Wireless Communications

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Public Wireless Cellular Networks

Background of Cellular Systems

- Key Components:
  - Mobile station, base station, switch.
  - Bottleneck is usually on the air interface due to the limitation on radio resource.
- Radio Resource:
  - Power, Bandwidth

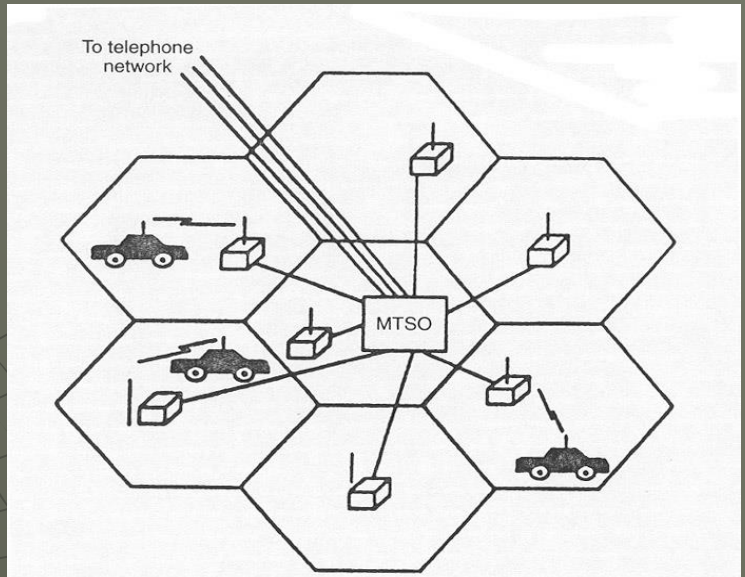
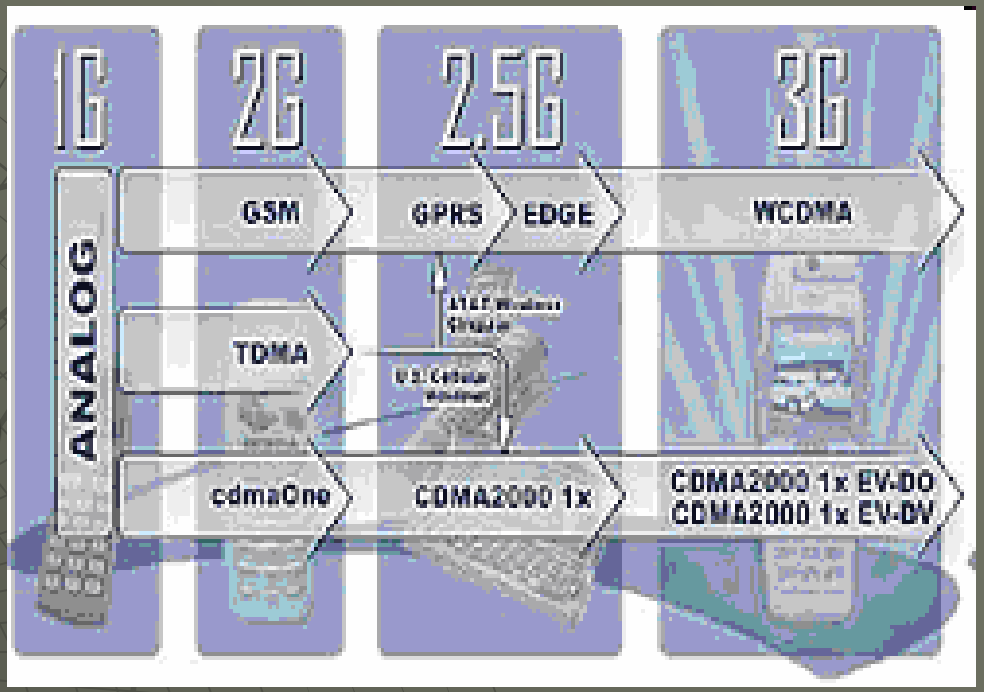


Figure 16.1 Conceptual layout of a cellular radio system.

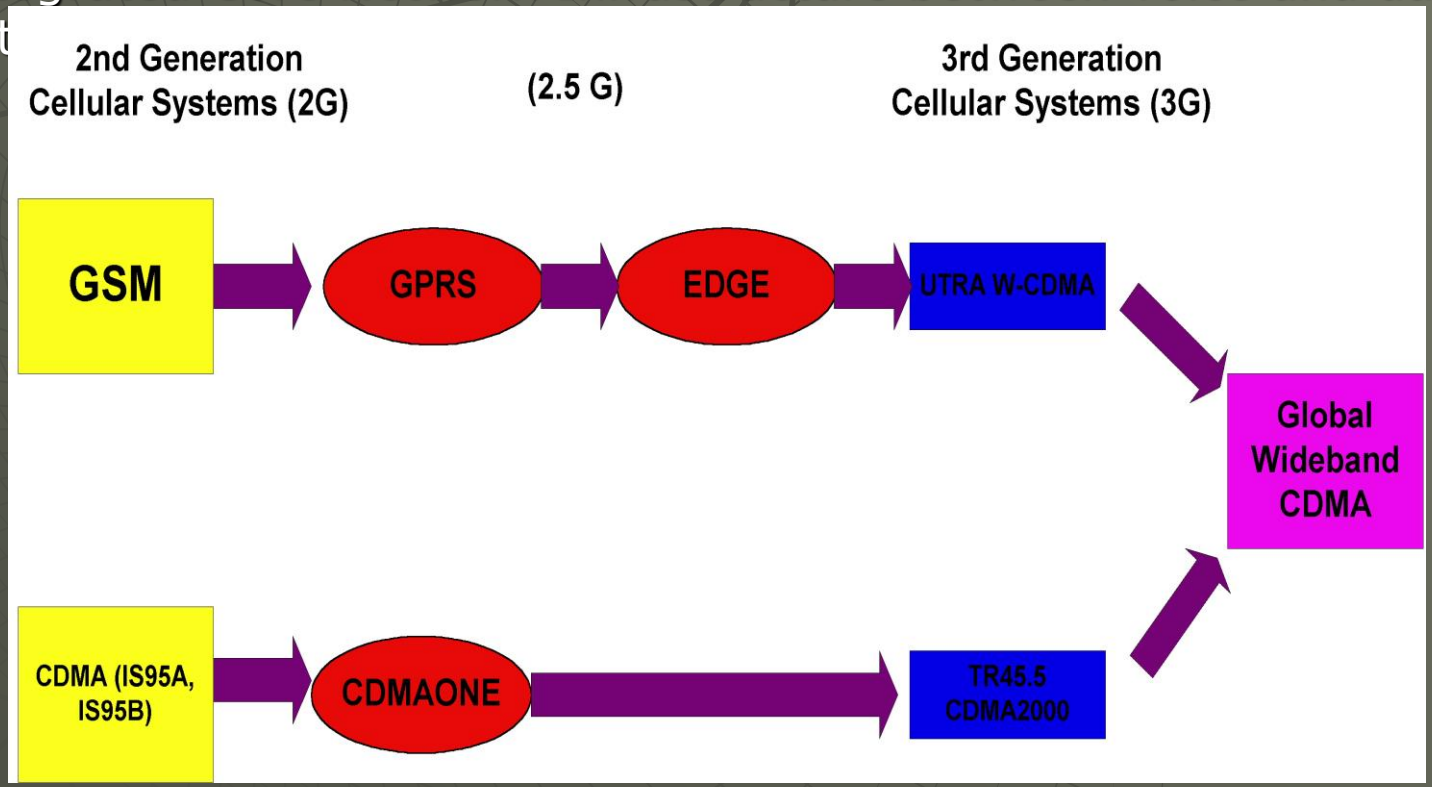
Evolution of Cellular Systems

- **1G systems (AMPS, TACS)**
  - Analog Transmission (FM).
  - Voice Applications only.
- **2G systems. (GSM, CDMA, IS54)**
  - Digital Transmission.
  - Voice and Data applications (Circuit Switched only).
- **2.5G systems (GPRS/EDGE)**
  - Digital Transmission,
  - Circuit Switched voice
  - Packet switched data (medium speed, No QoS)
  - Extension of 2G Systems
- **3G systems (UMTS)**
  - Evolved packet switched infrastructure
  - Higher data transfer speeds
  - VoIP is also possible

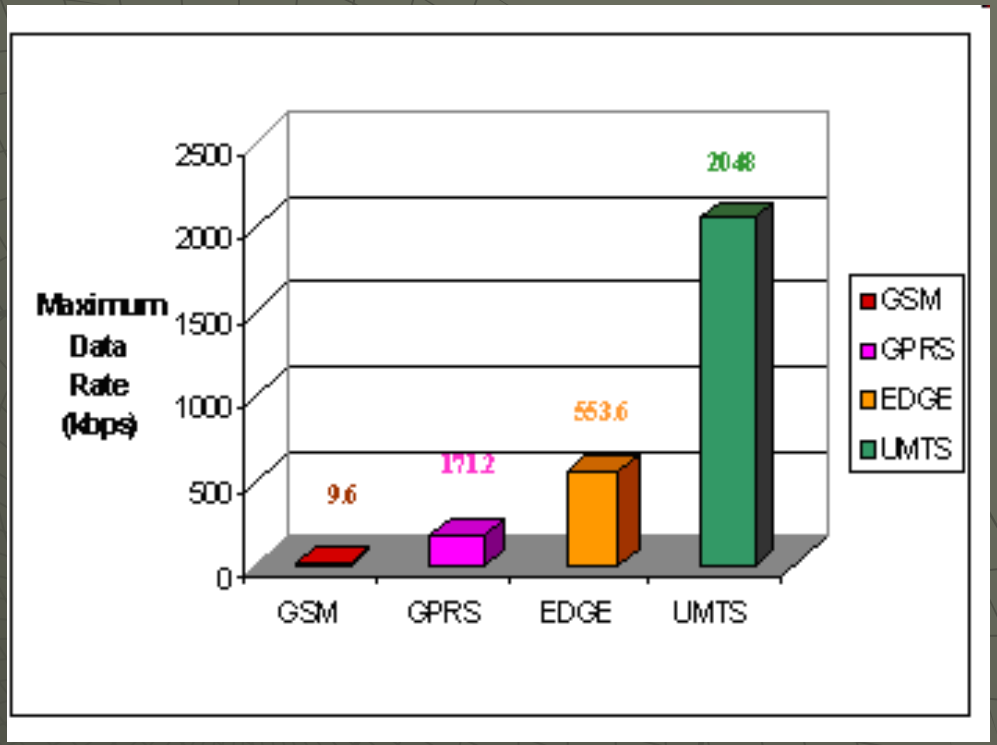


Evolution of Cellular Systems

- **3G systems**
  - Digital transmission,
  - Circuit switched voice and data (low speed)
  - Packet switched data services (high speed ~ 2Mbps, with QoS).
  - Integrated Core Network Infrastructure between voice and data pat

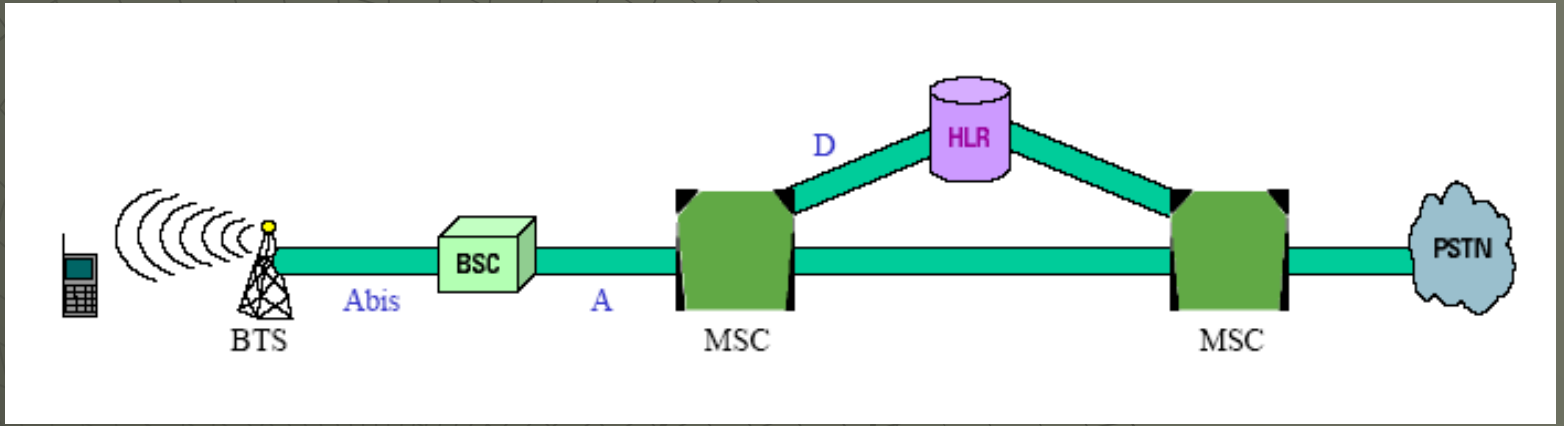


Data rates in cellular networks



Slide sources:
http://www.iec.org/online/tutorials/agilent_umts_network
http://www.tech-invite.com/Ti-ims-releases.html

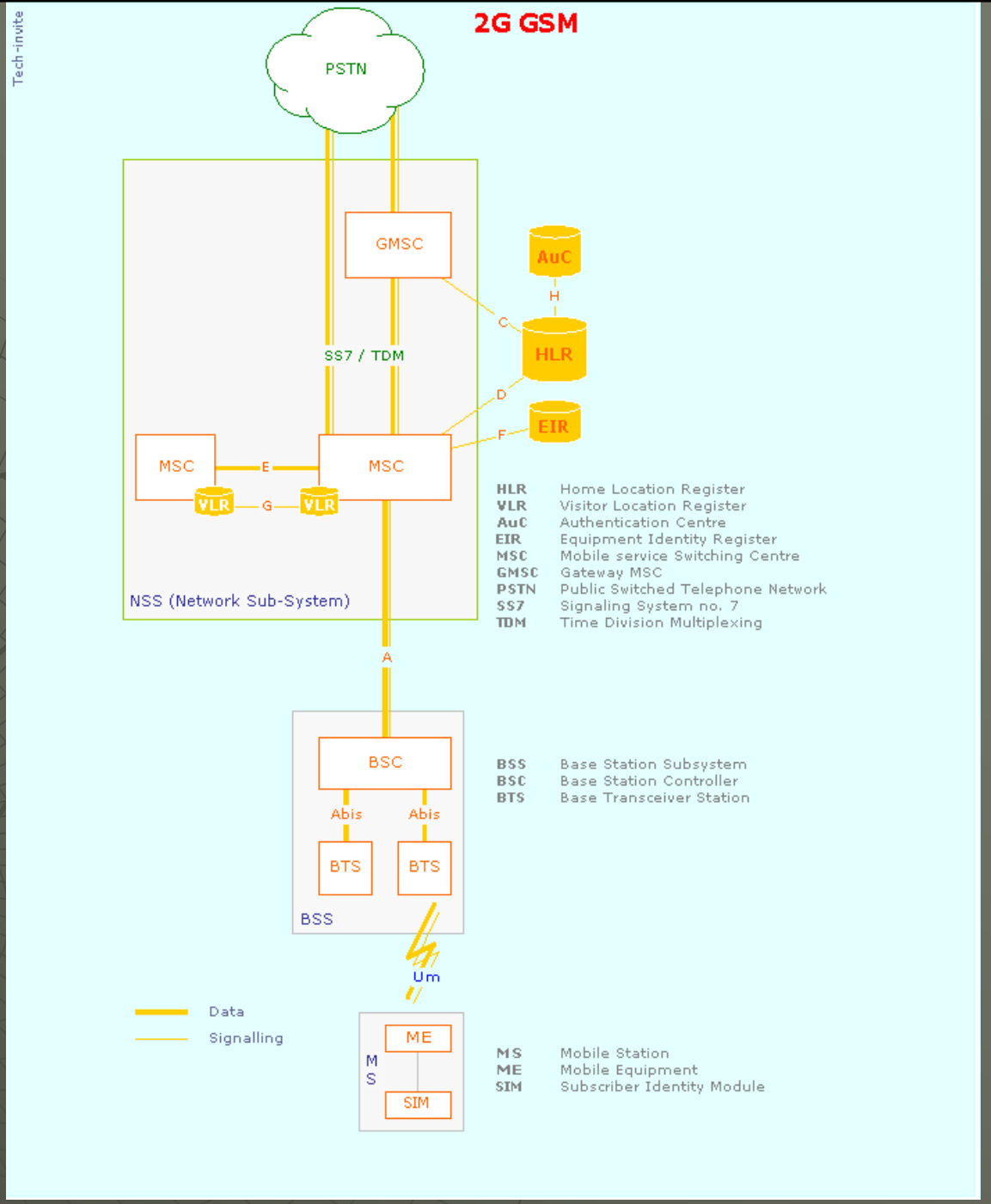
GSM reference model



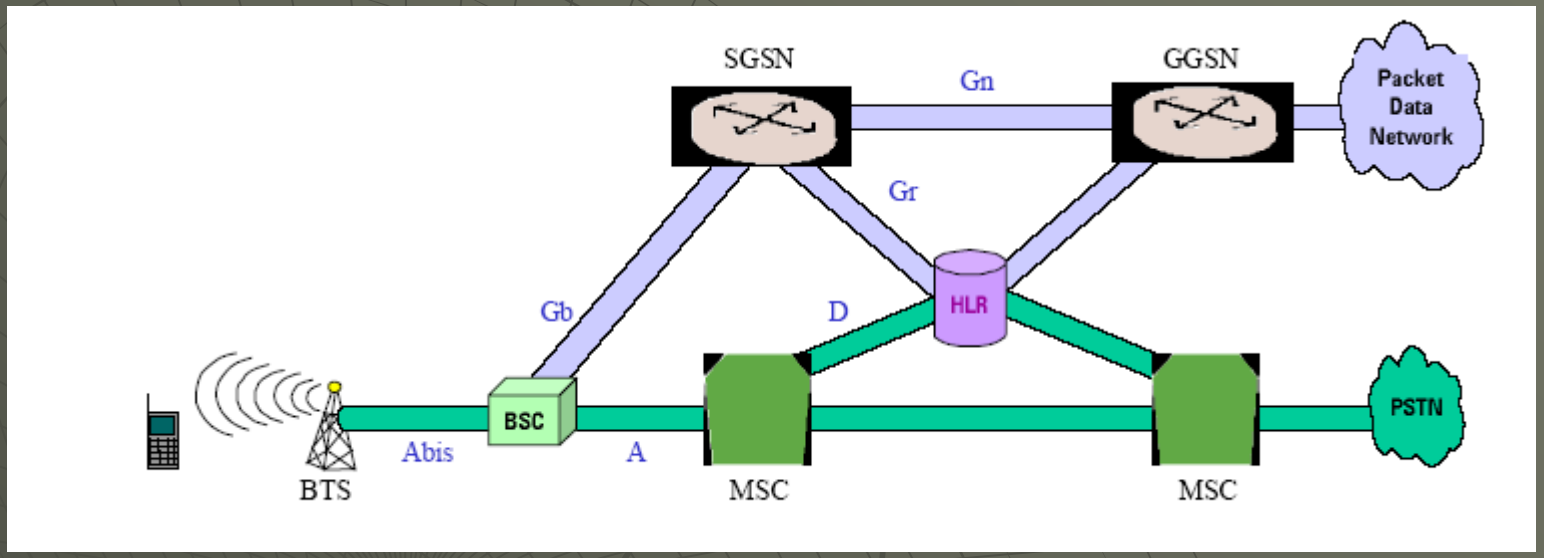
BTS – base station
BSC – base station controller
MSC – mobile switching center
HLR – home location register
PSTN – plain switched telephone network

GSM – 2G

- Digital system
- Data traffic transmitted like in the modems



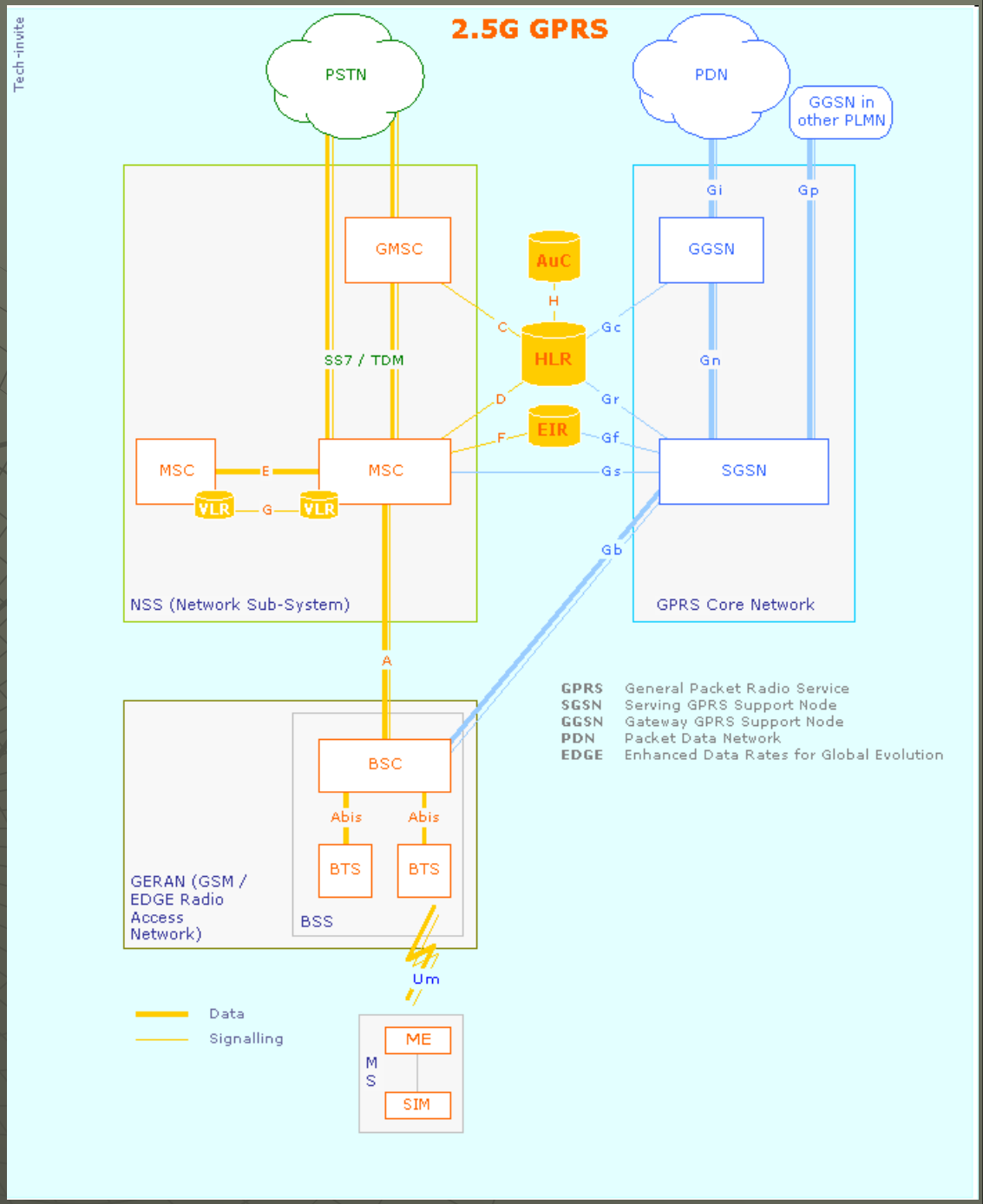
GPRS model



SGSN – Service GPRS Serving Node
GGSN – Gatewaying GPRS Serving Node

GPRS – 2.5G

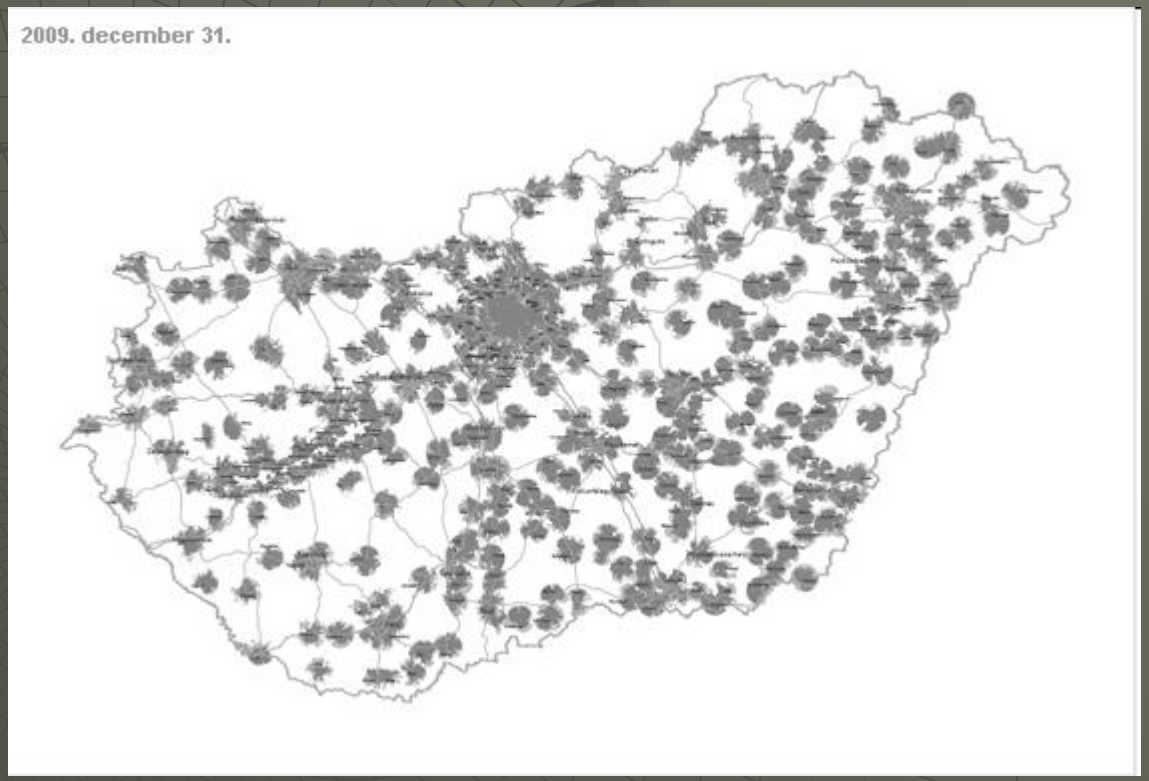
- GPRS introduces packet switching into the GSM core network and enables access to packet data networks.



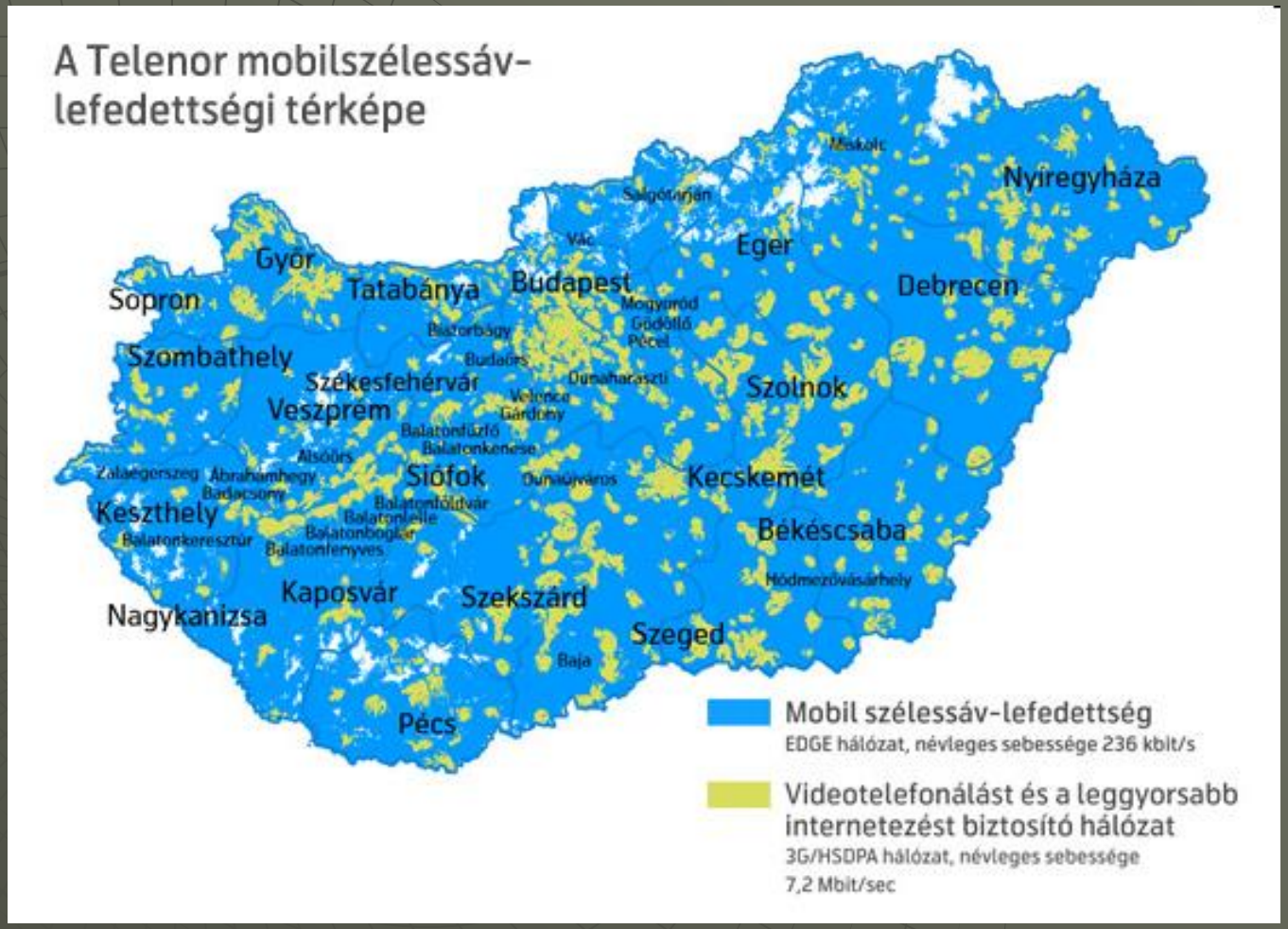
HSDPA

- HSDPA – High Speed Downlink Packet Access
- HARQ can be used in stop-and-wait mode or in selective repeat mode
- In stop-and-wait the receiver sends ACK for each packet
  - Inefficient
  - Multiple stop-and-wait HARQ processes can be done in parallel
  - While one process is waiting for the ACK, other process can use the channel and send data
- In selective repeat mode the sending continues (for specified window size) even after a frame loss
  - An ACK is sent for each received frame, the sequence number of the earliest missed frame is added
  - When the sending window is emptied, the missed frame is resent

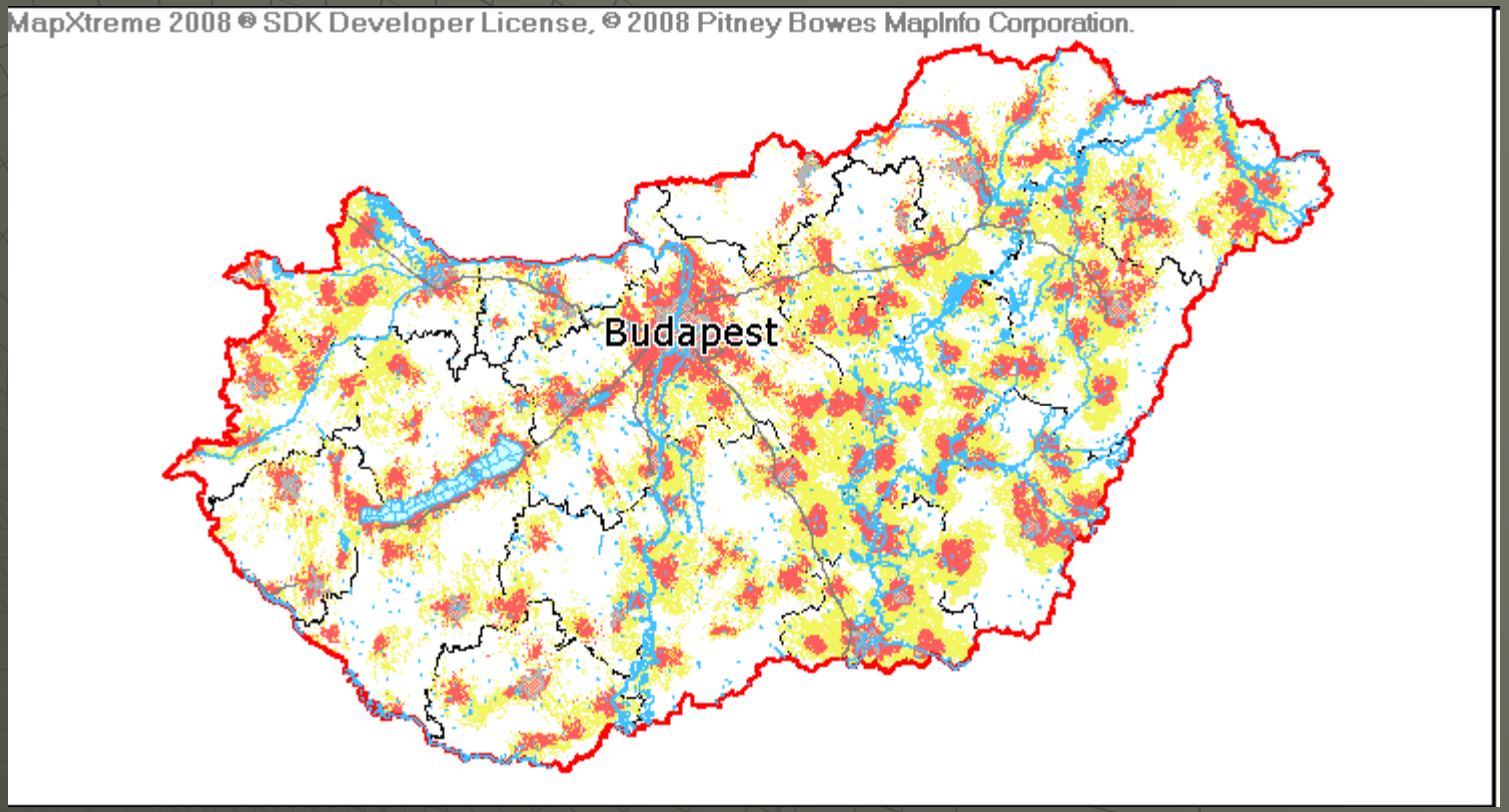
T-Mobile Hungary



Telenor Hungary



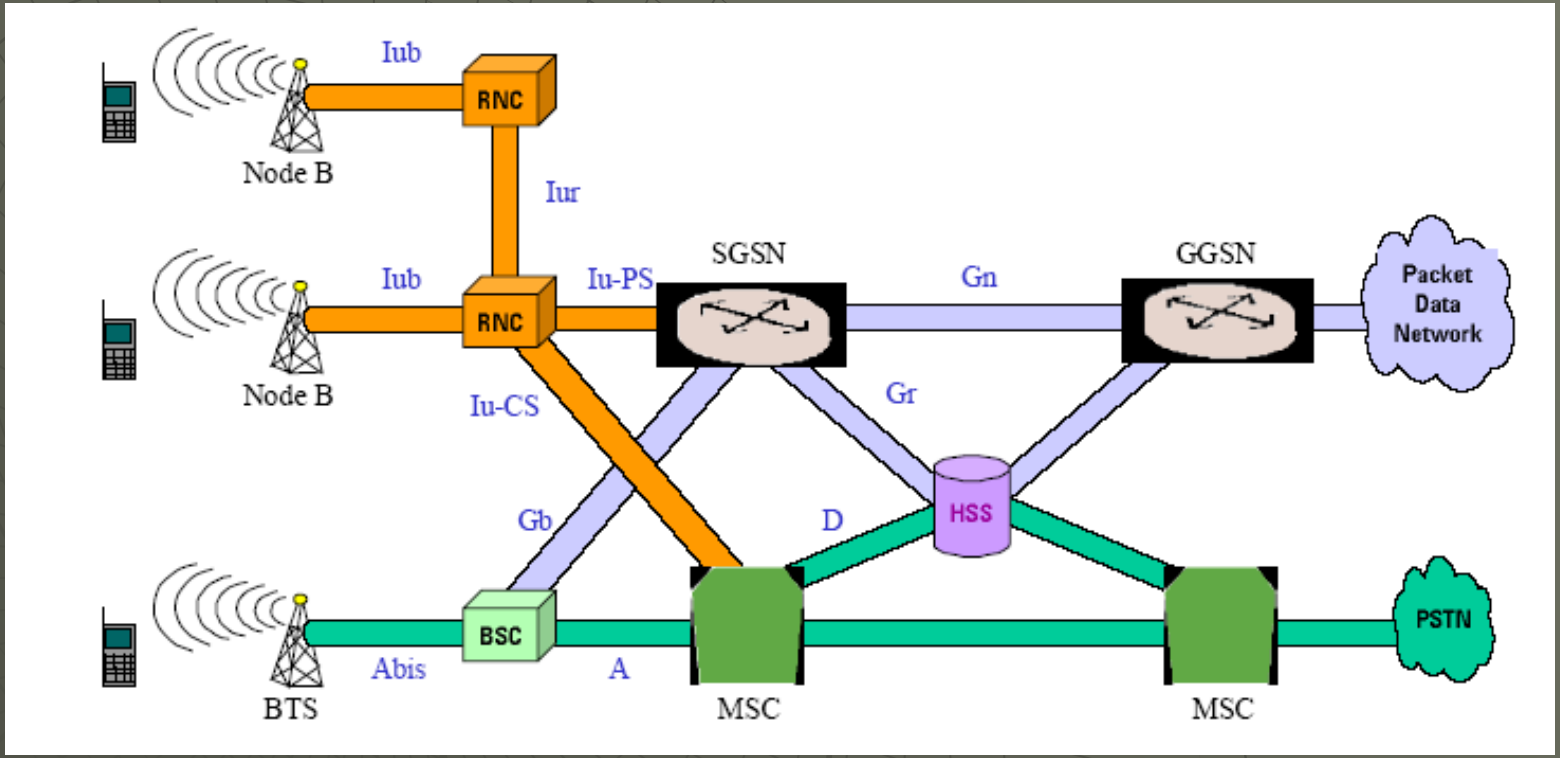
Vodafone Hungary



HSUPA

- HSUPA – High Speed Uplink Packet Access
  - 5.76 Mbps max. uplink speed
  - QPSK – a better modulation scheme would put too much load on the battery of the mobile device
  - HARQ with incremental redundancy
- Efficient scheduling
  - User devices ask permission for sending
  - The base station decides who can transmit and how much
  - Based on the sending buffer and the channel quality
- Multi-Code sending
  - The same user equipment can use several codes in parallel
  - Maximum 4 codes
  - Higher speed for those who need it
- EV-DO – Evolution Data Optimized
  - An upgraded version of CDMA2000
  - 1,25 MHz large channels
  - Very similar to HSPA

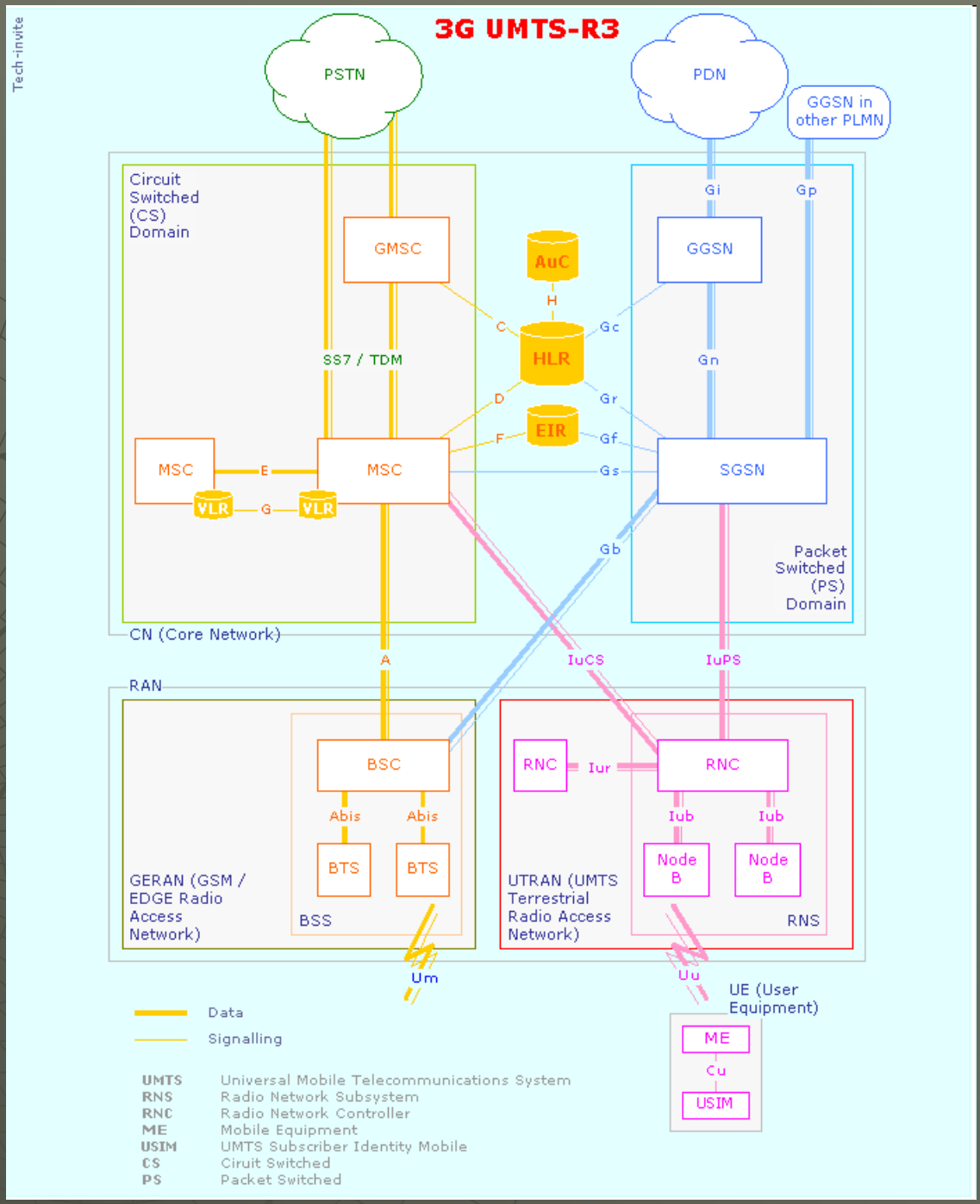
UMTS model



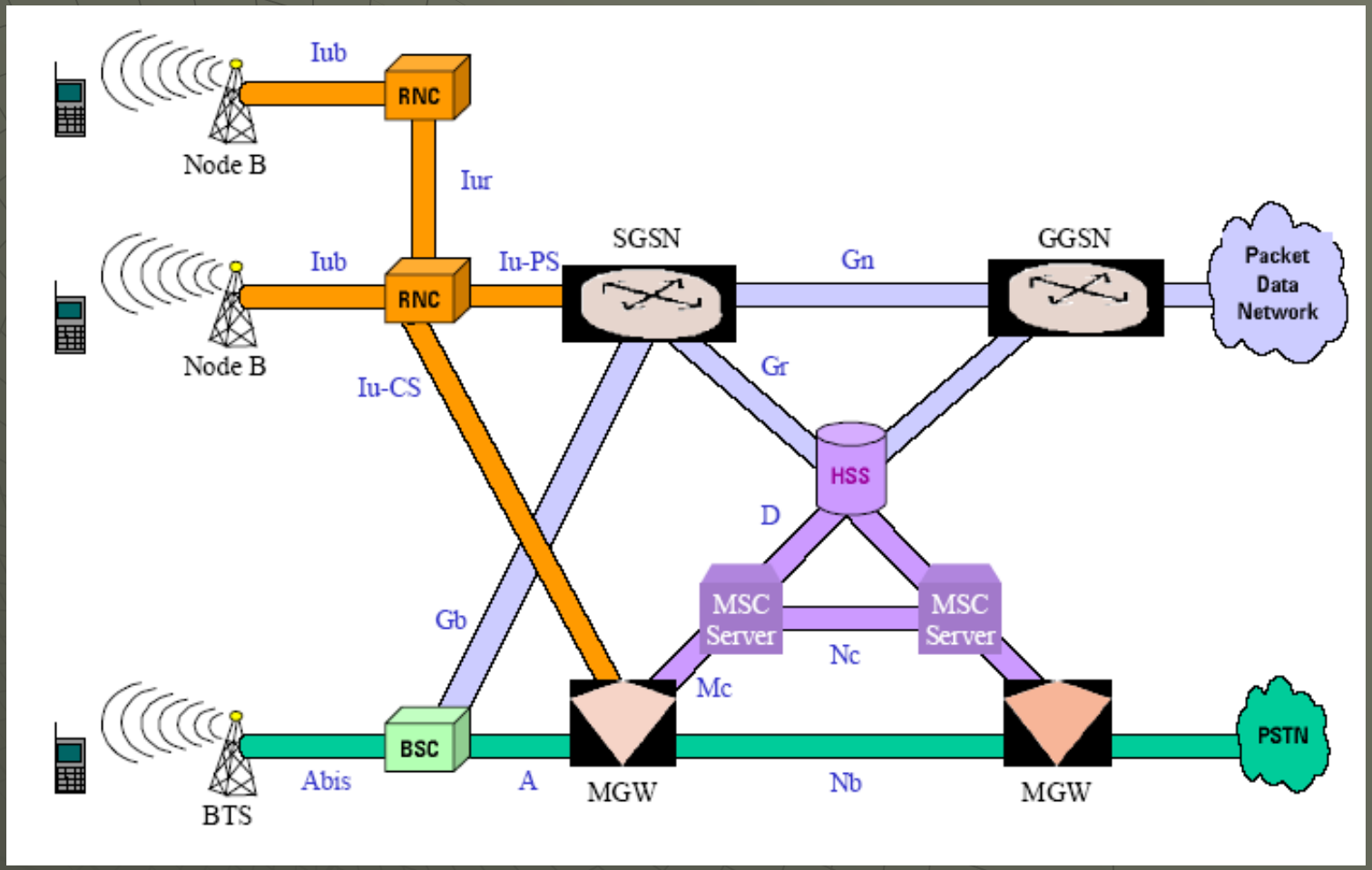
TE – terminal equipment
RNC – Radio Network Controller

UMTS – 3G

- With Release 3 (aka UMTS Phase 1) a new radio access network is introduced
  - It is called UTRAN (UMTS Terrestrial Radio Access Network)
  - based on W-CDMA (instead of TDMA/FDMA) air interface transmission



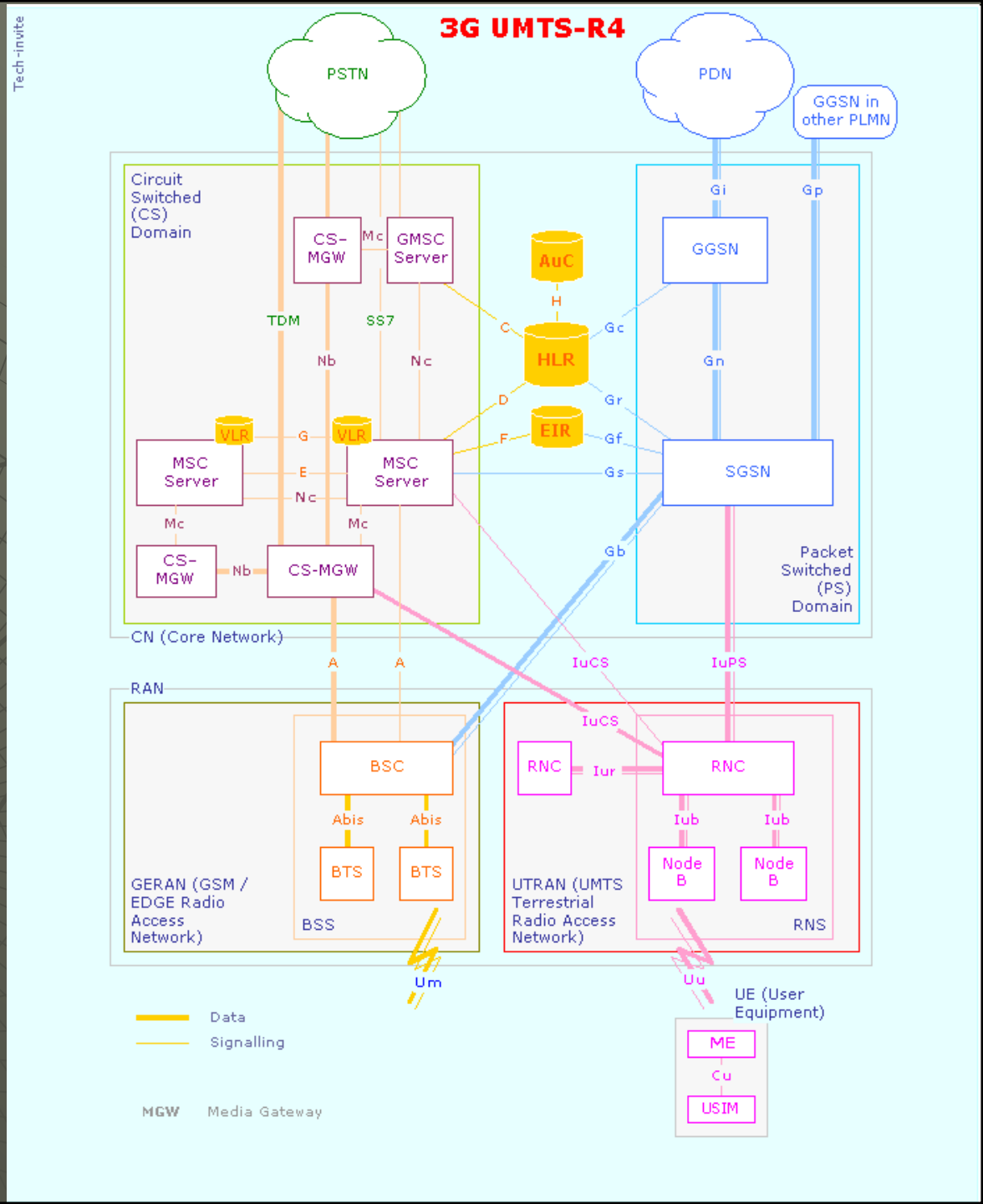
UMTS R4



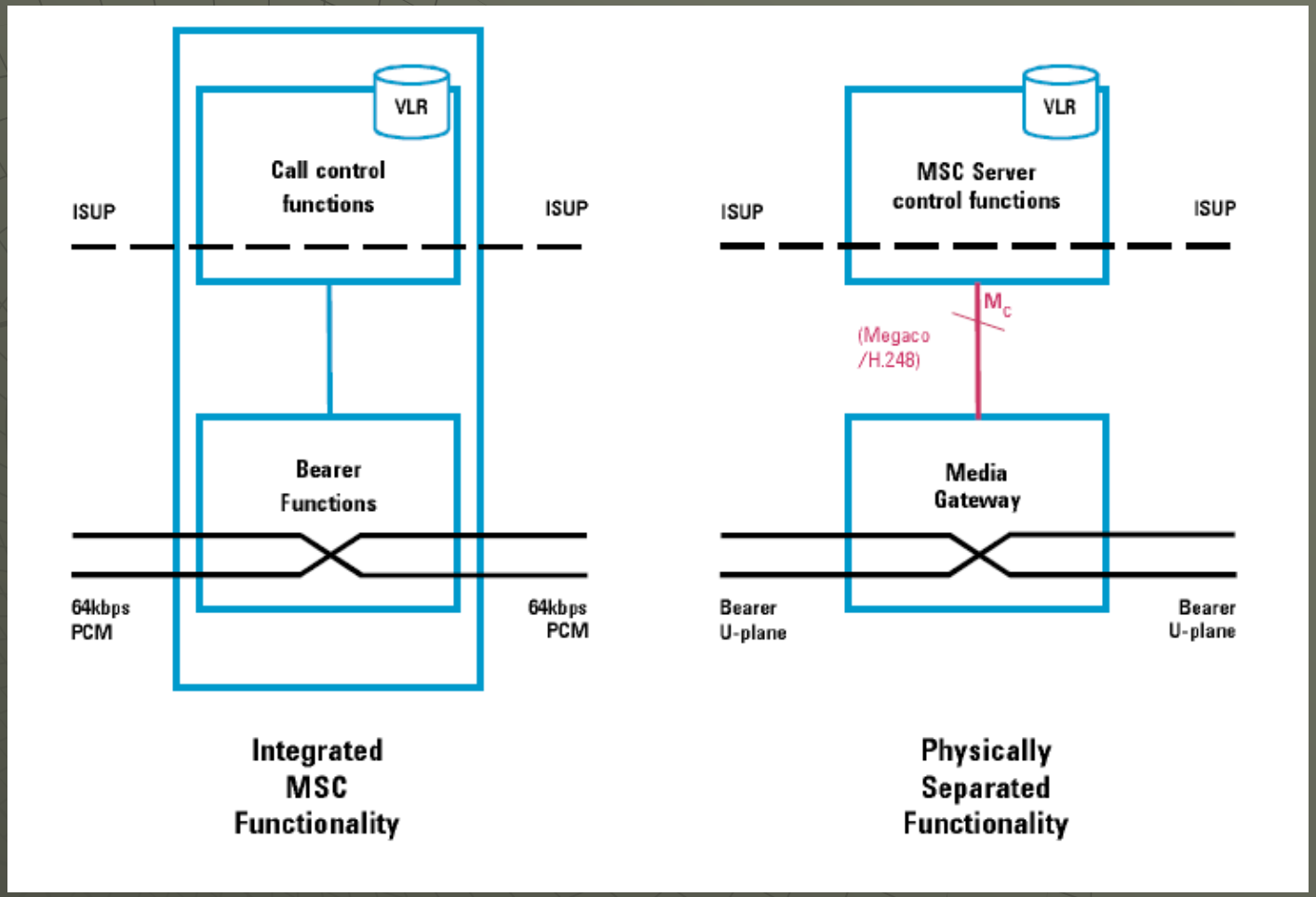
MGW – Media Gateway

UMTS R4

- With Release 4, the MSC functionality is split into two entities:
  - The MSC Server, which provides the control functions
  - The Media Gateway (MGW) which provides the bearer switching functions and, if necessary, the conversion fonctions between two different formats. A single MSC Server can control multiple MGWs.

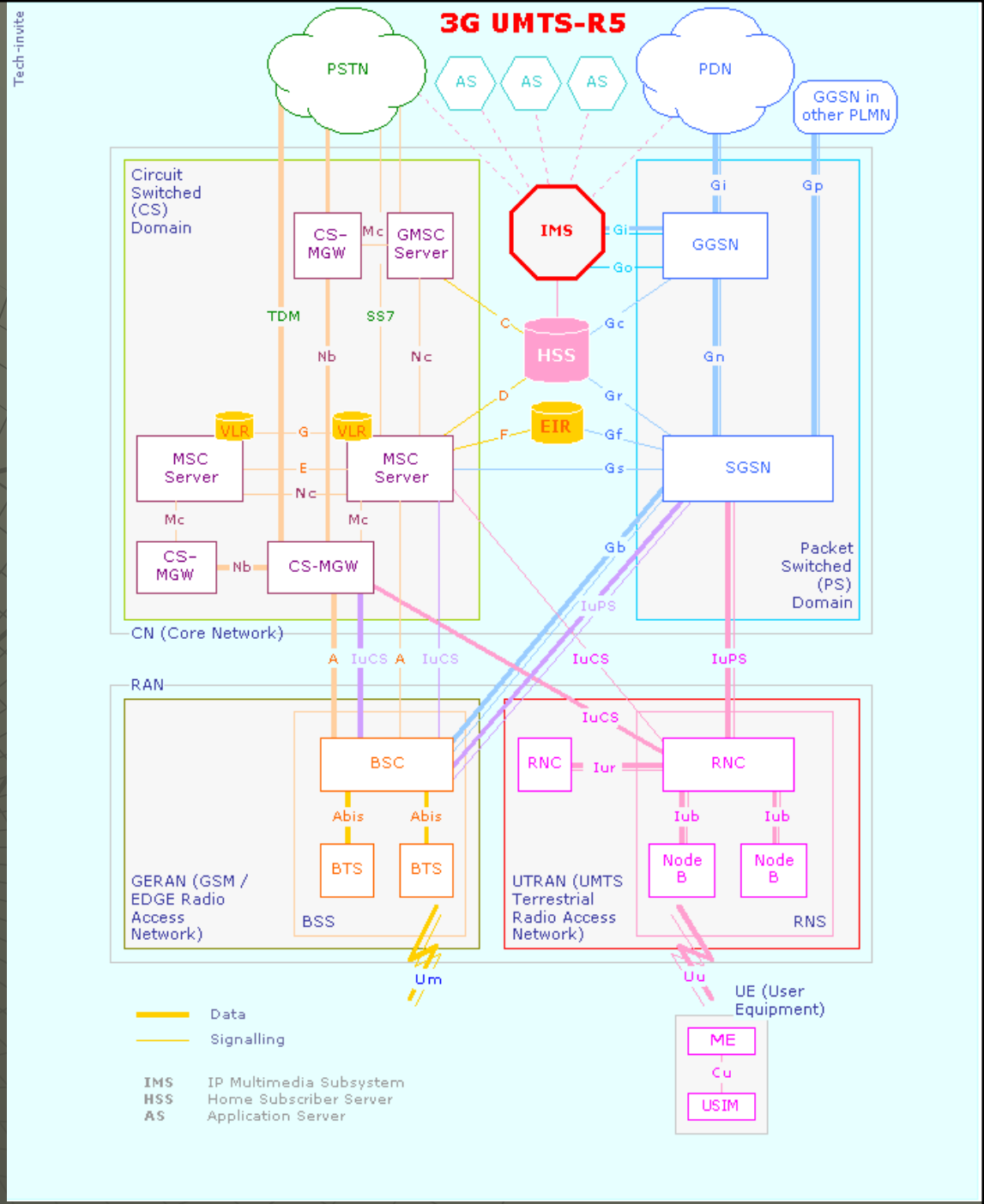


MSC split Release 4



UMTS R5

- Introduces the IMS
  - IP Multimedia Subsystem
  - Third parties can provide advanced services



References

- G. Sanders, L. Thorens, M. Reisky, O. Rulik, S, Deylitz, “GPRS Networks”, Wiley 2003, ISBN 0-470-85317-4
- H. Kaaranen, A. Ahtiainen, L. Laitinen, S. Naghian, V. Niemi, “UMTS Networks”, Wiley 2001, ISBN 0-471-48654-X
- J. P. Castaro, “All IP in 3G CDMA Networks”, Wiley 2004, ISBN 0-470-85322-0

UMTS spectrum concessions in Europe

Spectrum allocation - concessions

- Concession procedures:
- Auction
  - Who offers more for the spectrum
- „Beauty contest”
  - Comparative bidding
  - The government asks for a detailed deployment and operating plan from the operators
    - How many new jobs will be created?
    - What kind of services will be available, when, where, for how much?
    - How will rural users be reached?
  - The offered money is of secondary importance
- Mixed, hybrid solutions

UMTS concessions - Auctions

- UK
  - 5 licenses announced
  - Parallel auction for them
  - Dedicated band for newcomer operators
  - Total auction income: ~ 38,5 Billion EUR !!! (22,5 Billion GBP)
- Germany
  - 6 licenses announced
  - Total auction income: ~ 51 Billion EUR !!!
  - Winners:
    - T-Mobile (DT)
    - Mannesmann Mobilfunk (Vodafone – D2)
    - Group 3G (Sonera + Telefonica)
    - E-Plus Hutchison (KPN + NTT + Hutchison)
    - Mobilcom Multimedia (Mobilcom + FT)
    - Viag Intercom (BT + Viag + Telenor)
- Italy
  - 5 licenses, 6 candidate operators
  - Total auction income14,6 Billion EUR (10 auction rounds)

UMTS concessions - Contests

- „Scandinavian model” – Sweden, Finland
  - Beauty contest (analysis of financial, technical background)
  - No licensing fee (percentage paid based on amount of traffic)
- Sweden – Telia consortium
  - Telia lost the contest, although it was a 70% a state-owned company
- Spain, Portugal
  - An adapted Scandinavian model, minimal licensing fee, yearly payments
- Hungary
  - All three mobile operators received UMTS licenses
  - T-Mobile, Telenor, Vodafone
  - 52.5 Billion HUF (approx. 200mil EUR)

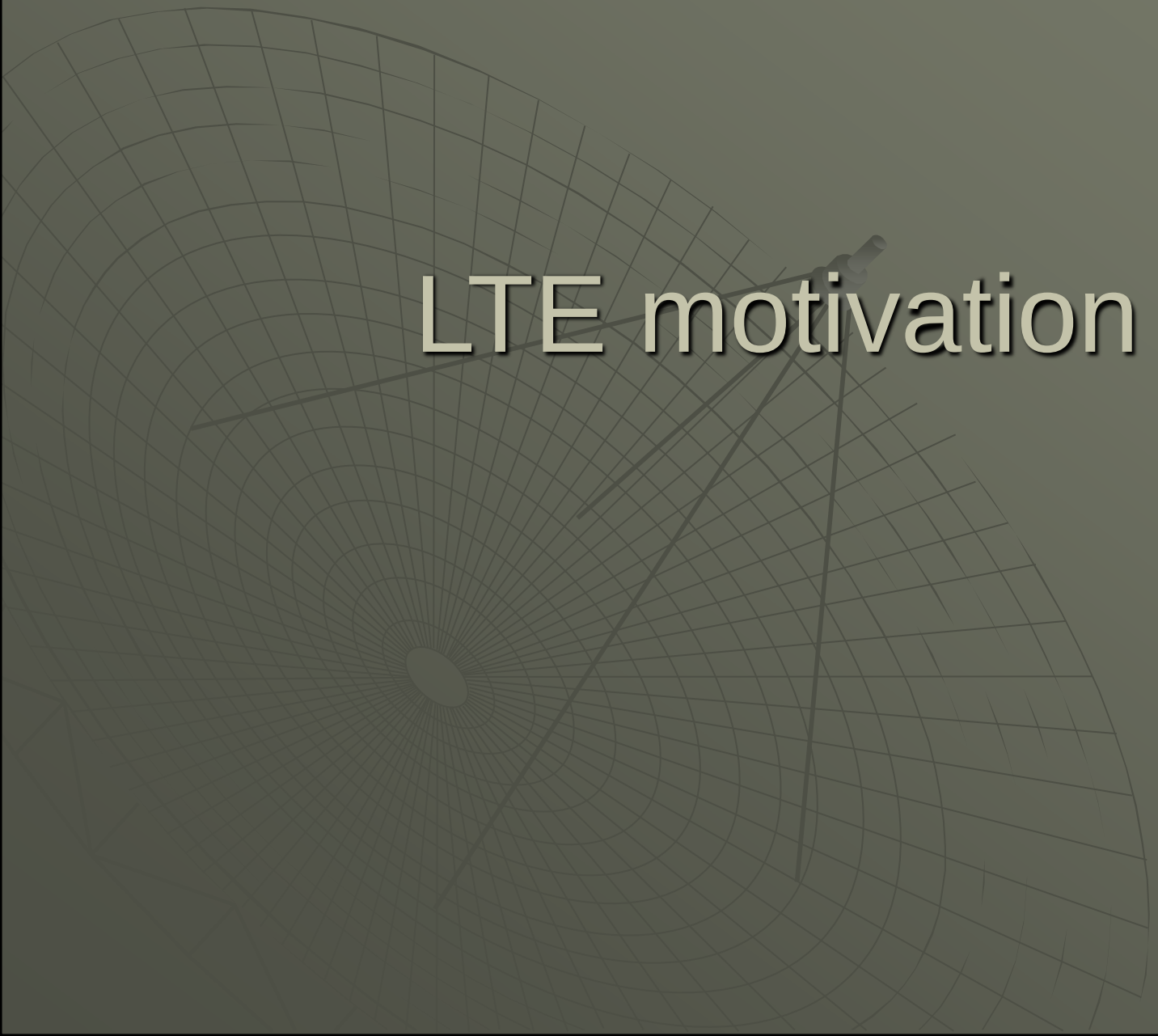
License fees obtained

	When	Type	Licenses	Income
England	2000.04	A	5	~38.5 Billion EUR
Holland	2000. 07	A	5	2,7 Billion EUR
Germany	2000. 08	A	6	~51 Billion EUR
Italy	2000.10	A	5	~14,6 Billion EUR
Austria	2000.11	A	6	~830 Million EUR
Switzerland	2000.12	A	4	~130 Million EUR
France	2001.05	B	2	~1,2 Billion EUR
Spain	2000.03	B	4	520 Million EUR
Portugal	2000.12	B	4	400 Million EUR
Belgium	2001.03	A	3	450 Million EUR
Denmark	2001.	A	4	490 Million EUR

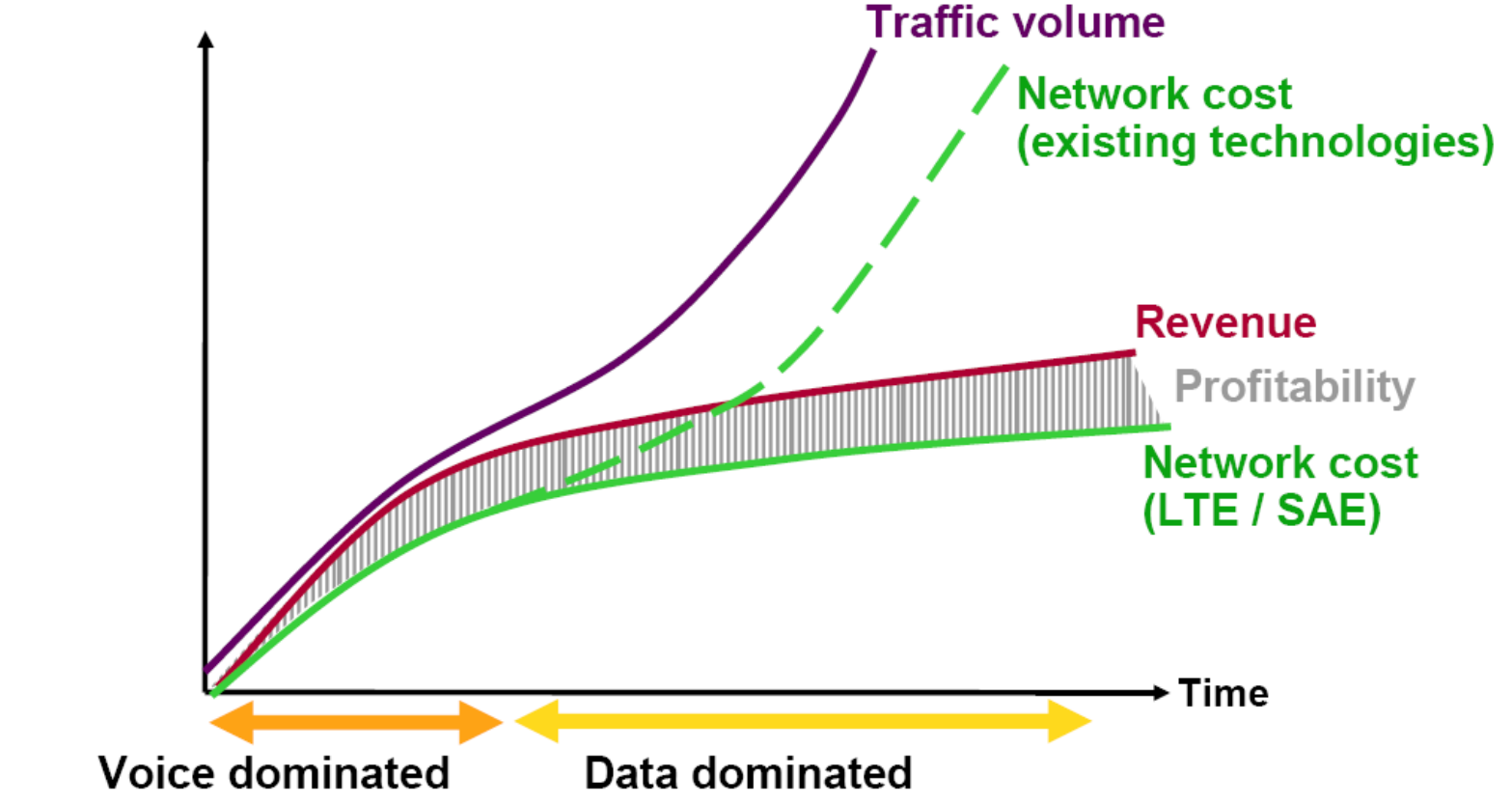
A – Auction

B – Beauty Contest

LTE motivation



Traffic vs Network cost



Expectations

- **Need for higher data rates and greater spectral e**
  - 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

- Mobility
- **Optimized for low mobility(0-15km/h) but supports high speed**

- Latency
- **user plane < 5ms**
- **control plane < 50 ms**

- **Improved broadcasting**
- **IP-optimized**
- **Scalable bandwidth of 20MHz, 15MHz, 10MHz, 5MHz and <5MHz**
- **Co-existence with legacy standards**
  - **users can transparently start a call or transfer of data in an area using an LTE standard, and, when there is no coverage, continue the operation without any action on their part using GSM/GPRS or W-CDMA-based UMTS**

LTE Benefits

Peak Performance DL

- OFDM/OFDMA in the DL
  - Spectral Efficiency (2-5x Rel'6)
  - Resistant to multi-path interference
- MIMO (Multiple Input Multiple Output) Antennas
  - Doubles the throughput
  - Deployment simplicity

Power Efficient UL

- SC-FDMA – Lower PAR
  - Longer mobile battery life
  - Larger cell coverage
- Collaborative (Multi-user or Virtual) MIMO
  - Simplifies mobile implementation
  - 80% capacity gain in uplink

Flat All IP Architecture for Cost Reduction and Performance

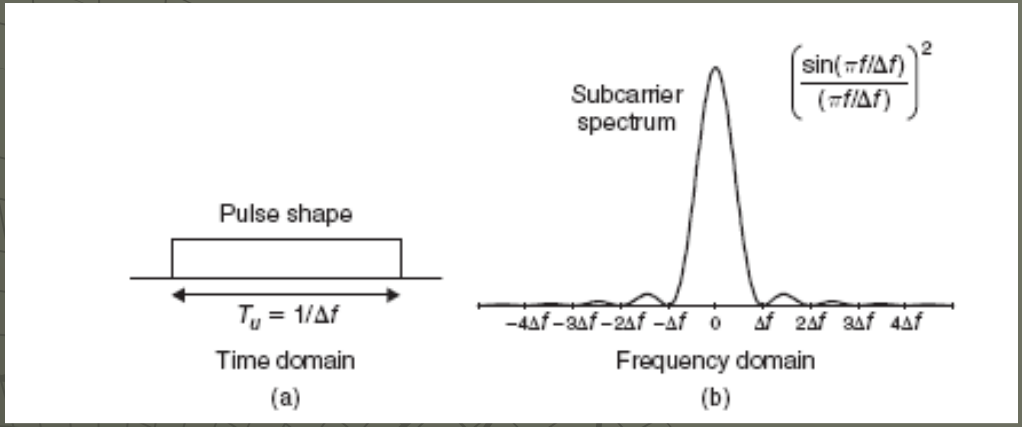
- Reduce CAPEX and OPEX Costs
- Higher Network Performance
  - Efficient IP routing - reduce Latency (20 ms e2e RTD)
  - Increasing Throughput (Peak @ 100/50Mbps DL/UL)
  - Fast state transition time (enhanced Always-on) – Less than 50ms transition from dormant to active

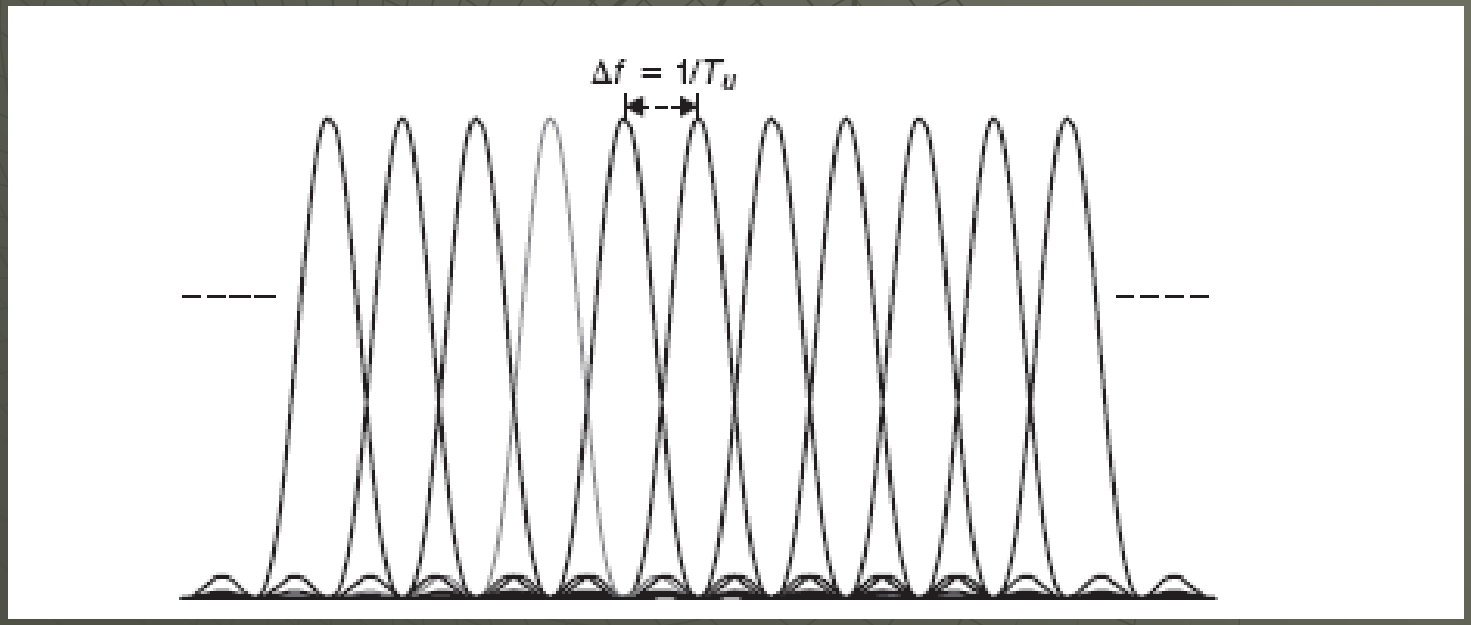
Scalable and Compatible with 3G Access Networks

- Scalable spectrum allocation (1.4, 3, 5, 10, 15, 20MHz) – great for in-band deployment
- Mobility with 3GPP & Non-3GPP access – smooth network migration to LTE and beyond
- Global roaming with other 3GPP networks – capture roaming revenue opportunity

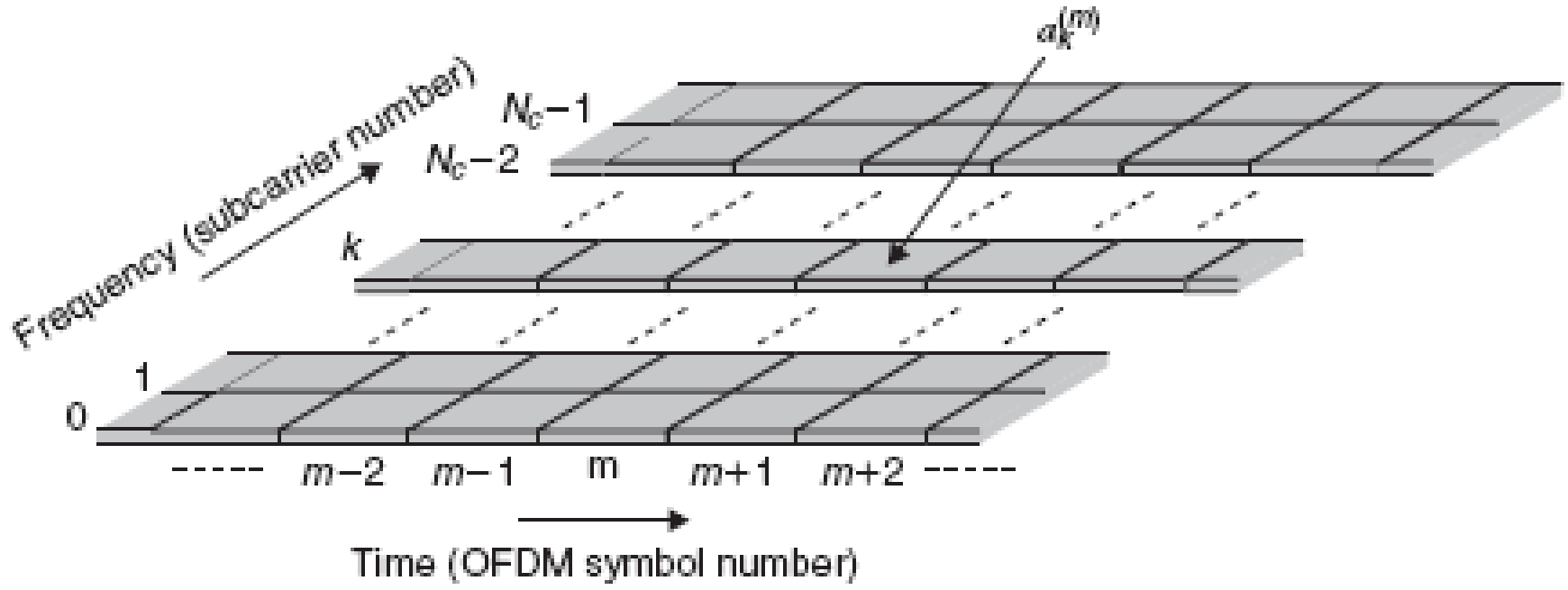
OFDM / OFDMA

OFDM

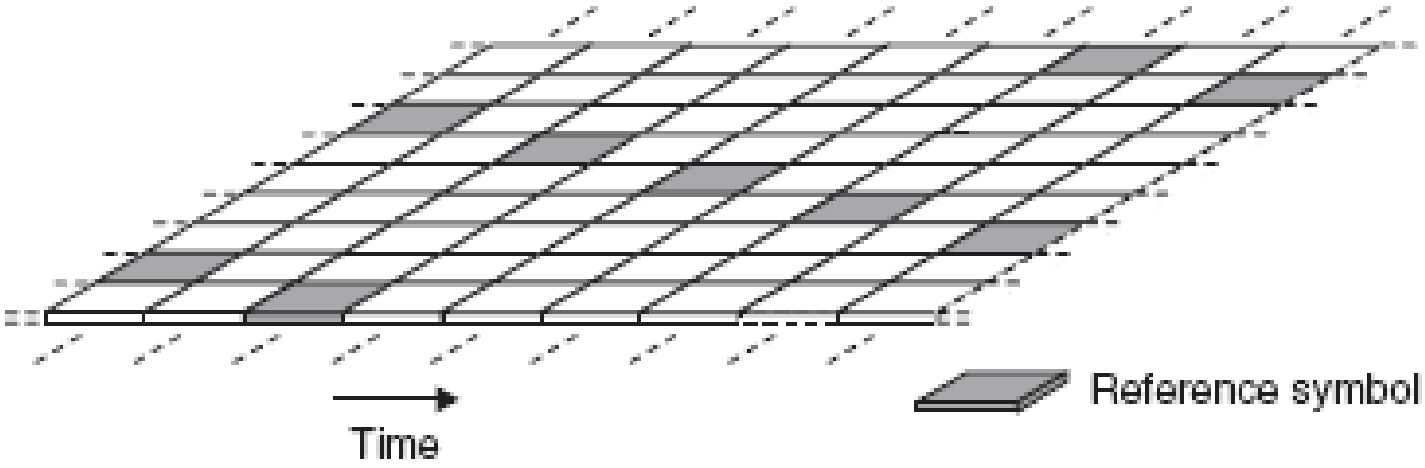

Pulse shape
$T_u = 1/\Delta f$
Time domain
(a)
Subcarrier spectrum
$\left(\frac{\sin(\pi f/\Delta f)}{(\pi f/\Delta f)}\right)^2$
$-4\Delta f$ $-3\Delta f$ $-2\Delta f$ $-\Delta f$ 0 Δf $2\Delta f$ $3\Delta f$ $4\Delta f$
Frequency domain
(b)


$\Delta f = 1/T_u$

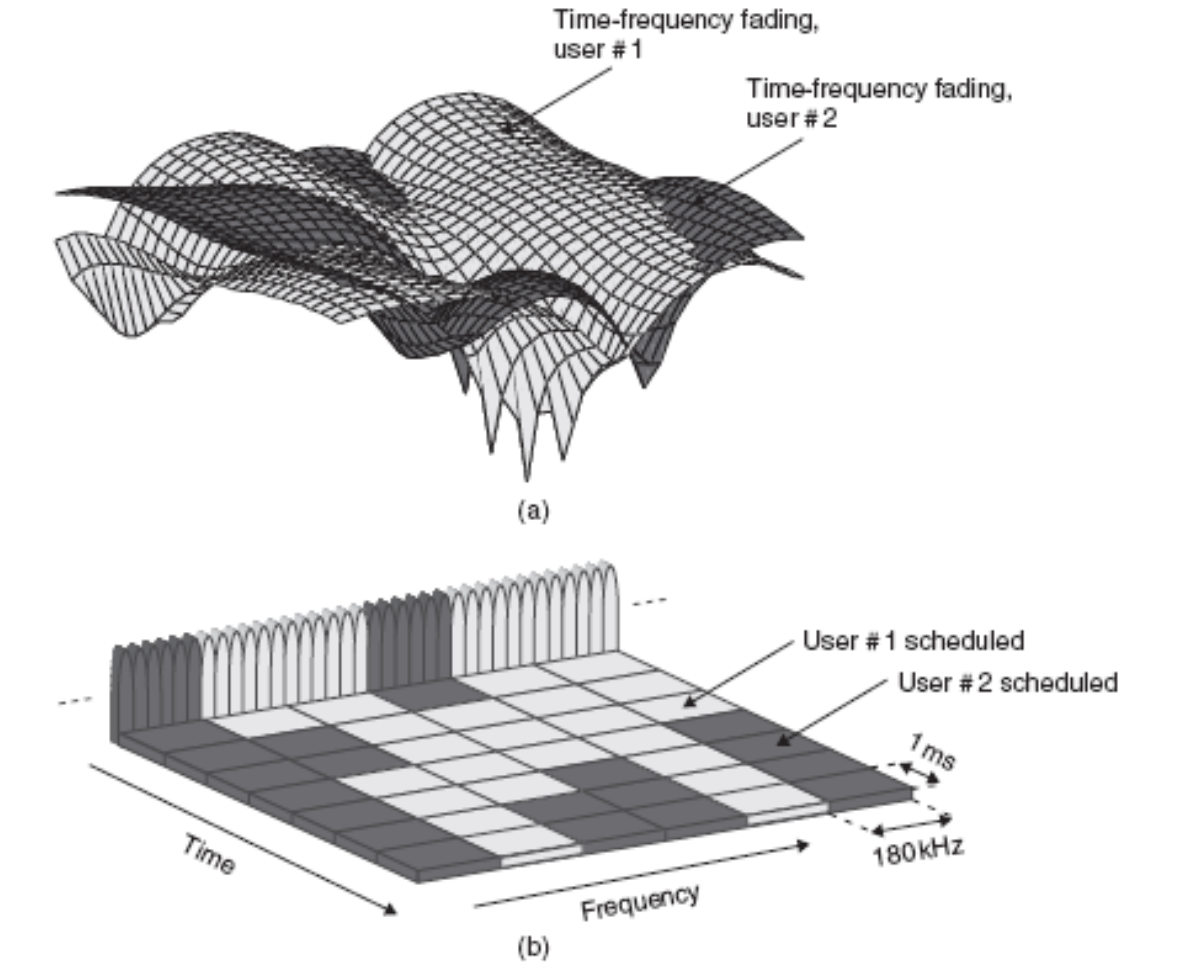
OFDM


$a_k^{(m)}$
N_c-1
N_c-2
Frequency (subcarrier number)
k
1
0
----- $m-2$ $m-1$ m $m+1$ $m+2$ -----
Time (OFDM symbol number)

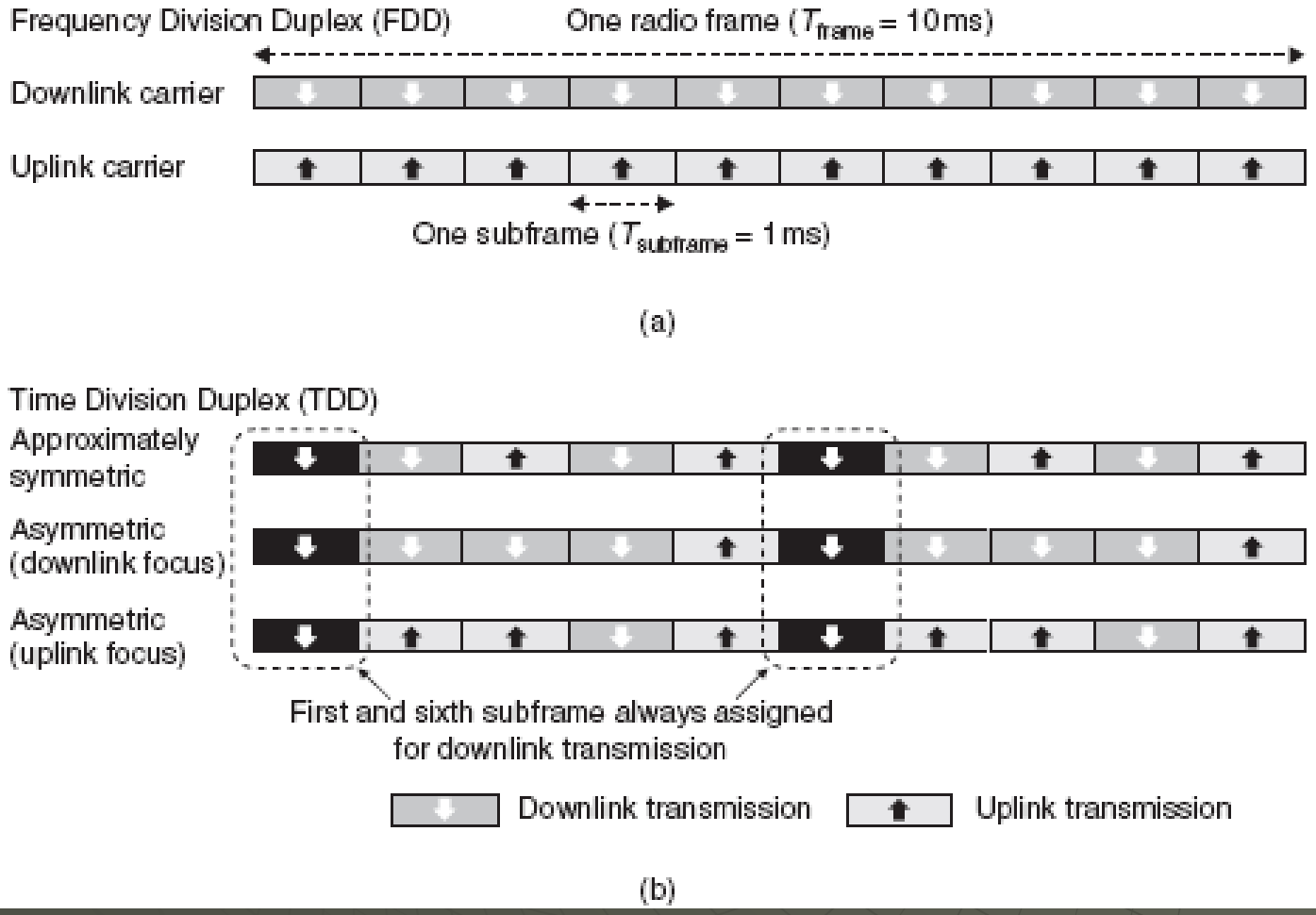
Reference signal (pilot)



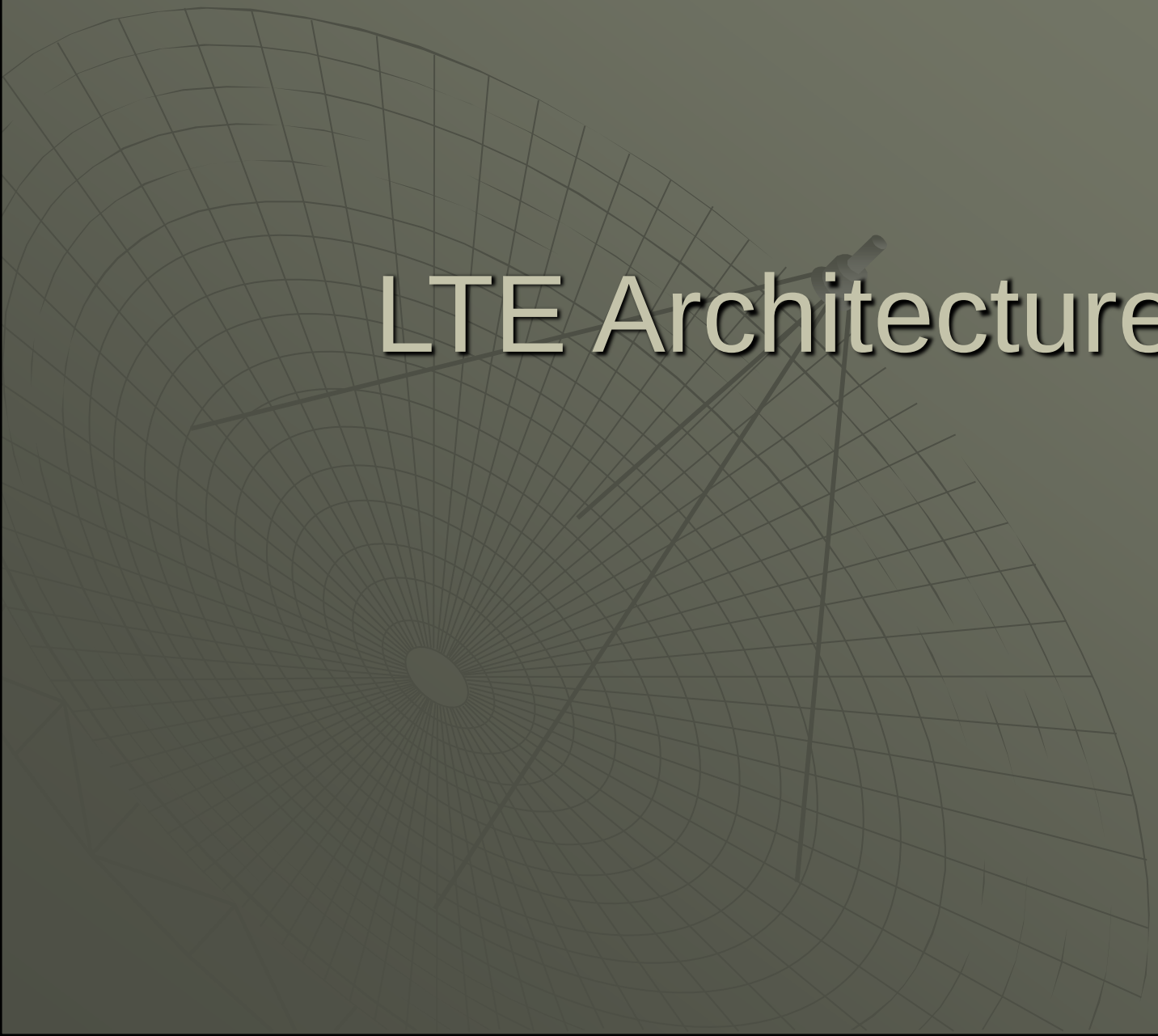
Example: downlink scheduling



TDD vs FDD

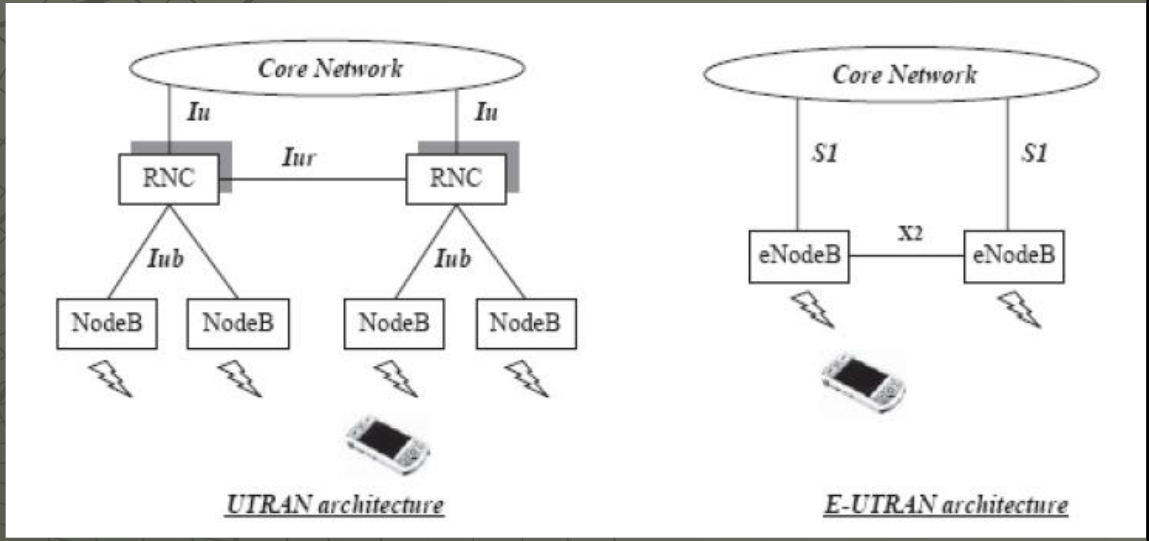

Frequency Division Duplex (FDD)
One radio frame (T_{frame} = 10 ms)
Downlink carrier
Uplink carrier
One subframe ($T_{subframe}$ = 1 ms)
(a)
Time Division Duplex (TDD)
Approximately symmetric
Asymmetric (downlink focus)
Asymmetric (uplink focus)
First and sixth subframe always assigned for downlink transmission
Downlink transmission
Uplink transmission
(b)

LTE Architecture



LTE – flat architecture

- More intelligence added to base station
  - UMTS architecture: hierarchical
  - Radio-related functionalities were located in RNC (radio network controller)
  - In the flat architecture the radio-related functionalities are located in BS
  - Packet scheduling
  - Frequency domain scheduling

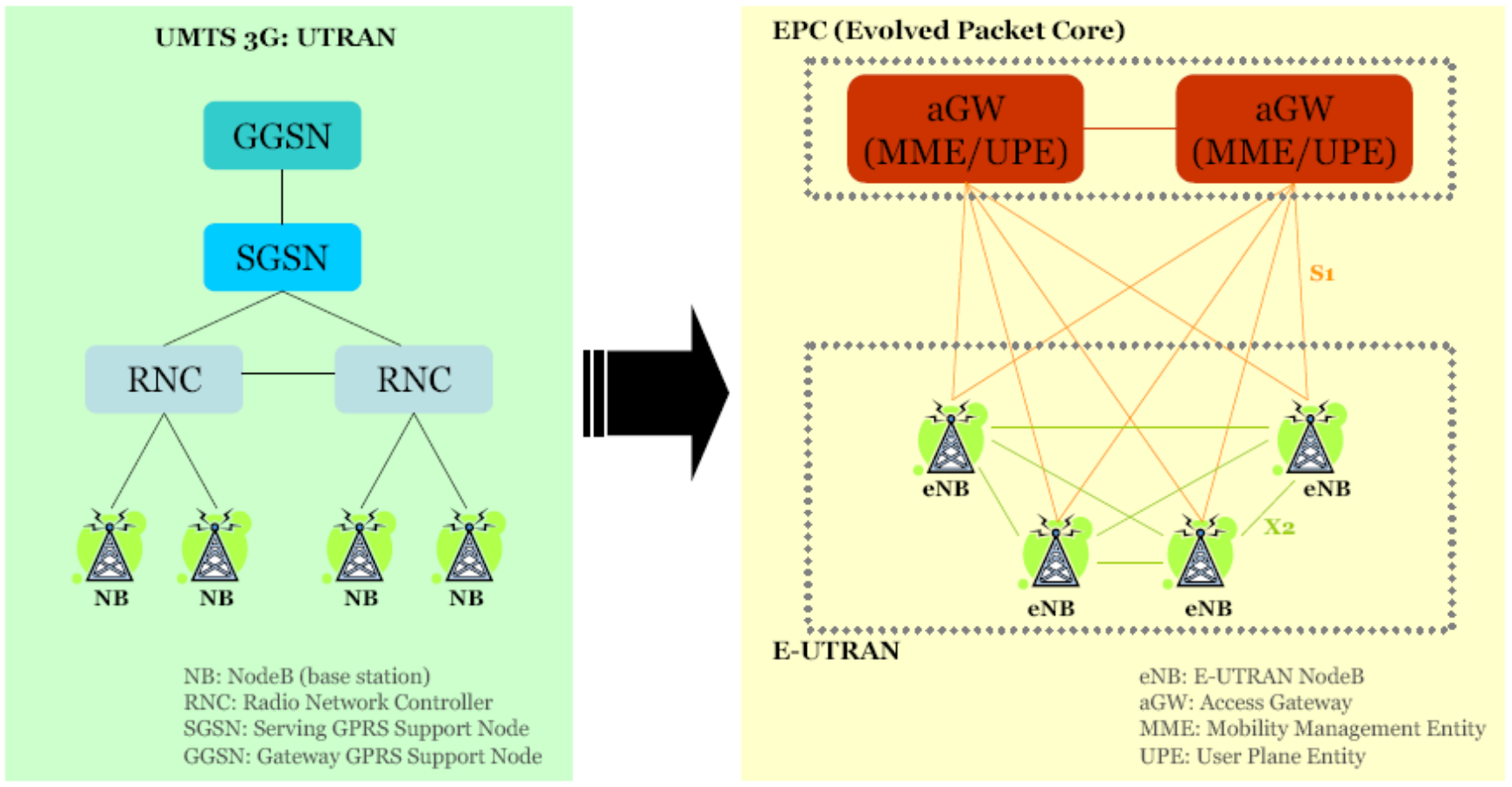


LTE key elements

- **2 main issues have been investigated:**
  - The physical layer
  - The access network internal architecture
- **Physical layer**
  - Downlink based on OFDMA
    - OFDMA offers improved spectral efficiency, capacity etc
  - Uplink based on SC-FDMA
    - SC-FDMA is technically similar to OFDMA but is better suited for uplink from hand-held devices
    - (battery power considerations)
  - For both FDD and TDD modes (User Equipment to support both)
    - With Similar framing + an option for TD SCDMA framing also
- **Access Network consideration**
  - For the access network it was agreed to get rid of the RNC which minimized the number of nodes

[Source:Technical Overview of 3GPP Long Term Evolution (LTE) Hyung G. Myung]

LTE Network Architecture

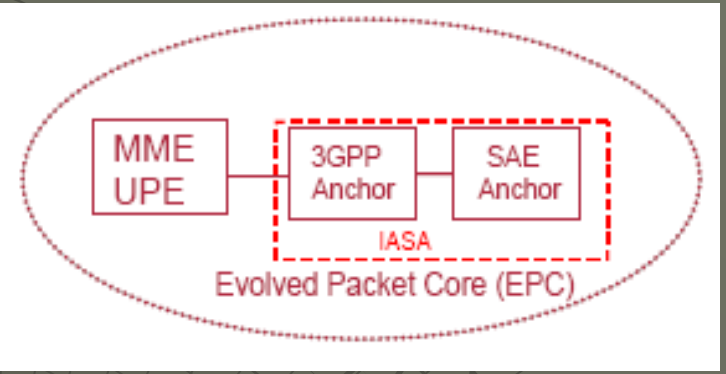


[Source:Technical Overview of 3GPP Long Term Evolution (LTE) Hyung G. Myung
http://hgmyung.googlepages.com/3gppLTE.pdf

System Architecture Evolution(SAE)

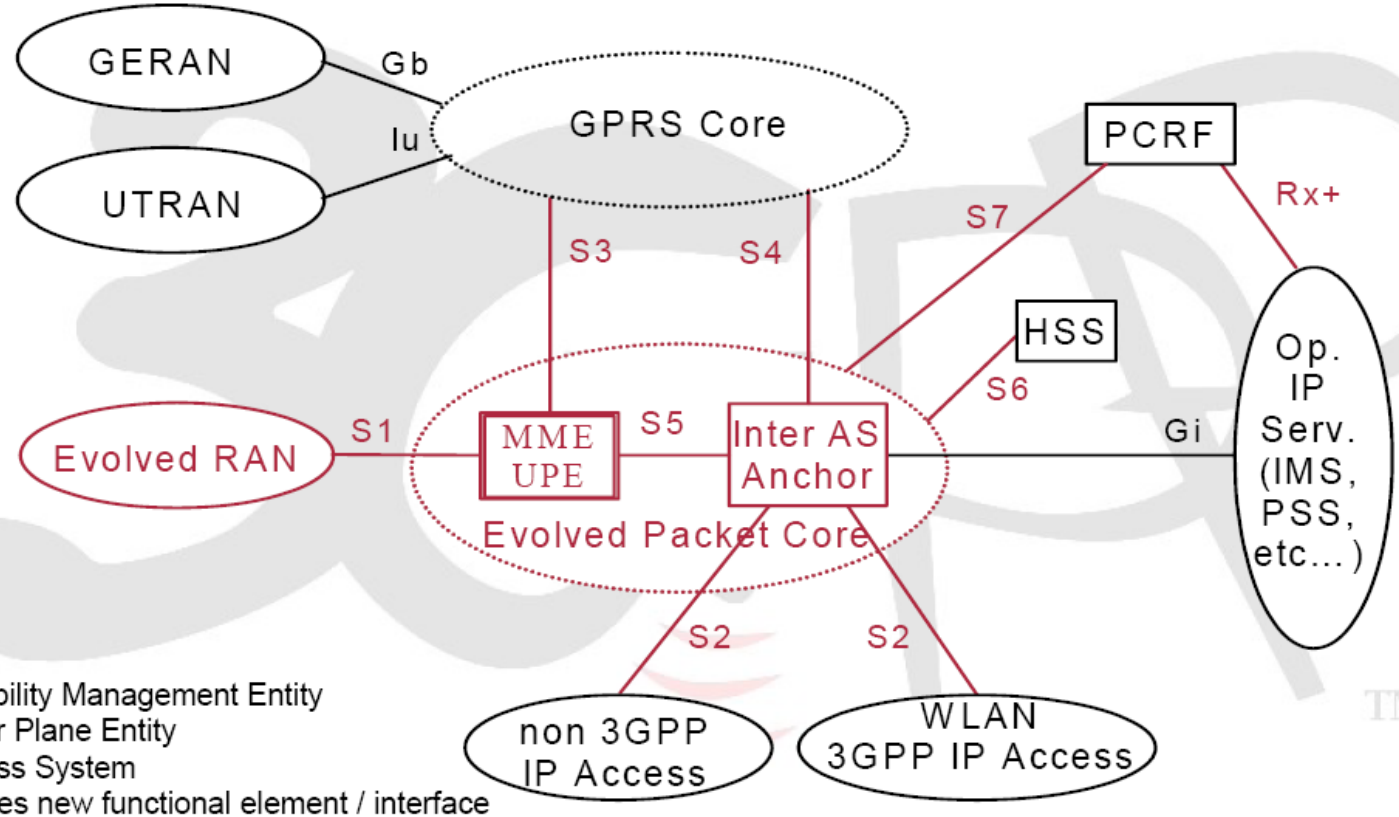
- **SAE is the core network architecture of 3GPP's future LTE wireless communication standard**
- **SAE is the evolution of the GPRS Core Network, with some differences**
- **The main principles and objectives of the LTE-SAE architecture include :**
  - **A common anchor point and gateway (GW) node for all access technologies**
  - **IP-based protocols on all interfaces;**
  - **Simplified network architecture**
  - **All IP network**
    - **All services are via Packet Switched domain**
  - **Support mobility between heterogeneous RATs, including legacy systems as GPRS, but also non-3GPP systems (say WiMAX)**
  - **Support for multiple, heterogeneous RATs, including legacy systems as GPRS, but also non-3GPP systems (say WiMAX)**

Evolved Packet Core(EPC)



- MME (Mobility Management Entity):
  - **Manages and stores the UE control plane context, generates temporary Id, provides UE authentication, authorization, mobility management**
- UPE (User Plane Entity):
  - **Manages and stores UE context, ciphering, mobility anchor, packet routing and forwarding, initiation of paging**
- 3GPP anchor:
  - **Mobility anchor between 2G/3G and LTE**
- SAE anchor:
  - **Mobility anchor between 3GPP and non 3GPP (I-WLAN, etc)**

LTE + SAE



MME – Mobility Management Entity
UPE – User Plane Entity
AS – Access System
Red indicates new functional element / interface

LTE – the simpler the better