

Outline



- A preliminary overview
- Propagation characteristics
- ISO-OSI Model
- Physical layer: modulation
- MAC layer:
 - Fixed resource assignment
 - Random access
 - Ethernet (CSMA/CD)
 - WiFi (CSMA/CA)
- Personal Area Networks
 - Bluetooth
 - Zigbee
- Cellular network dimensioning
- **Cellular networks**
 - From GSM (2G) to UMTS (3G)
 - **LTE (4G)**

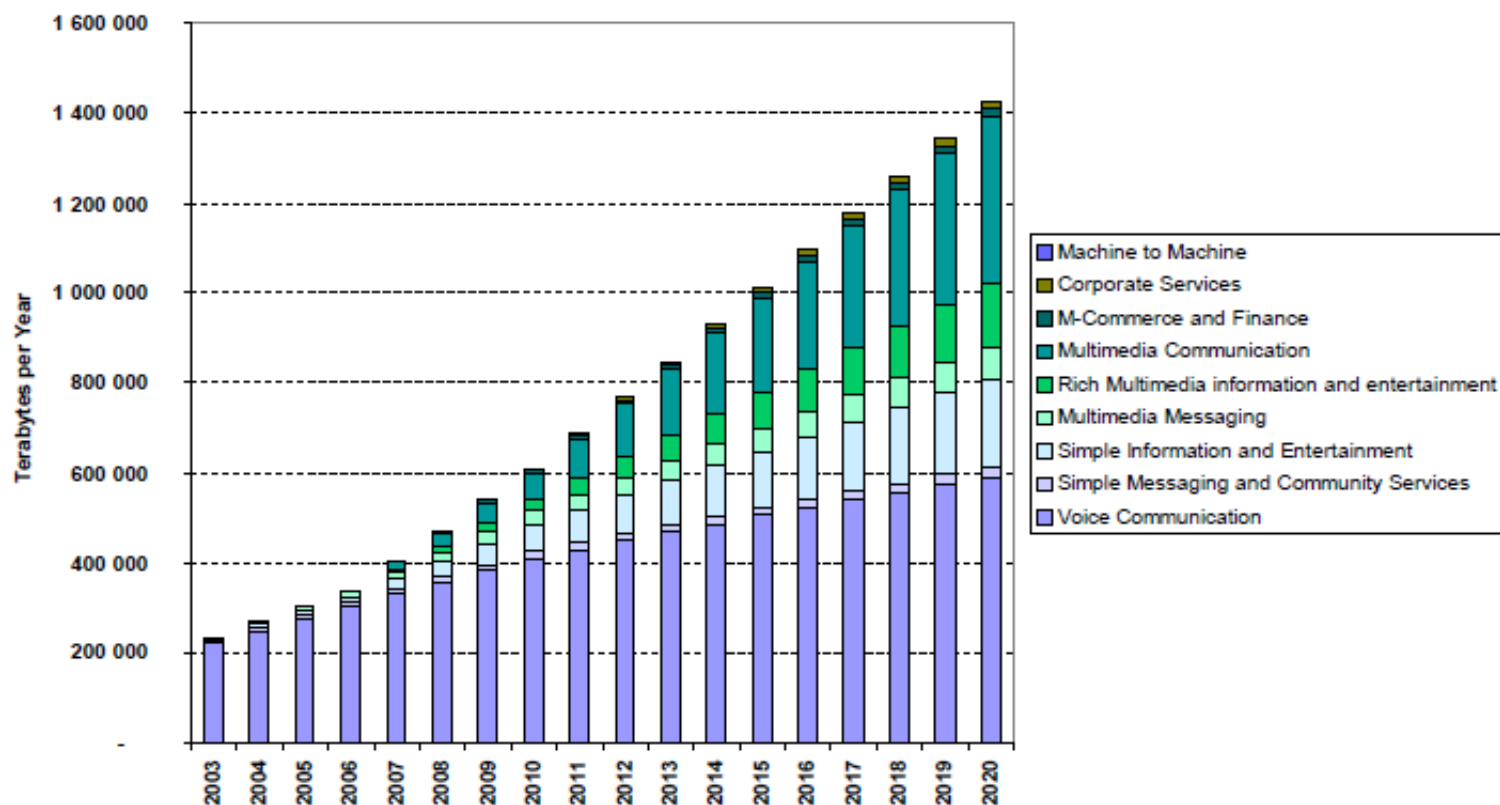


Agenda

- Standardization
- Motivation for LTE
- LTE performance requirements
- LTE challenges
- LTE/SAE Key Features
- LTE technology basics
- Air Interface Protocols

World Forecast per Service Category

Total World Usage Forecast - Voice and Data Services



Source: Report ITU-R M.2072 "World mobile telecommunication market forecast"

GLOBAL MBB HSPA SUBSCRIBER GROWTH



PC Connected Subs



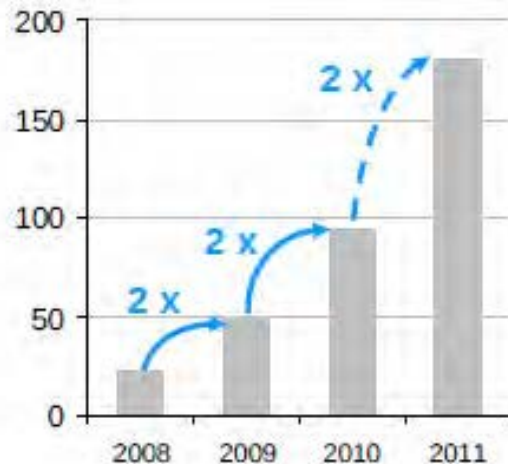
Smartphone Subs



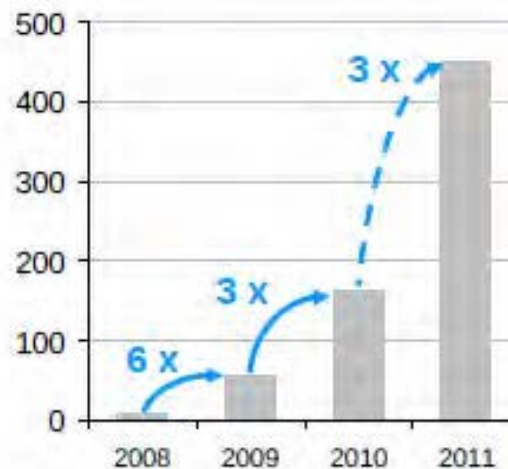
Tablet Subs



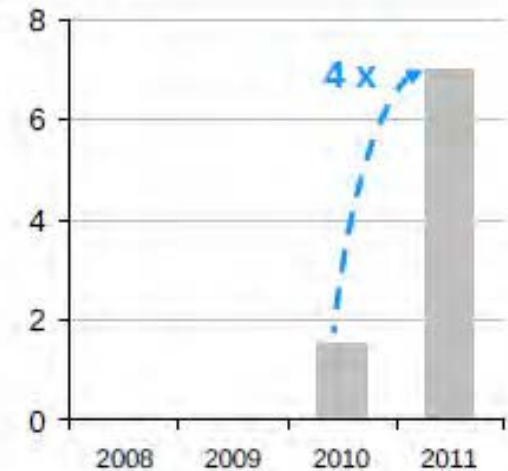
Subs [M]



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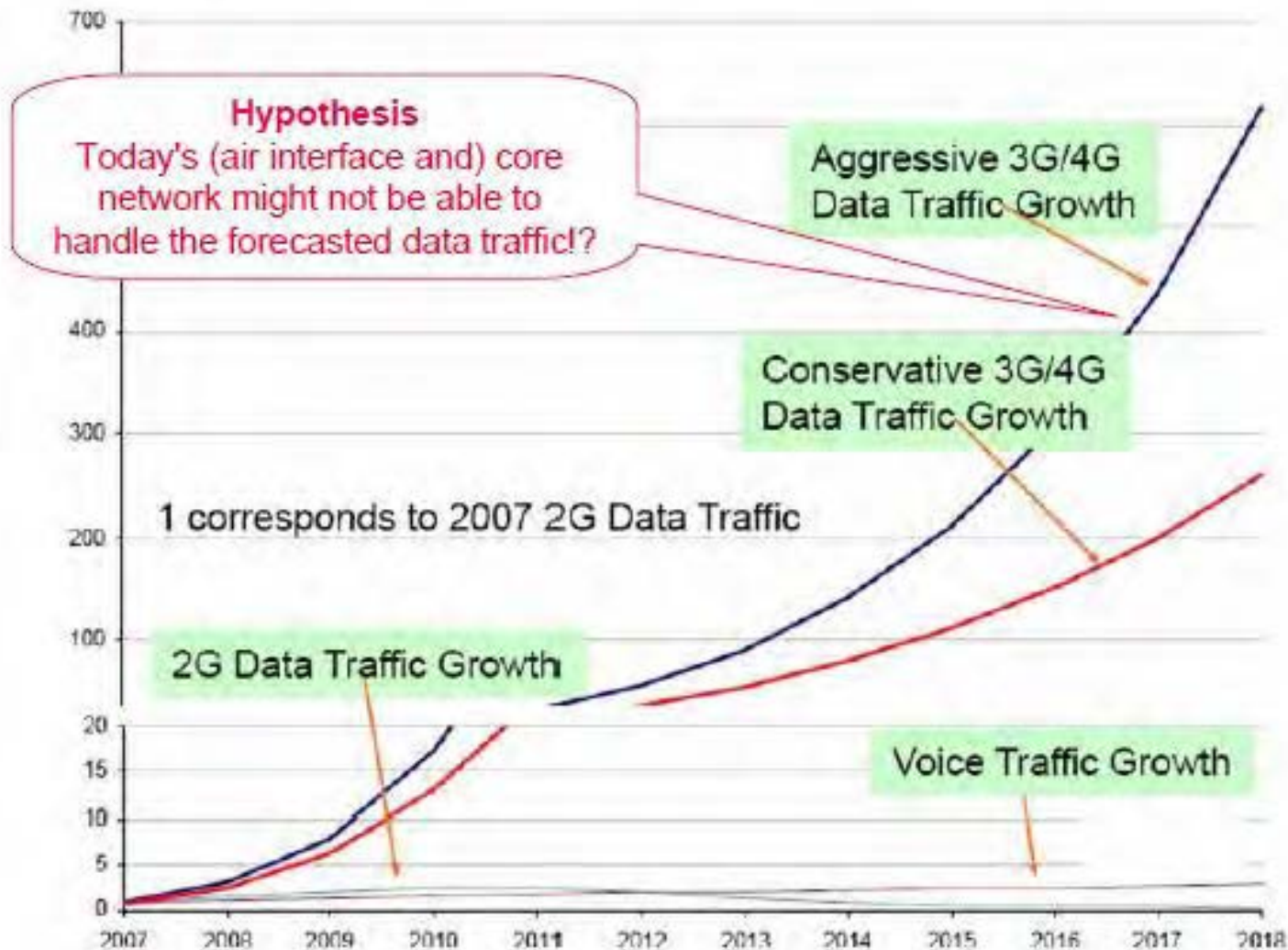


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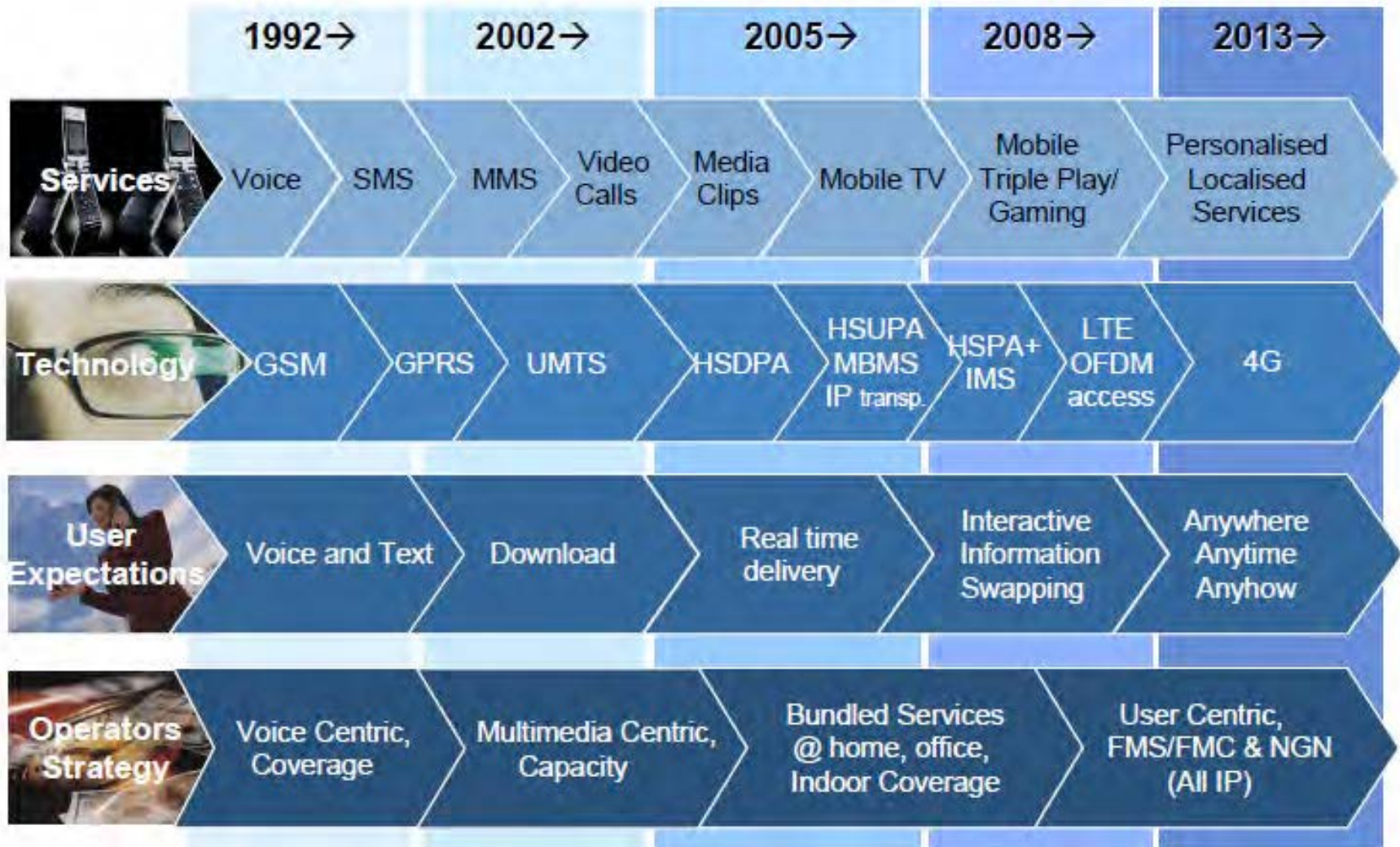
SMARTPHONE SURPASSING PC IN 2010
STRONG CONTINUED GROWTH EXPECTED

Data traffic growth forecast



Source: Peter Rysavy, 3G Americas

Mobile Evolution

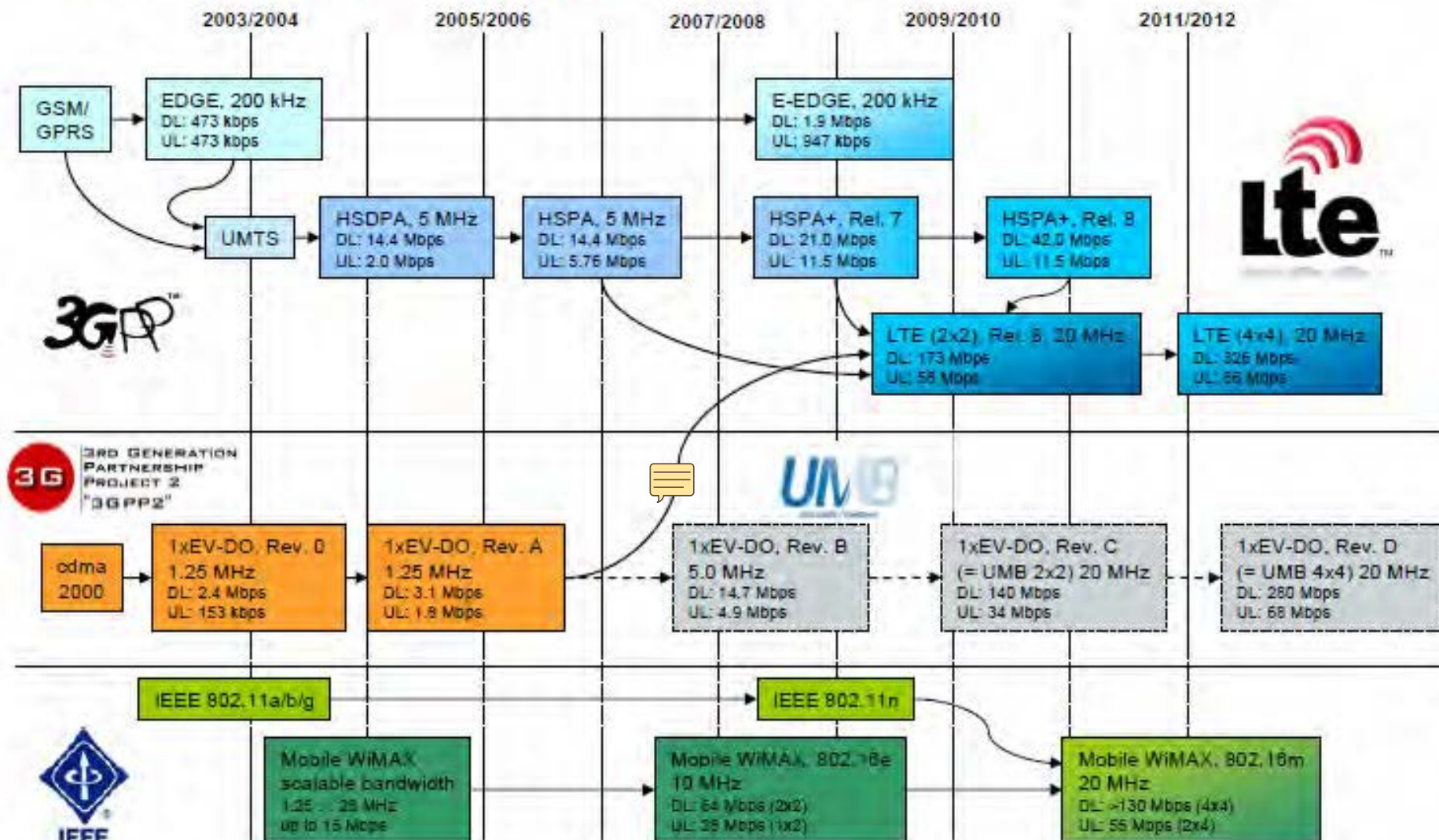


Standardization



- LTE is the latest standard in the mobile network technology tree that previously realized the GSM/EDGE and UMTS/HSPA network technologies that now account for over 85% of all mobile subscribers. LTE will ensure 3GPP's competitive edge over other cellular technologies.
- 3GPP work on the Evolution of the 3G Mobile System started in November 2004.
- Specifications scheduled finalized by the end of December 2009.
- Currently, standardization in progress in the form of Rel-9 and Rel-10.

Today's technology evolution path



Motivation for LTE

- **Need for higher data rates and greater spectral efficiency**
 - Can be achieved with HSDPA/HSUPA
 - and/or new air interface defined by 3GPP LTE
- **Need for Packet Switched optimized system**
 - Evolve UMTS towards packet only system
- **Need for high quality of services**
 - Use of licensed frequencies to guarantee quality of services
 - Always-on experience (reduce control plane latency significantly)
 - Reduce round trip delay
- **Need for cheaper infrastructure**
 - Simplify architecture, reduce number of network elements

LTE performance requirements

- **Data Rate:**
 - Instantaneous downlink peak data rate of 100Mbit/s in a 20MHz downlink spectrum (i.e. 5 bit/s/Hz)
 - Instantaneous uplink peak data rate of 50Mbit/s in a 20MHz uplink spectrum (i.e. 2.5 bit/s/Hz)
- **Cell range**
 - 5 km - optimal size
 - 30km sizes with reasonable performance
 - up to 100 km cell sizes supported with acceptable performance
- **Cell capacity**
 - up to 200 active users per cell(5 MHz) (i.e., 200 active data clients)

LTE performance requirements – Cont.

- **Mobility**
 - Optimized for low mobility(0-15km/h) but supports high speed
- **Latency**
 - user plane < 5ms
 - control plane < 50 ms
- **Improved spectrum efficiency**
- **Improved broadcasting**
- **IP-optimized**
- **Scalable bandwidth of 20, 15, 10, 5, 3 and 1.4MHz**
- **Co-existence with legacy standards**

The way to LTE: 3 main 3G limitations

1. The maximum bit rates still are factor of 20 and more behind the current state of the systems like 802.11n and 802.16e/m.
2. The latency of user plane traffic (UMTS: >30 ms) and of resource assignment procedures (UMTS: >100 ms) is too big to handle traffic with high bit rate variance efficiently.
3. The terminal complexity for WCDMA or MC-CDMA systems is quite high, making equipment expensive, resulting in poor performing implementations of receivers and inhibiting the implementation of other performance enhancements.

Suggested Technical Reading (see end)



LTE PART II: 3GPP RELEASE 8

LTE: The Evolution of Mobile Broadband

*David Astély, Erik Dahlman, Anders Furuskär, Ylva Jading, Magnus Lindström, and Stefan Parkvall,
Ericsson Research*

IEEE Communications Magazine • April 2009

ABSTRACT

This article provides an overview of the LTE radio interface, recently approved by the 3GPP, together with a more in-depth description of its features such as spectrum flexibility, multi-antenna transmission, and inter-cell interference control. The performance of LTE and some of its key features is illustrated with simulation results. The article is concluded with an outlook into the future evolution of LTE.



LTE Overview – Design Targets and Multiple Access Technologies

LTE CHALLENGES

What are the LTE challenges?

The Users' expectation...

Best price, transparent flat rate
Full Internet
Multimedia

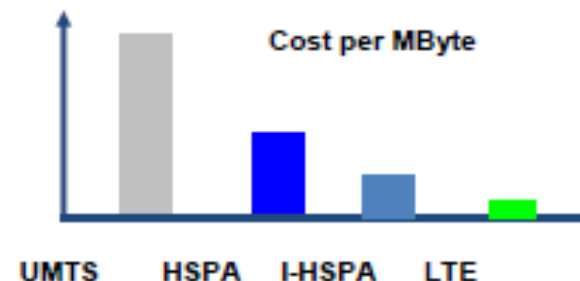
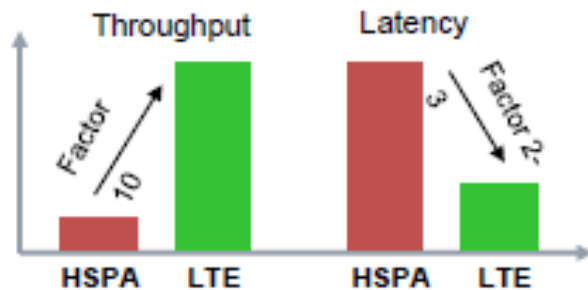


..leads to the operator's challenges

reduce cost per bit
provide high data rate
provide low latency

User experience will have an impact on ARPU

Price per Mbyte has to be reduced to remain profitable

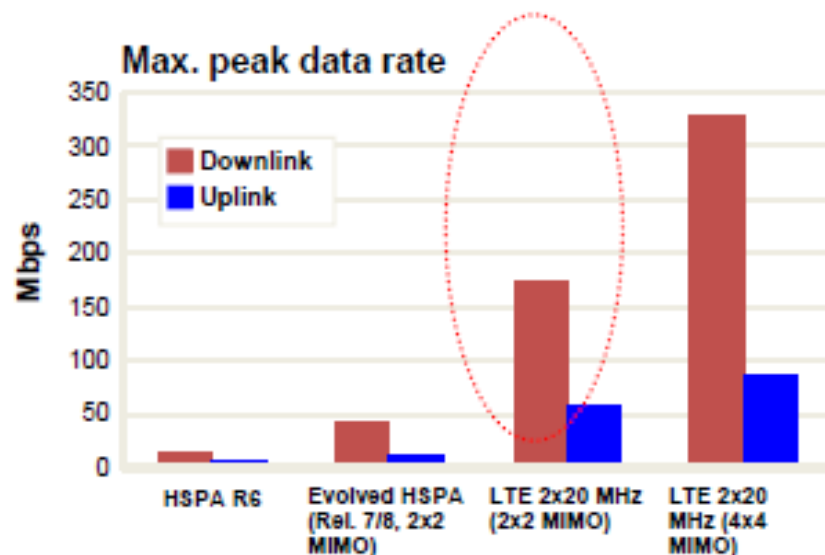


Comparison of Throughput and Latency

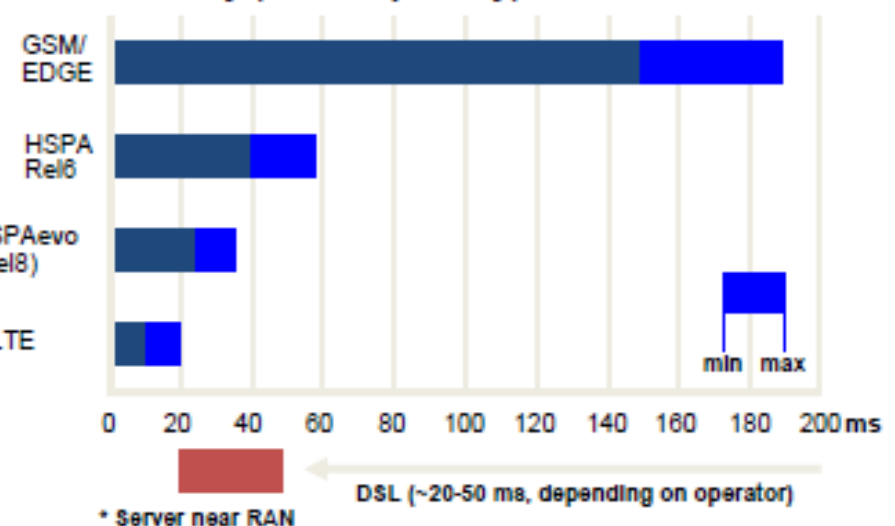
Peak data rates around 300Mbps/80 Mbps
Low latency 10-20 ms



Enhanced consumer experience:
drives subscriber uptake
allow for new applications
provide additional revenue streams

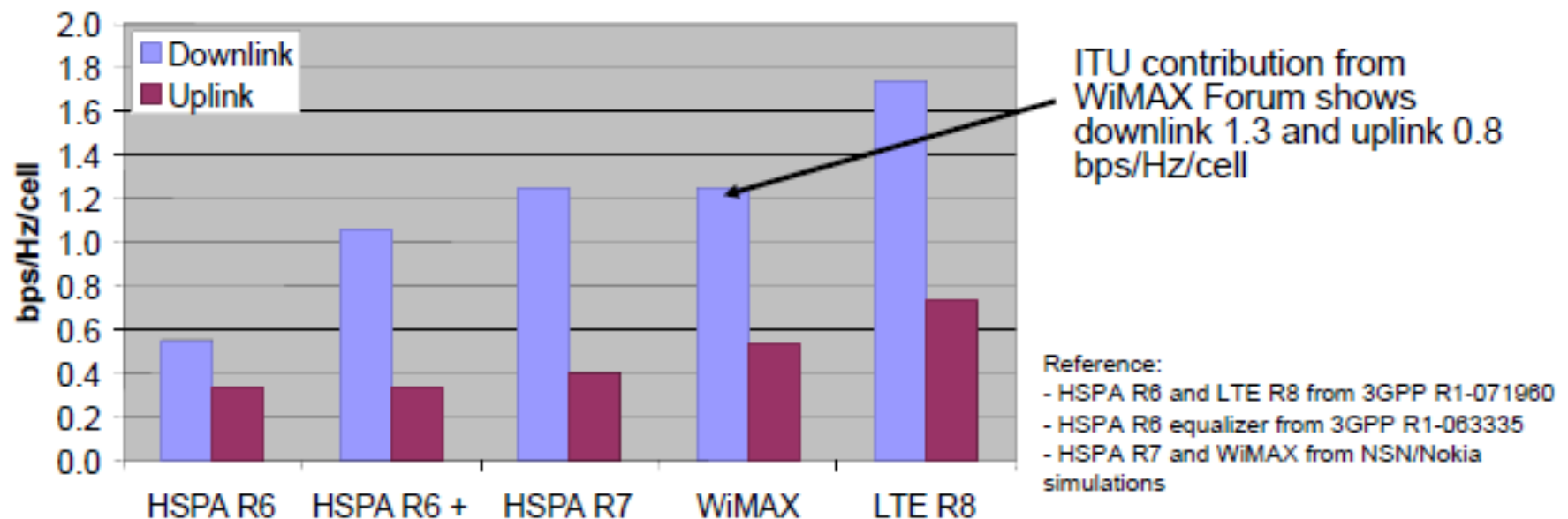


Latency (Rountrip delay)*



Increased Spectral Efficiency

- All cases assume 2-antenna terminal reception
- HSPA R7, WiMAX and LTE assume 2-antenna BTS transmission (2x2 MIMO)



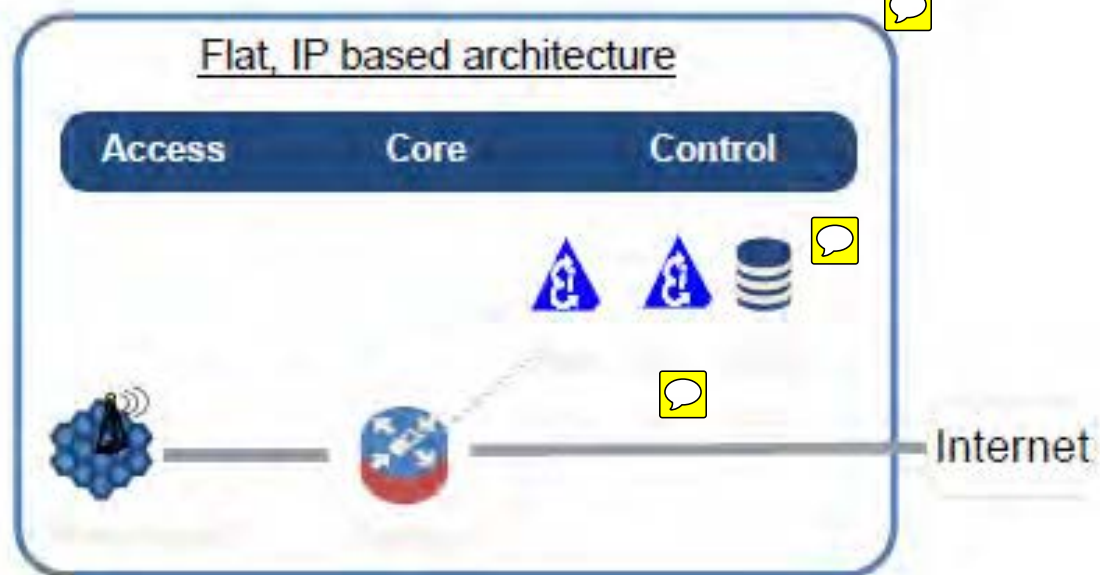
Reduced Network Complexity

Flat, scalable IP based architecture



Flat Architecture: 2 nodes architecture
IP based Interfaces

Flat networks are characterized by fewer network elements, lower latency, greater flexibility and lower operation cost





LTE Overview – Design Targets and Multiple Access Technologies

LTE/SAE KEY FEATURES

LTE Architecture

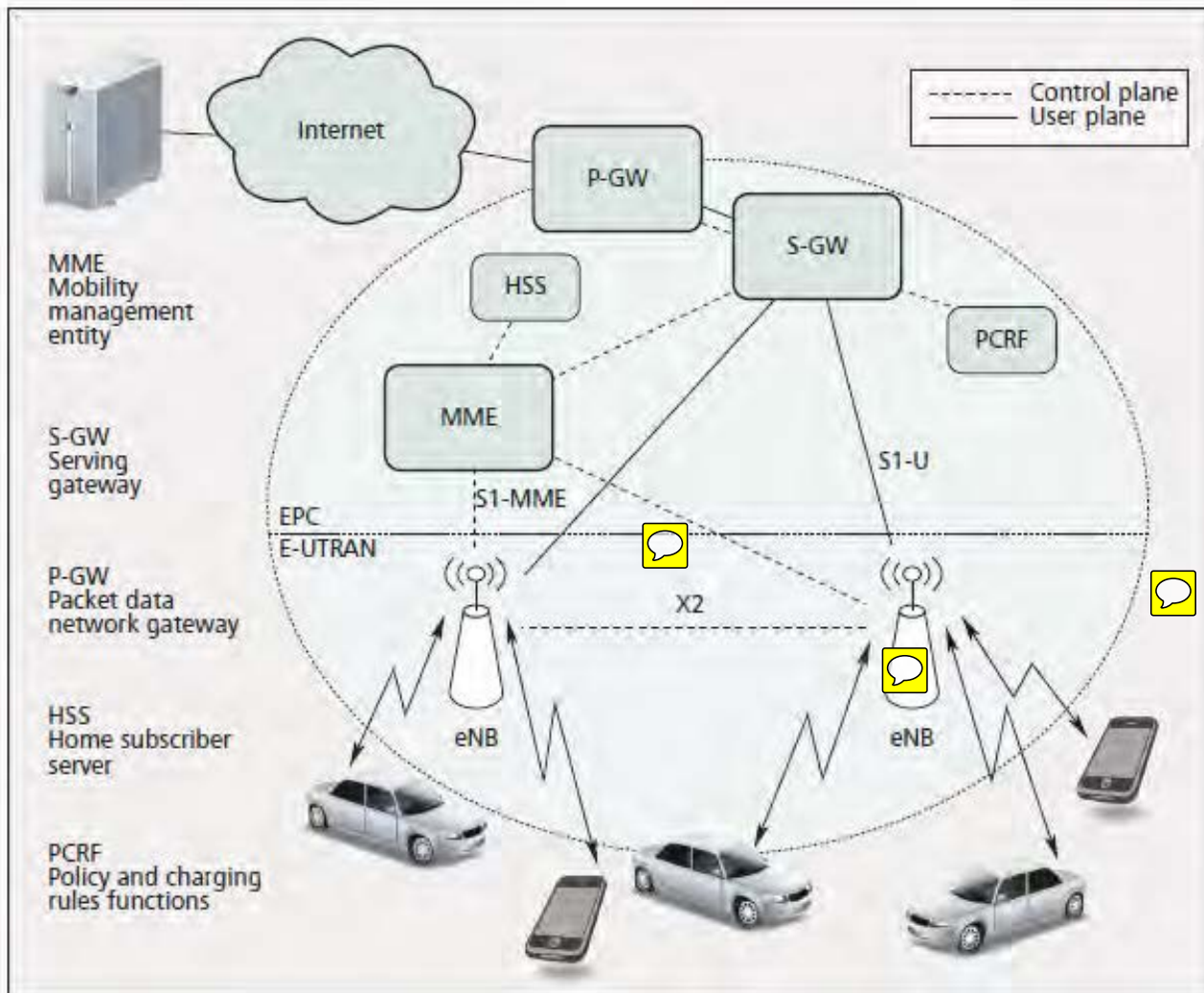
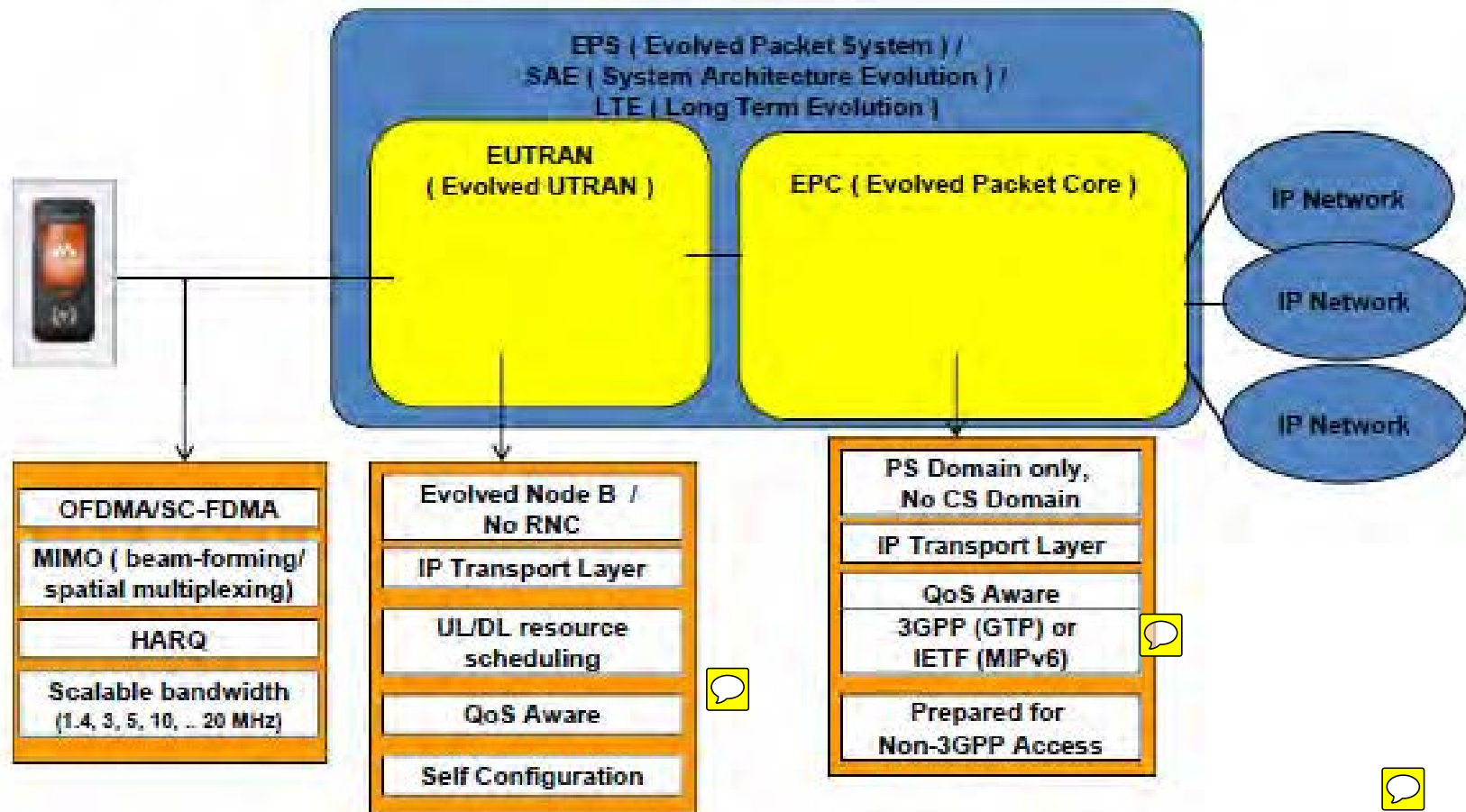


Figure 1. LTE architecture: access network (eUTRAN) and core network (EPC) entities.

LTE/SAE Key Features – Overview



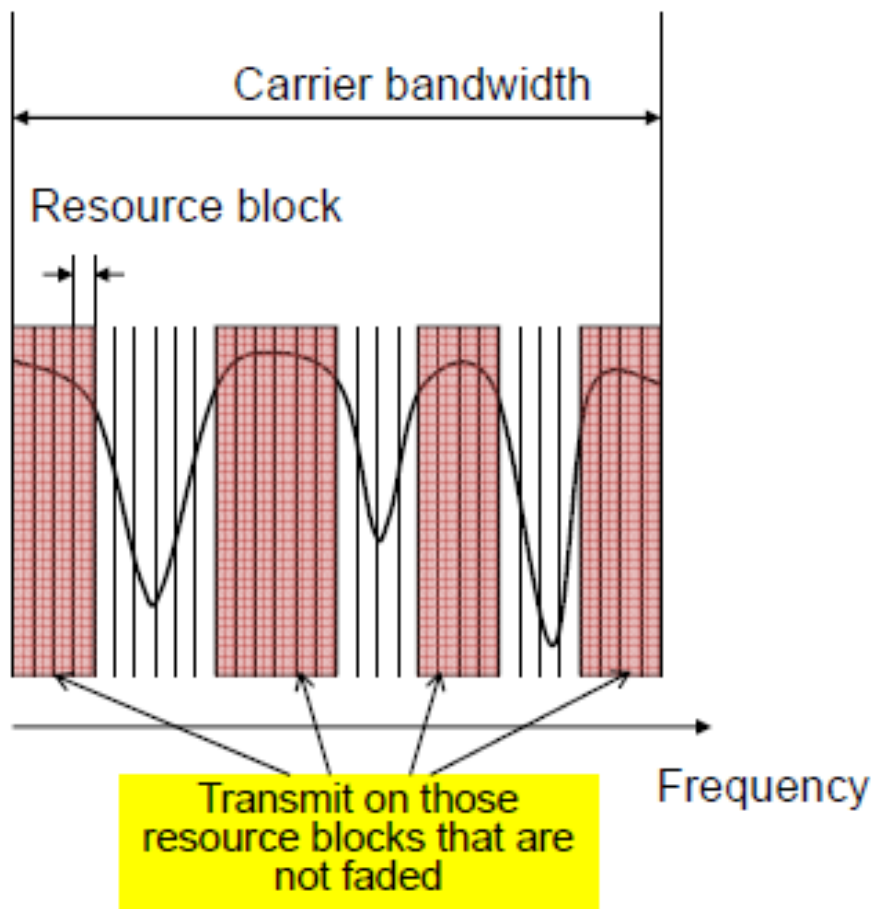
LTE/SAE Key Features



- **Evolved NodeB**
 - No RNC is provided anymore
 - The evolved Node Bs take over all radio management functionality.
 - This will make radio management faster and hopefully the network architecture simpler
- **IP transport layer**
 - EUTRAN exclusively uses IP as transport layer
- **UL/DL resource scheduling**
 - In UMTS physical resources are either shared or dedicated
 - Evolved Node B handles all physical resource via a scheduler and assigns them dynamically to users and channels
 - This provides greater flexibility than the older system

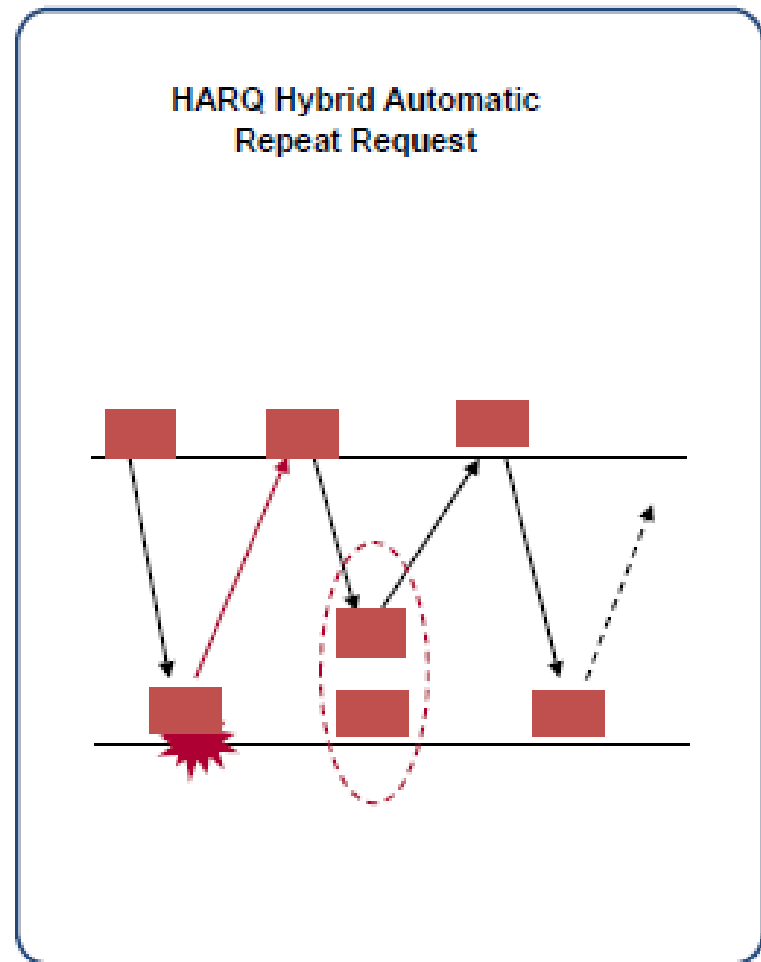
LTE/SAE Key Features – Cont.

- Frequency Domain Scheduling :
 - Frequency domain scheduling uses those resource blocks that are not faded
 - Not possible in CDMA based system



LTE/SAE Key Features – Cont.

- HARQ 
 - Hybrid Automatic Retransmission on reQuest
 - HARQ has already been used for HSDPA and HSUPA.
 - HARQ especially increases the performance (delay and throughput) for cell edge users.
 - HARQ simply implements a retransmission protocol on layer 1/2 that allows to send retransmitted blocks with different coding than the 1st one.



LTE/SAE Key Features – Cont.

- **QoS awareness**
 - The scheduler must handle and distinguish different quality of service classes
 - Otherwise real time services would not be possible via EUTRAN
 - The system provides the possibility for differentiated service
- **Self configuration**
 - Currently under investigation
 - Possibility to let Evolved Node Bs configure themselves
- **It will not completely substitute the manual configuration and optimization.**

LTE/SAE Key Features – Cont.

- Packet Switched Domain only
 - No circuit switched domain is provided
 - If CS applications are required, they must be implemented via IP
- Non-3GPP access
 - The EPC will be prepared also to be used by non-3GPP access networks (e.g. LAN, WLAN, WiMAX, etc.)
 - This will provide true convergence of different packet radio access system

LTE/SAE Key Features – Cont.

- MIMO
 - Multiple Input Multiple Output
 - LTE will support MIMO as an option,
 - It describes the possibility to have multiple transmitter and receiver antennas in a system.
 - Up to four antennas can be used by a single LTE cell (gain: spatial multiplexing)
 - MIMO is considered to be the core technology to increase spectral efficiency.



LTE Overview – Design Targets and Multiple Access Technologies

LTE TECHNOLOGY BASICS

LTE key parameters



Frequency Range	UMTS FDD bands and UMTS TDD bands					
Channel bandwidth, 1 Resource Block=180 kHz	1.4 MHz	3 MHz	5 MHz	10 MHz	15 MHz	20 MHz
	6 RB	15 RB	25 RB	50 RB	75 RB	100 RB
Modulation Schemes	DL: OFDMA (Orthogonal Frequency Division Multiple Access) UL: SC-FDMA (Single Carrier Frequency Division Multiple Access)					
Multiple Access	DL: OFDMA (Orthogonal Frequency Division Multiple Access) UL: SC-FDMA (Single Carrier Frequency Division Multiple Access)					
MIMO technology	DL: Wide choice of MIMO configuration options for transmit diversity, spatial multiplexing, and cyclic delay diversity (max. 4 antennas at base station and handset) UL: Multi user collaborative MIMO					
Peak Data Rate	DL: 150 Mbps (UE category 4, 2x2 MIMO, 20 MHz) 300 Mbps (UE category 5, 4x4 MIMO, 20 MHz) UL: 75 Mbps (20 MHz)					

Scalable
bandwidth



Easy to introduce in any frequency band:
Frequency refarming
(cost-efficient deployment on lower
Frequency bands supported)



LTE Overview – Design Targets and Multiple Access Technologies

OFDM/OFDMA/SC-FDMA

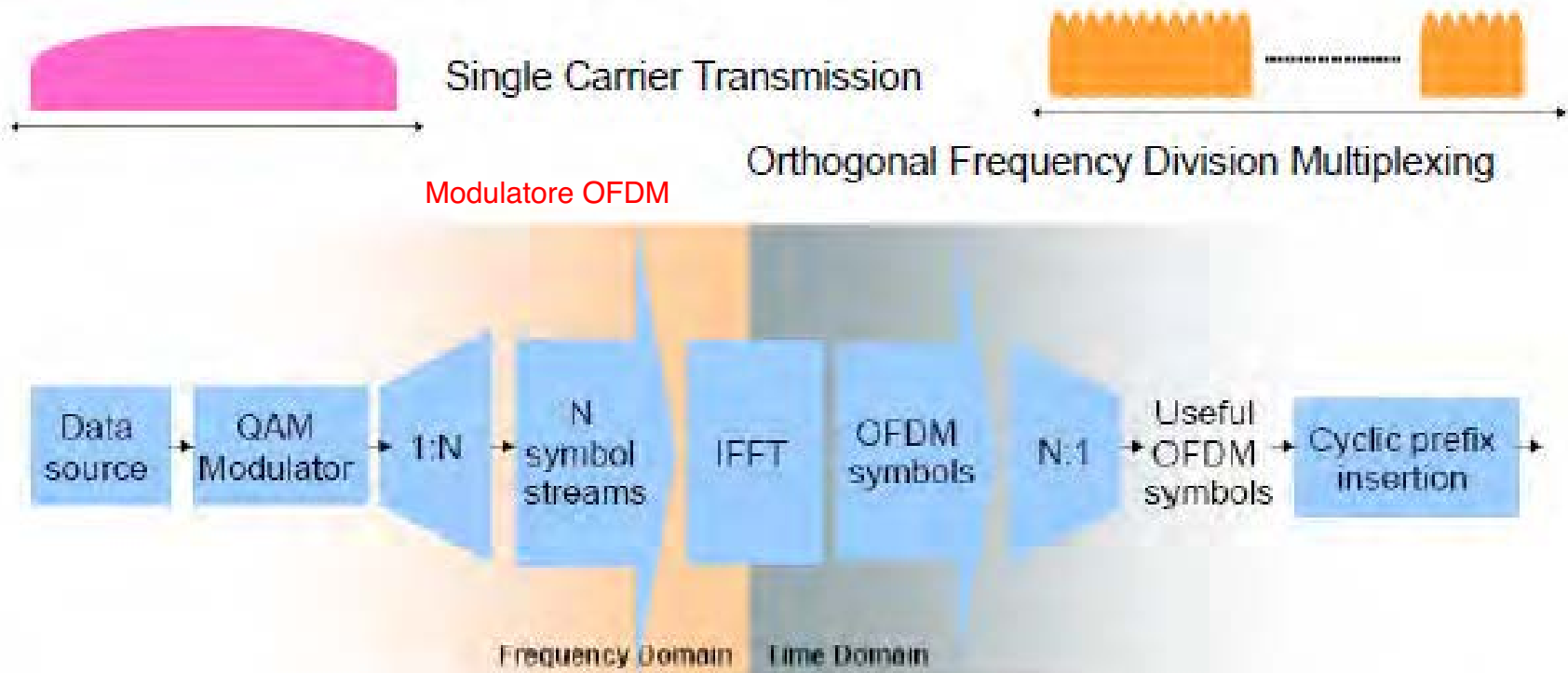
OFDM: Orthogonal Frequency Division Multi-Carrier

- LTE uses OFDM for the DL– that is, from the base station to the terminal. OFDM meets the LTE requirement for spectrum flexibility and enables cost-efficient solutions for very wide carriers with high peak rates.
- The basic LTE downlink physical resource can be seen as a time-frequency grid. In the frequency domain, the spacing between the subcarriers, Δf , is 15kHz. In addition, the OFDM symbol duration time is $1/\Delta f$ + cyclic prefix. The cyclic prefix is used to maintain orthogonality between the sub-carriers even for a time-dispersive radio channel.
- One resource element carries QPSK, 16QAM or 64QAM.





OFDM – Cont.

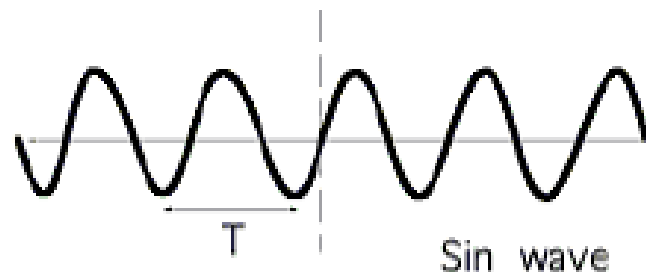


OFDM signal generation is based on Inverse Fast Fourier Transform (IFFT) operation on transmitter side. On receiver side, an FFT operation will be used.

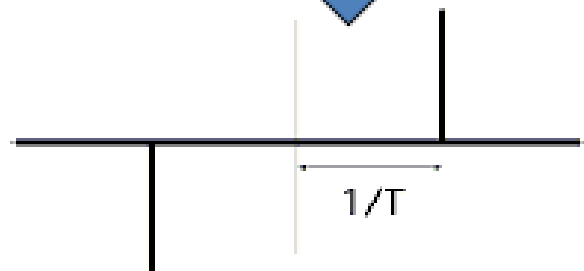
Pulse shaping and Spectrum

- Two characteristics are important for a Signal:
 - The time domain presentation:
 - It helps recognize “how long the symbol lasts on air”
 - The frequency domain presentation:
 - to understand the required spectrum in terms of bandwidth

The time domain presentation



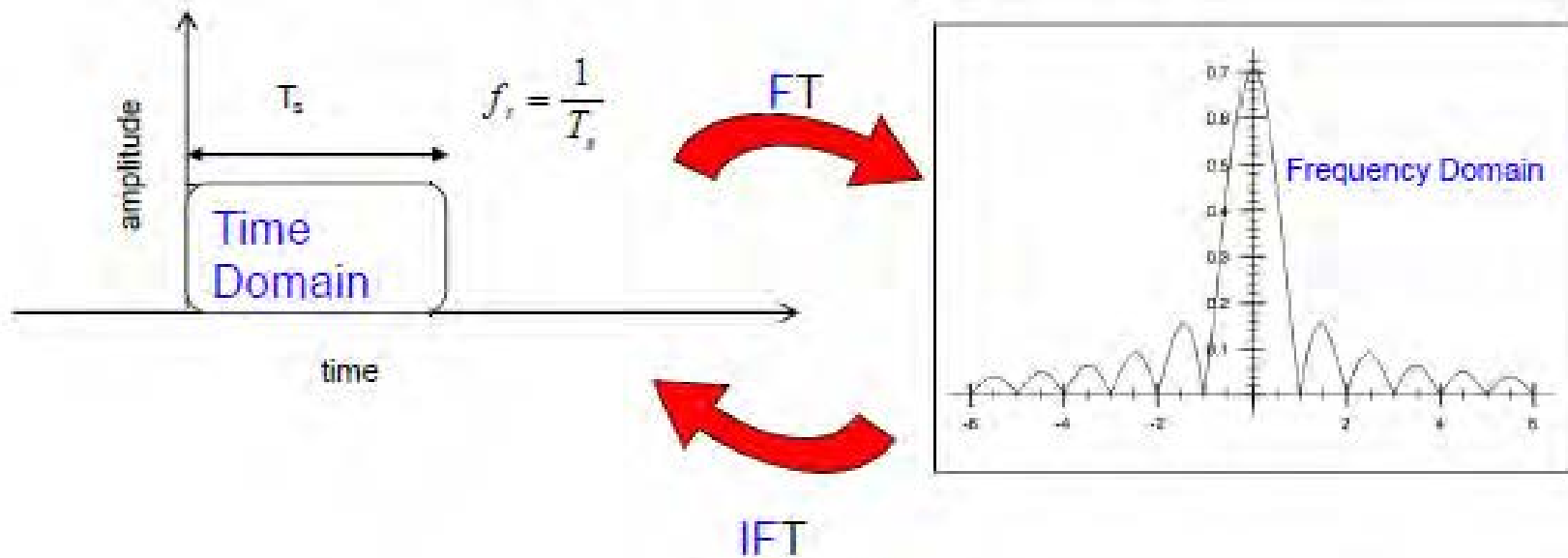
Fourier Transform



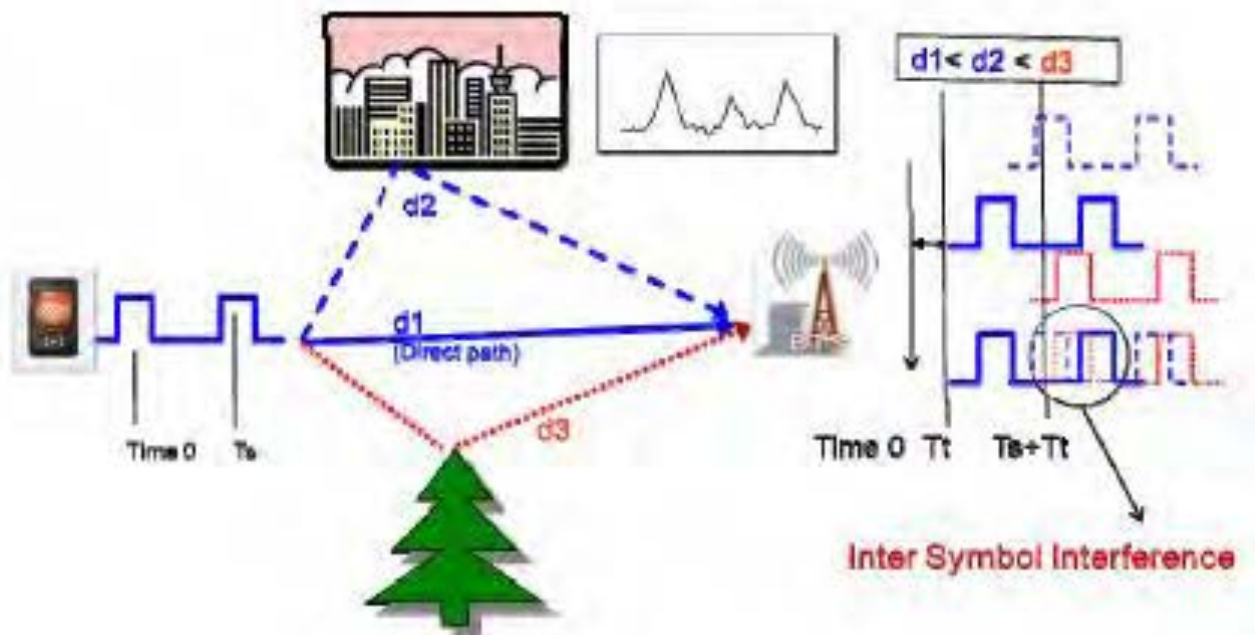
The frequency domain presentation

The rectangular Pulse

- It is one of the most simple time-domain pulses.
- It simply jumps at time $t=0$ to its maximum amplitude and after the pulse duration T_s just goes back to 0.



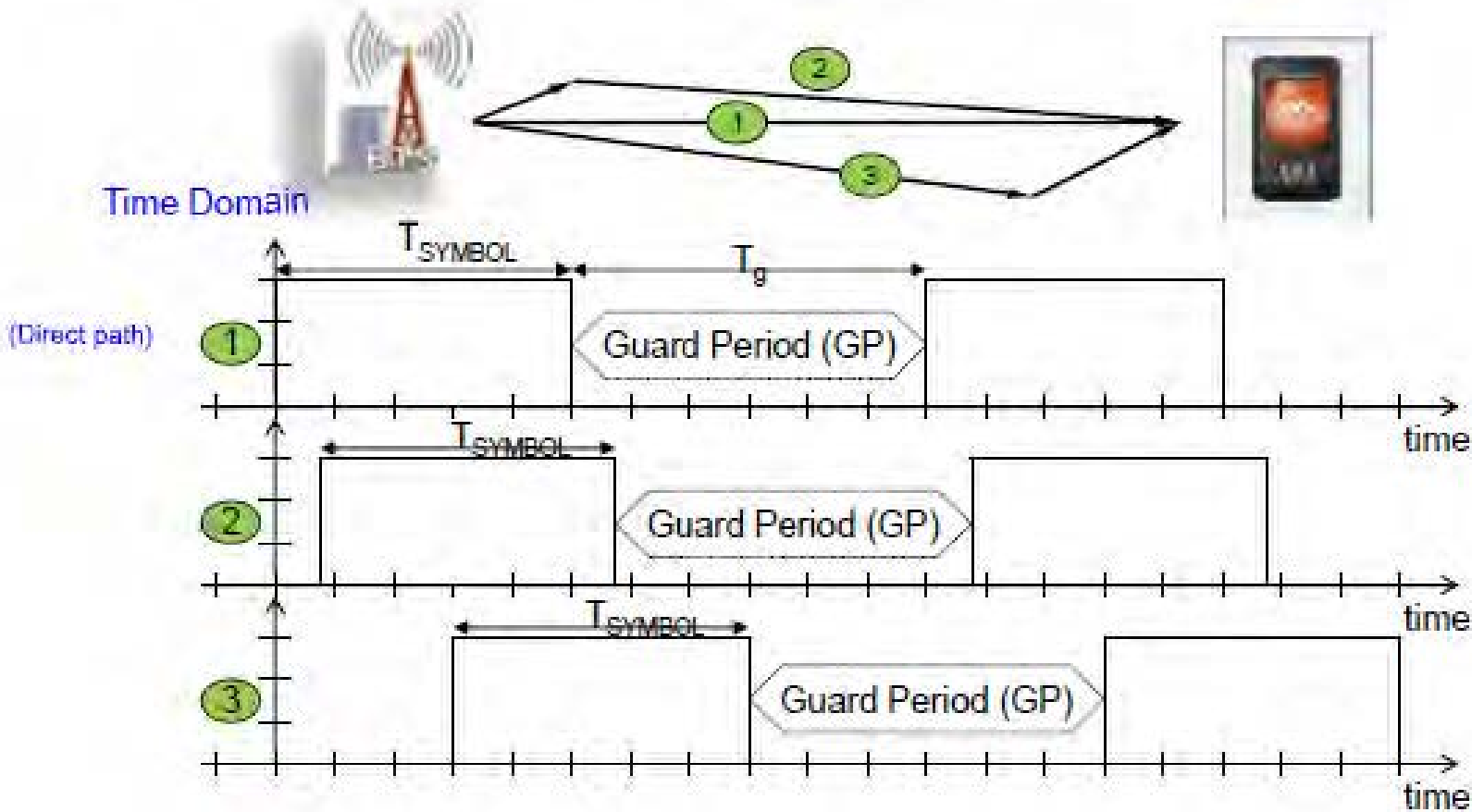
Multi-Path Propagation and Inter-Symbol Interference



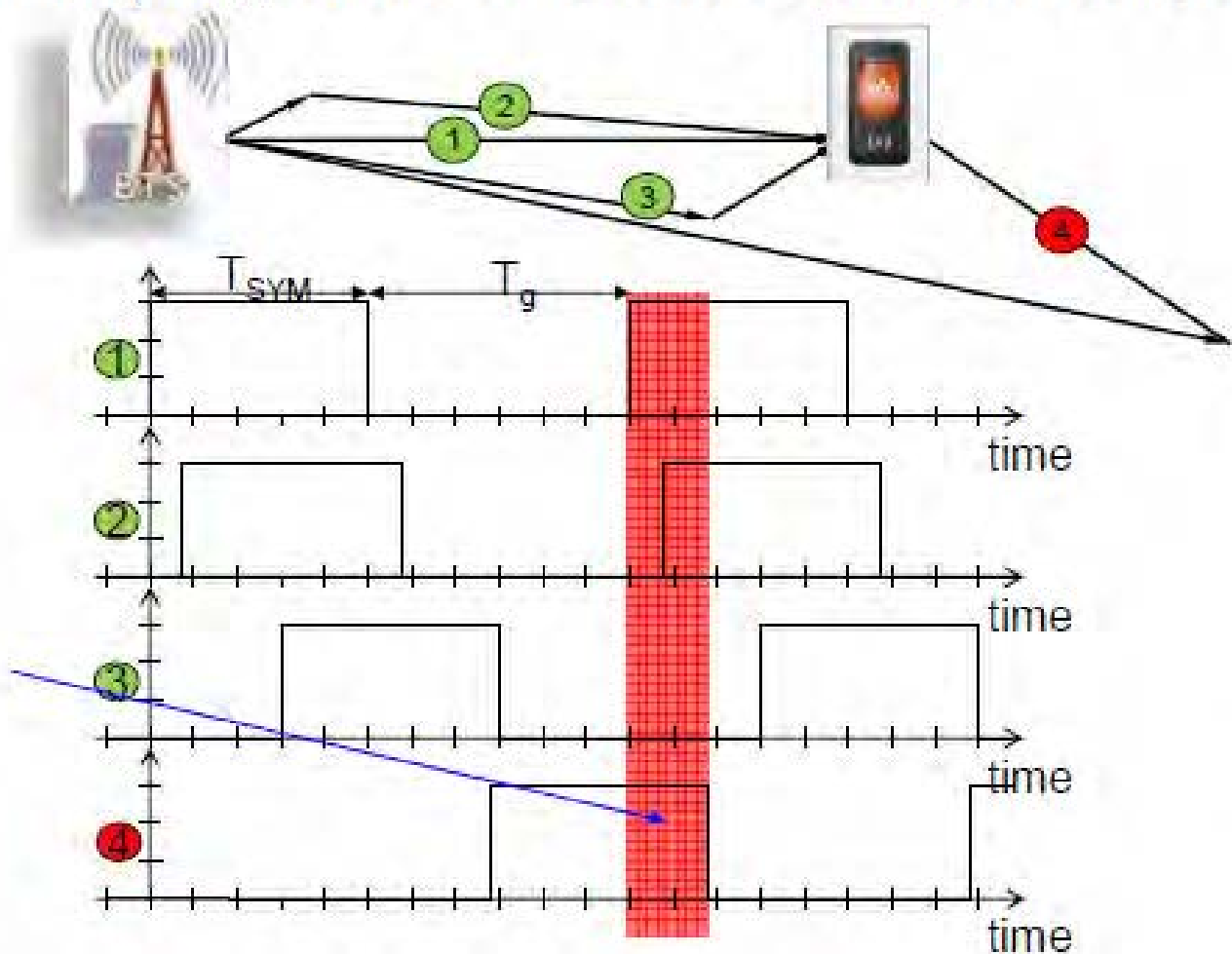
Multi-Path Propagation and Inter-Symbol Interference

- The cancellation of inter-symbol interference makes more complex the hardware design of the receivers.
- In WCDMA for instance the RAKE receiver requires a huge amount of DSP capacity.
- One of the goals of future radio systems is to simplify receiver design.
- Inter-symbol interference originating from the pulse form itself is simply avoided by starting the next pulse only after the previous one finished completely, therefore introducing a Guard Period (T_g) after the Pulse.
- There is no inter-symbol interference between symbols as long as the multi-path delay spread (e.g. delay difference between first and last detectable path) is less than the guard period duration T_g .

Multi-Path Propagation and the Guard Period



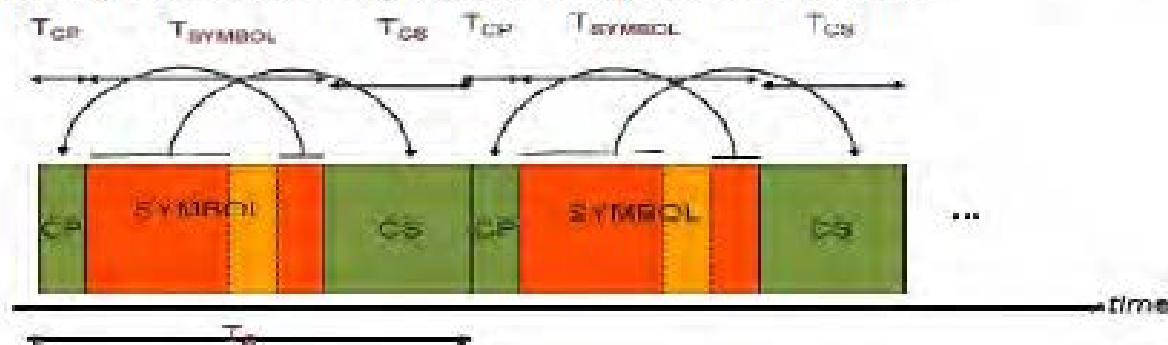
Multi-Path Propagation and the Guard Period



when the delay spread of the multi-path environment is greater than the guard period duration (T_g), then we encounter inter-symbol interference (ISI)

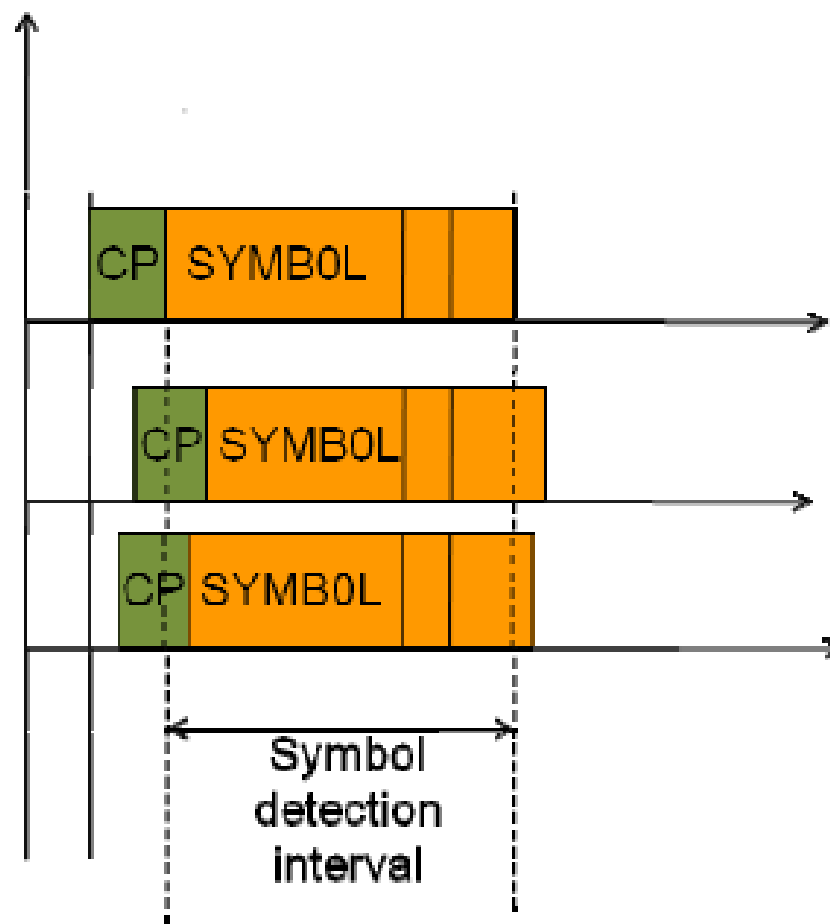
Reuse of the Guard Period

- There is the possibility to use the lost transmission time during the Guard Period by repeating part of the symbol during this period.
- This is achieved by filling the guard period with either one or both of the following two solutions: Cyclic Prefix (CP) and Cyclic Suffix (CS).
- CP: The cyclic prefix is filling the final part of the guard period. It simply consists of the last part of the following symbol. Cyclic prefixes are used by all modern OFDM systems and their sizes range from $1/4$ to $1/32$ of a symbol period.
- CS: The cyclic suffix fills the initial part of the guard period and it is simply occupied by the beginning part of the previous symbol.



Cyclic Prefix

- In multi-path propagation environments the delayed versions of the signal arrive with a time offset, so that the start of the symbol of the earliest path falls in the cyclic prefixes of the delayed symbols.
- As the CP is simply a repetition of the end of the symbol this is not a inter-symbol interference and can be easily compensated by the following decoding based on discrete Fourier transform.



Limitations of the Single-Carrier Modulation

- Using a single radio frequency carrier with rectangular pulse shaping has a major drawback:
- The cyclic prefix duration is fixed by the maximum expected delay spread over the multi-path propagation models for the system.

$$\text{delay}_{\max} = T_{CP}$$

- The symbol duration can be made as small as the cyclic prefix size, but then only one half of the time is used for data transmission, the other half is for the cyclic prefix, providing a very low efficiency (E)

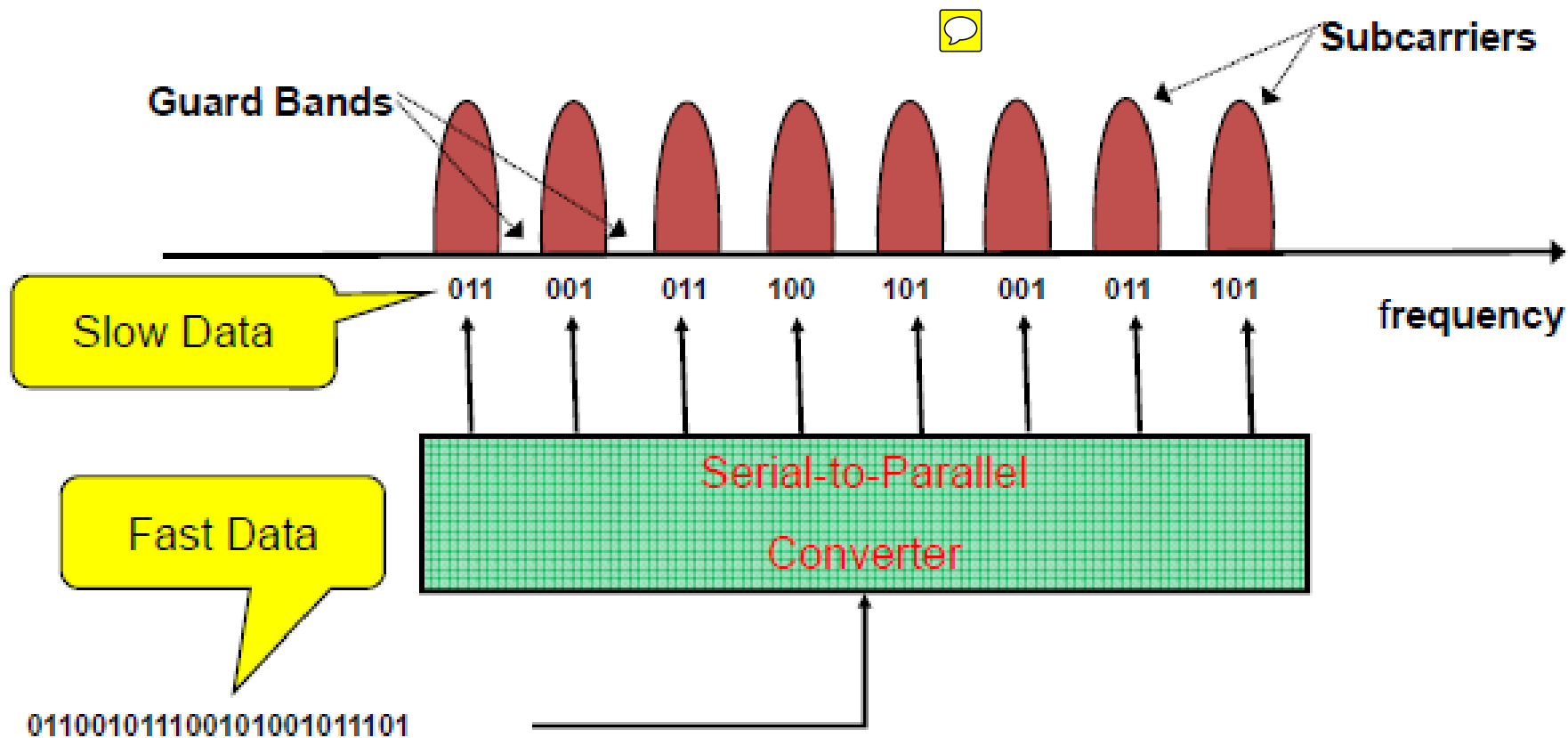
$$E = \frac{T_{SYMBOL}}{T_{SYMBOL} + T_{CP}}$$

- Also shorter symbol duration mean a broader spectrum bandwidth (f_s) to be used for a carrier.

$$f_s = \frac{1}{T_s} = \frac{1}{T_{SYMBOL} + T_{CP}}$$

- To increase efficiency the symbol duration must be made longer, but then the symbol rate is reduced.

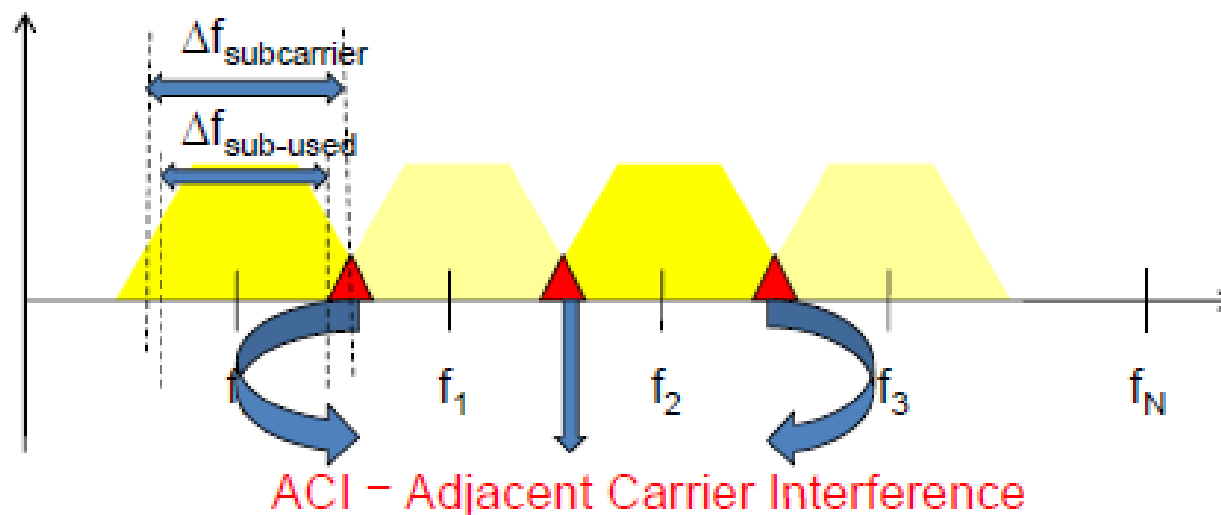
Multi-Carrier Modulation



Multi-Carrier Modulation –Cont.

The center frequencies must be spaced so that interference between different carriers, known as **Adjacent Carrier Interference ACI**, is minimized; but not too much spaced as the total bandwidth will be wasted.

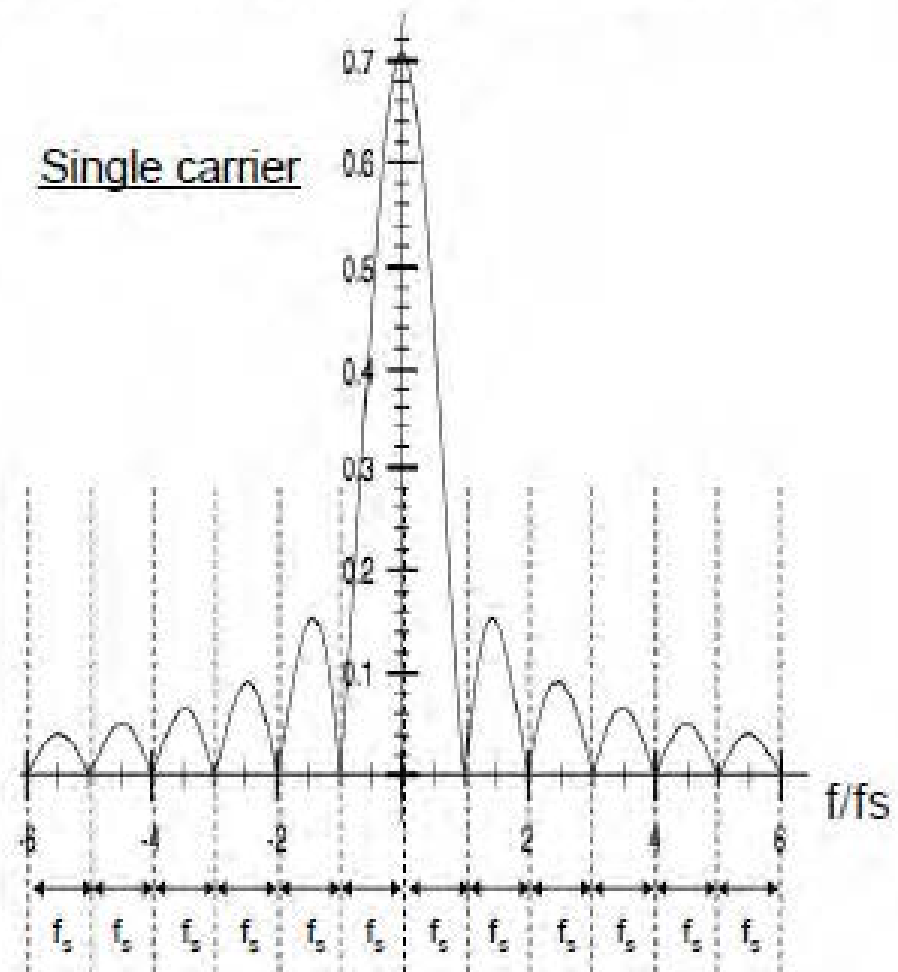
Each carrier uses an upper and lower guard band to protect itself from its adjacent carriers. Nevertheless, there will always be some interference between the adjacent carriers.



OFDM: Orthogonal Frequency Division Multi-Carrier

- For the rectangular pulse there is a better option possible and it is even easier to implement.
- We must just notice that the spectrum of a rectangular pulses shows null points exactly at integer multiples of the frequency given by the symbol duration.
- The only exception is the center frequency (peak power)

Single carrier

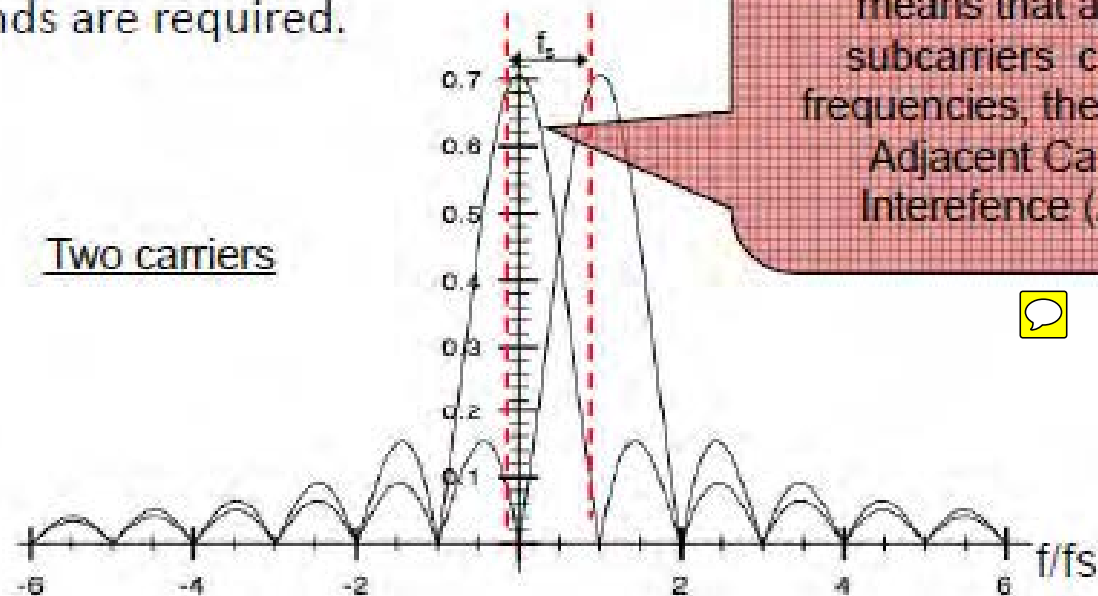


OFDM: Orthogonal Frequency Division Multi-Carrier

Thus OFDM simply places the next carrier exactly in the first null point of the previous one.

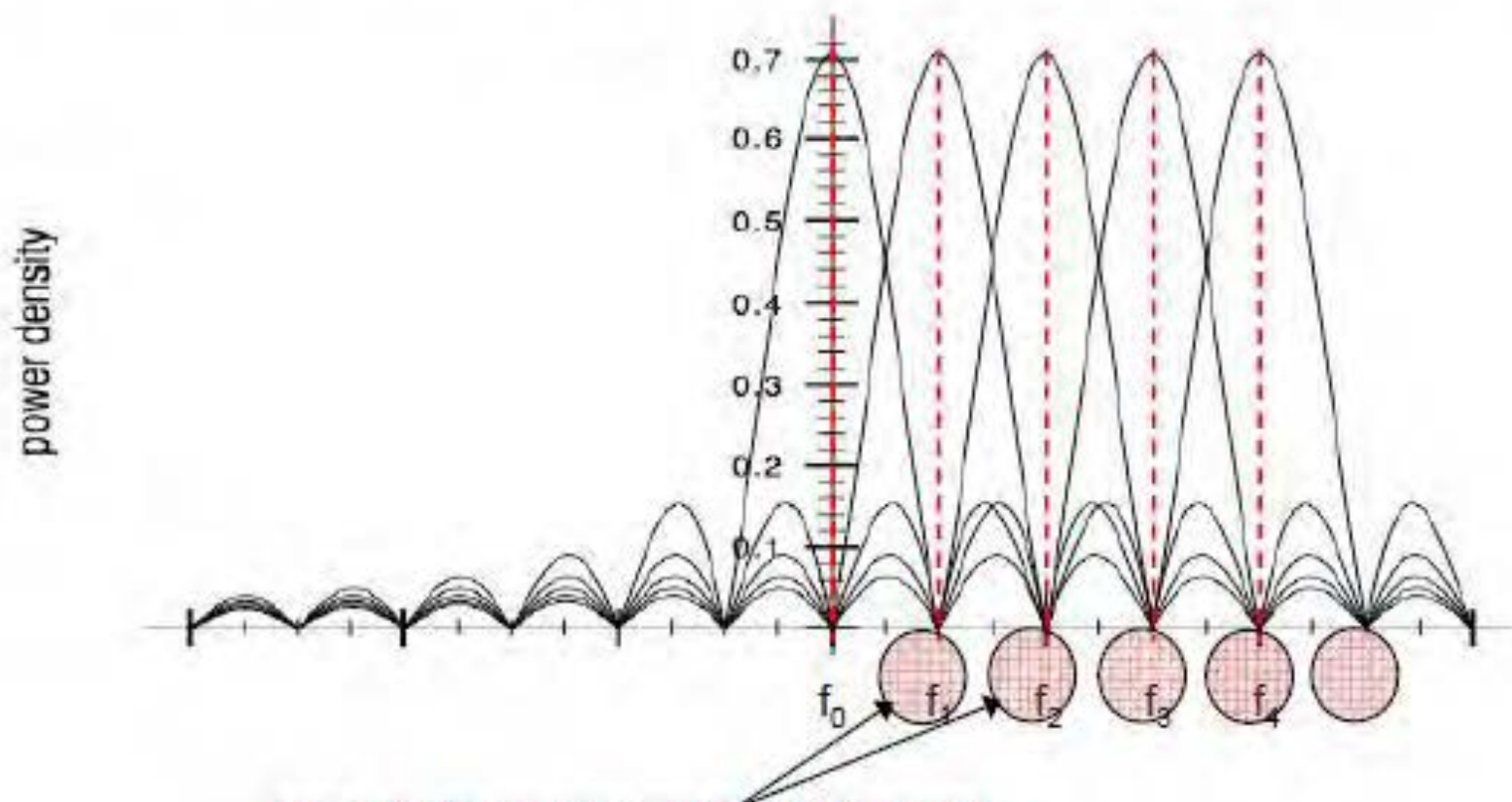
With this we don't need any pulse-shaping.

Between OFDM carriers using the same symbol duration T_s , no guard bands are required.



Spectrum Overlapping of multiple OFDM carriers

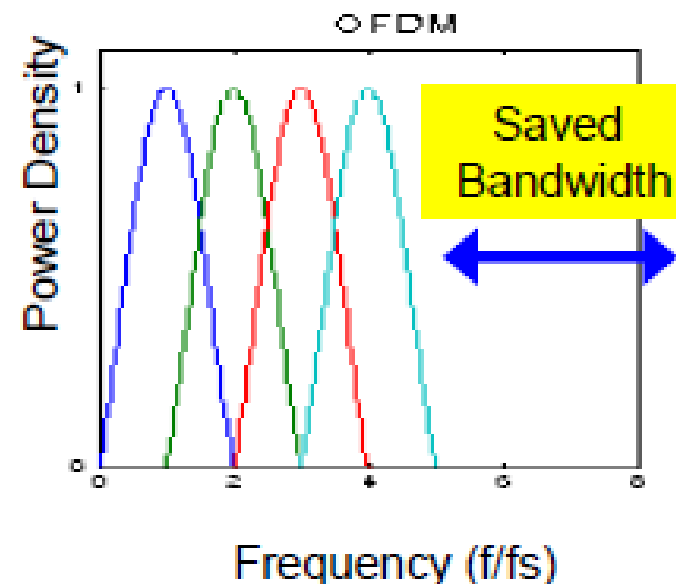
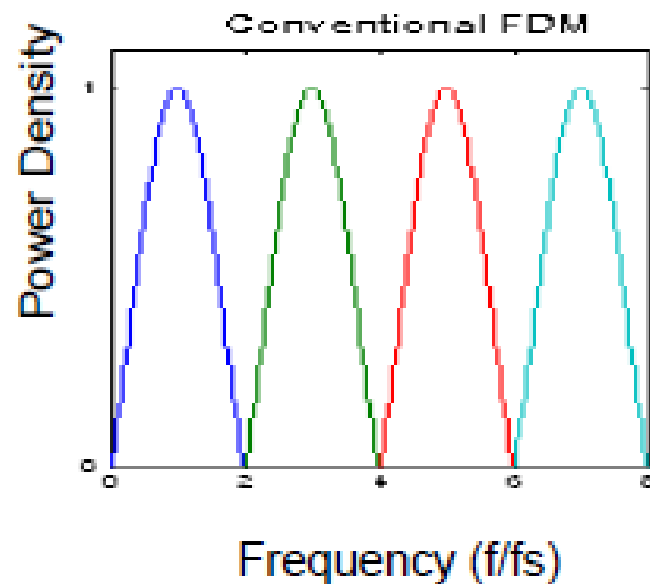
$$f_n = f_0 + n f_s = f_0 + n \frac{1}{T_s} \quad n = \dots, -1, 0, 1, 2, \dots$$



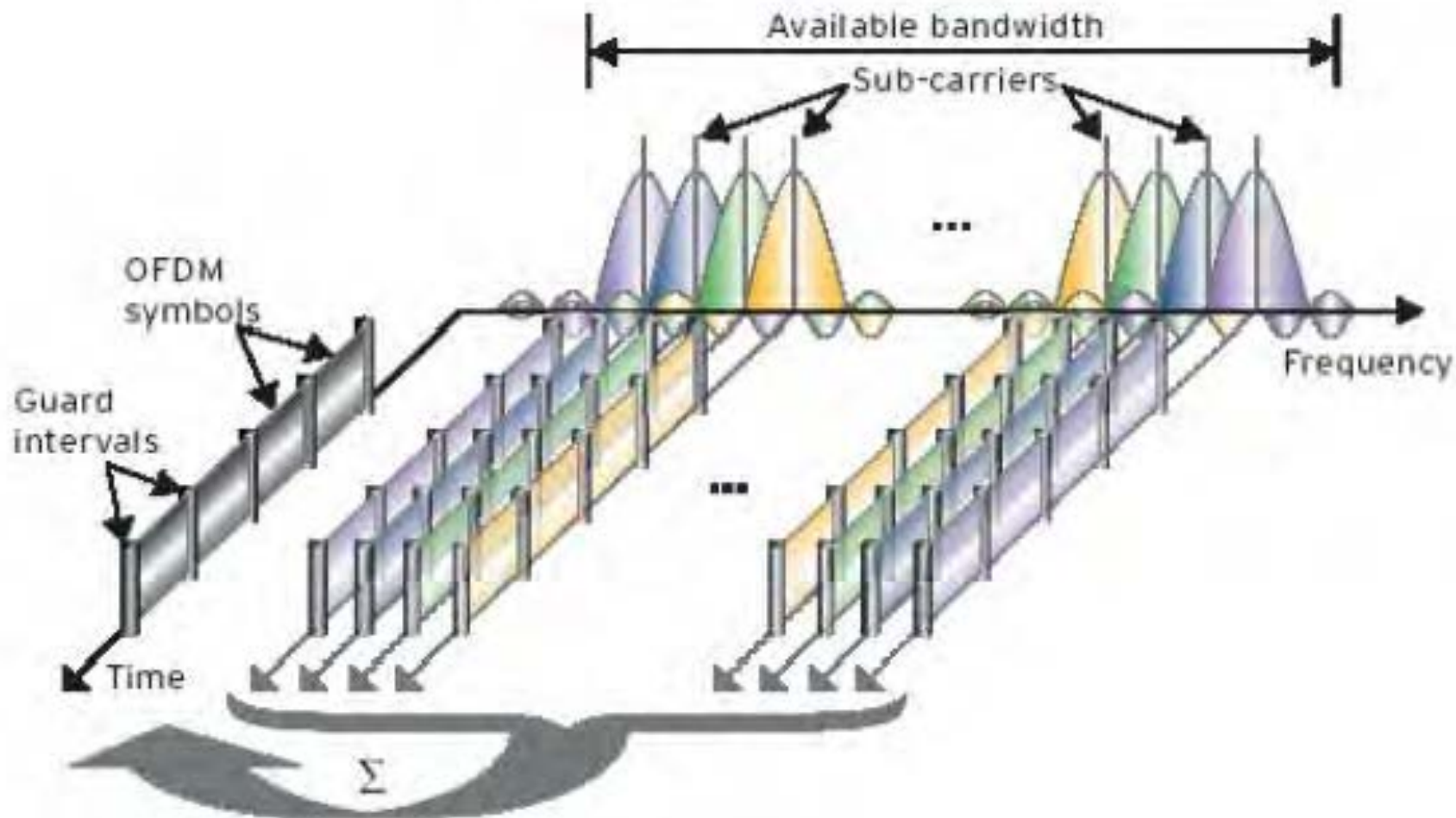
No ACI (Adjacent Carrier Interference)

OFDM: Orthogonal Frequency Division Multi-Carrier

OFDM allows a tight packing of small carrier - called the **subcarriers** into a given frequency band.



The OFDM Signal

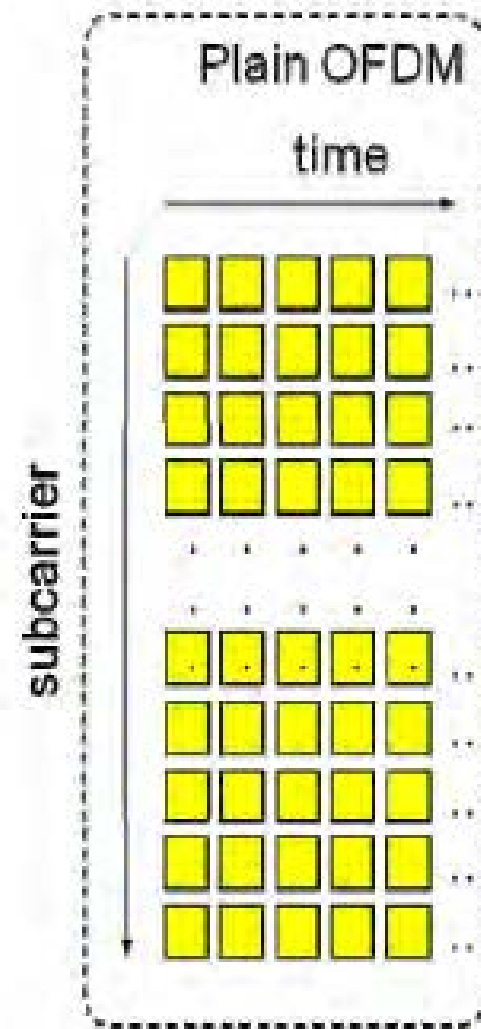


OFDM and Multiple Access

- Up to here we have only discussed simple point-to-point or broadcast OFDM.
- Now we have to analyze how to handle access of multiple users simultaneously to the system, each one using OFDM.
- OFDM can be combined with several different methods to handle multi-user systems:
 - Plain OFDM
 - Time Division Multiple Access via OFDM
 - Orthogonal Frequency Division Multiple Access OFDMA

Plain OFDM

- **Plain OFDM:** Normal OFDM has no built-in multiple-access mechanism.
- This is suitable for broadcast systems like DVB-T/H which transmit only broadcast and multicast signals and do not really need an uplink feedback channel (although such systems exist too).



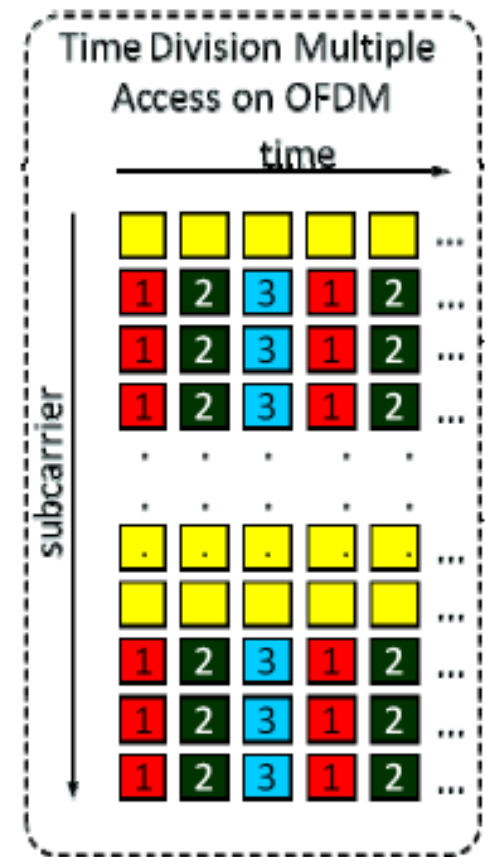
Time Division Multiple Access via OFDM

Time Division Multiple Access via

OFDM: The simplest model to implement multiple access handling is by putting a time multiplexing on top of OFDM.

The disadvantage of this simple mechanism is, that every user gets the same amount of capacity (subcarriers) and it is thus rather difficult to implement flexible (high and low) bit rate services.

Furthermore it is nearly impossible to handle highly variable traffic (e.g. web traffic) efficiently without too much higher layer signaling and the resulting delay and signaling overhead.



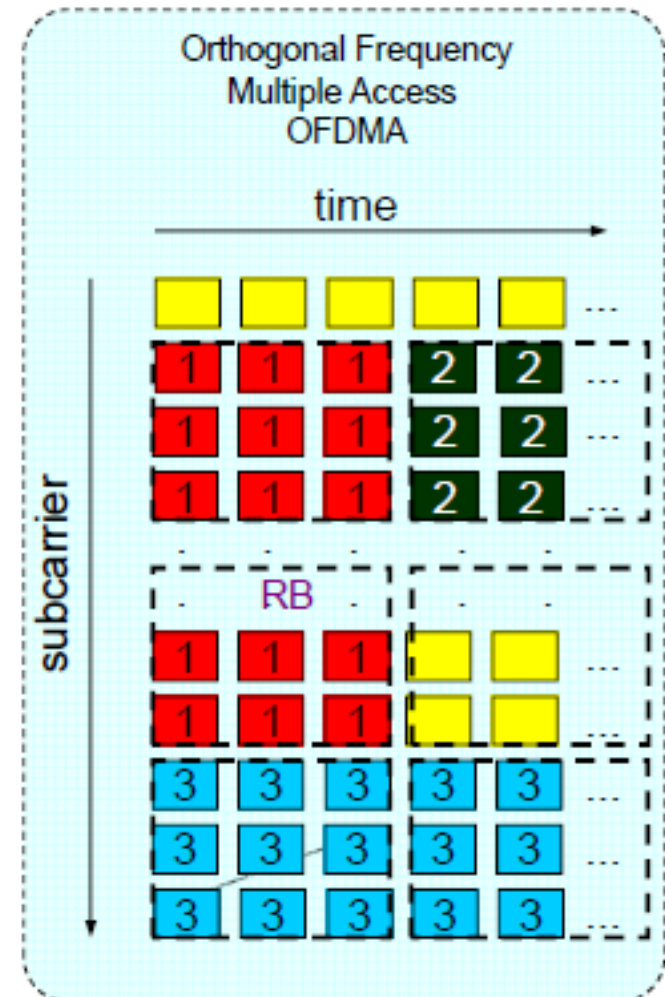
1 UE 1 2 UE 2 3 UE 3 common info

Orthogonal Frequency Division Multiple Access OFDMA

The basic idea is to assign subcarriers to users based on their bit rate services. With this approach it is quite easy to handle high and low bit rate users simultaneously in a single system. But still it is difficult to run highly variable traffic efficiently. The solution to this problem is to assign to a single users so called **resource blocks** or **scheduling blocks**.

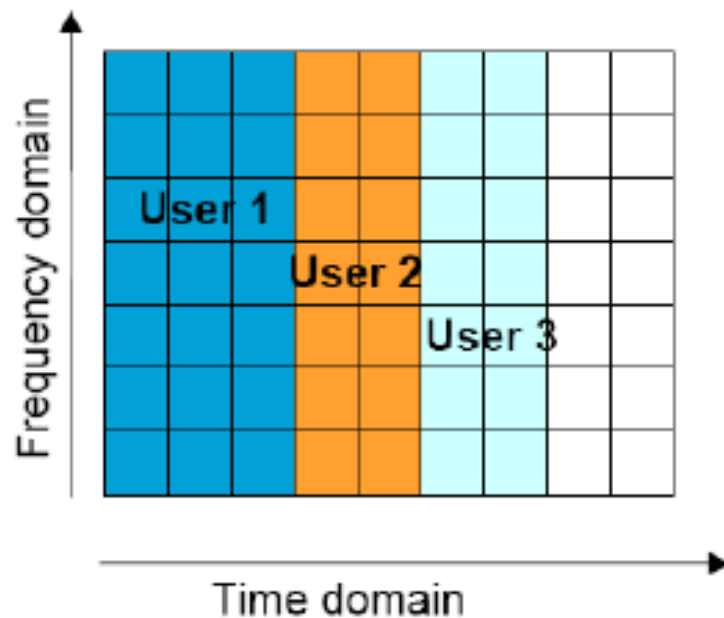
Such block is simply a set of some subcarriers over some time. A single user can then use one or more Resource blocks.

1 UE 1 2 UE 2 3 UE 3 common info

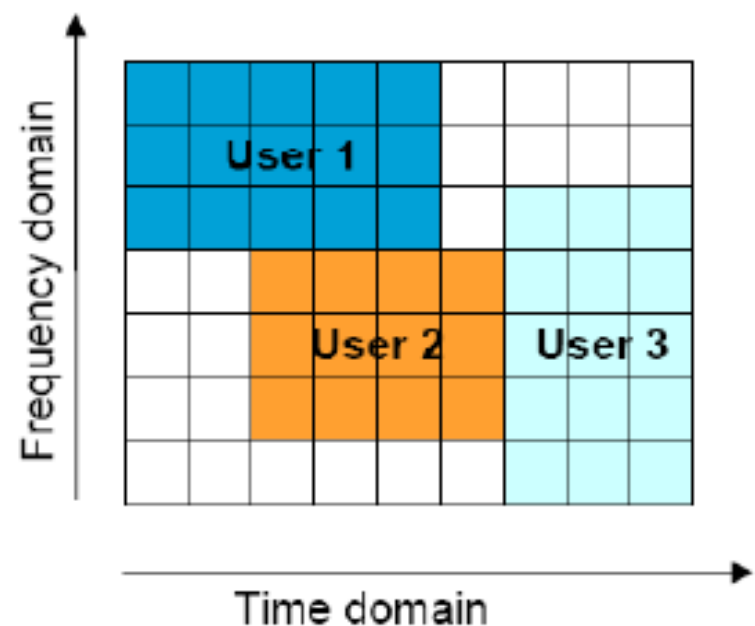


Difference between OFDM and OFDMA

OFDM allocates users in time domain only



OFDMA allocates users in time and frequency domain



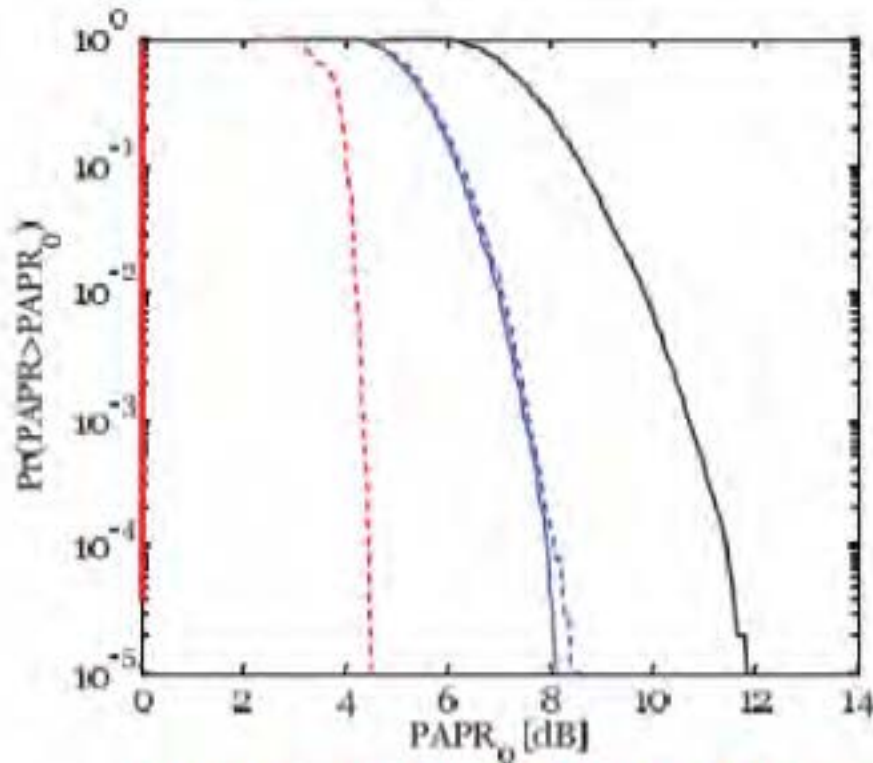
SC-FDMA

- SC-FDMA :Single Carrier Frequency Division Multiple Access
- SC-FDMA is a new hybrid modulation scheme that cleverly combines the low PAR of single-carrier systems with the multipath resistance and flexible subcarrier frequency allocation offered by OFDM.
- SC FDMA solves this problem by grouping together the resource blocks in such a way that reduces the need for linearity, and so power consumption, in the power amplifier. A low PAPR also improves coverage and the cell-edge performance.
- SC-FDMA signal processing has some similarities with OFDMA signal processing, so parameterization of DL and UL can be harmonized.
- SC-FDMA is one option in WiMAX (802.16d) and it is the method selected for LTE in the uplink direction.

Comparison of CCDF of PAPR for IFDMA, LFDMA and OFDMA

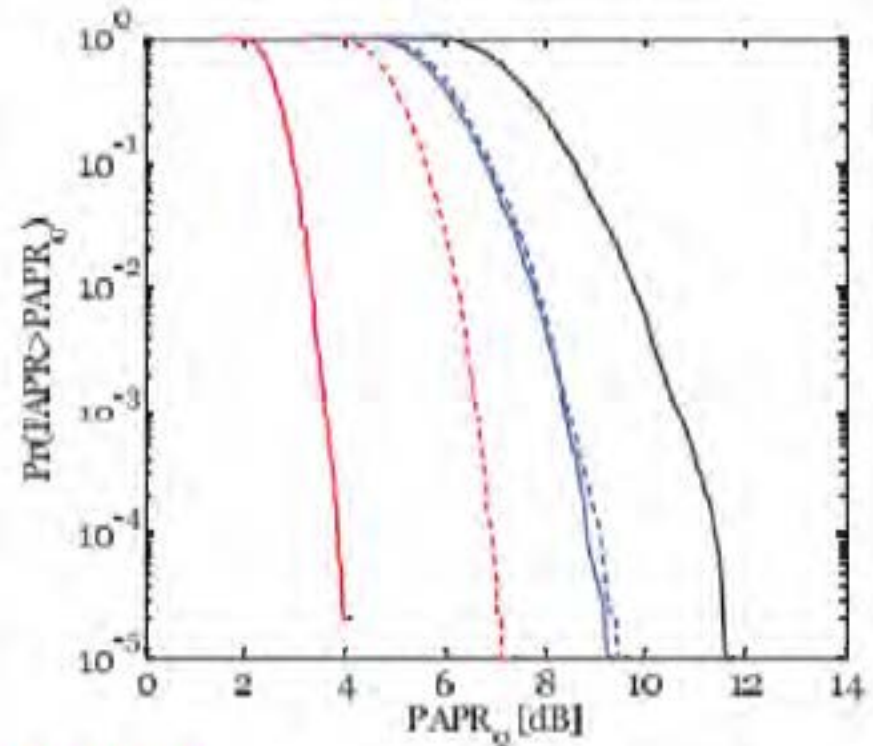
(a) :QPSK

(a)



(b) :16QAM

localized mode (LFDMA)
is used in LTE
(b)

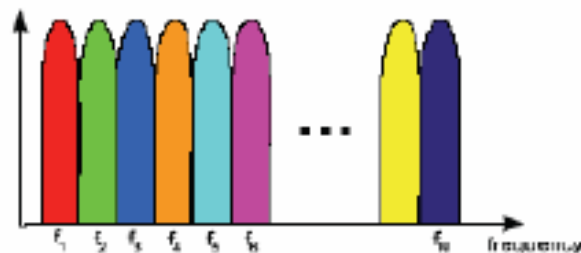


IFDMA = "Interleaved FDMA" = Distributed SC-FDMA

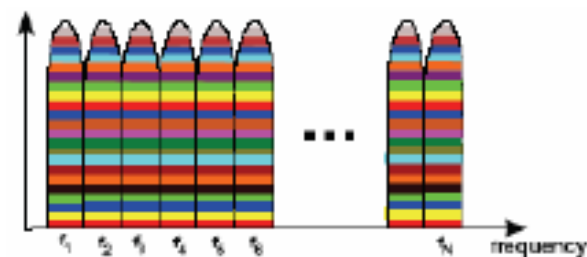
LFDMA = "Localized FDMA" = Localized SC-FDMA

How does a SC-FDMA signal look like?

- Similar to OFDM signal, but...
 - in OFDMA, each sub-carrier only carries information related to one specific symbol,
 - in SC-FDMA, each sub-carrier contains information of ALL transmitted symbols.

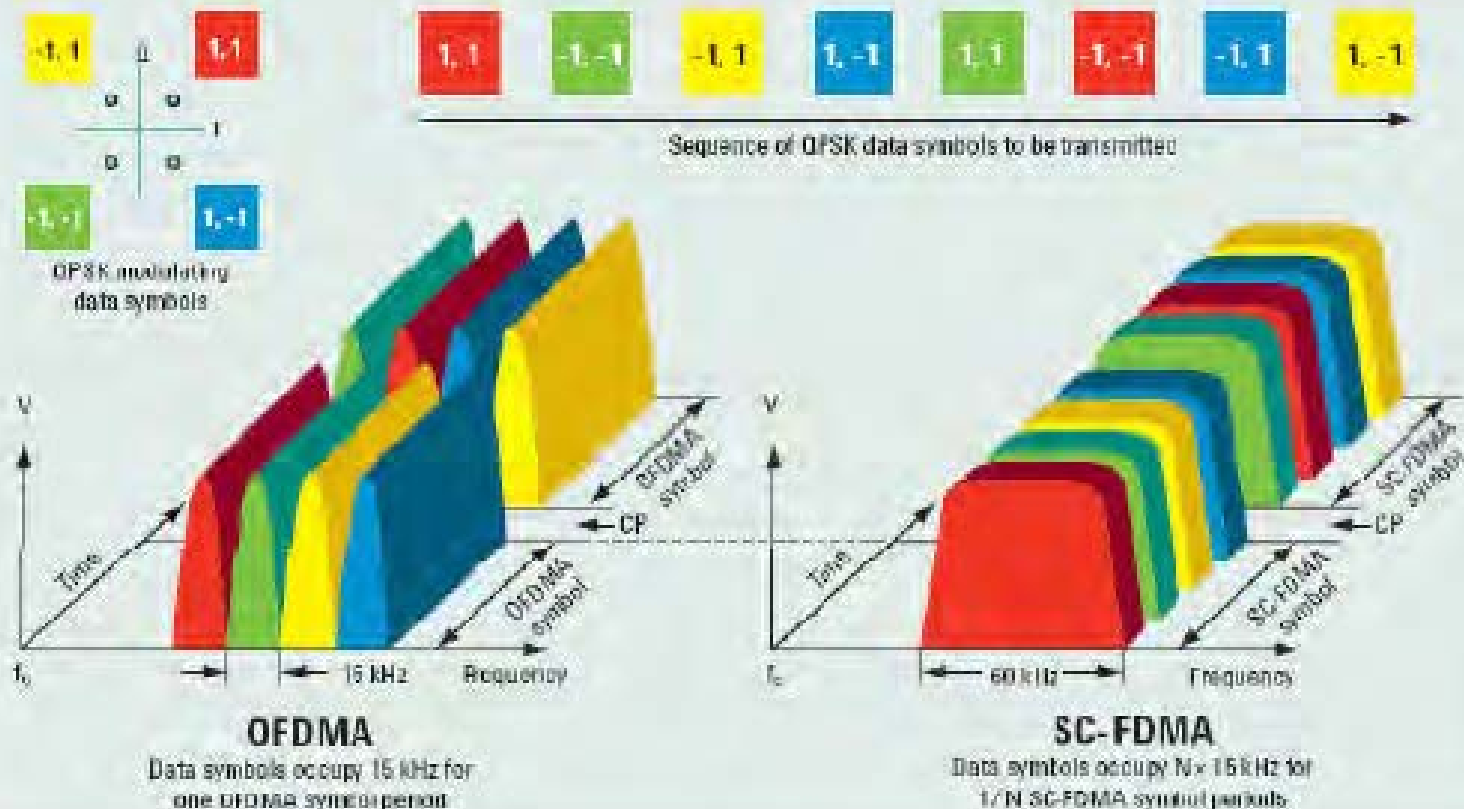


(a) OFDM subcarriers

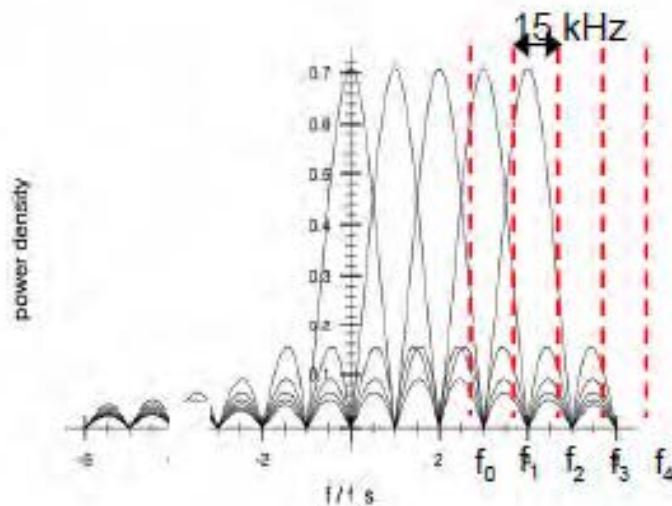
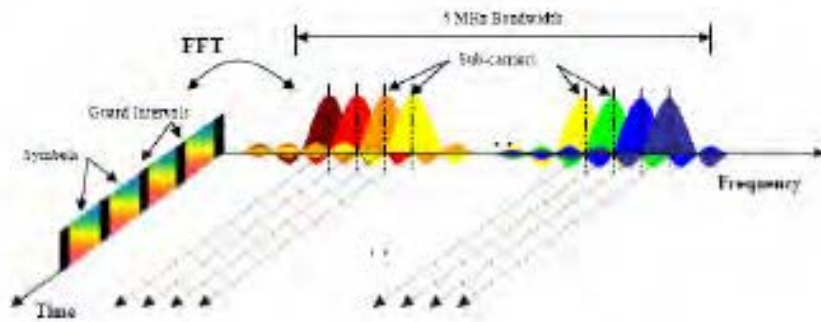


(b) DFT-s-OFDM subcarriers

Comparing OFDMA & SC-FDMA

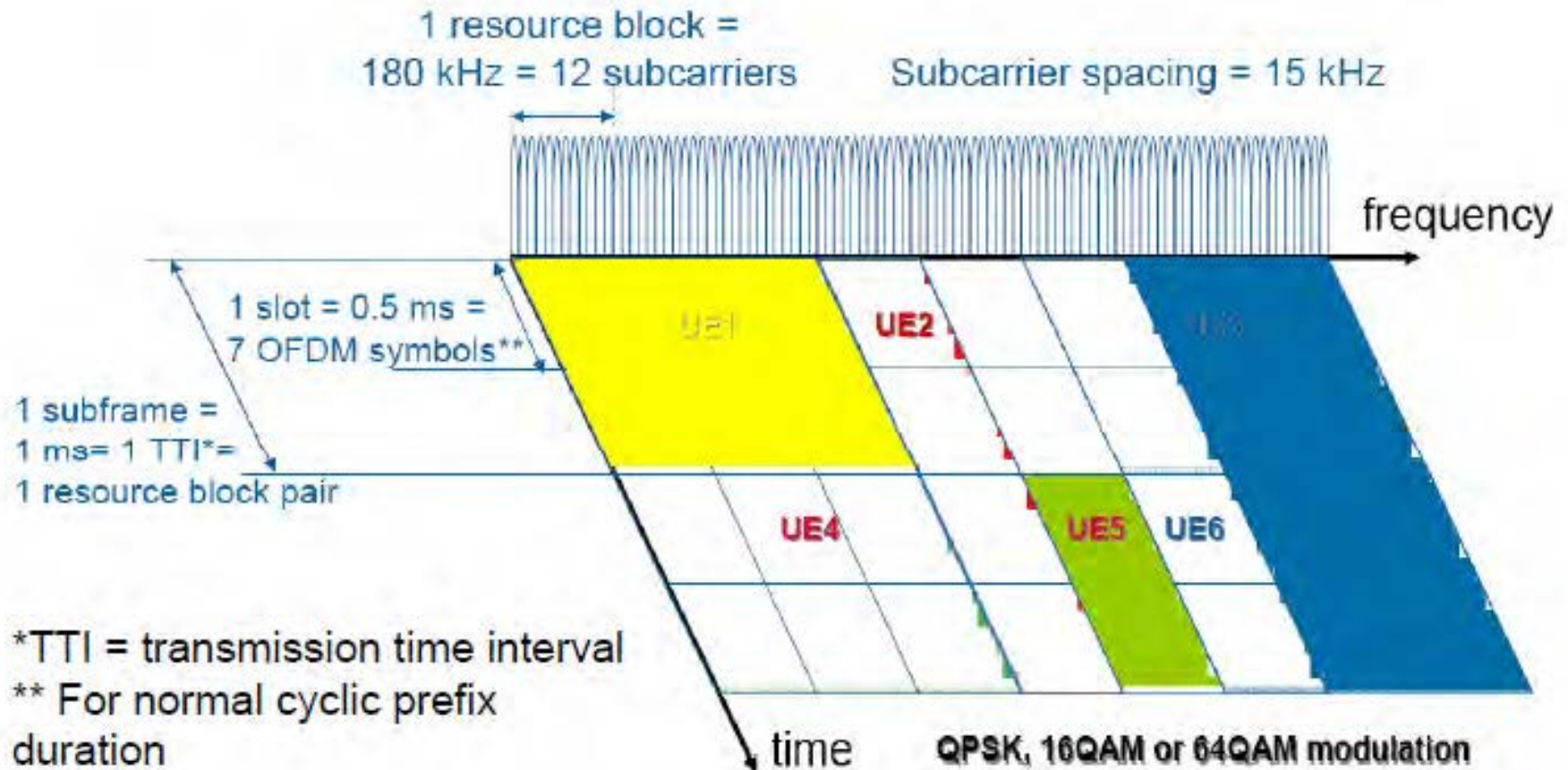


LTE downlink : conventional OFDMA

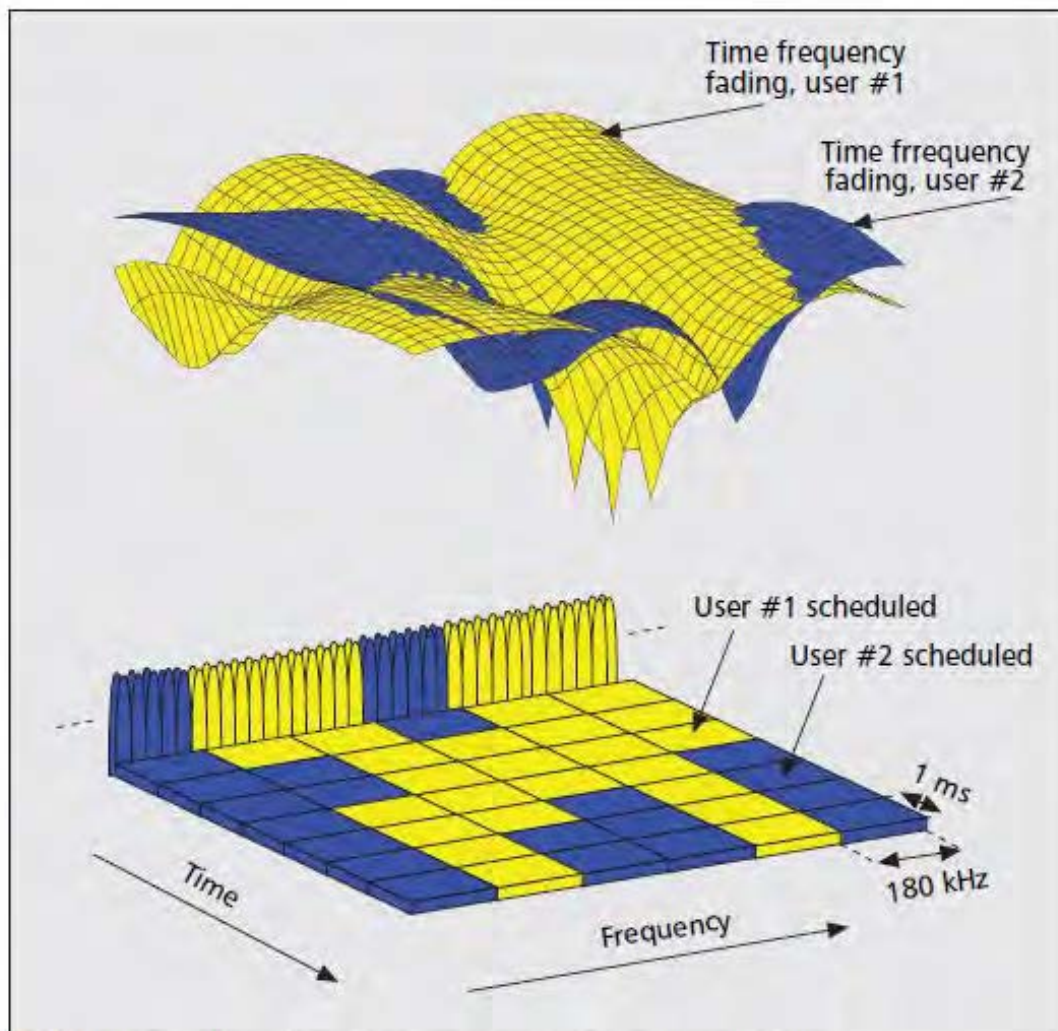


- LTE provides QPSK, 16QAM, 64QAM as downlink modulation schemes
- Cyclic prefix is used as guard interval, different configurations possible:
 - Normal cyclic prefix with $5.2 \mu\text{s}$ (first symbol) / $4.7 \mu\text{s}$ (other symbols)
 - Extended cyclic prefix with $16.7 \mu\text{s}$
- 15 kHz subcarrier spacing
- Scalable bandwidth

OFDMA time-frequency multiplexing



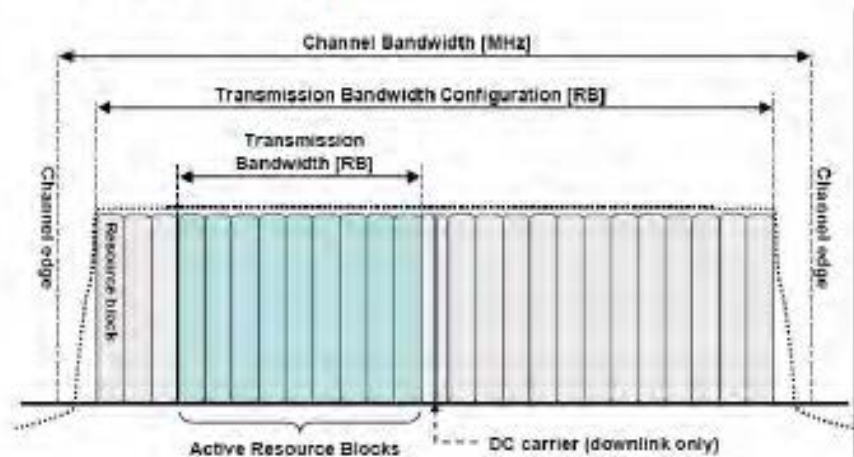
OFDMA: adapts to fading



■ Figure 3. Channel-quality variations in frequency and time.

Spectrum flexibility

- LTE physical layer supports any bandwidth from 1.4 MHz to 20 MHz in steps of 180 kHz (resource block)
- Current LTE specification supports a subset of 6 different system bandwidths
- All UEs must support the maximum bandwidth of 20 MHz



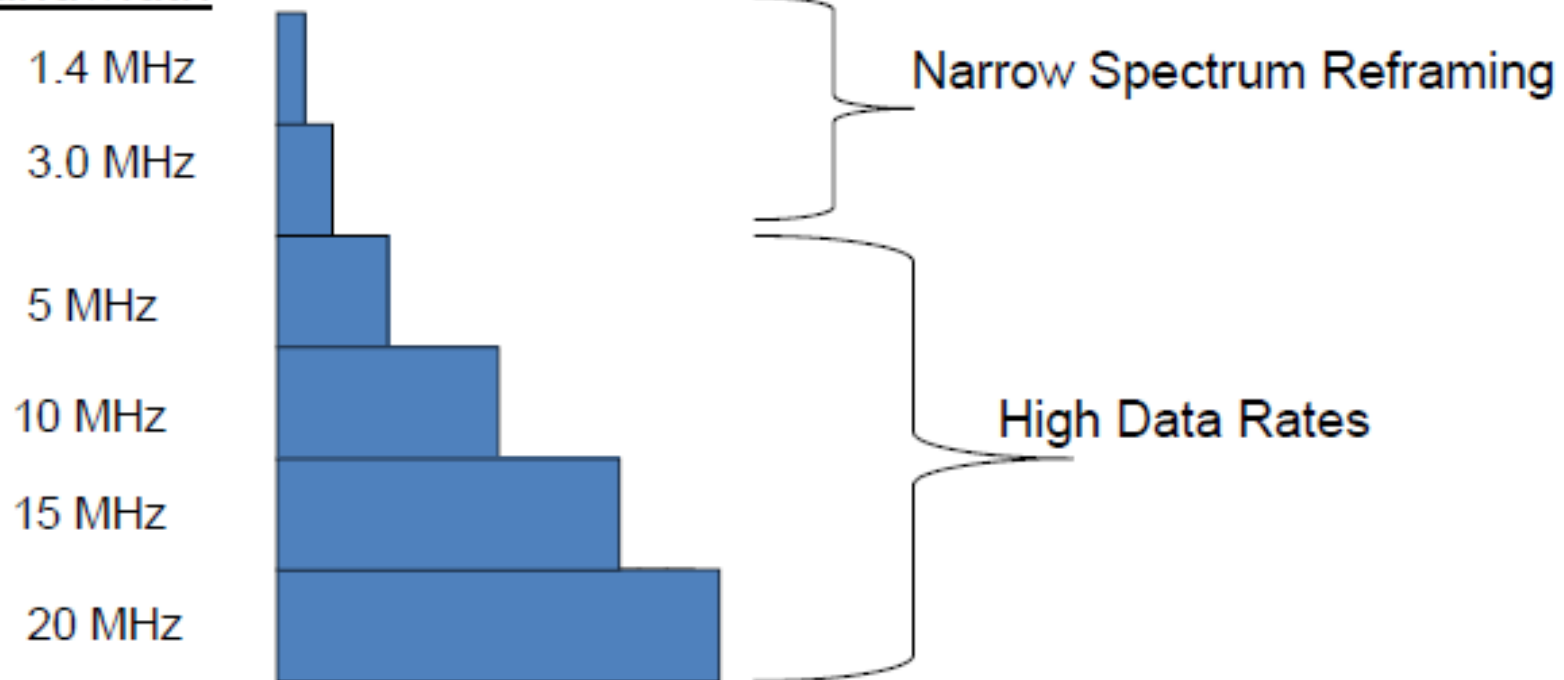
Channel BW [MHz]	1.4	3	5	10	15	20
Number of RBs	6	15	25	50	75	100

Bandwidth Scalability

Scalable bandwidth 1.4 – 20 MHz using different number of subcarriers

Large bandwidth provides high data rates Small bandwidth allows simpler spectrum reframing, e.g. 450 MHz and 900 MHz

Bandwidth



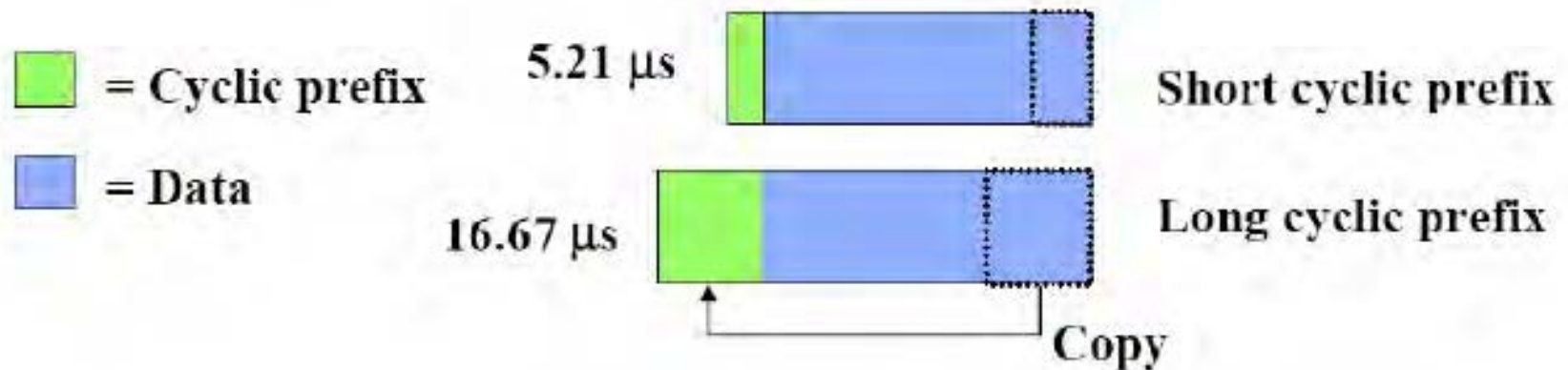


LTE Frame Structure

- LTE frames are 10 msec in duration. They are divided into 10 subframes, each subframe being 1.0 msec long. Each subframe is further divided into two slots, each of 0.5 msec duration. Slots consist of either 6 or 7 OFDM symbols, depending on whether the normal or extended cyclic prefix is employed

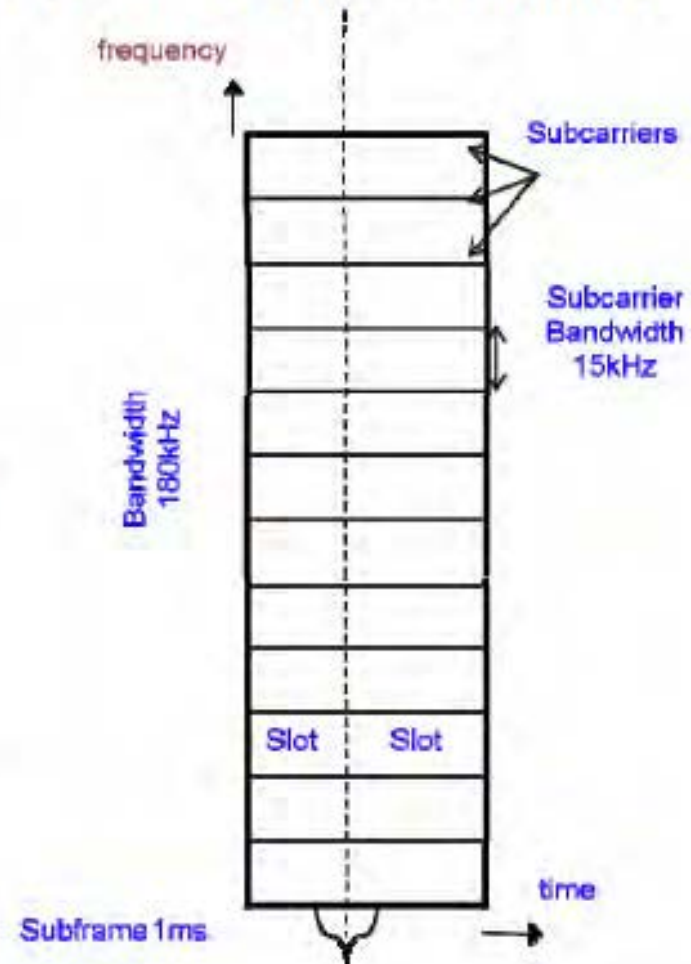
LTE Slot

- The LTE Slot carries:
 - 7 symbols with short cyclic prefix
 - 6 symbols with long prefix



OFDM Resource Block for LTE/EUTRAN

- EUTRAN combines OFDM symbols in so called resource blocks RB.
- A single resource block is always 12 consecutive subcarriers during one subframe (2 slots, 1 ms):
 - $12 \text{ subcarriers} * 15 \text{ kHz} = 180 \text{ kHz}$
- It is the task of the scheduler to assign resource blocks to physical channels belonging to different users or for general system tasks.
- A single cell must have at least 6 resource blocks (72 subcarriers) and up to 110 are possible (1320 subcarriers).

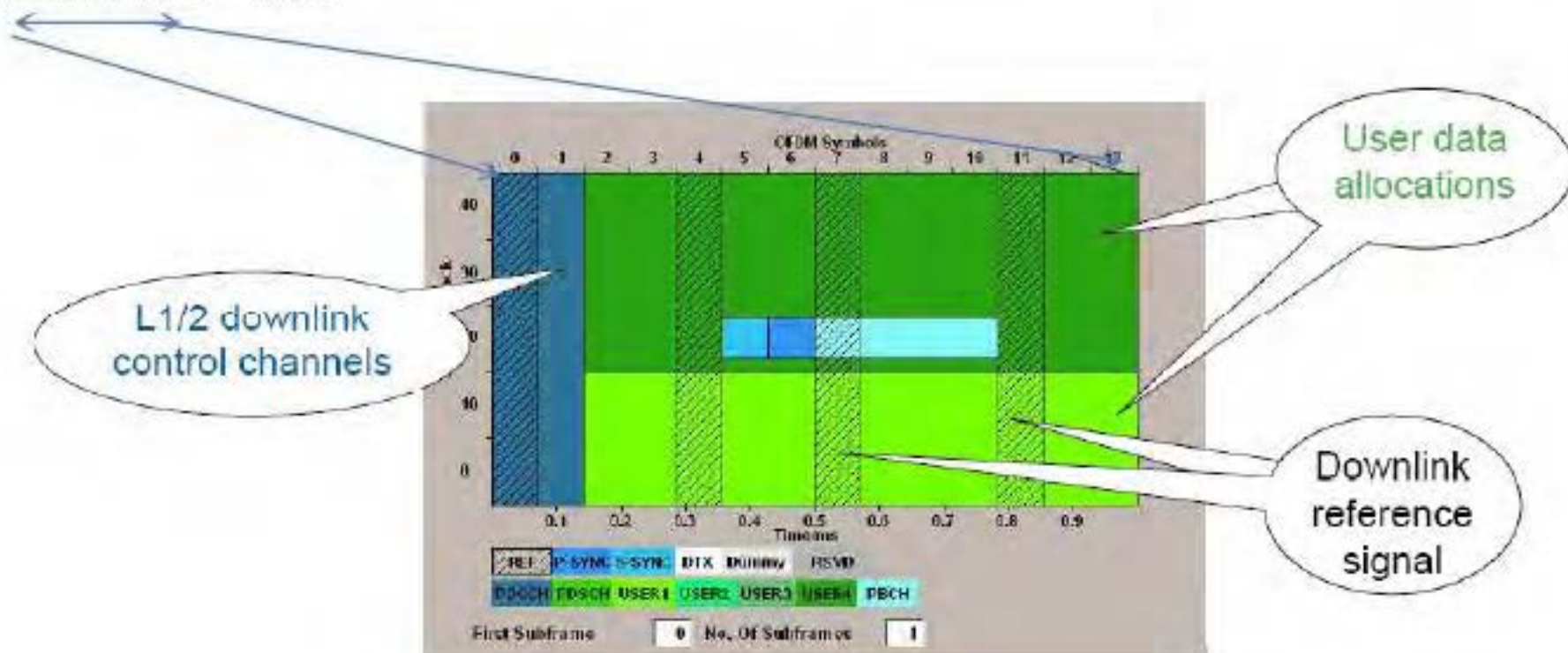


LTE DL frame structure type 1 (FDD), DL

#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19

↔ 1 slot = 0.5 ms

1 subframe = 1 ms

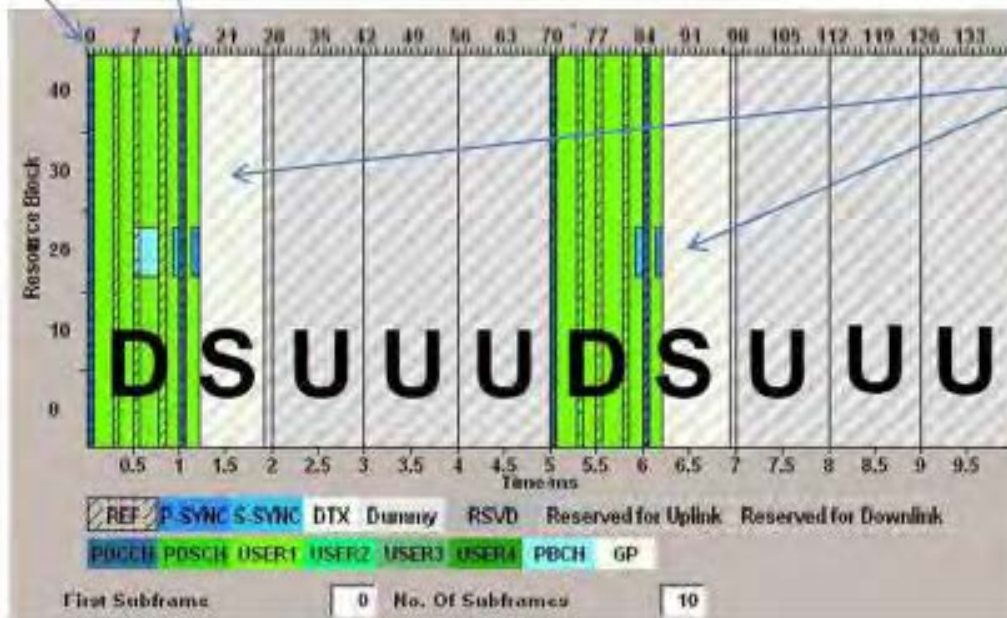


LTE DL frame structure type 2 (TDD)

1 subframe = 1 ms

1 slot = 0.5 ms

#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19



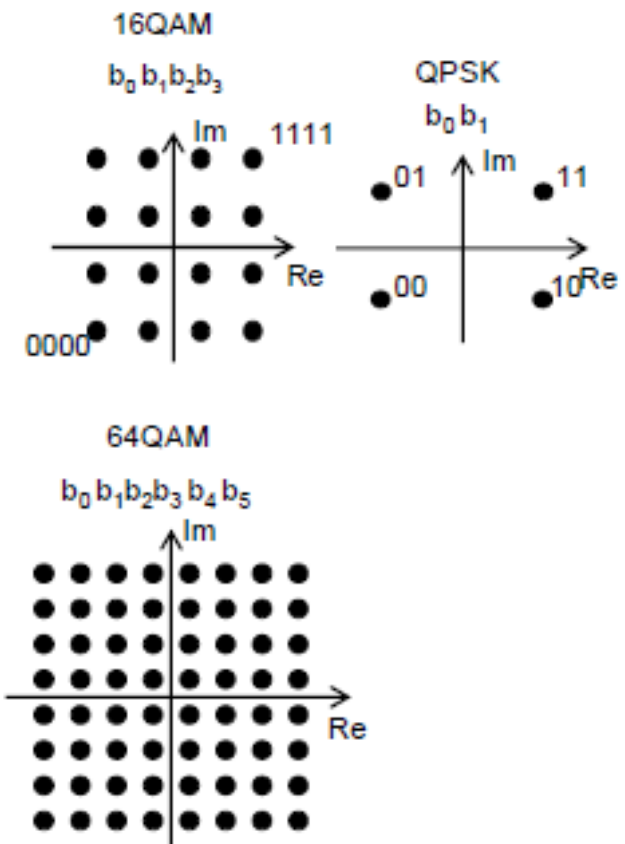
Special subframes containing:
DwPTS: downlink pilot time slot
UpPTS: uplink pilot time slot
GP: guard period for TDD operation

Possible UL-DL configurations

UL-DL config	Subframe number									
	0	1	2	3	4	5	6	7	8	9
0	D	S	U	U	U	D	S	U	U	U
1	D	S	U	D	D	D	S	U	D	D
2	D	S	U	U	U	D	D	D	D	D
3	D	S	U	U	U	D	D	D	D	D
4	D	S	U	U	D	D	D	D	D	D
5	D	S	U	D	D	D	D	D	D	D
6	D	S	U	U	U	D	S	U	U	D

Modulation Schemes for LTE/EUTRAN

- Each OFDM symbol even within a resource block can have a different modulation scheme.
- EUTRAN defines the following options: QPSK, 16QAM, 64QAM.
- Not every physical channel will be allowed to use any modulation scheme: Control channels to be using mainly QPSK.
- In general it is the scheduler that decides which form to use depending on carrier quality feedback information from the UE.





LTE Overview – Design Targets and Multiple Access Technologies

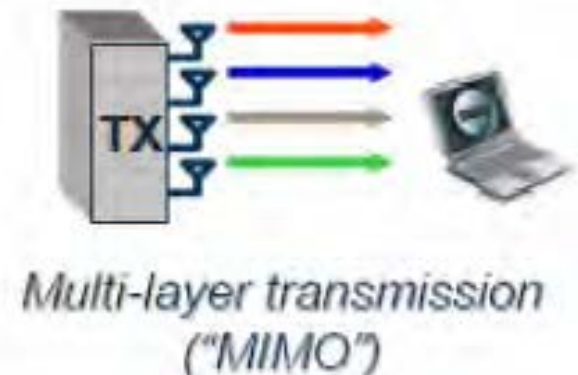
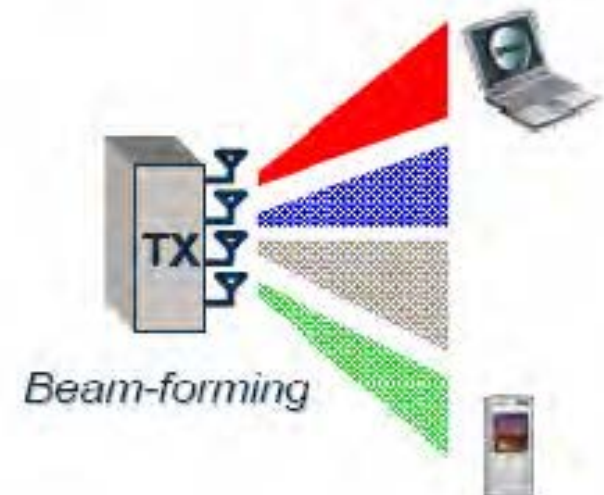
MIMO

Multiple Antenna Techniques

- MIMO employs multiple transmit and receive antennas to substantially enhance the air interface.
- It uses space-time coding of the same data stream mapped onto multiple transmit antennas, which is an improvement over traditional reception diversity schemes where only a single transmit antenna is deployed to extend the coverage of the cell.
- MIMO processing also exploits spatial multiplexing, allowing different data streams to be transmitted simultaneously from the different transmit antennas, to increase the end-user data rate and cell capacity.
- In addition, when knowledge of the radio channel is available at the transmitter (e.g. via feedback information from the receiver), MIMO can also implement beam-forming to further increase available data rates and spectrum efficiency

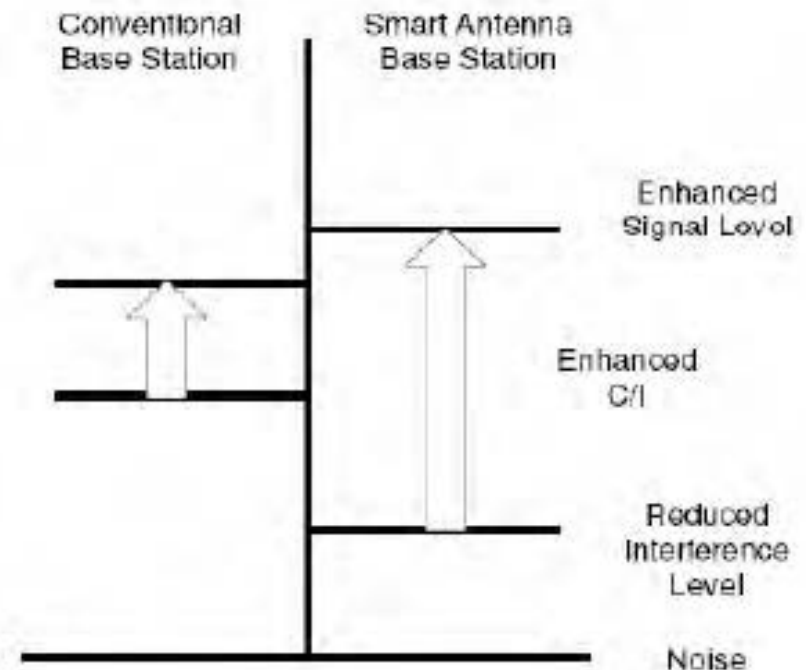
Advanced Antenna Techniques

- Single data stream / user
- Beam-forming
 - Coverage, longer battery life
- Spatial Division Multiple Access (SDMA)
 - Multiple users in same radio resource
- Multiple data stream / user Diversity
 - Link robustness
- Spatial multiplexing
 - Spectral efficiency, high data rate support



MIMO – Beamforming

- Enhances signal reception through directional array gain, while individual antenna has omni-directional gain
- Extends cell coverage
- Suppresses interference in space domain
- Enhances system capacity
- Prolongs battery life
- Provides angular information for user tracking





LTE Overview – Design Targets and Multiple Access Technologies

AIR INTERFACE PROTOCOLS

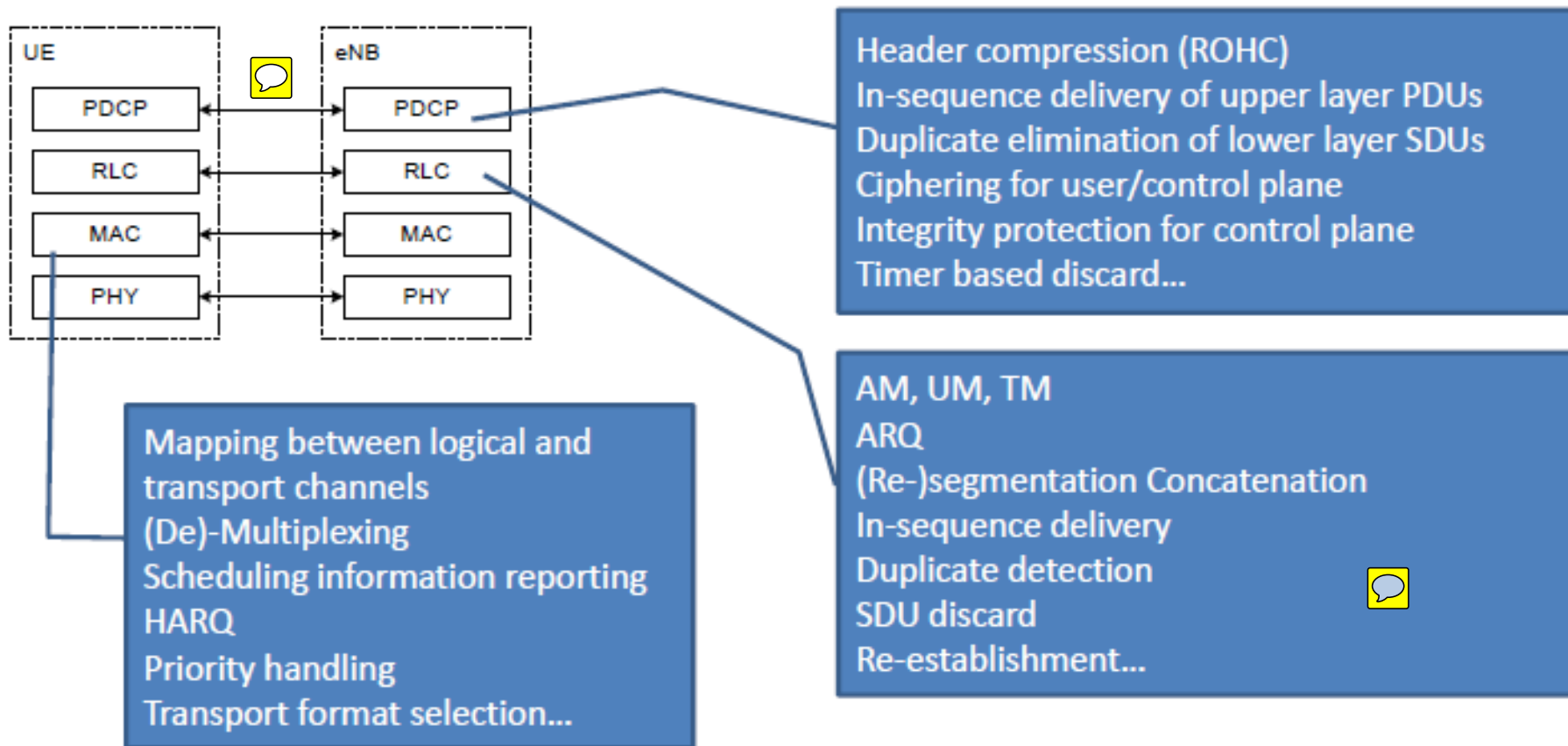


Radio Protocols Architecture

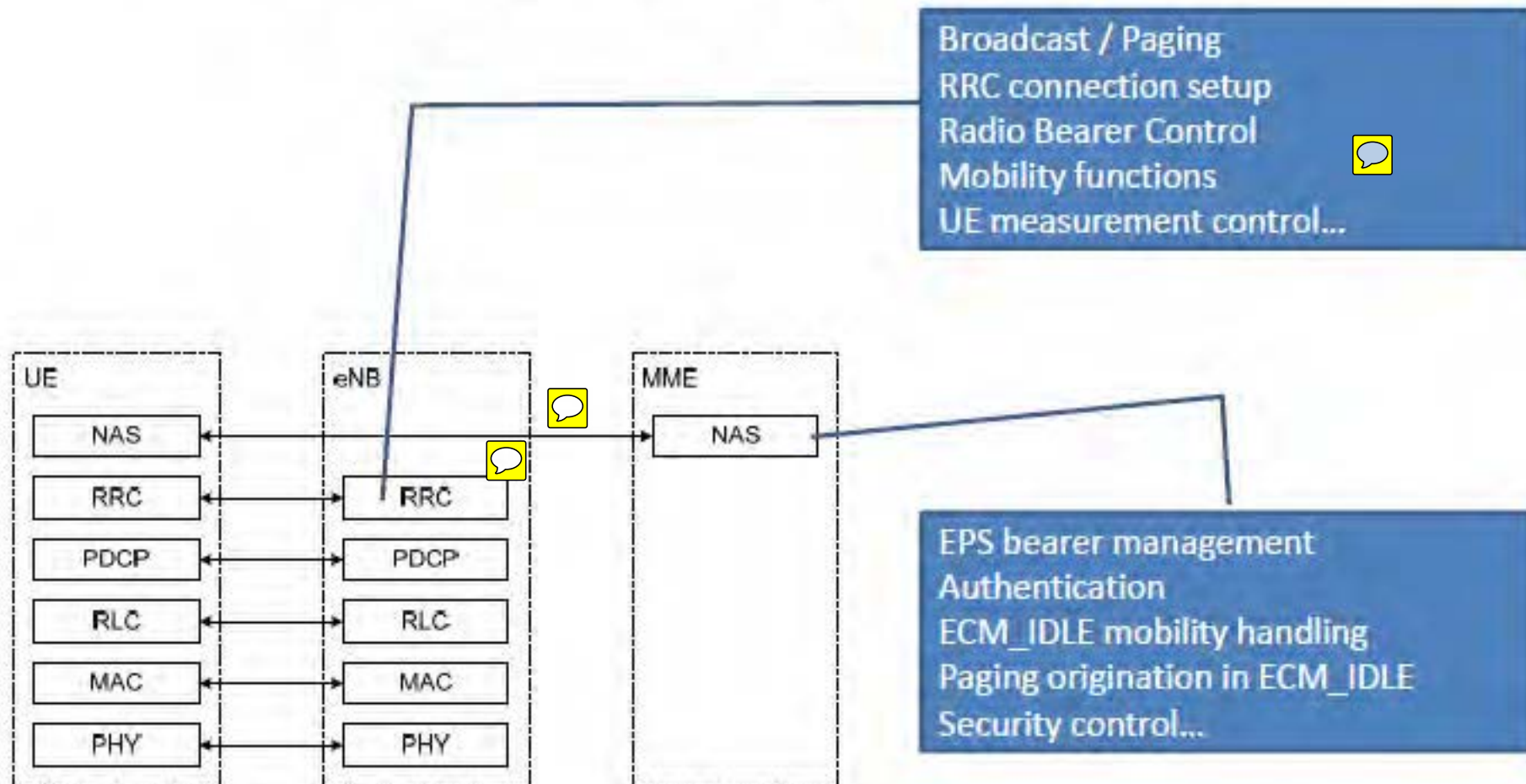
- It is quite similar to the WCDMA protocol stack of UMTS.
- The protocol stack defines three layers:
- the physical layer (layer 1)
- data link and access layer (layer 2)
- layer 3 (hosting the AS, the NAS control protocols as well and the application level)



Radio Protocol architecture- User plane



Control-plane protocol stack





Physical Layer

- It provides the basic bit transmission functionality over air.
- the physical layer is driven by OFDMA in the downlink and SC-FDMA in the uplink.
- Physical channels are dynamically mapped to the available resources (physical resource blocks and antenna ports).
- To higher layers the physical layer offers its data transmission functionality via transport channels.
- Like in UMTS a transport channel is a block oriented transmission service with certain characteristics regarding bit rates, delay, collision risk and reliability.
- in contrast to 3G WCDMA or even 2G GSM there are no dedicated transport or physical channels anymore, as all resource mapping is dynamically driven by the scheduler.

Medium Access Control (MAC)

- MAC is the lowest layer 2 protocol.
- Its main function is to drive the transport channels.
- From higher layers MAC is fed with logical channels which are in one-to-one correspondence with radio bearers.
- Each logical channel is given a priority and MAC has to multiplex logical channel data onto transport channels (demultiplexing in reception)
- Further functions of MAC will be collision handling and explicit UE identification.
- An important function for the performance is the HARQ functionality which is official part of MAC and available for some transport channel types.



Radio Link Control (RLC)

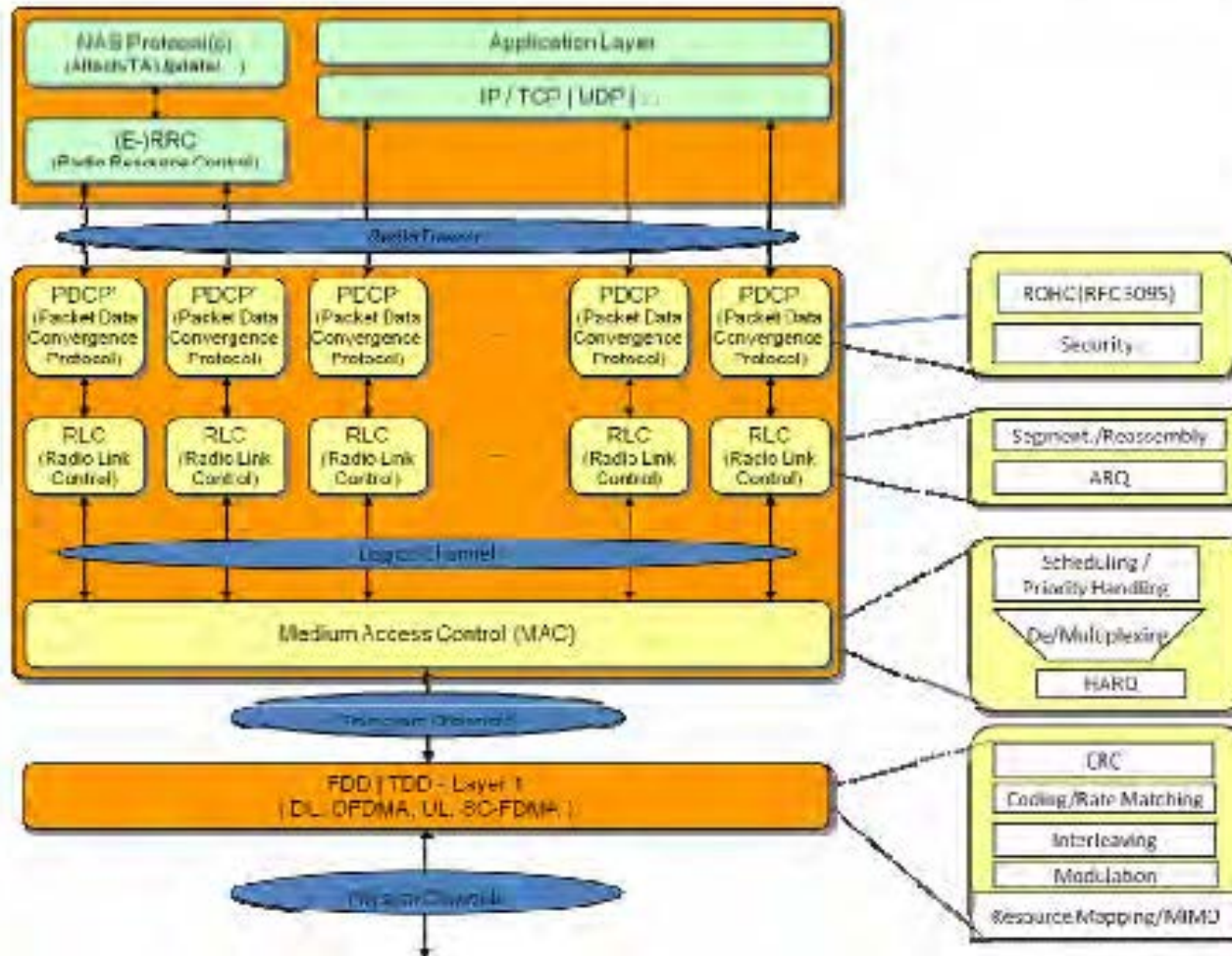
- There is a one to one relationship between each Radio Bearer and each RLC instance
- RLC can enhance the radio bearer with ARQ (Automatic Retransmission on reQuest) using sequence numbered data frames and status reports to trigger retransmission.
- The second functionality of RLC is the segmentation and reassembly that divides higher layer data or concatenates higher layer data into data chunks suitable for transport over transport channels which allow only a certain set of transport block sizes.



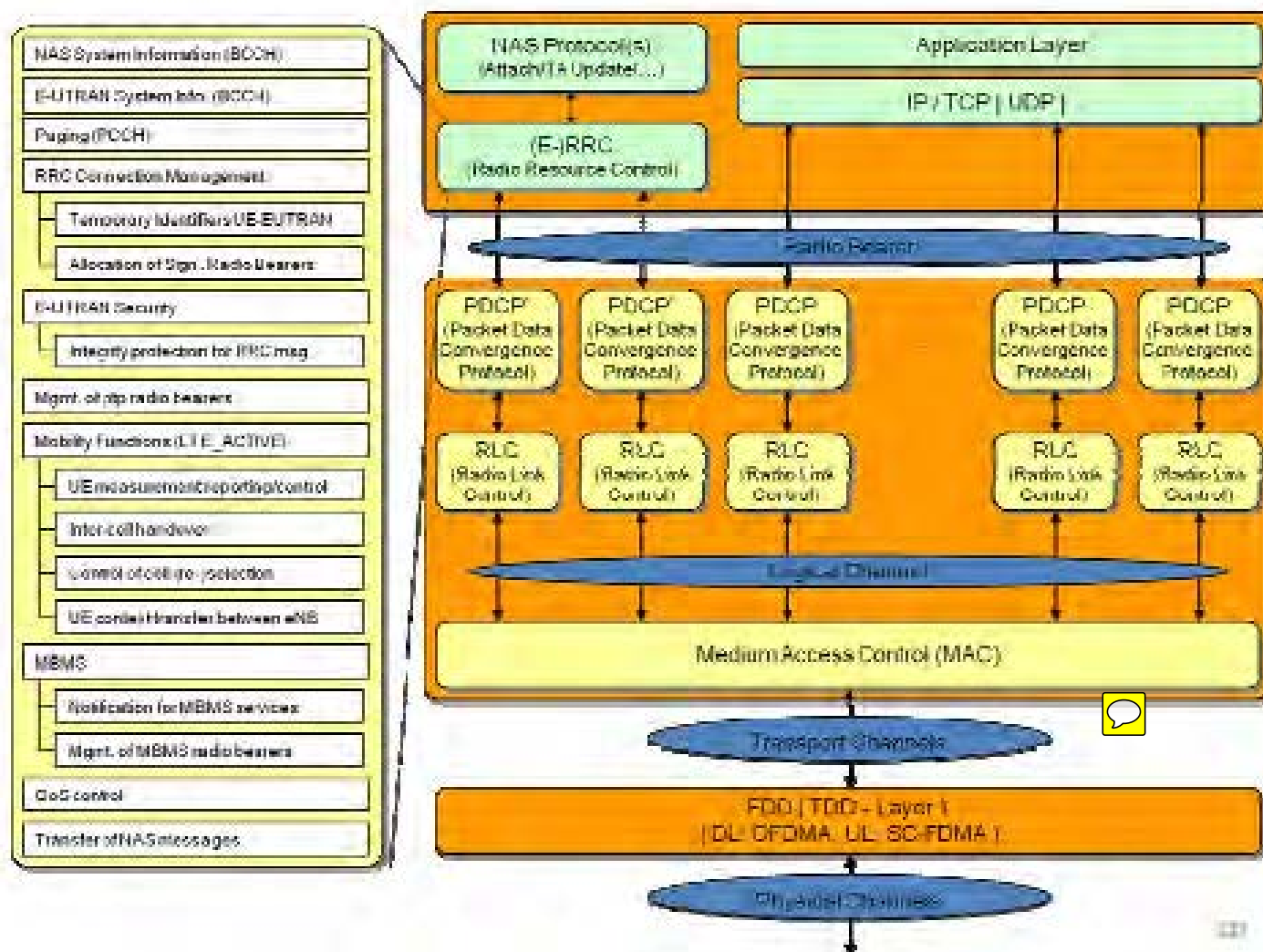
Layer 3 Radio Protocols

- PDCP (Packet Data Convergence Protocol)
 - Each radio bearer also uses one PDCP instance.
 - PDCP is responsible for header compression (ROHC: RObust Header Compression; RFC 3095) and ciphering/deciphering.
 - Obviously header compression makes sense for IP datagram's, but not for signaling. Thus the PDCP entities for signaling radio bearers will usually do ciphering/deciphering only.
- RRC (Radio Resource Control)
 - RRC is the access stratum specific control protocol for EUTRAN.
 - It will provide the required messages for channel management, measurement control and reporting, etc.
- NAS Protocols
 - The NAS protocol is running between UE and MME and thus must be transparently transferred via EUTRAN.
 - It sits on top of RRC, which provides the required carrier messages for NAS transfer

Layer 1/2 Radio Protocols – Summary



RRC Protocol



LTE MBMS Concept

- MBMS (Multimedia Broadcast Multicast Services) is an essential requirement for LTE. The so-called E-MBMS will therefore be an integral part of LTE.
- In LTE, MBMS transmissions may be performed as single-cell transmission or as multi-cell transmission. In case of multi-cell transmission the cells and content are synchronized to enable for the terminal to soft-combine the energy from multiple transmissions.
- The superimposed signal looks like multipath to the terminal. This concept is also known as Single Frequency Network (SFN).
- The E-UTRAN can configure which cells are part of an SFN for transmission of an MBMS service. The MBMS traffic can share the same carrier with the unicast traffic or be sent on a separate carrier.
- For MBMS traffic, an extended cyclic prefix is provided. In case of subframes carrying MBMS SFN data, specific reference signals are used. MBMS data is carried on the MBMS traffic channel (MTCH) as logical channel.



LTE vs WiMAX

- Both are designed to move data rather than voice and both are IP networks based on OFDM technology.
- WiMax is based on a IEEE standard (802.16), and like that other popular IEEE effort, Wi-Fi, it's an open standard that was debated by a large community of engineers before getting ratified. The level of openness means WiMax equipment is standard and therefore cheaper to buy.
- As for speeds, LTE ~~will~~ is faster than the current generation of WiMax.
- However, LTE will take time to roll out, with deployments reaching mass adoption by 2012 . WiMax is out now, and more networks should be available later this year.
- The crucial difference is that, unlike WiMAX, which requires a new network to be built, LTE runs on an evolution of the existing UMTS infrastructure already used by over 80 per cent of mobile subscribers globally. This means that even though development and deployment of the LTE standard may lag Mobile WiMAX, it has a crucial incumbent advantage.



Summary

- The 3GPP Long Term Evolution (LTE) represents a major advance in cellular technology.
- LTE is designed to meet carrier needs for high-speed data and media transport as well as high-capacity voice support well into the next decade.
- LTE is well positioned to meet the requirements of next-generation mobile networks. It will enable operators to offer high performance, mass-market mobile broadband services, through a combination of high bit-rates and system throughput – in both the uplink and downlink – with low latency.

Summary– Cont.



- LTE infrastructure is designed to be as simple as possible to deploy and operate, through flexible technology that can be deployed in a wide variety of frequency bands.
- LTE offers scalable bandwidths, from from 1.4 MHz up to 20MHz, together with support for both FDD paired and TDD unpaired spectrum.
- The LTE–SAE architecture reduces the number of nodes, supports flexible network configurations and provides a high level of service availability.
- Furthermore, LTE–SAE will interoperate with GSM, WCDMA/HSPA, TD-SCDMA and CDMA.



Summary – Cont.

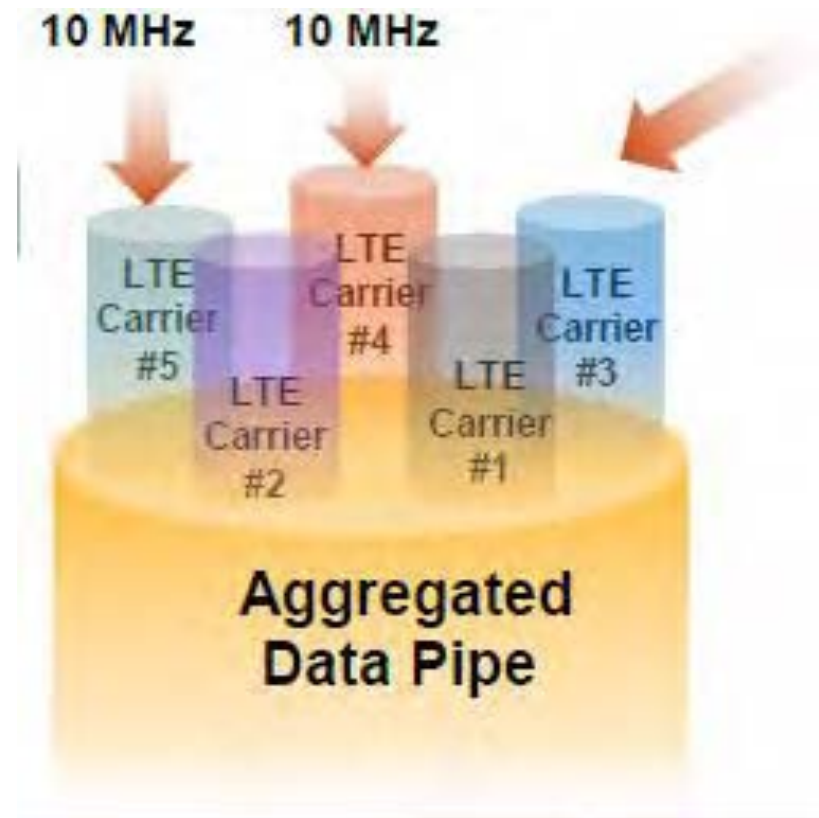
Technologies/Features		Benefits	Requirements
OFDMA with CP/SC-FDMA with CP	+	Equalizer simpler Scheduling time/frequency Better PAPR (SC-FDMA) ISI suppression (CP)	
QPSK, 16 QAM, 64 QAM	+	Higher bitrates Adaptative modulation	
Canaux communs	+	Variable traffic Better capacity	- Scheduling is needed
TTI = 1 ms	+	Better response to channel variation Higher bitrates	

Summary– Cont.

Technologies/Features		Benefits	
TTI = 1 ms	+	Better response to channel variation Higher bitrates	
Flat architecture	+	Simpler Architecture Better latency	
All IP	+	Architecture simpler Convergence	Scheduling with priorities is needed
MIMO	+	Higher bitrates	
Bande passante flexible(1.4 → 20 MHz)	+		
Universal frequency reuse (1/1)	+	Better spectral efficiency	ICIC

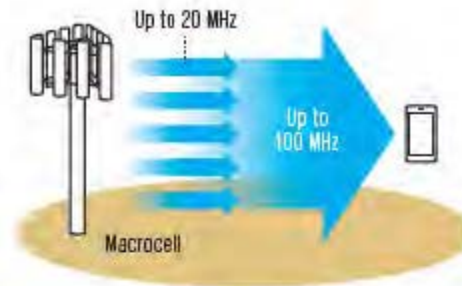
LTE Releases

- Release 8
 - Initial LTE release
 - Up to 4x4 MIMO
- Release 9
 - Minor enhancements
 - Currently built out by VZ, ATT & S
- Release 10, LTE Advanced
 - 2013 Commercial Availability
 - Channel bonding up to 5X
 - 8x8 MIMO, SON 



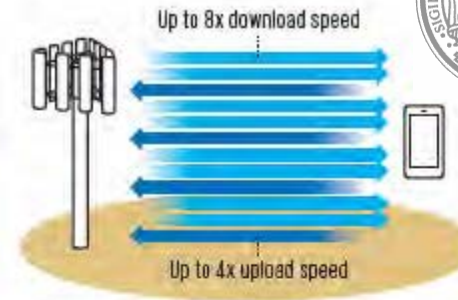
THE LTE-ADVANCED ADVANTAGE

Known as “true 4G,” LTE-Advanced includes a menu of wireless technologies that will boost the capacity of current 4G LTE networks and make possible mobile download rates as high as 3 gigabits per second. Here are five key features that distinguish the new standard from its predecessors.



WIDER BANDWIDTH

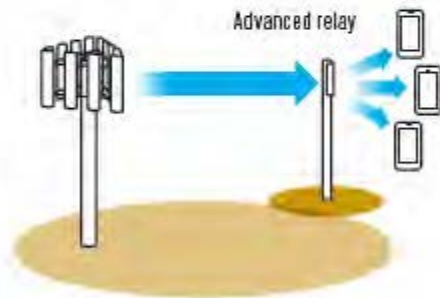
Using a technology called **carrier aggregation**, operators can combine up to five LTE frequency channels, or carriers, as wide as 20 megahertz that reside in different parts of the radio spectrum.



MORE DATA STREAMS

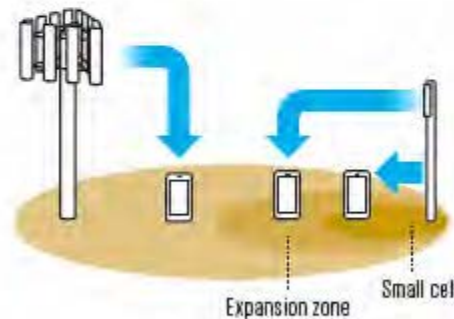
LTE-Advanced supports more sophisticated **multiple input, multiple output (MIMO)** techniques, which enable several antennas to send and receive data. One use of MIMO, called **spatial multiplexing**, separates transmissions into many parallel streams, increasing data rates in proportion to the number of antennas used.

IEEE Spectrum, January 2014



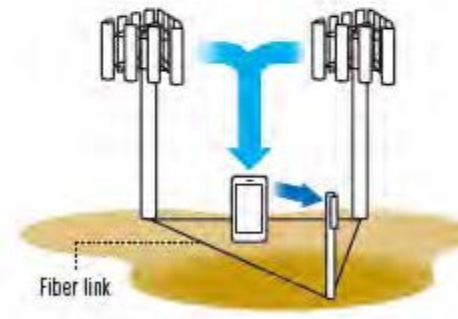
SMARTER RELAYS

Conventional radio repeaters, such as those used in LTE networks, simply amplify transmissions from a base station. LTE-Advanced allows for more **advanced relays**, which first decode the signals and then forward only those meant for nearby users, increasing the total number each relay can serve.



SUPPORT FOR SMALL CELLS

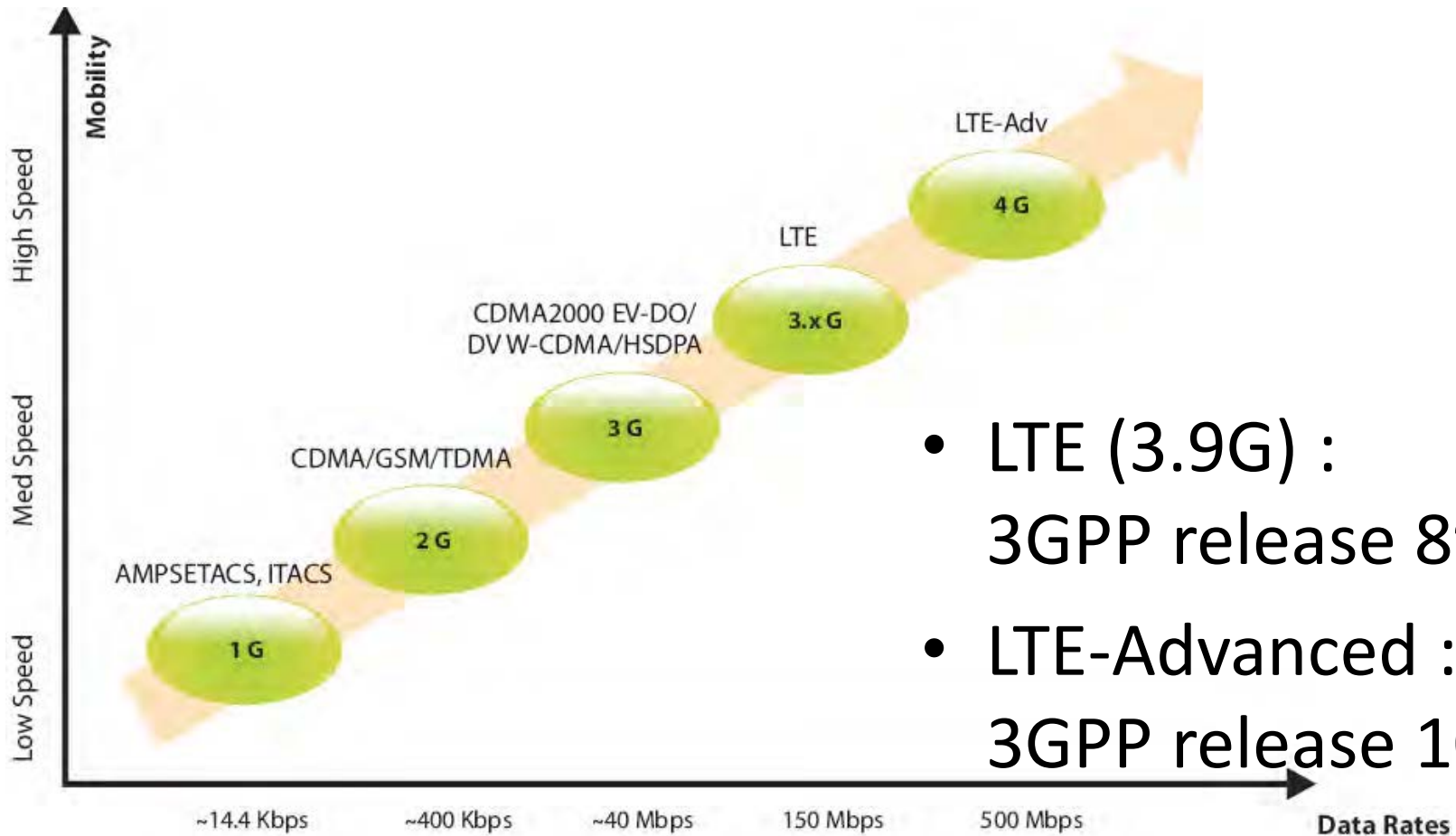
A protocol called **enhanced inter-cell interference coordination (eICIC)** alleviates interference to a small cell—a low-power base station whose coverage zone lies inside a traditional macrocell. The two cells can dynamically coordinate their use of spectrum, letting the small cell expand its transmission range.



COORDINATED TRANSMISSIONS

To improve reception, LTE-Advanced introduces **coordinated multipoint (CoMP)**. It permits several base stations to form a single cell, allowing a mobile unit to connect with all of them at the same time. For example, the unit could receive downloads from high-power towers while uploading to a nearby small cell.

From the past to the future



- LTE (3.9G) :
3GPP release 8~9
- LTE-Advanced :
3GPP release 10+