$ is given by:

$$a(h_{mu}) = 3.2[\log_{10}(11.75 h_{mu})]^2 - 4.97 \qquad f_0 \geq 400\, MHz$$

- For small and medium cities, the correction factor $a(h_{mu})$ is given by:

$$a(h_{mu}) = [1.1\log_{10}(f_0) - 0.7]h_{mu} - [1.56\log_{10}(f_0) - 0.8]$$

Fading

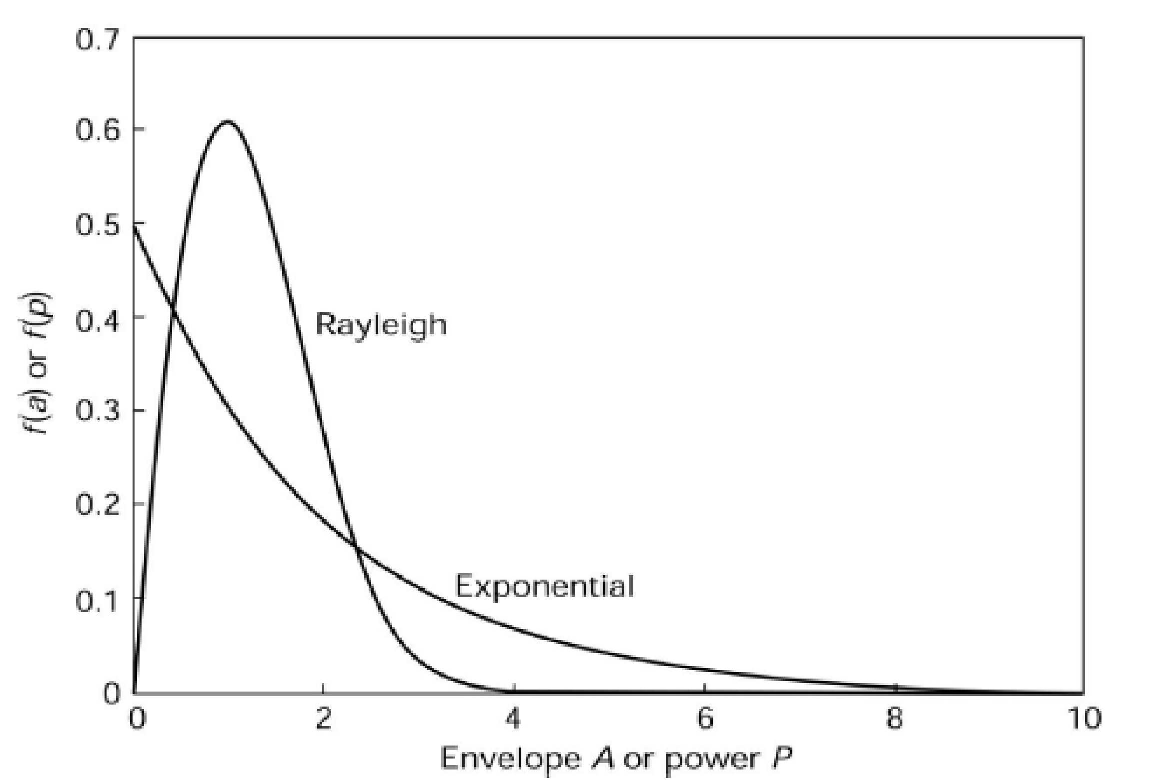
- In addition to propagation loss, attenuation may also fluctuate with *geographical position*, *time* and *frequency* which is referred as “fading” and usually modeled as *random* process.
- Propagation fluctuates around mean value
- Fading describes this signal fluctuation around mean value
- Primary cause of fading is signal traversing multiple path. Another reason is the shadowing from large objects along the wave propagation

Fading can be described in three ways:

- Multipath
- The statistical distribution of the received signal envelope (e.g. Rayleigh)
- Duration of fading (e.g. long-term, short-term)

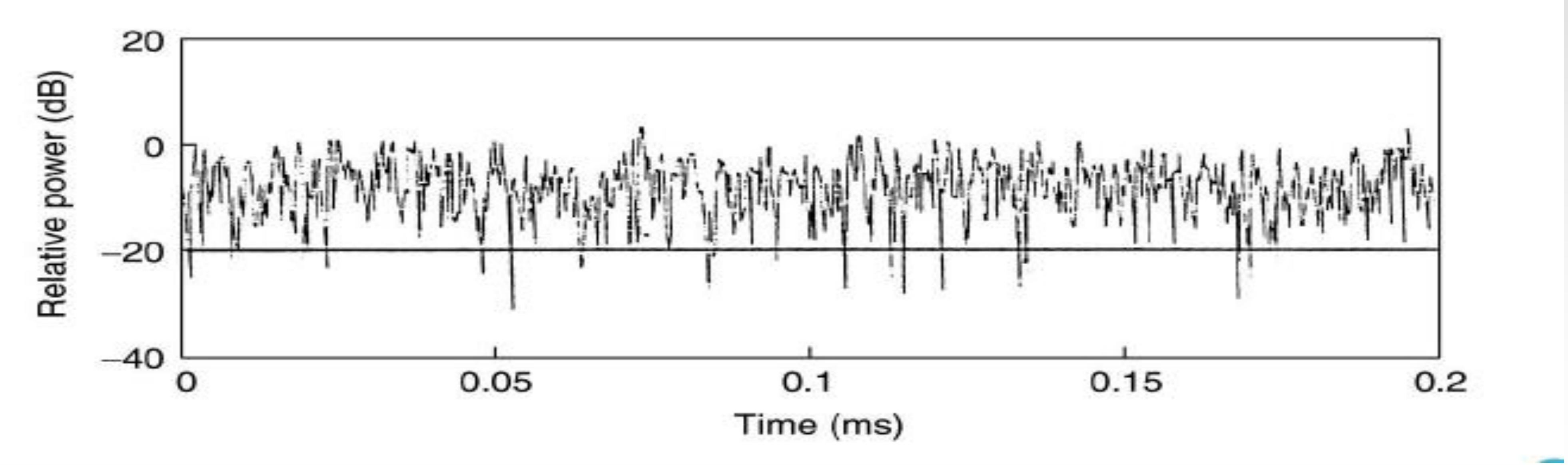
Rayleigh Model

- Rayleigh distribution represents worst case fading as no LOS is considered.
- This is the most used signal model in wireless communication.

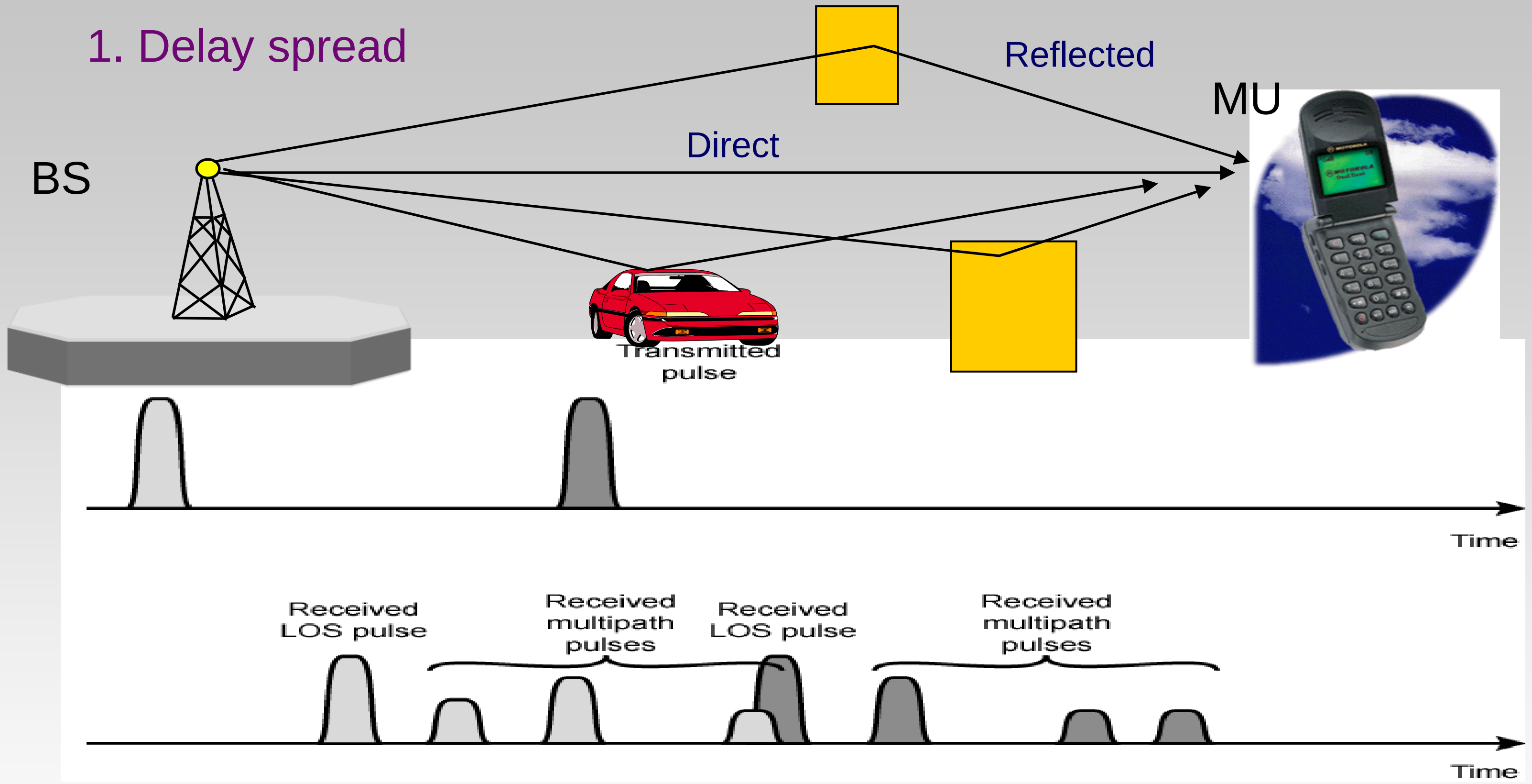


Outage

- Every receiver is designed to operate at an acceptable level only if a certain minimum power, P_{thr}, is being received
- The receiver will be in outage whenever power goes below this threshold value. Also termed as “deep fade”.
- Outage is the implication of fading; following system goes into outage if the threshold is set to -20 dB of relative power



Multipath and Intersymbol interference



- Intersymbol interference (ISI) occurs if the delay spread of the channel exceeds the symbol time (or the sampling interval)
- Cancellation of ISI is done via an equalizer at the receiver

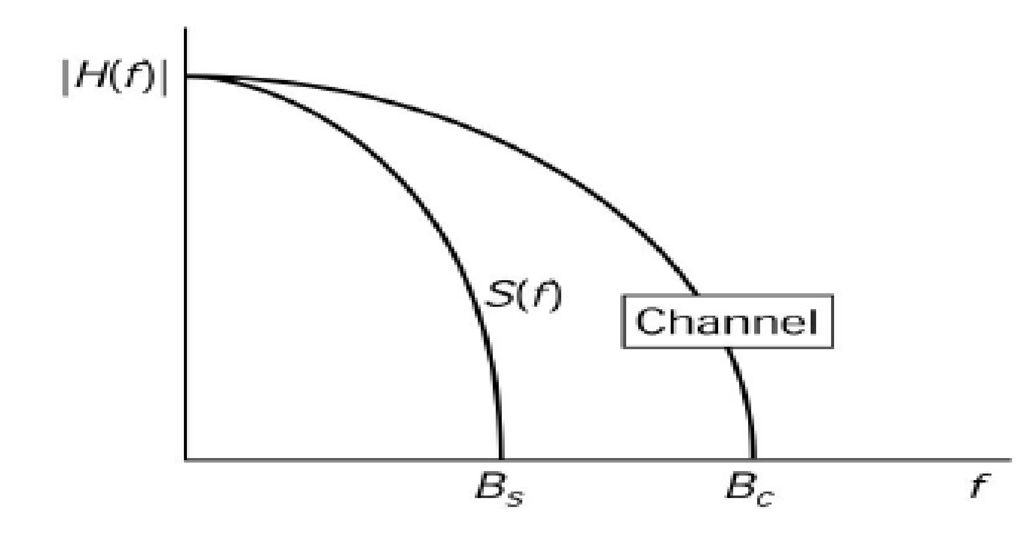
Flat fading channel

If the channel bandwidth B_c is larger than message bandwidth B_s, all the frequecy components in the message will arrive at the receiver with little or no distortion

ISI will be neligible

The channel will be defined as **flat fading channel**

Rural areas can be characterized as nearly flat fading channel



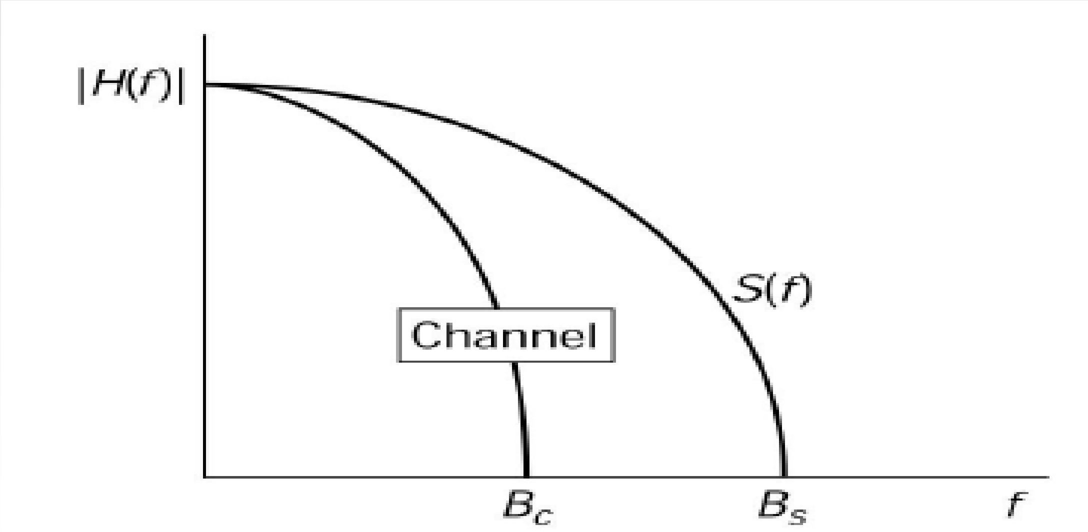
Frequency selective channel

If the message bandwidth B_s is larger than channel bandwidth B_c, different frequecy components in the message will arrive at the receiver at different time

Resulting pulse broadening – ISI

The channel is classified as **frequency selective channel**

The flat fading channel can become frequency selective channel if the information is transmitted with higher and higher bandwidth



Doppler effect

Taking all the direction into account, the instantaneous frequency of the doppler shifted signal is:

$$f_{in} = f_0 + f_d \cos(\theta)$$

Coherenc Time: $T_C \approx \dfrac{9}{16\pi f_d}$

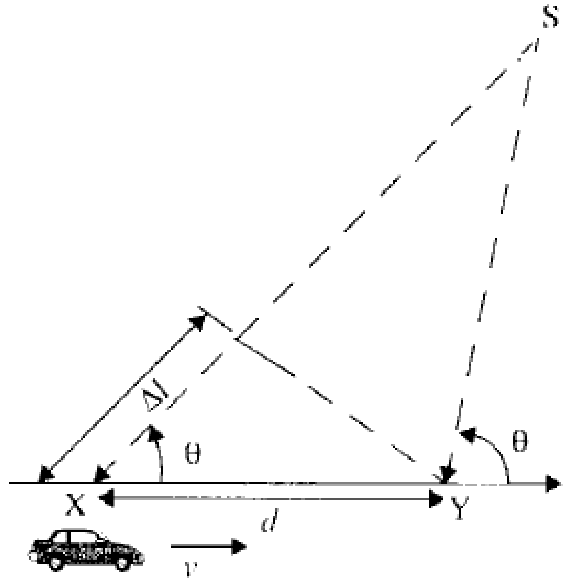


Illustration of Doppler effect.

Slow and fast fading can be also explained by coherence time, Tc-

- If pulse duration is smaller than Tc, then it is unlikely to undergo distortion→ slow fading
- If pulse duration is larger than Tc, then will be distorted→ fast fading

Slow and Fast Fading

Symbol period is smallar than coherence time, Ts < Tc

- Slow fading
- Symbol doesn’t experience distortion

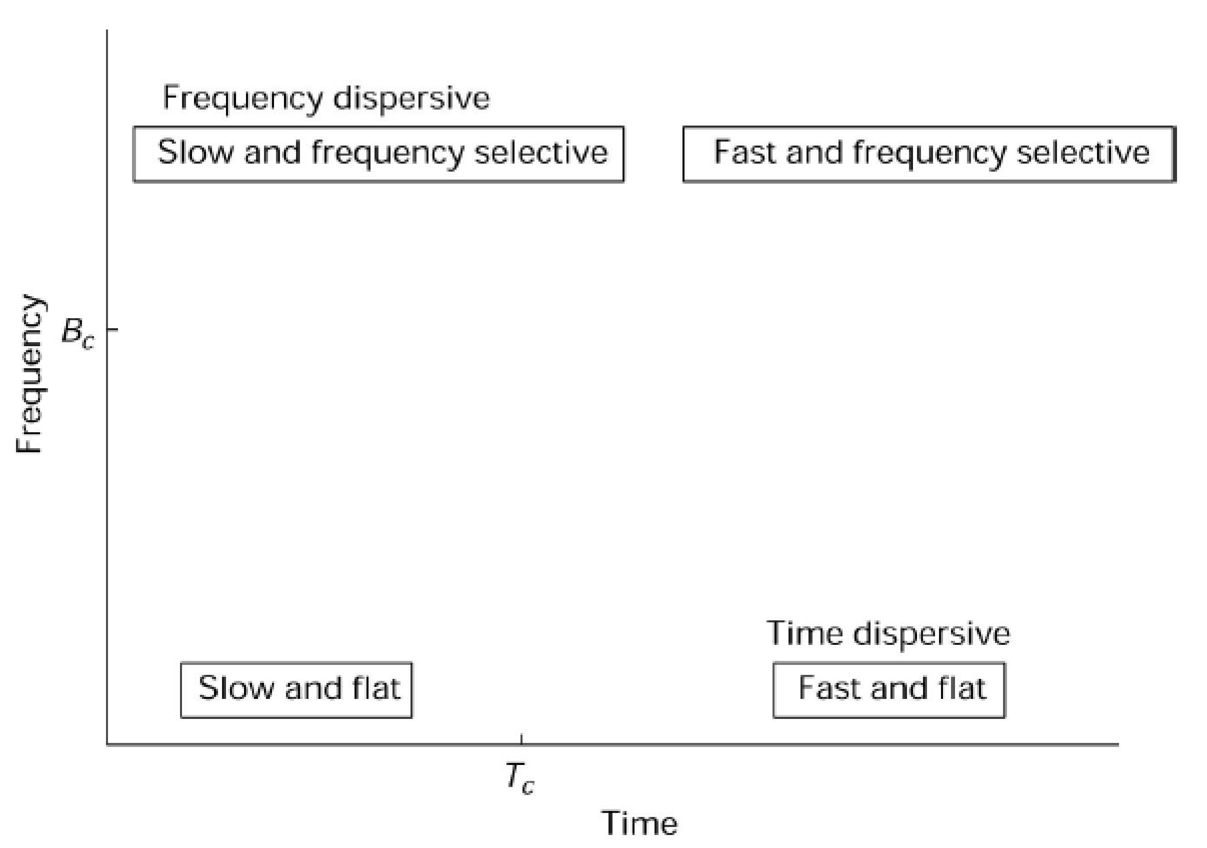
Symbol period is larger than coherence time, Ts > Tc

- Fast fading
- Symbol undergoes distortion

Frequency dispersion verses Time dispersion

- Fading can occur in frequency domain (due to multipath) and in time domain (due to movement of MU)

- At low data rate and when MU has low mobility then channel is slow and flat
- If data rate is high but MU is moving slowly then channel is slow but frequency selective
- If however, data rate is high and MU is moving at high speed then channel will be both fast and frequency selective. Channel will be both time and frequency dispersive.



Rician Model

- Rician model considers a LOS path in the received signal in addition to number of random paths
- This LOS adds a deterministic component in the received signal and makes Gaussian random variable of nonzero mean and Rician distributed envelope.

The power distribution fucntion (pdf) of Rician distribution is given by-

$$f_A(a) = \frac{a}{\sigma^2} \exp\left(-\frac{a^2 + A_0^2}{2\sigma^2} \right) \cdot I_0\left(\frac{aA_0}{\sigma^2} \right)$$

Where Ao is the component from LOS part and Io(.) is the modified Bessel function.

Rayleigh and Rician Model

- Rayleigh fading model assumes there is no line of sight (LOS) or most applicable when there is no dominant propagation along the LOS.

- Rician fading occurs when one of the paths, typically a line of sight signal is much stronger than the others. That means it assumes a LOS

- Hence, Rayleigh model can be also considered a special case of Rician model

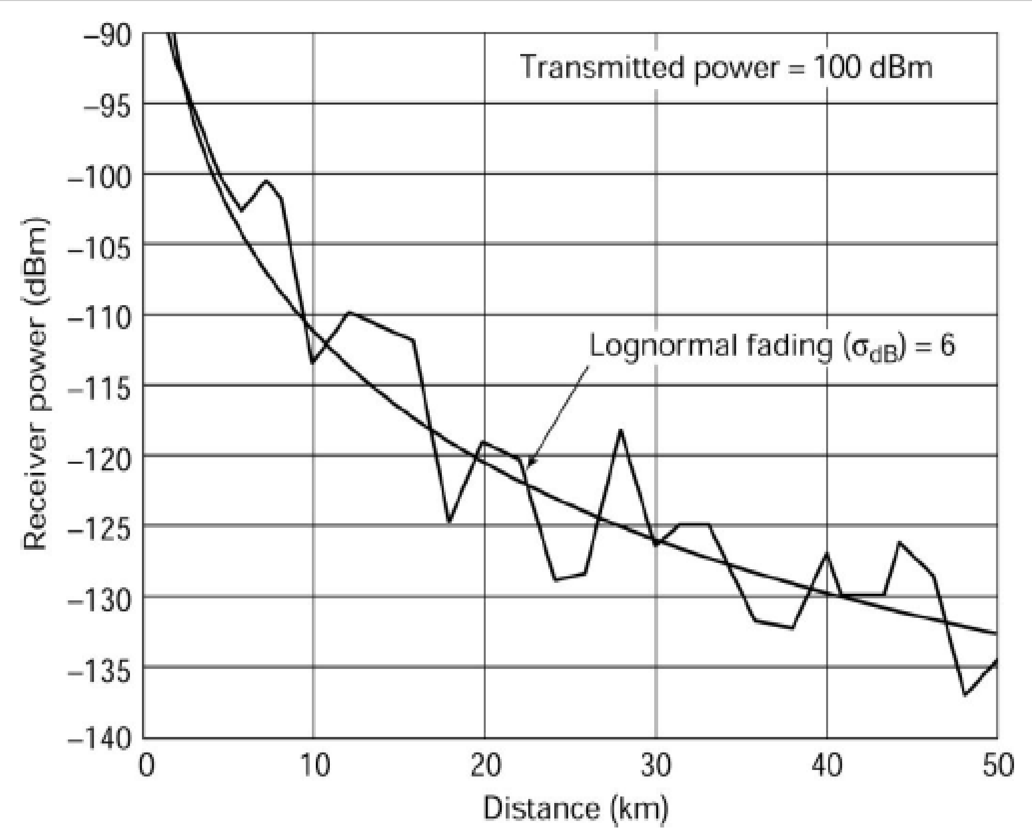
Lognormal fading

- Fading described so far falls under “short-term” fading. However, received signal also undergoes “long-term” fading as discussed earlier

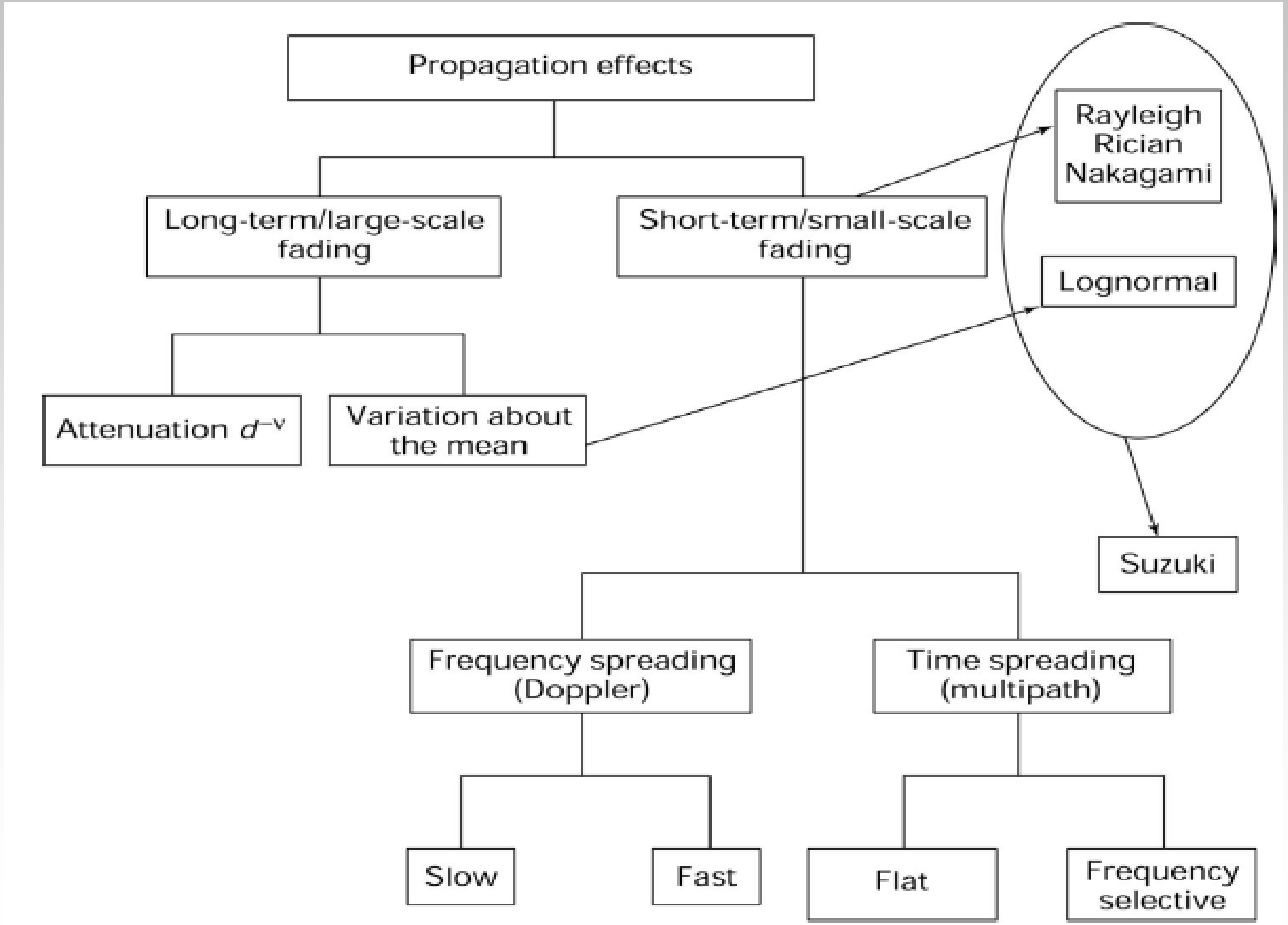
- Long-term fading occurs where propagation takes place in an environment with tall structures (e.g. trees, building)

- Under these conditions, the signal likely to have multiple reflected and scattered before taking multiple paths to the receiver

- Long-term fading is also referred as “shadowing”.



Summary of Fading



Summary

- Attenuation is a result of reflection, scattering, diffraction and refraction of the signal by natural and man-made structure
- The received power of radio signal is inversely proportional to the (distance)^v, where v is the loss parameter (2 for free space and 2-4 for other environments)
- The loss in outdoor can be modeled by Hata Model
- Indoor propagation models are based on the characteristics of interior of building, materials and other factors and described in terms of various zone model
- The random fluctuations in the received power are due to fading
- Multipaths and Dopper effect contribute to short-term fading and multiple reflections, scattering lead to long-term fading (shadowing)
- Short-term fading can be described using Rayleigh distribution if no direct paths exists between the transmitter and receiver
- Short-term fading can be described using Rician distribution if there is a direct paths exists between the transmitter and receiver

Summary

- Short-term fading due to multipath not only causes random fluctuations in the received power, but also distorts the pulses carrying the information
- If bandwidth of the channel is higher than the bandwidth of the message, the signal is characterized by “flat fading” and no pulse distortion. In opposite case, the result is “frequency selective fading” channel.
- If there is relative motion between transmitter and receiver the result is Dopper fading.
- In general, worst case fading occurs when it is both fast and frequency selective fading
- Both short-term and long-term fading leads to outage. The system goes outage when the SNR or received signal goes below a certain level or threshold.

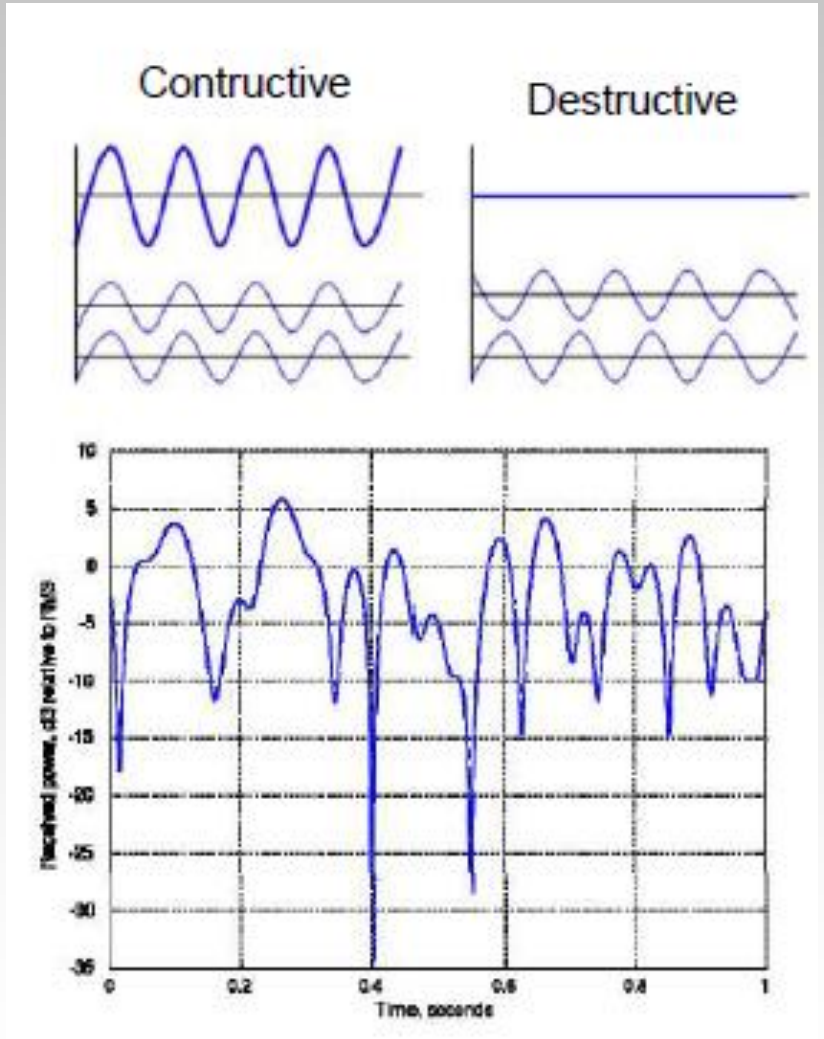
Lecture-5: Combating the Effect of Fading in Mobile Systems

- Introduction of fading
  - Effect of fading
- Diversity and types of diversity
- Combining techniques of diversity

Introduction

- **Fading leads to-**
  - Quick signal variation (Rayleigh, short term)
  - Slow signal variation (lognormal, long term)
  - Inter-Symbol Interference (ISI)

- **Varies ways to combat fading-**
  - Micro diversity
  - Macro diversity
  - Channel equalizer



Lecture-6,7: Cells and Cellular Traffic

- Introduction
- Hexagonal Cell Geometry
- Co-Channel Interference (CCI)
- CCI Reduction techniques
- Cell Splitting
- Hierarchical Cell Structure
- Coverage Area Estimation
- Traffic Capacity and Trunking
- Adjacent Channel Interference
- Summary

Why frequency reuse?

- **Why we reuse the frequency?**

  8 MHz = 40 channels * 8 timeslots = 320 users
  ==> max. 320 simultaneous calls!!!

- **Limited bandwidth**

- **Interference are unavoidable**
- Minimize total interference in network

Hexagonal cell geometry

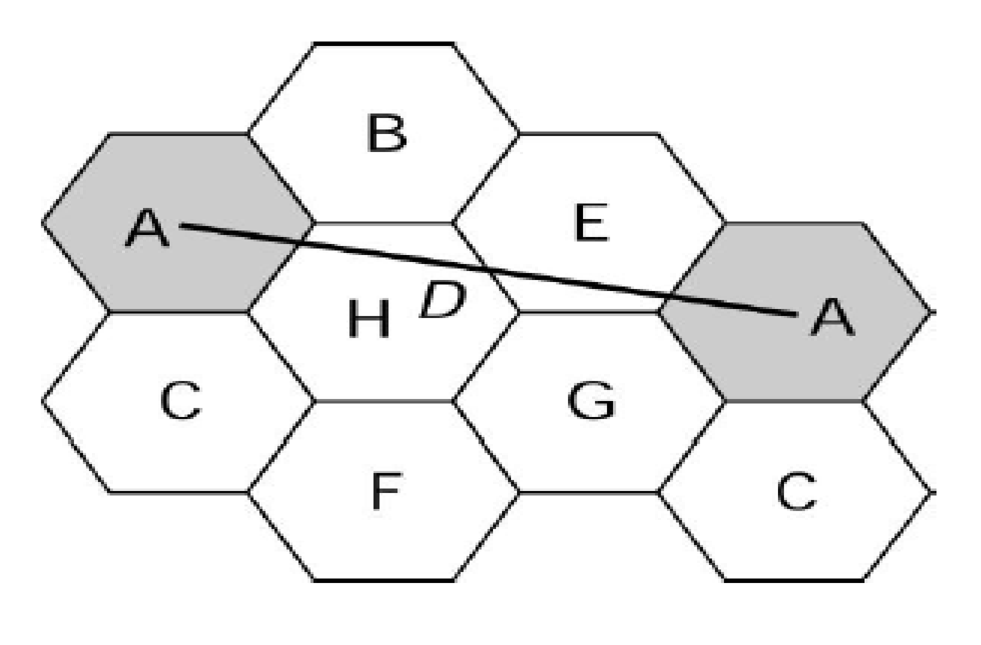
- A Cell Cluster (Nc) is a group of cells where each one uses different channel or frequency

- The normalized separation between any two cells depends only on the cell number counted from the cell at the origin or from reference cell:

$$N_c = D_R^2$$

where

$$D_R = \sqrt{i^2 + j^2 + ij}$$



Hexagonal cell geometry

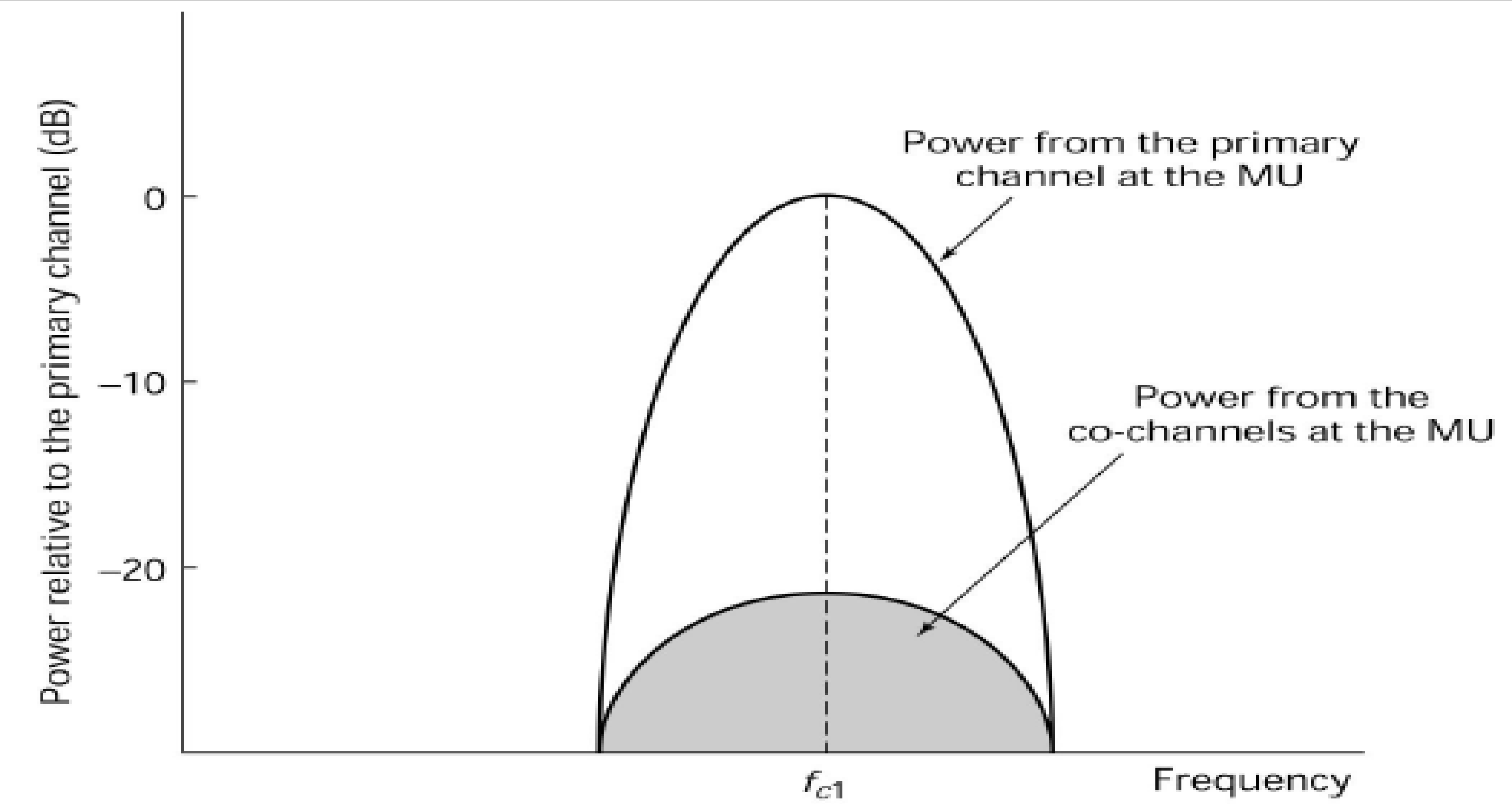
Table shows the relationship between [i,j] and number of cells in a cluster (Nc)

i	j	N_c	$q = D/R$
1	0	1	1.73
1	1	3	3
2	0	4	3.46
2	1	7	4.58
3	0	9	5.2
2	2	12	6

- q = D/R [sqrt(3Nc)] is also called frequency reuse factor or CCI reduction factor
- High q means a low CCI

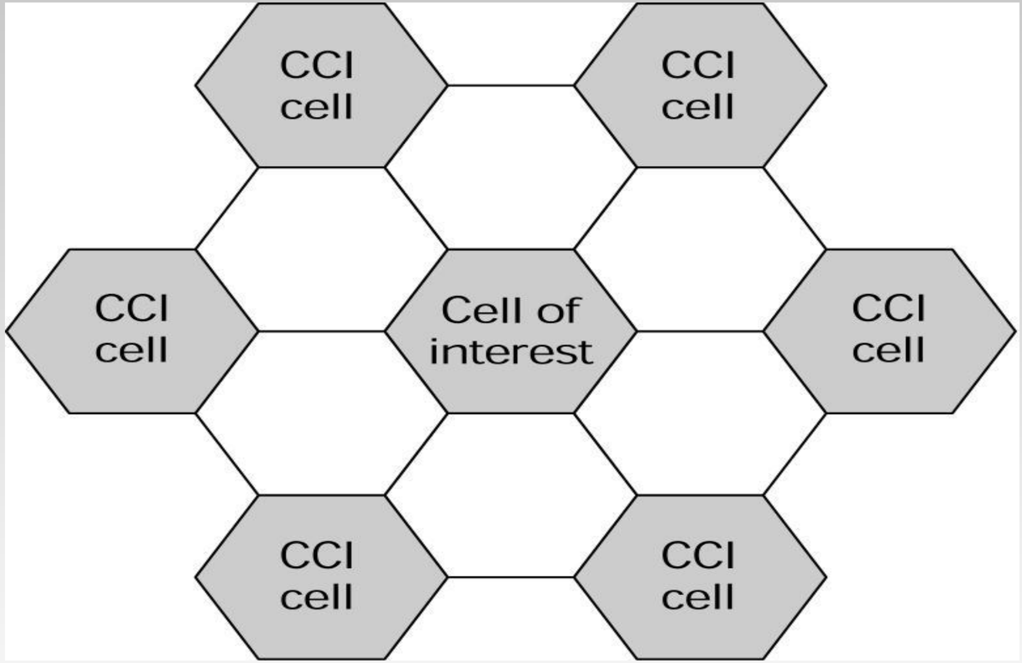
Co-channel Interference (CCI)

CCI: Interference from other cells used the same channel (frequency)



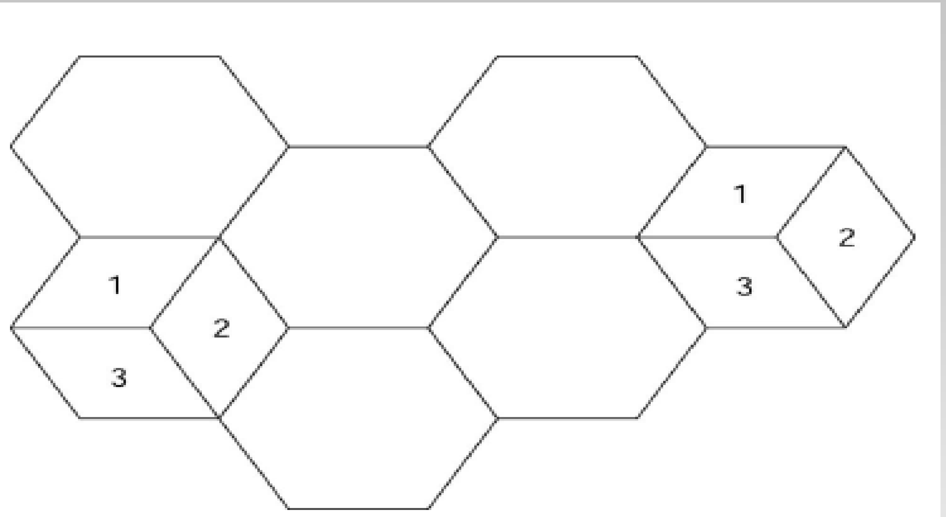
Co-channel Interference (CCI)

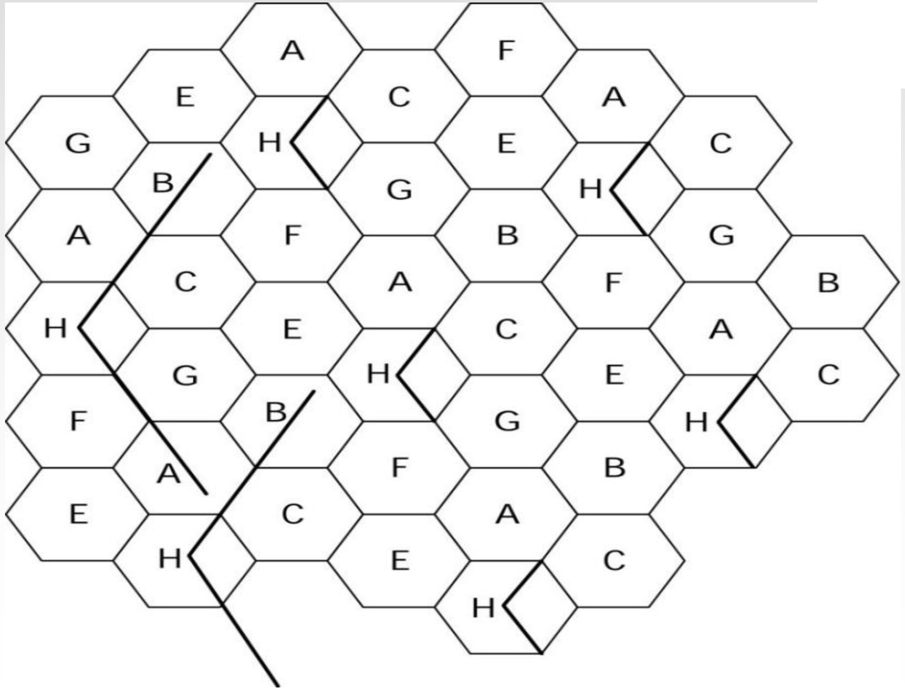
- The number of interfering cells is always 6, regardless of the size of the cell group. (The figure shows an example for Nc = 3)
- The distance and thus the interference is determined by group size
- q = D / R is called frequency reuse factor or CCI interference reduction factor



CCI Reduction

- CCI reduction by using sector antennas
- Interference is reduced when directional antennas are used to divide a cell into sectors



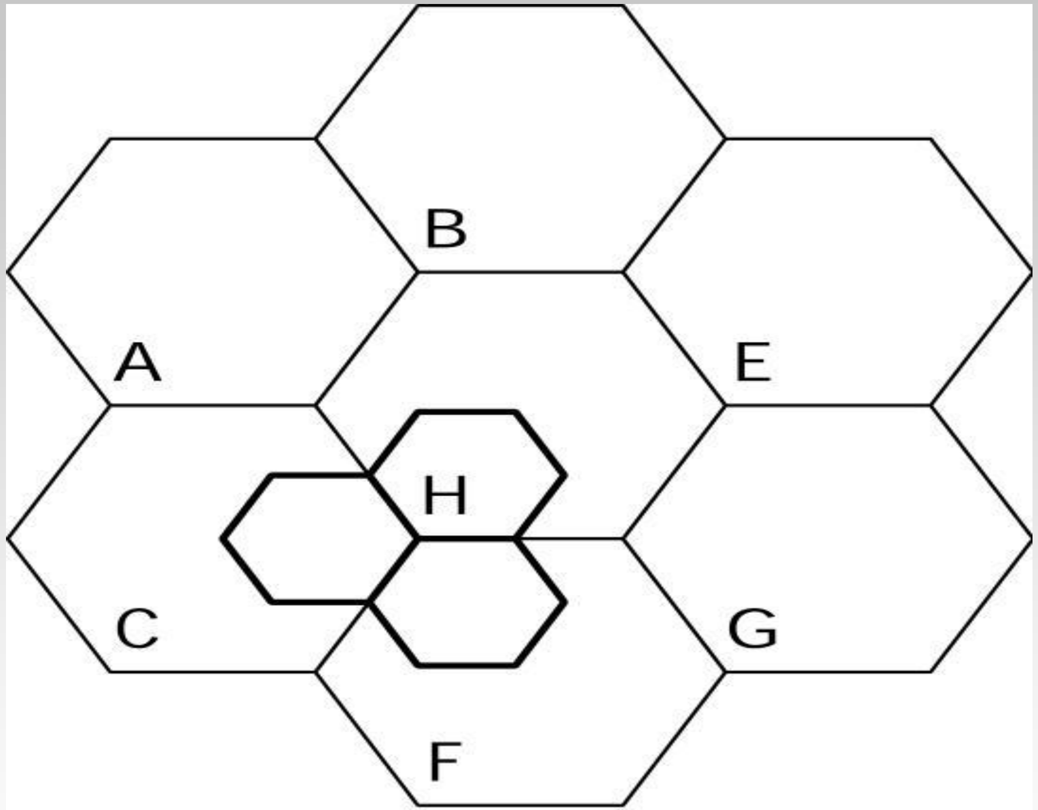


Cell Splitting

- Cell splitting is a technique to divide a cell (congested) into smaller cells to increase capacity

- Cell splitting allows channels to be reused

- Cell splitting also requires adjustment to the antenna transmission power



Cell Coverage Area Estimation

- Transmitter power, P_T (dBm)
- Sensitivity of the receiver or threshold power, P_{th} (dBm)

  Receive sensitivity indicates how faint an RF signal can be successfully received by the receiver. The lower the power level that the receiver can successfully process, the better the receive sensitivity.
- Power loss from transmission, L_p (dB)

$$L_p = P_T - P_{th}$$

- As signal undergoes long-term fading, fade margin, M should be included
  - The amount by which a received signal level may be reduced without causing system performance to fall below a specified threshold value

$$L_p = P_T - P_{th} - M$$

  - Fade margin reduces the permitted loss
  - Reducing the transmission distance

Trunking and Grade of Service

Trunking: There are more users than there are available channels (trunks), based on the assumption that not all going to try to set up a call at the same time. Trunking allows to accommodate a large number of users using a limited bandwidth.

Grade of Service (GOS): However, problem arises when everybody in the system willing to make call at the same time. Only limited number of them allowed and the rest are blocked.

GOS is a measure of the probability of blocking. It is the ability of the user to gain access to the system during the busiest hour. To understand GOS traffic intensity needed to be defined

Traffic intensity

- The traffic intensity generated by a user, A_I:

$$A_I = \lambda T_H \, Erl$$

$$\lambda \text{ is the avergae number of calls / hr}$$

$$T_H \text{ is the duration of the call (hr)}$$

$$For \quad K \quad users/operator:$$

$$A_{tot} = KA_I = K.\lambda T_H \, Erl$$

Offered traffic

- To achieve a certain performance (blocking probability), the operator must provide a certain number of channels or trunks: ***Offered traffic***

  C = Number of available channels

  p(B) = Blokcing probability

- The calls arrival can be modeled using a Poisson process (events occur continuously and independently of one another)

  The duration of calls is exponentially distributed

$$p(B) = \frac{\left[\dfrac{A^C}{C!}\right]}{\sum_{k=0}^{C} A^k / k!}$$

$$A\ offered\ traffic,\ A = \frac{\Lambda}{\mu}$$

$$Mean\ rate\ of\ call\ arrival\ \Lambda$$

$$Mean\ duration\ of\ call\ \frac{1}{\mu}$$

$$The\ carried\ traffic,\ A_c = A[1 - p(B)]$$

$$Channe\ lefficienc\ y,\ \eta = \frac{A_c}{C} = \frac{A[1 - p(B)]}{C}$$

Trunking efficiency Omni Vs Sector antenna

- Signal to Interference (CCI) ratio increases by using sectored cells

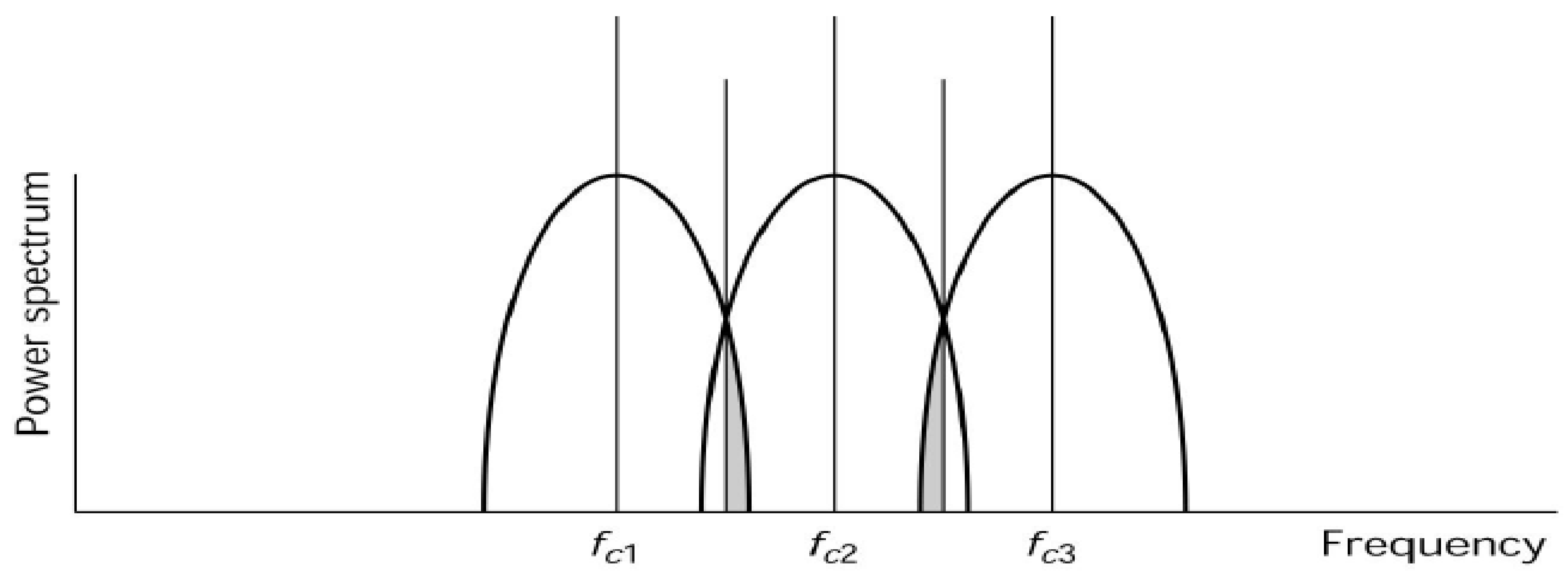
  S/I(120) < S/I(60)

- But at what cost?

Using of sectors lowers trunking efficiency!

Adjacent Channel Interference (ACI)

- ACI is caused primarily by inadequate filtering and nonlinearity of the amplifiers
- In most cases, it is sufficient to take under consideration only the interference coming from the two channels on either side of the primary channel.
- ACI is typically attenuated by the receiver filter whereas CCI is unaffected



Summary (1/2)

- Hexagonal structure is the optimal cell shape
- The signal-to-CCI ratio S/I improves as the number of cells in the pattern goes up
- CCI reduction/frequency reuse factor q is given by D/R, where R is the radius of the cell. Higher values of q result in lower values of interference
- Sector antenna reduce interference since the number of interfering cells goes down as the number of sectors goes up
- Capacity can be increased through cell splitting
- For a given spectral width (a given set of frequency channels), more channels per cell means smaller cluster size
- Smaller cell means lower transmission power
- Smaller cell => More reuse => more capacity ----- good for city center
- Bigger cell => less number of radio antenna station but less capacity ----- good for rural area

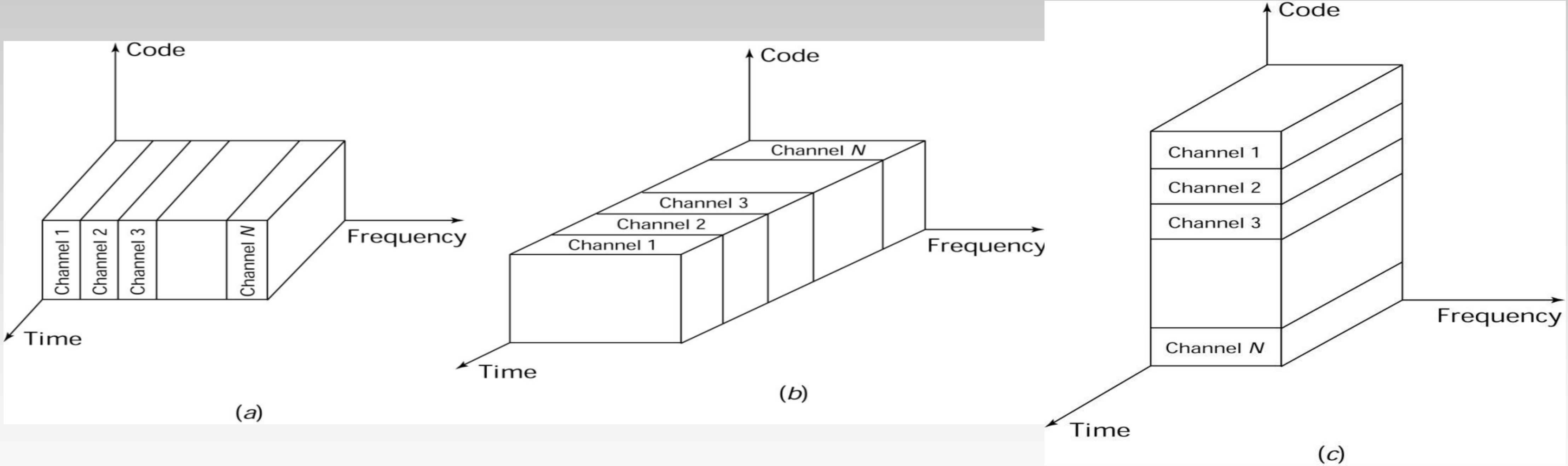
Summary (2/2)

- Bigger cell preferred for high-speed traffic in order to reduce frequent handover
- High-speed traffic through high-call area => overlay cell (more than one cell at a place; one is bigger than the other)
- Traffic volume per cell together with GOS (Grade of Service) sets the minimum channel requirements
- GOS is a measure of the ability of a user to gain access to a channel during busiest period

Lecture-8: Multiple Access

- Introduction
- FDMA (Frequency Division Multiple Access)
- TDMA (Time Division Multiple Access)
- CDMA (Code Division Multiple Access)
- Spread Spectrum
  - Direct Sequence
  - Frequency Hopping
- Rake Receiver
- OFDMA (Orthogonal Frequency Division Multiple Access)
- Summary

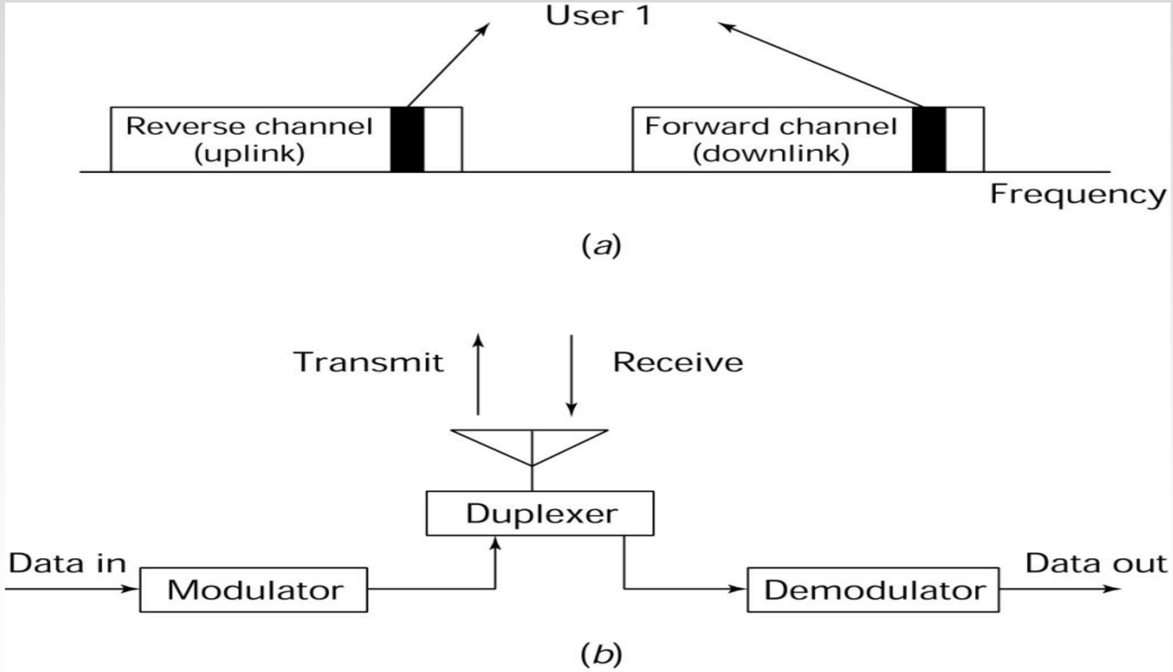
(O) FDMA, TDMA and CDMA

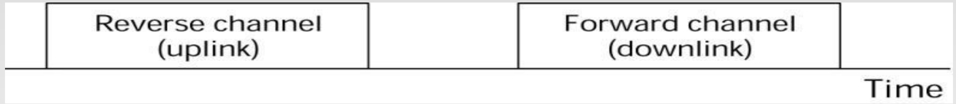


Duplex Transmission

FDD: A duplexer is needed since same antenna is used for both way transmissions

TDD: No duplexer is needed





Advantages of FDMA

- The major advantage of FDMA is the “hardware simplicity” since discrimination between users is done by simple bandpass filters.
- No timing information or synchronization is required
- Little problem of frequency-selective fading and Intersymbol Interference (ISI)

Disadvantages of FDMA

- Little flexibility in resource allocation
  - Available channels may not be granted to existing users and enhance capacity of the system
  - Dynamic channel assignment may overcome this limitation by assigning unused channels to other cells which needs more capacity
- Inability to be used as variable rate transmission which is common in digital systems. This eliminates FDMA as the choice for combined voice and data transmission
- Filter with excellent cut-off characteristics necessary since FDMA depends on bandpass filters.
- Crosstalk due to interference from neighboring channels produced by nonlinear effects.

Advantages of TDMA (compare to FDMA)

Flexibility in resource allocation

- Based on availability, more time slots can be assigned to the same user. Allows for variable data rate.
- Not so strong cut-off filters requirement, or problems with crosstalk.
- It is relatively easy to measure power levels and hence to perform hand-off procedures
- Better utilization of resources. Overhead in the form of Guardbits between the time slots and Synchronization bit requires less resources than the resulting Guardband between the carrier channels in FDMA

Disadvantages of TDMA (compare to FDMA)

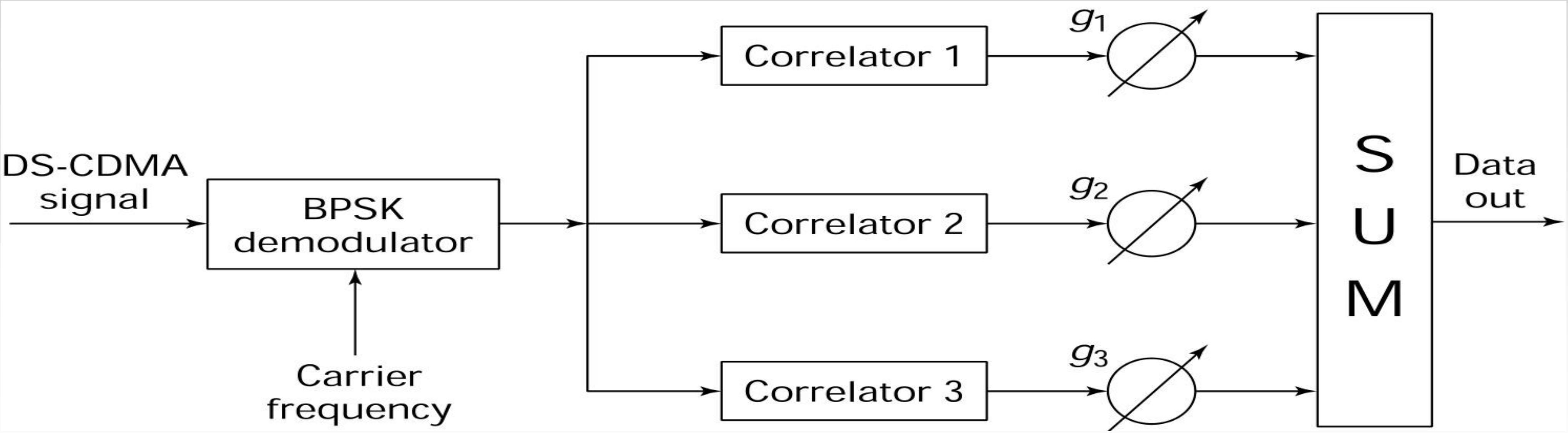
- The need for synchronization, both the frames and time slots
- Greater bandwidth allows more frequency selective fading and ISI

Spread Spectrum

- Spread spectrum is a generic term for techniques that spread the information over a wide frequency range (broadband)
- Can be various reasons for this, for example:
  - Avoid fast fading
  - Avoid jamming (especially in military applications)
- Available in two main types of spread spectrum:
  - Direct-Sequence
  - Frequency Hopping
- CDMA uses direct sequence spread spectrum to achieve multiple access

RAKE Receiver

- In DS-CDMA, the chip duration is very narrow and under the assumption that multipath delays is larger than chip duration, those delayed version of chips are resolvable
- Figure shows a conceptual RAKE receiver. The different correlators is synchronized to various paths with different delays and programmed to captured the strongest signal



OFDMA- Advantages and Disadvantages

Advantages

- Robust against frequency selective fading and interference
- Scalable bandwidth

Disadvantages

- High amplitude variation which gives high *peak to average power ratio* (PAPR). This increases in-band noise and BER (bit error rate)
- Tight synchronization between users are required for FFT in receiver
- Dealing CCI is more complex in OFDMA than CDMA

Summary (1/2)

- Multiple access allows multiple users the opportunity to share the available bandwidth
- FDMA is a simple scheme with each channel is allocated a frequency band. The main advantage is easy implementation, and that there is no need for synchronization and timing information. The main disadvantages are less flexibility in resource allocation and the need for very sharp cut-off filters.
- In TDMA users are separated in time. The main advantage (compared to FDMA) is the flexibility in resource allocation, and the possibility of variable data rate. The biggest drawback is the need for synchronization. TDMA schemes are also susceptible to fading.
- In CDMA each user is assigned a unique PN code. Each code consists of K chips, each with duration of T_c, and $KT_c=T$, the bit duration. Thus, CDMA uses a much larger bandwidth than TDMA or FDMA. All user share the same bandwidth all the time
- In CDMA, PN sequences are almost orthogonal to each other

Summary (2/2)

- Spread spectrum is a generic term for techniques that spread the information over a wide frequency range. There are two main types of spread spectrum:
  - Direct Sequence (used in CDMA)
  - Frequency Hopping

- In OFDMA orthogonal carrying waves are distributed on multiple users
  - This technique provides high robustness against frequency selective fading
  - Scalable OFDMA, which is used in LTE, provides the opportunity for flexible bandwidth utilization

Lecture-9,10: Mobile Broadband

UMTS Air Interface technologies

UMTS Air interface is built based on two technological solutions

- WCDMA – FDD
- WCDMA – TDD

WCDMA – FDD is the more widely used solution

- FDD: Separate UL and DL frequency band

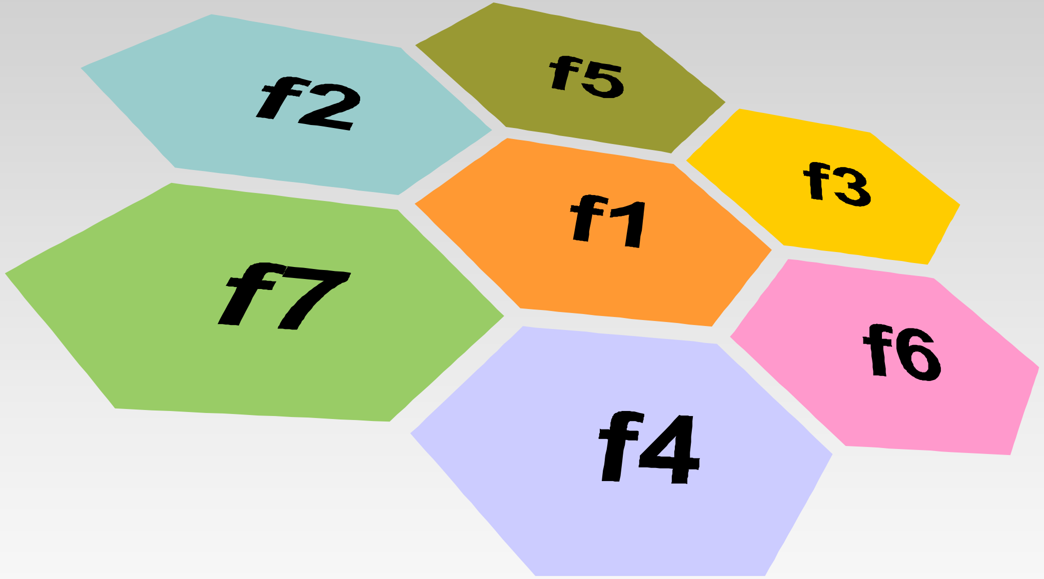
WCDMA – TDD technology is currently used in limited number of networks

- TDD: UL and DL separated by time, utilizing same frequency

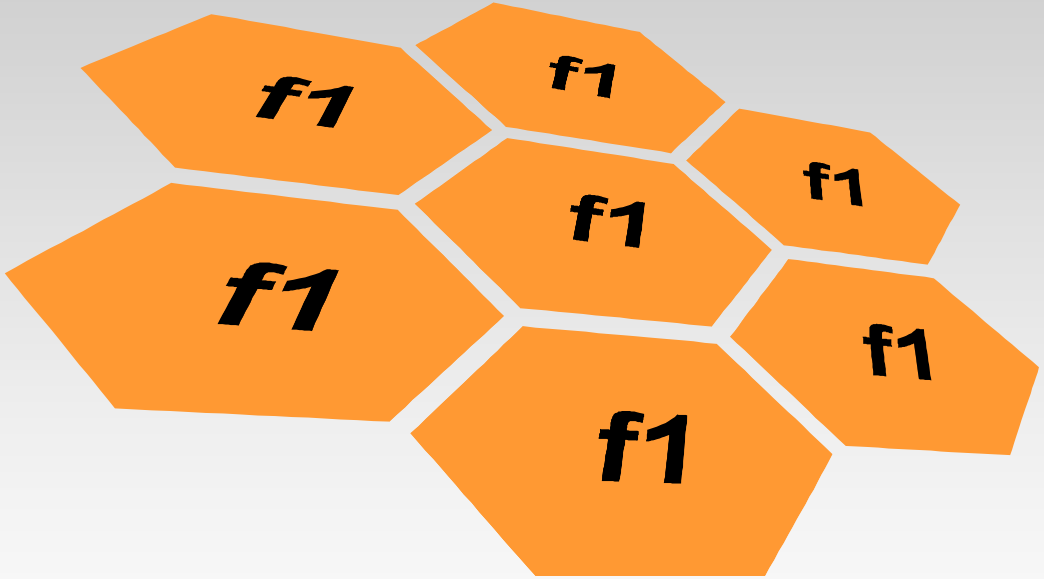
Both technologies have own dedicated frequency bands

UMTS & GSM Network Planning

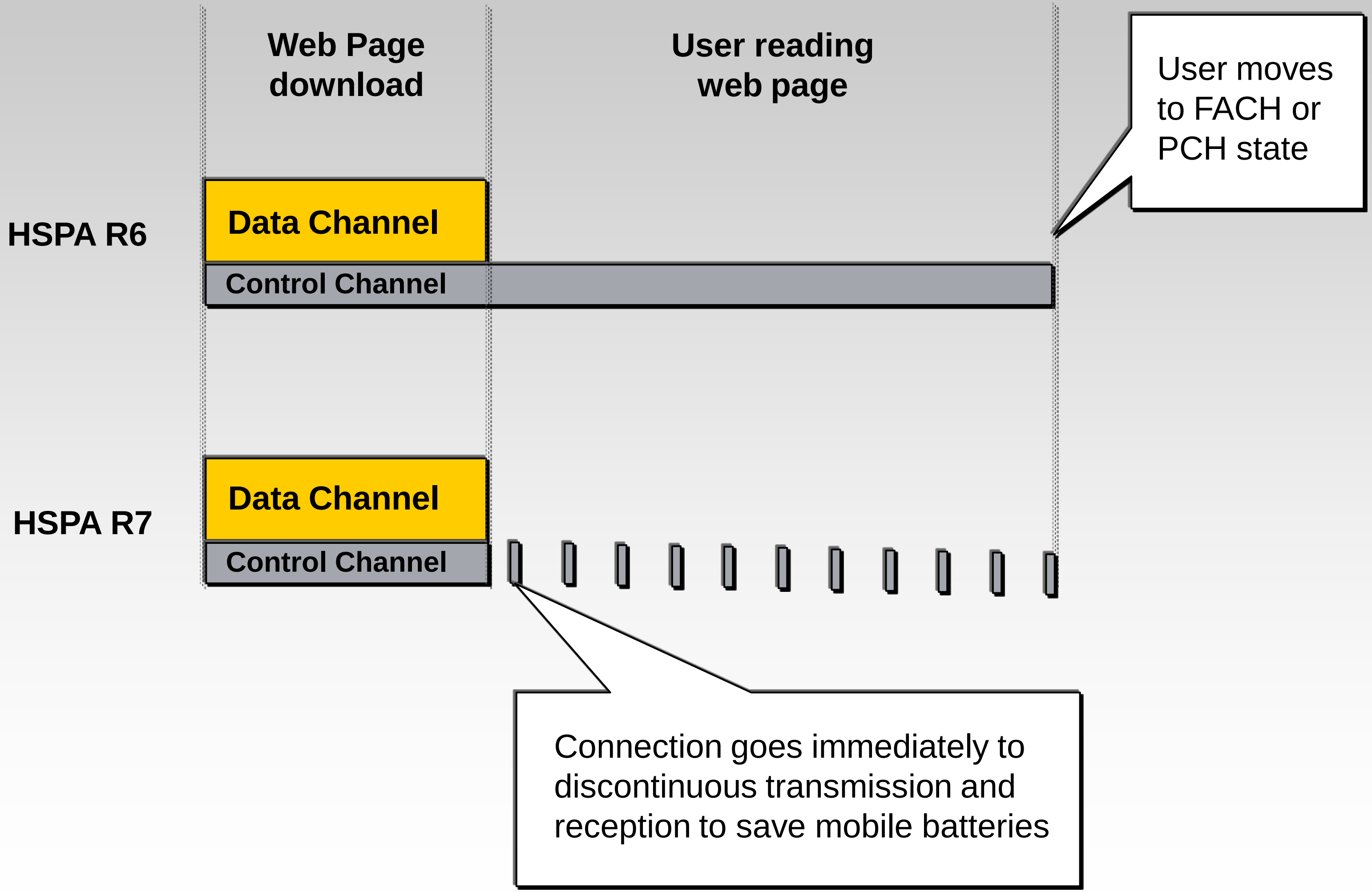
GSM900/1800:



3G (WCDMA):



Discontinuous Transmission and Reception (DTX/DRX)

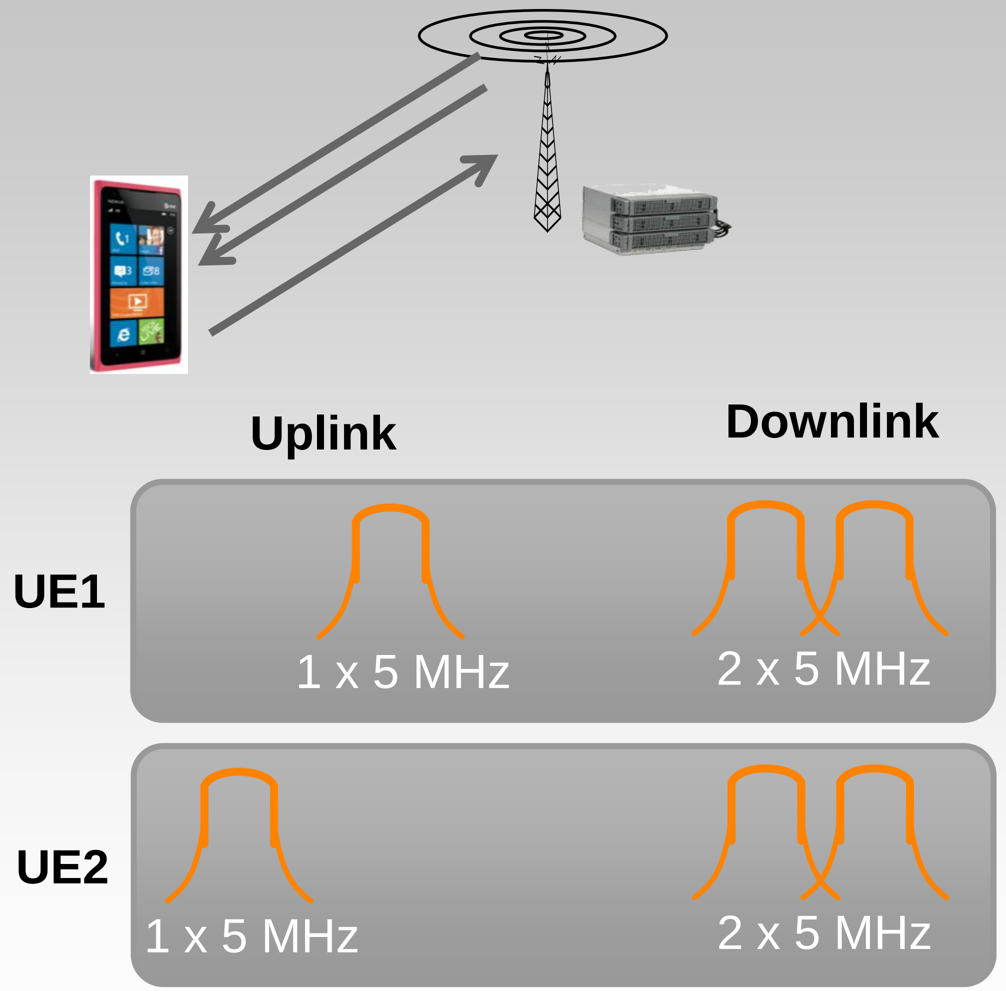


Dual Cell HSDPA and HSUPA

- DC-HSDPA is a Release 8 enhancement. It provides a method to aggregate two adjacent carriers in the downlink.

- Enables transmission of 2 adjacent carriers of 10MHz bandwidth to single terminal.

- The main reason behind DC-HSDPA, i.e. multi-carrier, is to improve resource utilization and therefore increase spectrum efficiency. This is achieved by having joint resource allocation, as well as load balancing across both carriers.

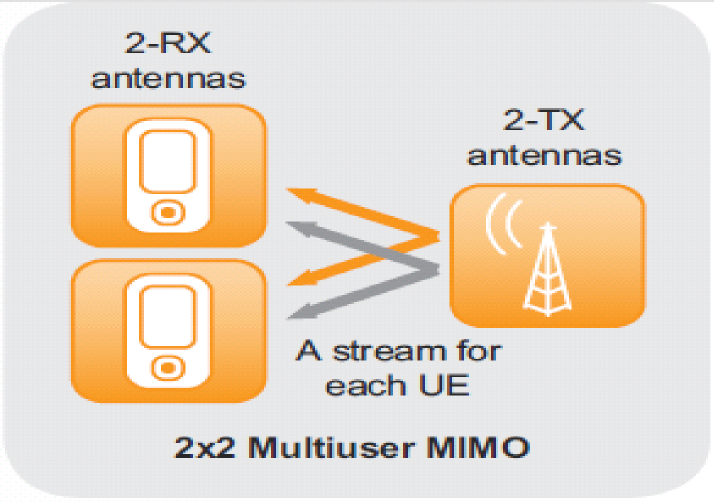


Downlink DC HSDPA concept

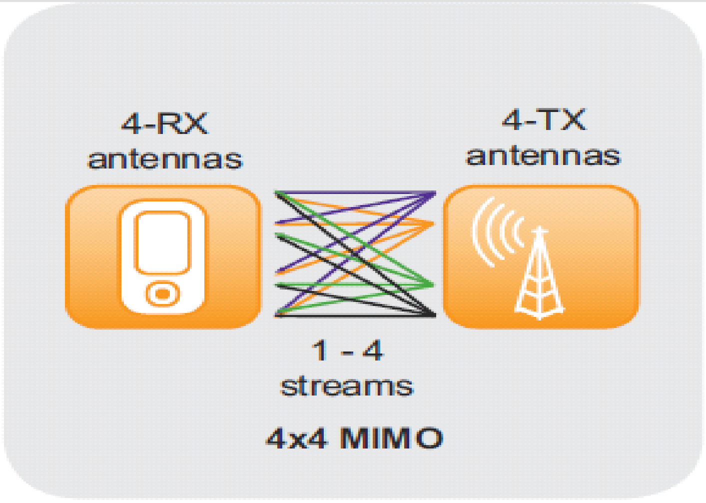
MIMO Evolution

- Multi-antenna transmission and reception increases
  - peak data rates,
  - cell throughput and
  - cell edge data rates

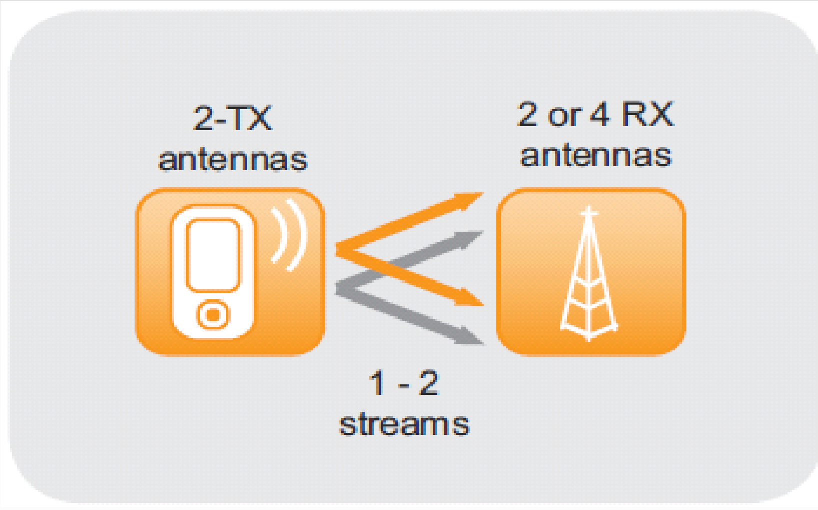
Downlink Multiuser MIMO



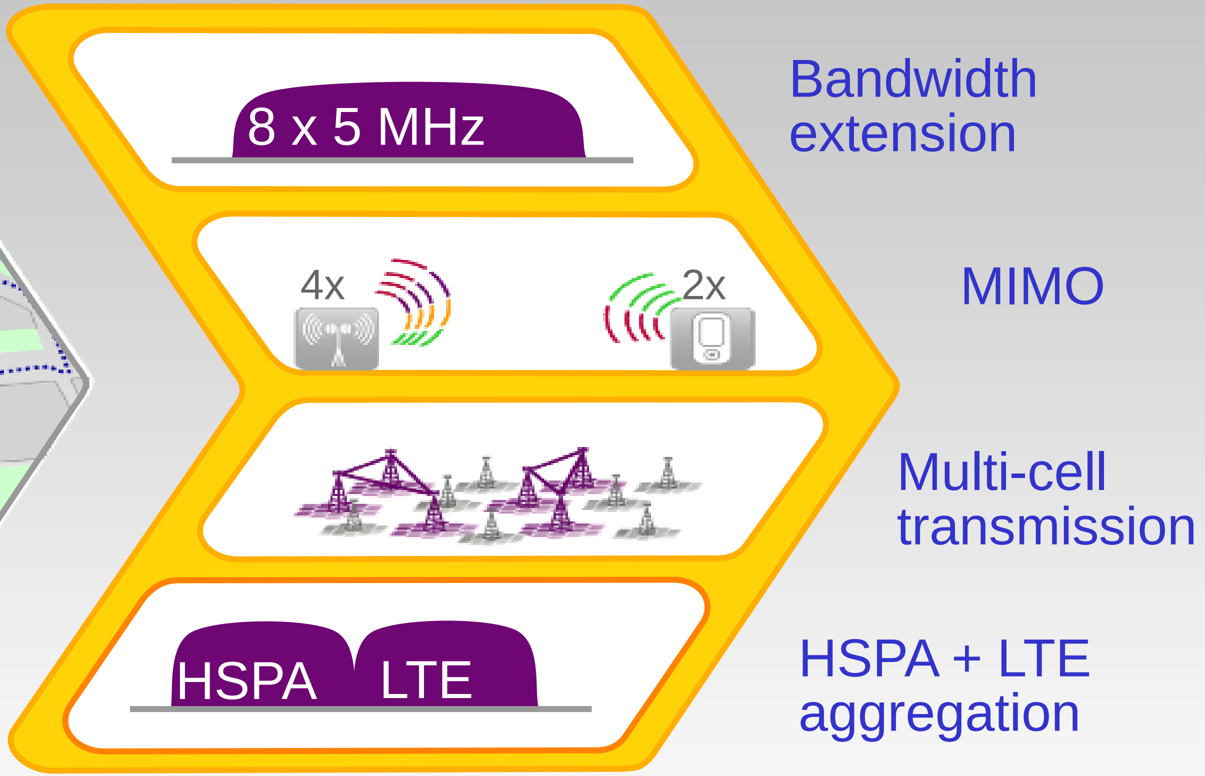
Downlink 4x4 MIMO



Uplink 2x2 MIMO



Long Term HSPA Evolution – Technology Components



Similar technical solutions in Long Term HSPA Evolution and in LTE Advanced

Motivation and Targets for LTE

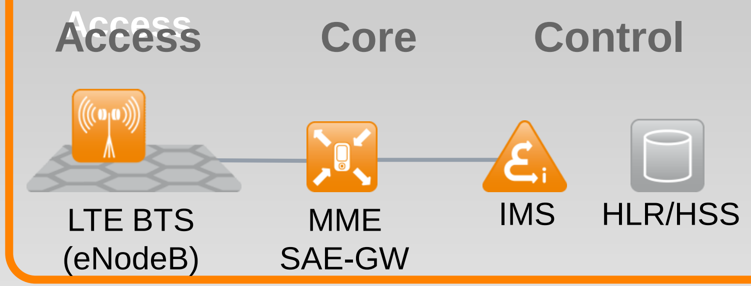
- Spectral efficiency 2 to 4 times more than with HSPA Rel-6
- Peak rates exceed 100 Mbps in downlink and 50 Mbps in uplink (which is 10 times more than HSPA Rel-6)
- Enable a round trip time of < 10 ms
- Packet switched optimized
- High level of mobility and security
- Optimized terminal power efficiency
- Frequency flexibility with allocations from below 1.5 MHz up to 20 MHz

LTE: Basic Concepts / Architecture

LTE / SAE introduces the mechanism to fulfill the requirements of a next generation mobile network

Flat Overall Architecture

- 2-node architecture
- IP routable transport architecture

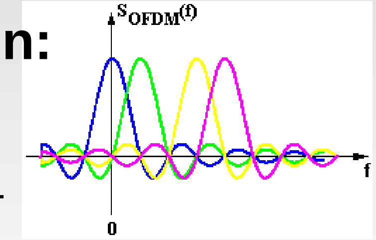


Improved Radio Principles

- peak data rates [Mbps] 173 DL , 58 UL
- Scalable BW: 1.4, 3, 5, 10, 15, 20 MHz
- Short latency: 10 – 20 ms

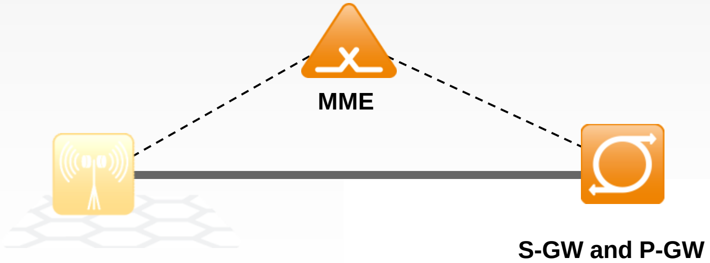
RF Modulation:

- OFDMA in DL
- SC-FDMA in UL



New Core Architecture

- Simplified Protocol Stack
- Simple, more efficient QoS
- UMTS backward compatible security

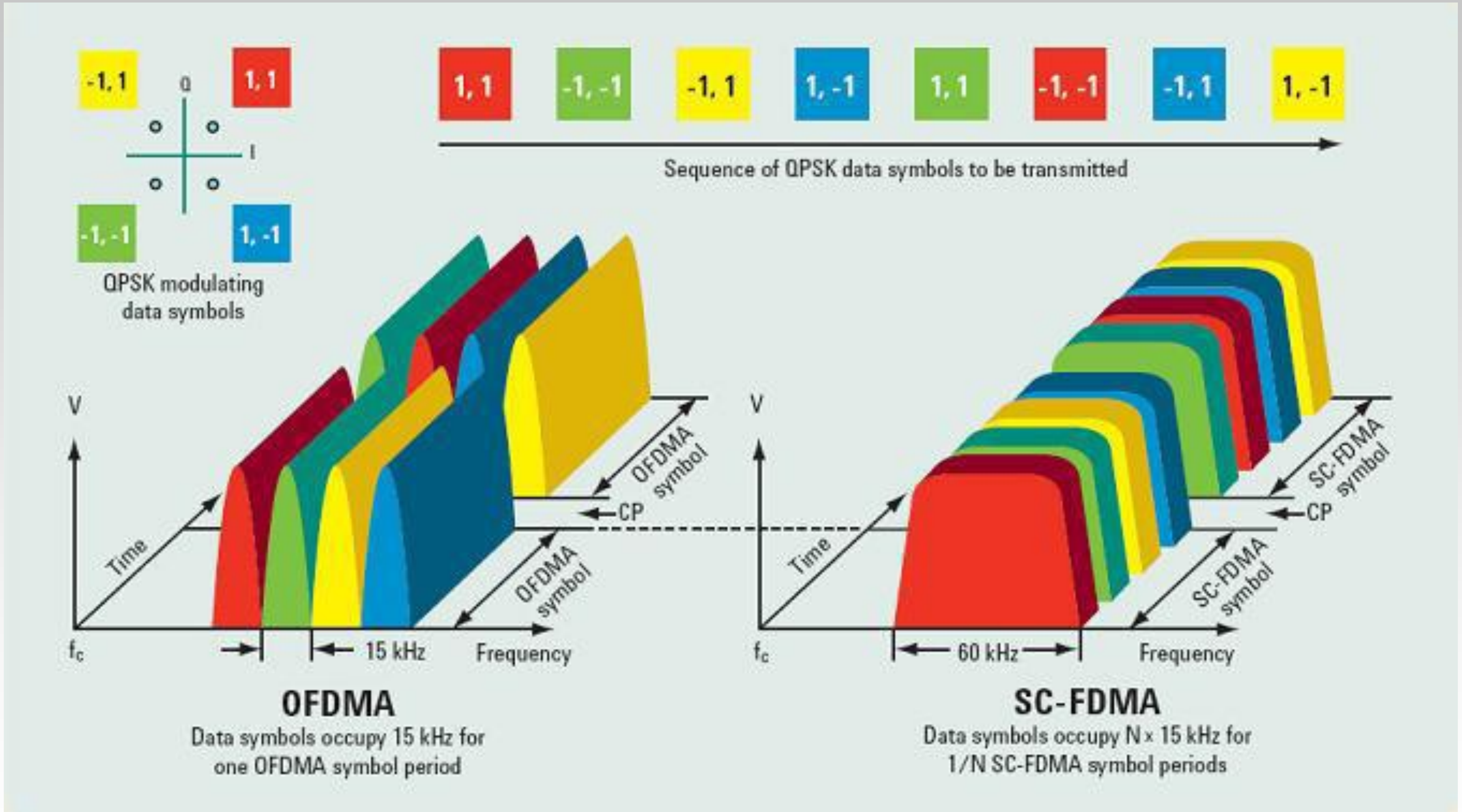


Spectrum Resources – Europe

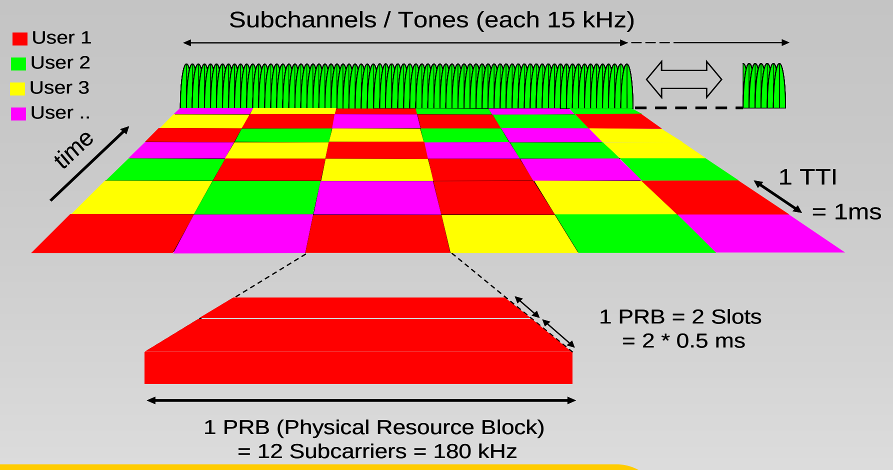
- Main LTE bands in **Europe: *800, 1800 and 2600 MHz***

Overall spectrum available		Typical future CSP deployment scenario	
2600 (2x70 MHz + 50 MHz)	*new spectrum*	LTE 20 MHz TD-LTE 20 MHz	**LTE capacity & highest data rates**
2100 (2 x 60 MHz)	*WCDMA/HSPA*	Multicarrier HSPA	*HSPA capacity*
1800 (2 x 75 MHz)	*GSM*	LTE 10+MHz & GSM (defragmentation)	**LTE capacity +** *GSM capacity*
900 (2 x 35 MHz)	*GSM*	HSPA 5+MHz & GSM (defragmentation)	*HSPA coverage + GSM maintenance*
EU800 (2 x 30 MHz)	*new spectrum, Digital Dividend / TV-transition*	LTE 10 MHz	**LTE coverage**

OFDMA vs SC-FDMA



LTE Radio principles



Downlink:
OFDMA

- Improved spectral efficiency
- Reduced interference
- Very well suited for MIMO

Uplink:
SC-FDMA

- Power efficient uplink increasing battery lifetime
- Improved cell edge performance by low peak to average ratio
- Reduced Terminal complexity

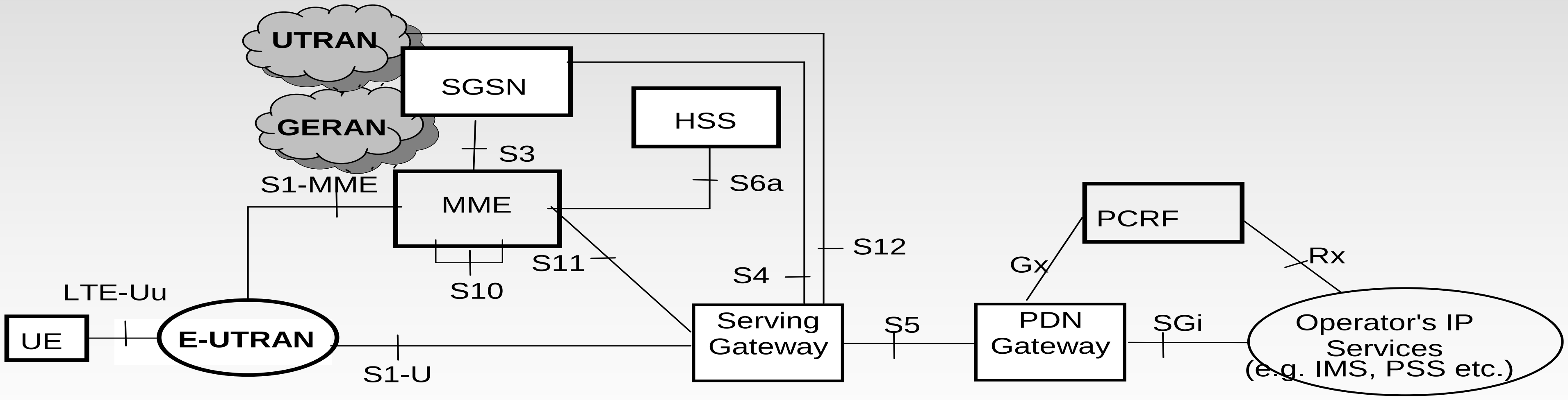
- Enabling peak cell data rates of 173 Mbps DL and 58 Mbps in UL *
- Scalable bandwidth: 1.4 / 3 / 5 / 10 /15 / 20 MHz also allows deployment in lower frequency bands (rural coverage, refarming)
- Short latency: 10 – 20 ms **

* At 20 MHz bandwidth, FDD, 2 Tx, 2 Rx, DL MIMO, PHY layer gross bit rate

** roundtrip ping delay (server near RAN)

Main EPS Standards: 23.401

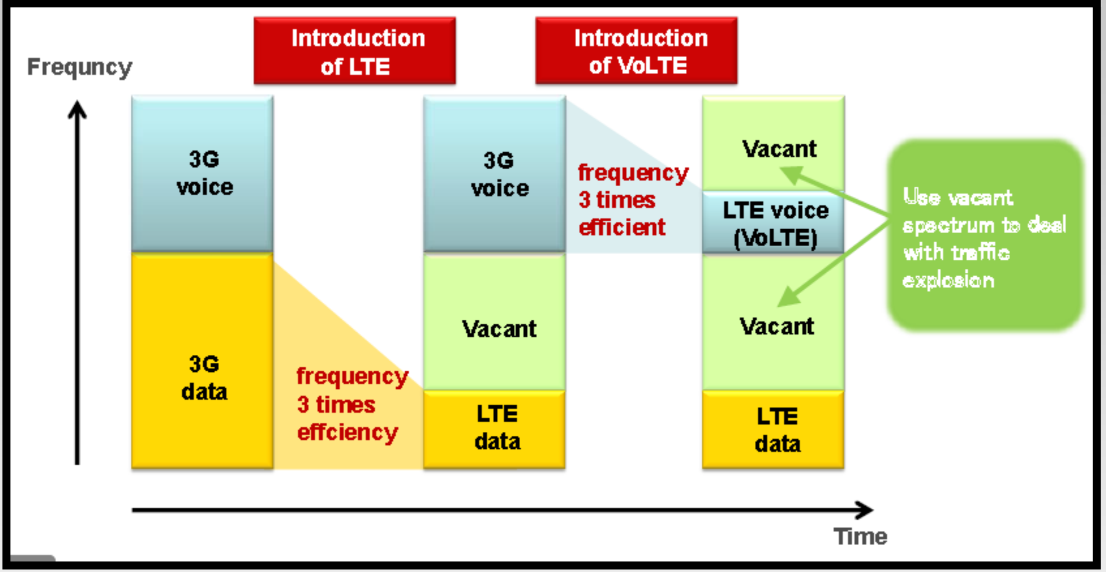
- Defines EPS architectures for 3GPP accesses using GTP protocol (GTP on S5/S8)
  - One example is given below
- Defines role of MME, SGW and PGW
- Two GW configurations: standalone SGW and PGW, co-located SGW/PGW
- Defines high level procedures (mobility management, session management, interworking with existing accesses, etc.)



Non-roaming architecture for 3GPP accesses

Why VoLTE – Operator view (DoCoMo)

Benefit for the operator



- Benefits for customers
  - Faster call set-up
  - Mobile broadband still available during voice call
  - Service quality better than OTT VoIP apps
    - Priority handling, SRVCC
  - Existing supplementary services are supported

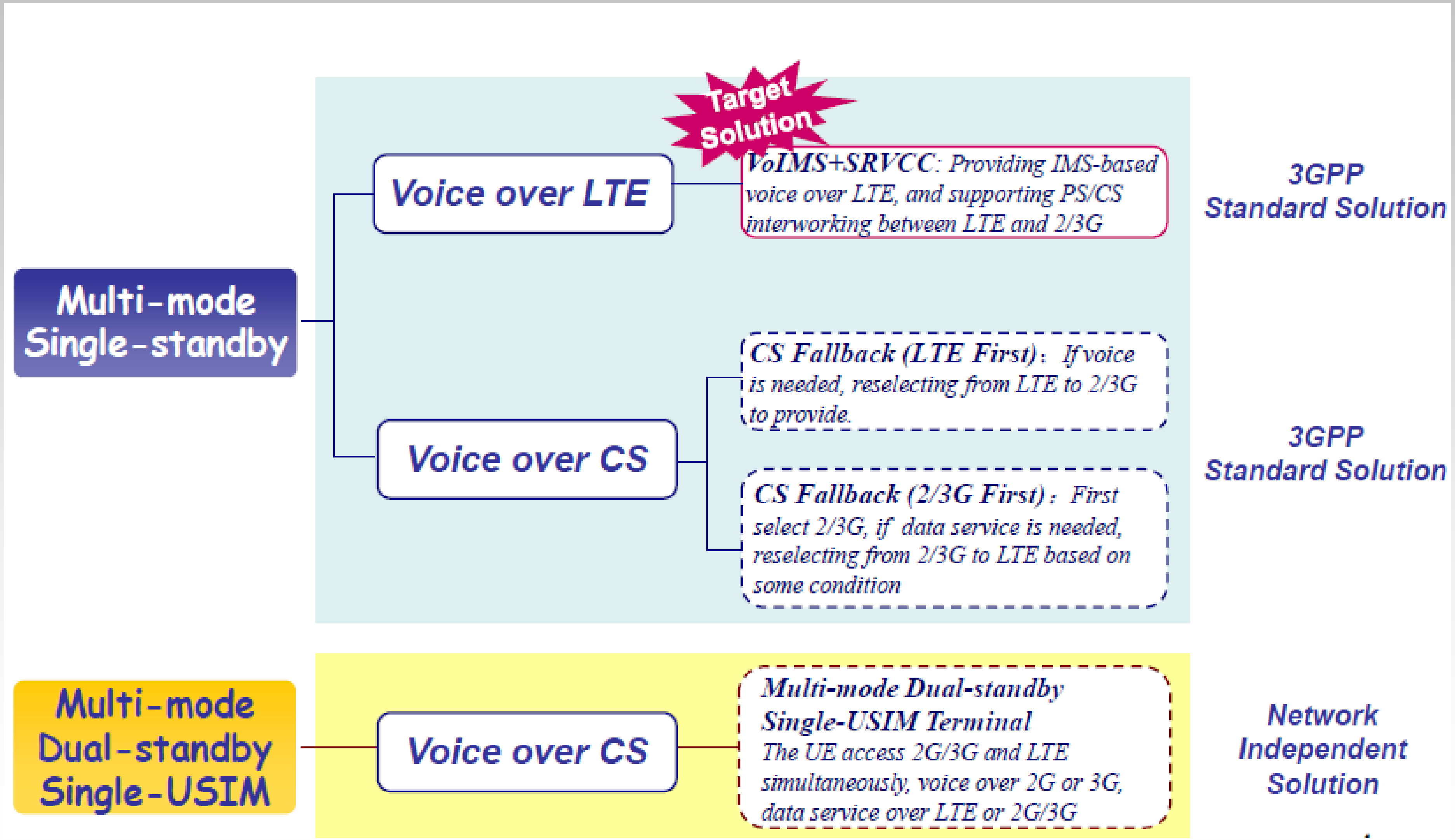
Our philosophy behind: Maintain the same service quality as the existing 3G voice service to satisfy customer needs.

Comparison vs. OTT VoIP

Services	VoLTE	OTT VoIP Apps	
Use of E.164 Number	✓	Limited	Limited to certain numbers/operators
Emergency Call	✓	✗	
CLIP/CLIR	✓	✗	Originating number not always displayed
Priority Calls	✓	✗	
Voice mails	✓	✓	Supported by certain app e.g. Skype
Call Diversion	✓	✓	
Other supplementary services	✓	✗	

… however, DoCoMo has not launched VoLTE yet.

Alternative of LTE voice solution



Mapping of 3G and LTE QoS Parameters

LTE	UMTS QoS			
QCI	Traffic class	Traffic handling priority	Signalling indication	Source statistic descriptor
1	Conversational	-	-	Speech
2	Conversational	-	-	Unknown
3	Streaming	-	-	Speech
4	Streaming	-	-	Unknown
5	Interactive	1	Yes	-
6	Interactive	1	-	-
7	Interactive	2	-	-
8	Interactive	3	-	-
9	Background	-	-	-

What is SON?

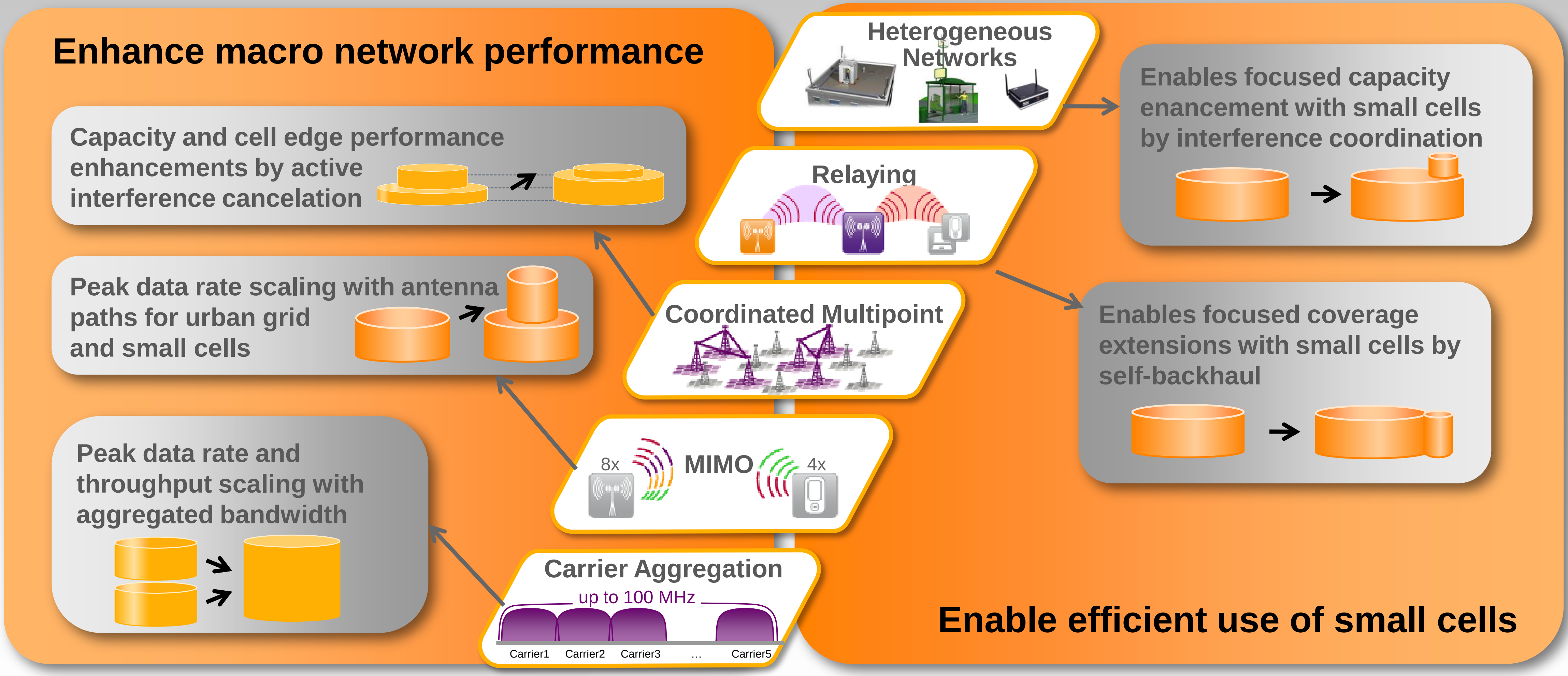
- SON originally refers to a network that can organize itself in the form of
  - **Self-Configuration**, e.g. initial parameter deployment,…
  - **Self-Optimization**, e.g. tuning the handover thresholds, …
  - **Self-Healing**, e.g. recovering from eNB failures automatically,…
- This is implemented as closely network related automation by
  - **Centralized SON:** associated with slow update rate and based on long term statistics where many cells are involved in optimization process. Implemented using network/element management system (OAM).
  - **Distributed SON:** require fast reaction time which affect only few cells, parameters have only local impact but configuration or status about neighbour cells are required. Optimization algorithms are implemented in eNodeB
  - **Localized SON:** require fast reaction time and only single cell involved- no impact on neighbour cells. Implemented by Radio Resource Management (RRM) in eNodeB
  - **Hybrid SON:** all the above 3 processes are used simultaneously for different use cases.

- SON can be considered as a specific type of automation

SON- some important use cases

- Configuration of Physical Cell ID (*self configuration*)
- Automatic Neighbor Relations (ANR) (*self configuration*)
- Mobility Load Balancing (MLB) (*self optimization*)
- Mobility Robustness Optimization (MRO) (*self optimization*)
- Energy Saving (*self optimization*)
- Minimization of Drive Test (MDT)

The LTE-Advanced toolbox for delivering more data efficiently to wide areas and hotspots



Summary (1/3)

WCDMA/HSPA/HSPA+

- Strong momentum and growth in Mobile Broadband with terminals, network technology and applications
- WCDMA has both FDD (widely used) and TDD variant with FDD using 5+5 MHz and TDD 5 MHz as single carrier
- HSPA/HSPA+ is a mature technology with broad ecosystem support, which will further evolve and will remain dominant technology for many years to come
- Carrier aggregation and MIMO pushes the peak data rates and cell throughput

Summary (2/3)

LTE

- Motivation of LTE is need for higher peak data rate, spectral efficiency, less round trip delay, packet optimized network, high degree of mobility and spectrum flexibility
- LTE has both FDD and TDD variant with frequency allocation flexibility with 1.4, 3, 5, 10, 15 and 20 MHz spectrum
- LTE frequency bands for Europe are 2600 (capacity), 1800 (capacity) and 800 (coverage) MHz
- LTE uses OFDMA in DL and SC-FDMA UL for multiple access technology. OFDMA in DL minimizes receiver complexity while SC-FDMA improves battery life time in receiver
- LTE is packet oriented flat network with minimum no. of nodes- only eNodeB in access and MME, SAE-GW (S-GW/P-GW) in core networks. (additionally, HLR/HSS, PCRF and IMS is required in core)
- Voice in LTE is accomplished by CS Fallback (initially) and SR-VCC (later).

Summary (3/3)

SON

- SON is a set of network algorithms for simplifying network configuration, optimization and healing
- SON algorithms can be centralized targeting multi-cell optimization or distributed for fast and local optimization or a hybrid (combination of all)
- SON is not limited to LTE only but many of these SON algorithms are applied to 3G/HSPA networks as well

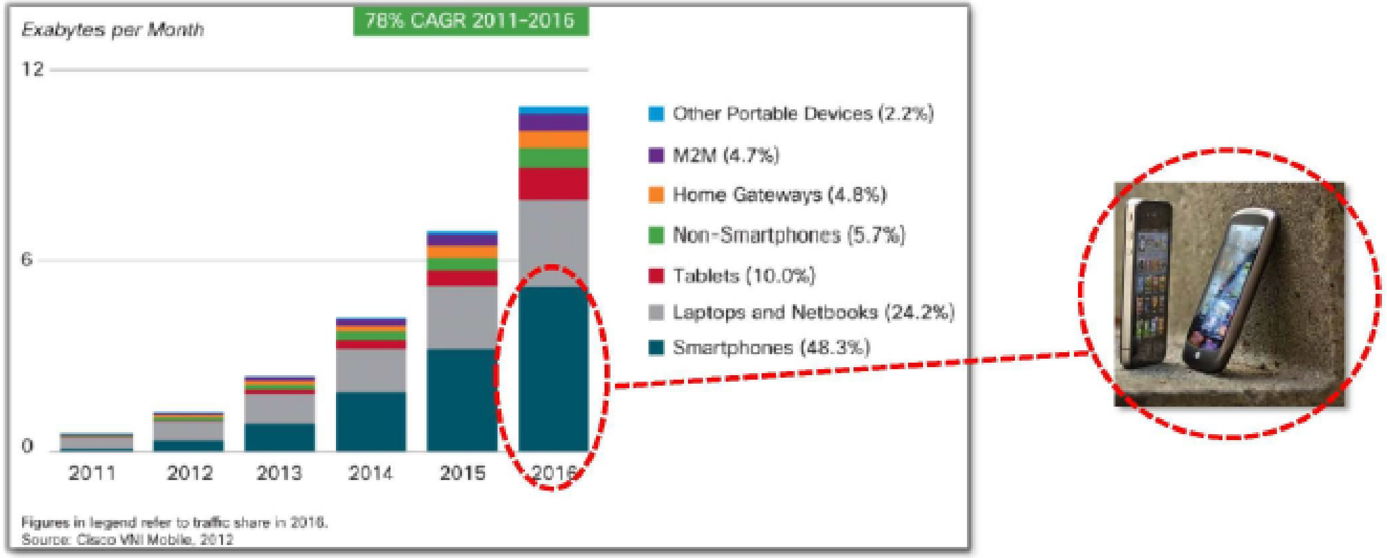
LTE-Advanced

- LTE-A in Rel-10 adds several enhancements in LTE
- Improvements in peak and average data rates using carrier aggregation, increased number of antennas and advanced antenna technologies
- Further improvements by use of relay and interference management
- LTE-A with Rel-10 fulfills and exceeds requirements for IMT-Advanced
- LTE-A can achieve peak data rates as high as 3 Gbps in DL and 1.5 Gbps in UL direction with 100 MHz spectrum

Lecture-11: Refarming and Challenges in Mobile Communication

1	Background – Technology and frequency bands
2	Challenges for mobile operators
3	Heterogeneous networks
4	The concept of re-farming and its motivation
5	Planning the future – A portfolio of frequency spectrum

Challenge: Current network is not ready for the expected traffic growth



- Exponential growth in data traffic in mobile broadband
- Customer expectation is rising quickly
- Current mobile network is based on macro (large) sites
- Adding costly macro sites in certain geographical areas is challenging because of unsuccessful site acquisition
- The majority of mobile broadband users are indoors

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Challenge: Operating multiple technology generations in parallel

	Technology	Typical Usage	Typical terminal	Handset penetration (Norway 2011)
2G	GSM/GPRS	Voice, messaging	Handsets	100%
3G	UMTS/HSPA/ HSPA+	Voice, handset data, mobile broadband	Handsets, dongles	60%
4G	LTE	Mobile broadband	Dongles, PC cards	0%

Operate 2G because:

- *Legacy handsets*: Long time till all handsets support 3G
- *Footprint*: Operators do not have the same coverage for 3G as 2G

Operate 3G because:

- *Efficiency*: More efficient than 2G
- *Mobile broadband*: Data rates and capacity
- *Terminals*: 4G not a handset technology (yet), long time till penetration reaches significant levels

Operate 4G because:

- *Efficiency*: More efficient technology
- *Cost*: Lower production cost

17

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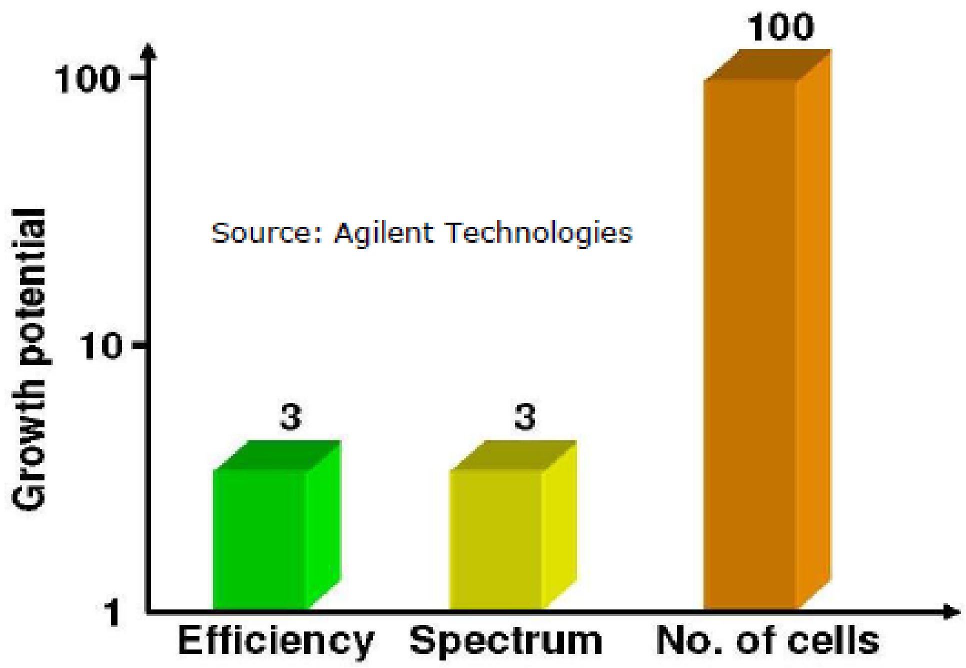
Out of the three ways to increase network capacity, adding new, smaller cells has by far the highest growth potential.



Spectrum and efficiency still matter but the future is all about small cells

For doubled spectrum size, required number of new cells can be halved

A Small cell provides similar capacity as a macro cell, but at a fraction of the cost

What is "refarming"

In agriculture: Switch from growing one type of product to another: E.g. from potato to carrot.

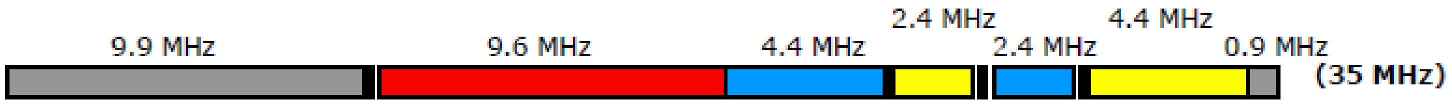
In mobile communications: Switch from one technology to another (in the same frequency band) – e.g. from GSM to GSM + UMTS

Requirements:

- Licenses are *technology neutral*
- (Often) Spectrum holding is *contiguous*
- Operators have a *minimum amount of spectrum each*

Refarming example 900 MHz

Before:



9.9 MHz + 0.9 MHz not allocated

Only red operator are able to refarm from GSM to GSM + UMTS (requires ~10 MHz and contiguous spectrum)

After

Government has:

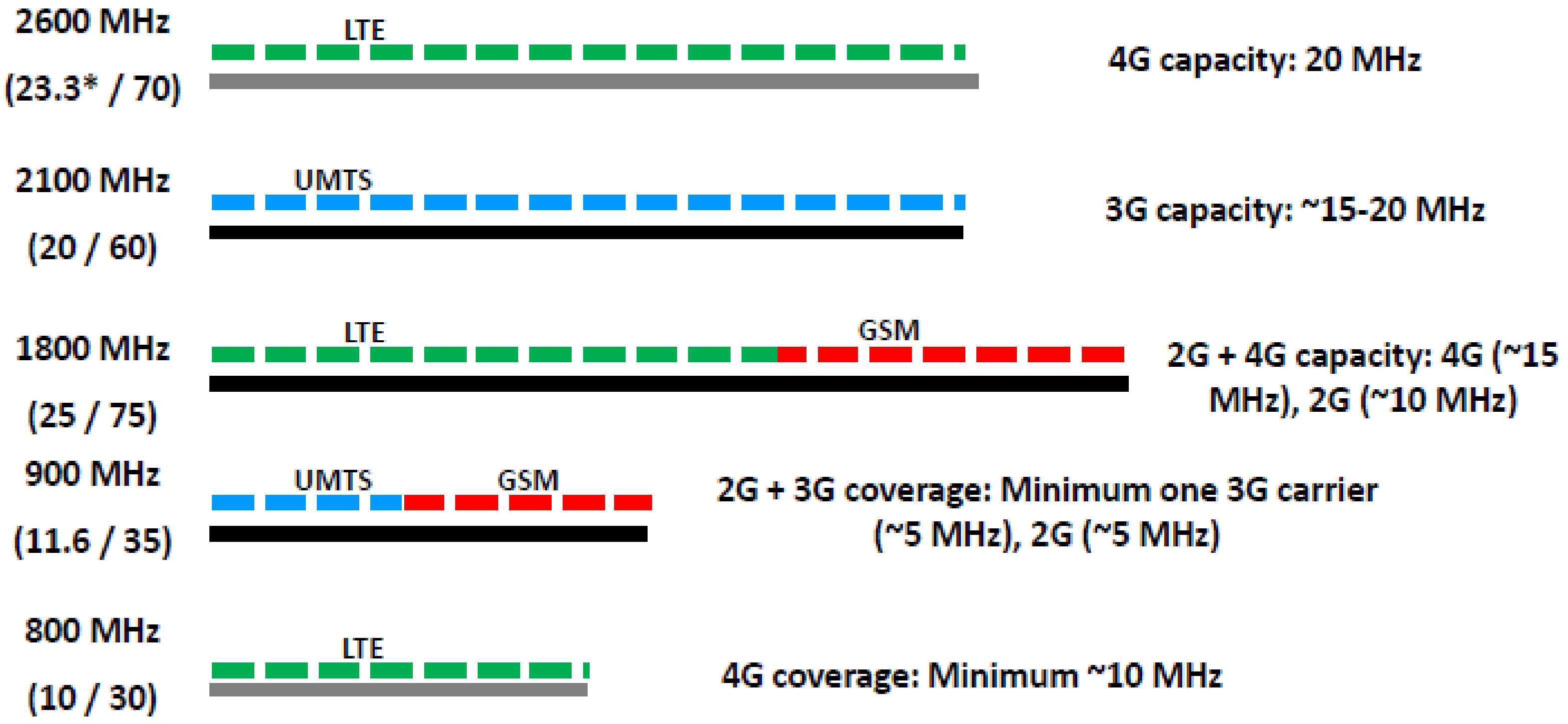
- **Allocated the unassigned spectrum to the three operators**
- **Reshuffled the spectrum so that all operators have contiguous spectrum**
- **All operators can refarm from GSM to GSM + UMTS**

Legends: **Red operator** **Blue operator** **Yellow operator** **Unassigned**

Planning a portfolio – The magical number three? (1/2)

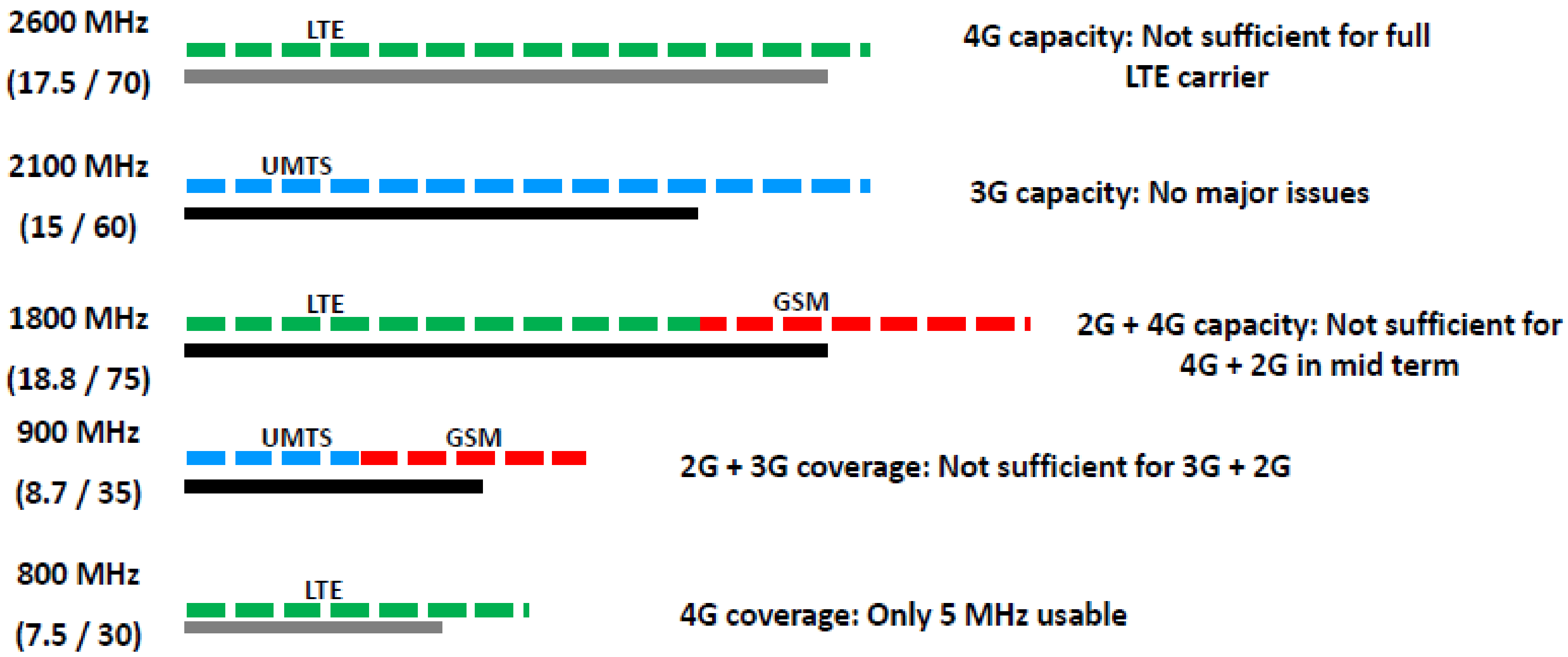
Imagine a situation where an operator has **one third of the maximum available spectrum** in the most important spectrum bands.

What would typically be the spectrum usage in mid term (2-5 years):



Planning a portfolio – The magical number three? (2/2)

Imagine a situation where an operator instead has **one fourth of the maximum available spectrum** in the most important spectrum bands:



Technology constraints one major reason for **consolidation** among mobile network operators in recent years, as well as the focus on **network sharing**

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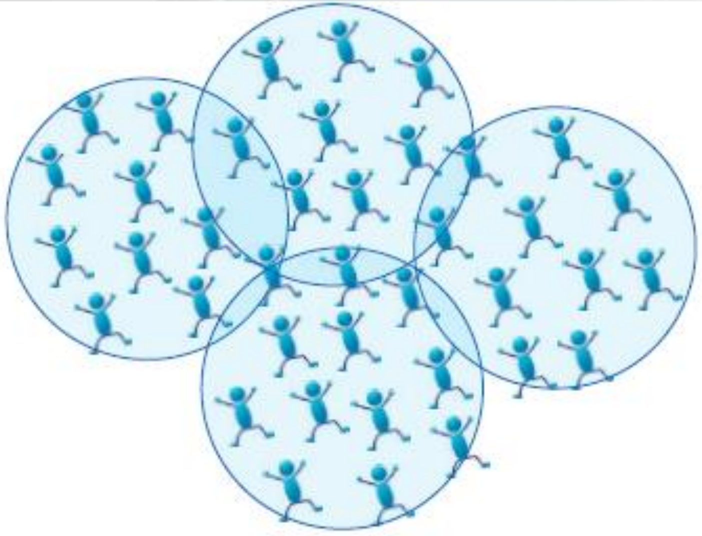
Building profitably across different area types

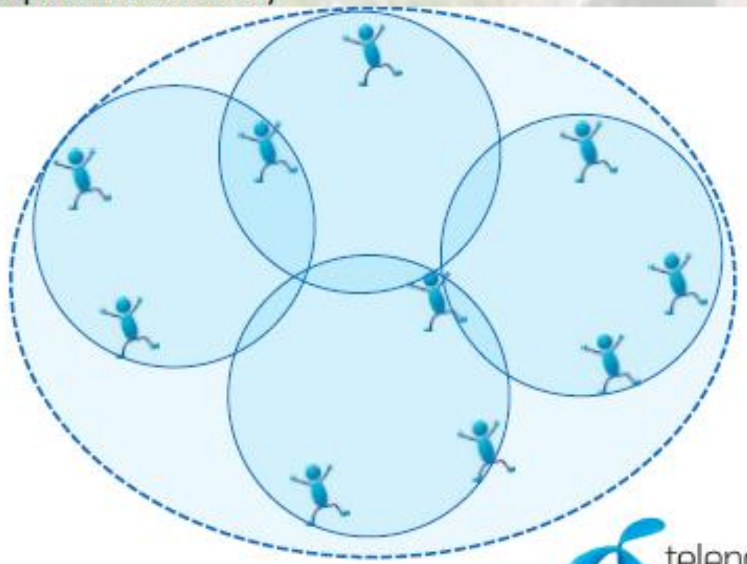
Urban area

- In this example, one must cover at least five customers in order for it to be commercially viable to set up a site
- In urban areas, the population density supports profitable rollout

Rural area

- Population density too low to support commercial rollout
- Larger coverage areas might ensure profitability
- Low market share ‘looks like’ low population density
- Low device penetration also ‘looks like’ low population density





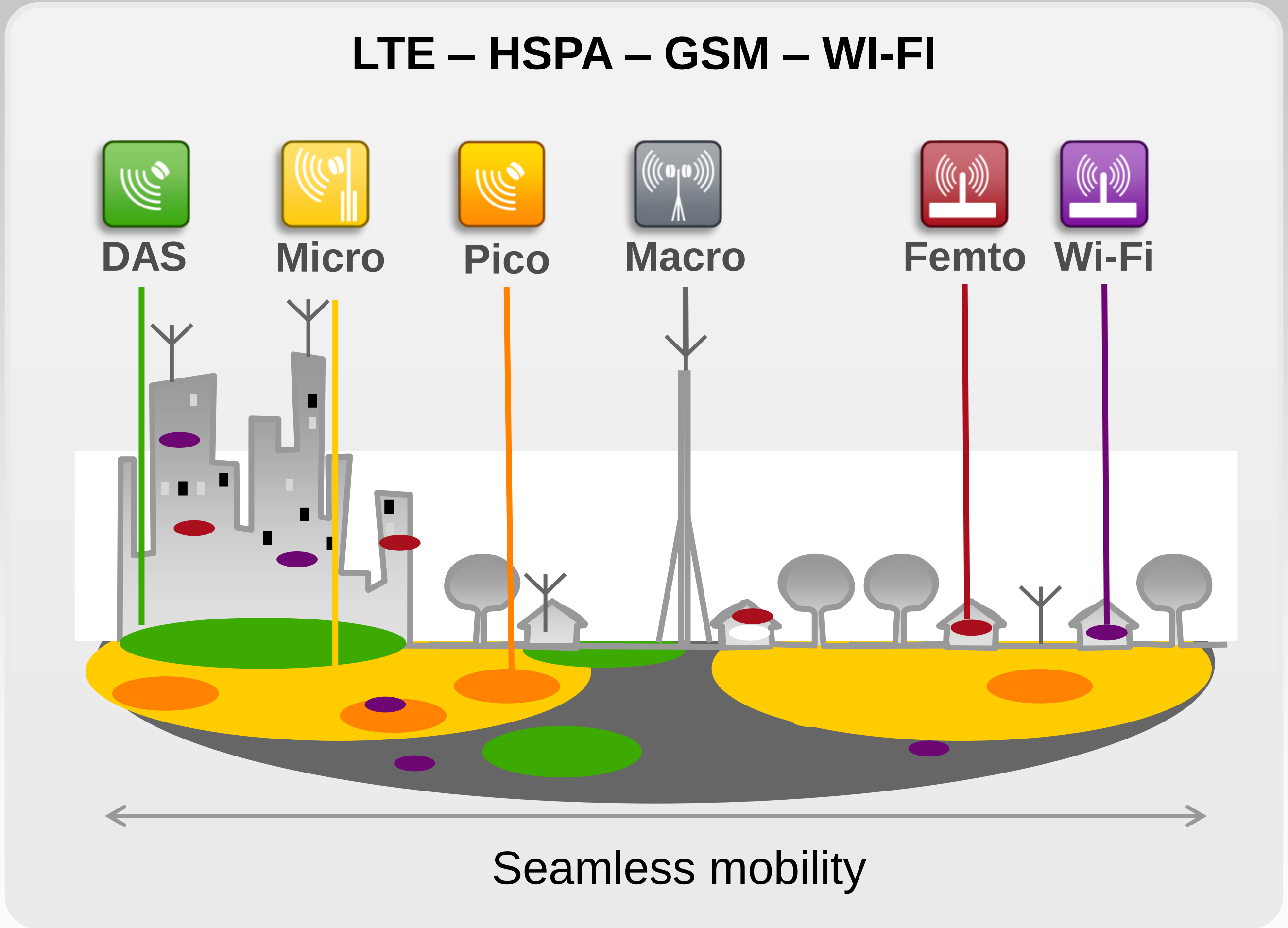
Lecture-12: Small cells and HetNet

- **Overview & market drivers**
  - **Introduction**
  - Deployment scenarios
  - Small cell site approach
  - Macro scalability
- Small cell and HetNet architecture
- Deployment considerations

Different small cell deployment scenarios

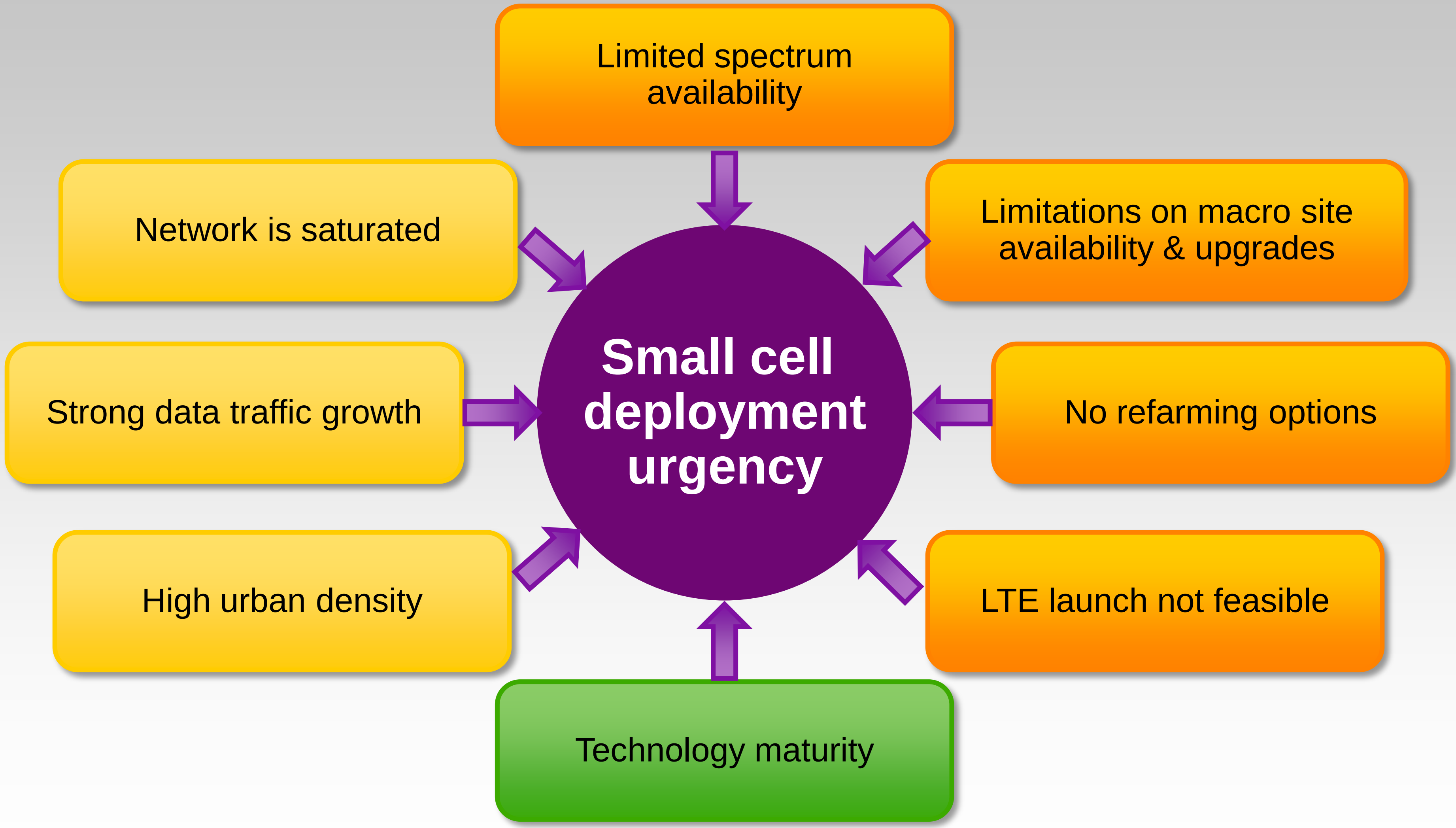
Femto	Indoor:	10-100mW
	Outdoor:	0.2-1W
	Coverage radius:	10s of meters
Wi-Fi	Indoor:	20-100mW
	Outdoor:	0.2-1W
	Coverage radius:	10s of meters
DAS	Indoor:	>10W
	Outdoor:	>10W
Pico	Indoor:	100-250mW
	Outdoor:	1-5W
	Coverage radius:	10s of meters
Micro	Outdoor:	5-10W
	Coverage radius:	100s of meters
Macro	Outdoor:	>10W
	Coverage radius:	kilometer(s)

Small cells and heterogeneous network



- Always best connected user experience
- Seamless interworking between different cell sizes, frequency layers and radio technologies
- Interference management
- Layer optimization and traffic steering
- Scalable smart network management and SON automation

Factors impacting operator small cell deployment timing



Definitions of different small cell types

	Indoor			Outdoor				
								
	Wi-Fi	Femto	Pico	Wi-Fi	Femto	Pico	Micro	Macro
Output transmit power	20mW - 100mW	Residential 10 -100mW Enterprise 100-250mW	100mW - 250mW	200mW - 1W	200mW – 1W	1 - 5W	5 - 10W	>10W
Architecture	LAN	Gateway	Macro / Gateway	Gateway	Gateway	Macro / Gateway	Macro	Macro
Coverage radius	<50 meters	<50 meters	<100 meters	10s of meters	10s of meters	~100 meters	100s of meters	Kilometer(s)
Size and weight	<1L <1kg	<1L <1kg	2-4L 1-3kg	3-8L 2-5kg	3-8L 2-5kg	5-10L 5-10kg	10-50L 8-20kg	30-500L 30-200kg
Max users	20-30	8-16	16-64	30-150	8-32	16-64	64-256	>256
Typical deployments	Consumer Enterprise Cafe	Consumer	Enterprise	Lamp posts Building walls Utility poles	Lamp posts Building walls Utility poles	Lamp posts Building walls Utility poles	Lamp posts Building walls Utility poles	Tower masts Rooftops

When might a new macro site not be feasible?

- No space for new macro site BTS or antennas.
- New macro site permits not granted or site lease is very expensive
- Site is too far from optimal location

- Cellular tower or pole is not accepted by authority community
- New macro site is overkill

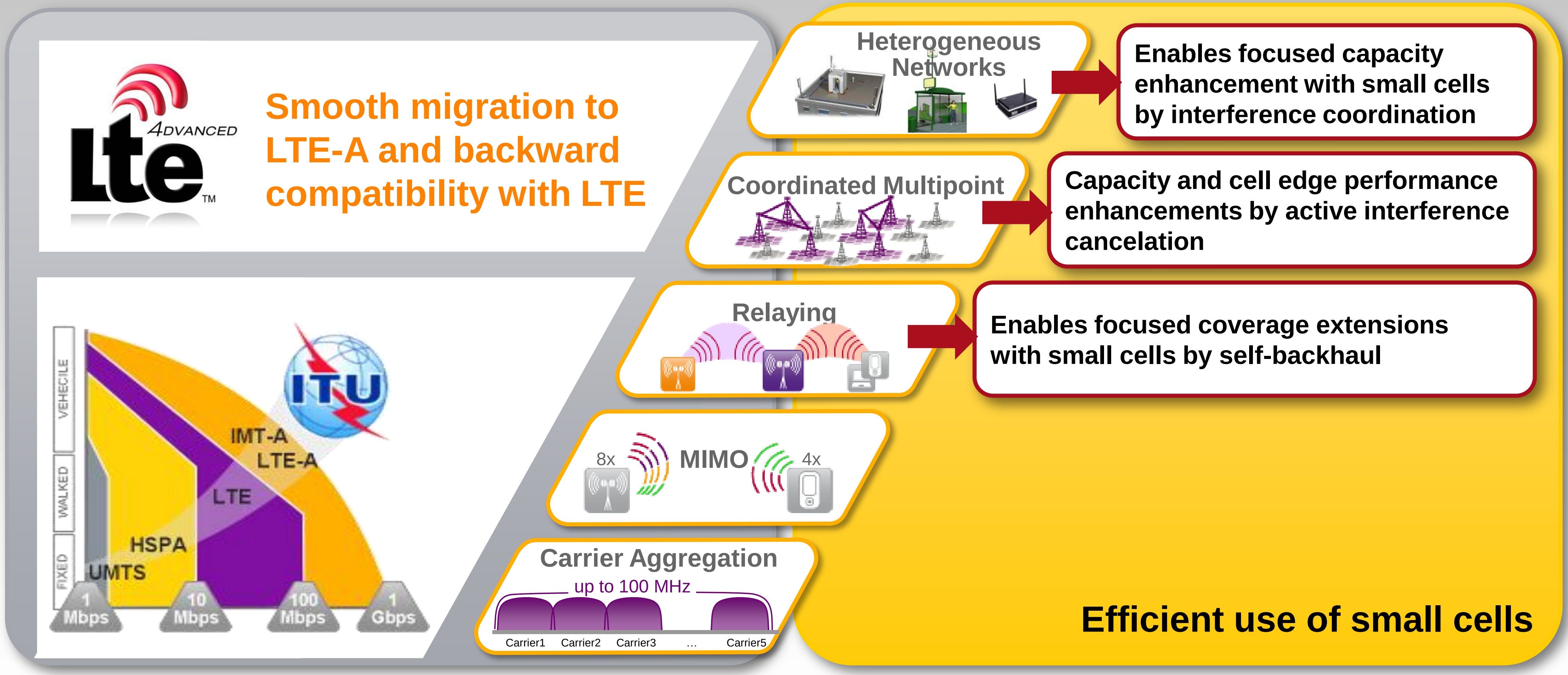
- Macro sites cells capacity is not enough
- More and smaller capacity cells need to be added

- Safety regulations limit the transmitted power at street level

- Smaller cell and low transmit power is optimized for e.g. indoor usage, tunnels and parking lots

- New macro site is overkill (cost, capacity, size) for coverage fix or extension

LTE-Advanced contains significant small cell features



Overview of selected 3GPP HetNet features

Emphasis on H(e)NB features, mobility, and interference management

Rel-9

H(e)NB related features such as:

More mobility options (e.g. hybrid and open access mode, HO between HeNBs), operator CSG lists, uplink user plane mux on Iuh for 3G HNB, LTE HeNB RF requirements, H(e)NB security aspects, H(e)NB OAM support, etc.

Rel-10

Additional H(e)NB architecture improvements such as:

intra 3G HNB-GW mobility, X2 for LTE HeNBs, LIPA/SIPTO in H(e)NB based networks, subsystem performance measurements, etc.

LTE Time-domain enhanced inter-cell interference coordination (TDM eICIC)

Addresses downlink interference management for co-channel scenarios with macro, pico, and HeNB deployment

Rel-11

Further H(e)NB architecture improvements:

Examples include HeNB network sharing, LIPA/SIPTO, more X2 options for HeNBs, etc. ...

Further improvement of LTE TDM eICIC – main focus is on UE interference supression enhancements

Nokia Siemens Networks/Nokia rapporteur for “Carrier based HetNet ICIC for LTE”

Study item “HetNet mobility improvements for LTE”

H(e)NB interference management in terms of power control discussed intensively for Rel-9/10 – but without any text going into specs (except for controlling adjacent interference level over macro level)

Thus, today we see many different implementation specific H(e)NB power setting schemes.

Notice: Currently no 3G HetNet inteference management features standadized (except for HNB adjacent channel requirements), and no such proposals for Rel-11. 3GPP HetNet focus seems to be on LTE.

Small cell network architecture