Note to all these slides: NOT all of them will be presented in detail in the class, but they are left for students to be able to have extra study material.
Some material will be lightly touched in the class, but students will be informed if it is relevant for the exam.

Cellular Networks

Mobile cellular networks

GSM to 5G

A technology evolution path learning

1

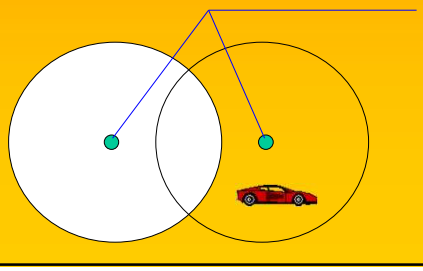
2

Recap: Wireless cellular network

Single hop widespread wireless connectivity to the wired world

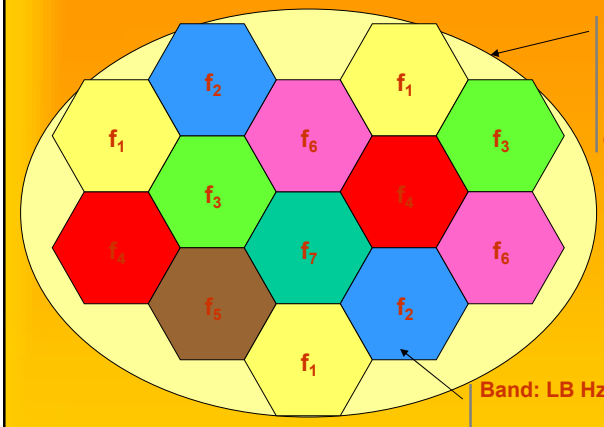
- **Usually space divided into cells, and MTs assigned to a cell**
- **A base station is responsible for communicating with MTs in its cell – typical communication: a voice call.**
- **Handoff occurs when a MT starts communicating via a new base station, while busy on a call**
- **Battery drain low.**

Cell size:
-Highly variable
-Technology dependent
-Varies with number of users



2

Recap: Cells and spectrum efficiency



Band: LB Hz

LB → k sub-bands (f_1, …, f_k)
1 sub-band → n channels (TDMA)

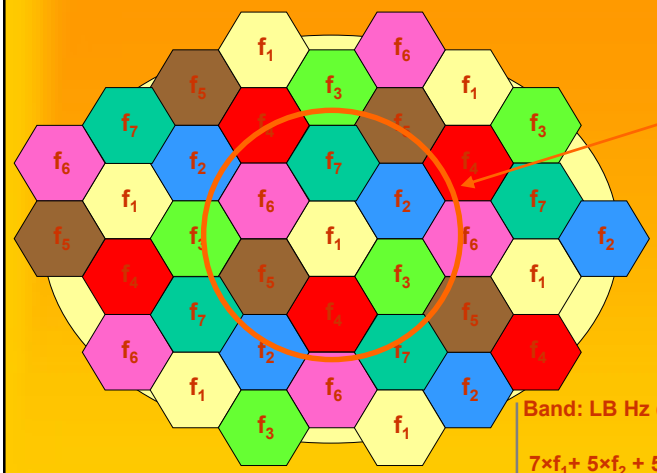
Capacity = k×n channels
(7×10 =70 channels)

Band: LB Hz (the same)
sub-bands:
$3\times f_1 + 2\times f_2 + 2\times f_3 + 2\times f_4 + 1\times f_5 + 2\times f_6 + 1\times f_7$
=13 sub-bands

Capacity = 13×10 = 130 channels!

3

Recap: Cells and spectrum efficiency



Smaller cells = higher network capacity

Cluster
Re-use factor: 7

Band: LB Hz (still the same)
sub-bands:
$7\times f_1 + 5\times f_2 + 5\times f_3 + 5\times f_4 + 5\times f_5 + 6\times f_6 + 5\times f_7$
=38 sub-bands

Capacity = 38×10 = 380 channels

4

5

Recap: Cell: Pros/Cons

Advantages:

- > capacity
- > # users
- < power
- > Reliability (distributed system)

Disadvantages

- Needs interconnection network between cells
- Needs to support Handovers!
- Needs to handle inter-cell interference!

Fundamental:

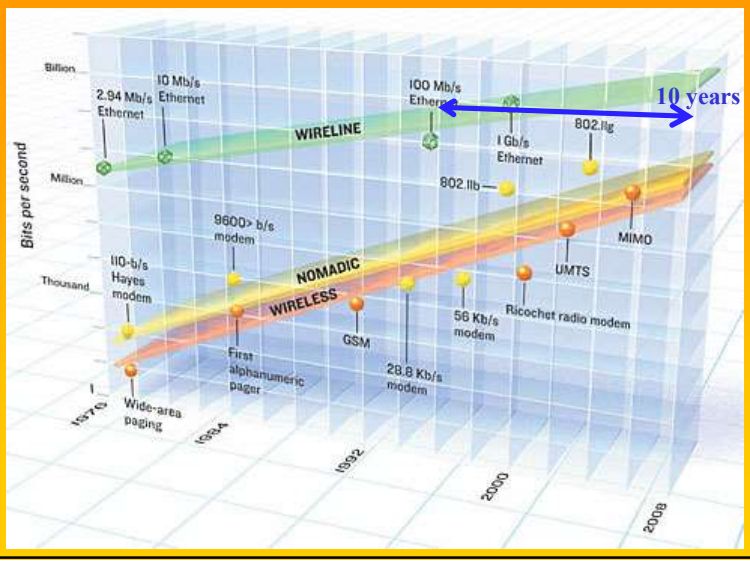
Each cell handles interferences, coverage areas, etc… *locally*

- Cell planning
- Cell size
- Frequency/code usage
- Channels (logical/physical) reservation

5

7

The fundamentals of wireless: Edholm's Law

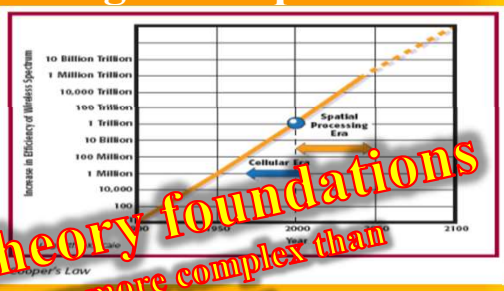


7

The controversial fundamentals: Shannon, Isenberg & Cooper

Shannon's Law

- There *is* a limit to capacity
- ... and we are getting close to it
- Best way to increase capacity is shrink cells
- Shorter range, improves SNIR
- Improves capacity & quality



Information theory foundations

Systems are now way more complex than the founding assumptions

8

The controversial fundamentals: Shannon, Isenberg & Cooper

Shannon's Law

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- ... and we are getting close to it
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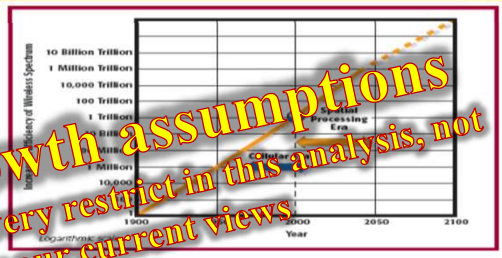


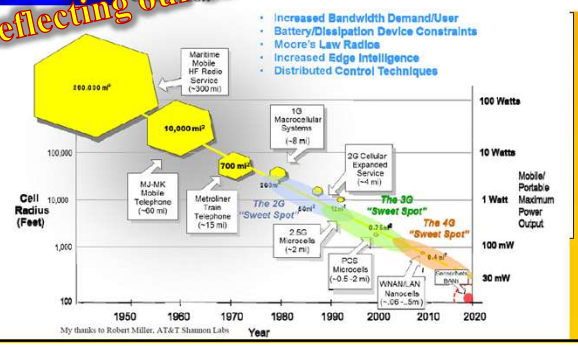
Model of growth assumptions

the notion of cell was very restrict in this analysis, not reflecting our current views

Cooper's Law

- Capacity of wireless has doul
  months for the past 105
- The gains come from a range
  most significant is the reuse of
  smaller and smaller

"Since 1950 wireless capacity h
million fold; the primary factor
move to many, smaller,



My thanks to Robert Miller, AT&T Shannon Labs

9

The controversial fundamentals: Shannon, Isenberg & Cooper

Shannon's Law

- There *is* a limit to capacity
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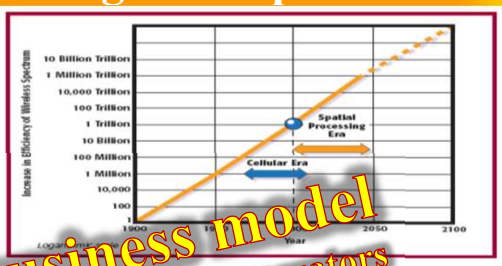
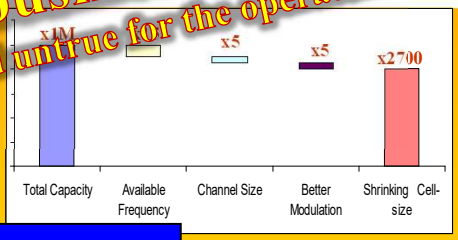
- Improves capacity & quality



Cooper's Law

- Capacity of wireless has doubled every 30 months over the past 105 years
- The gains come from a range of sources, but most significant is the use of frequencies in smaller and smaller cells.



"Since 1950 wireless capacity has increased 1 million fold; the primary factor in this is the move to many, smaller, cells"

Isenberg

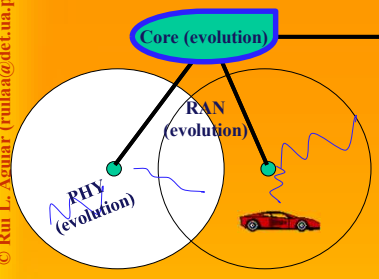
- "The rise of the stupid network"
- Push intelligence out to the edge

Internet business model
undesirable and untrue for the operators

10

12

What is this lesson about



Evolution of mobile cellular networks as legally defined

- There is a legal definition here
- Increasingly focused on the concept of "mobile service provision"

- **Operator networks**
  - **What technologies they have (had)**
  - **Presented following the logic of its deployment**
    - Operator networks are evolutive
    - Large complexities appeared because of that
- **Evolution presented as broken in two parts:**
  - **Pre-data**
  - **Data-dominated evolution**

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Cellular Networks

Mobile cellular networks

GSM to 3G

The teenager phone network wants to be independent in parents' home

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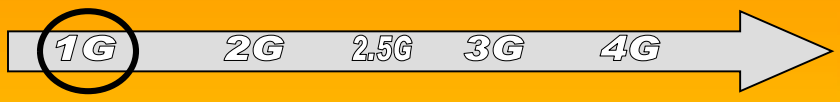
Evolution of Mobile Wireless

Advance Mobile Phone Service (AMPS)
- FDMA
- 824-849 MHz (UL), 869-894 MHz (DL)
- U.S. (1983), So. America, Australia, China



European Total Access Communication System (E-TACS)
- FDMA
- 872-905 MHz (UL), 917-950 MHz (DL)
- Deployed throughout Europe

1st Mobile services
Frequency shift keying; FDMA for spectrum sharing

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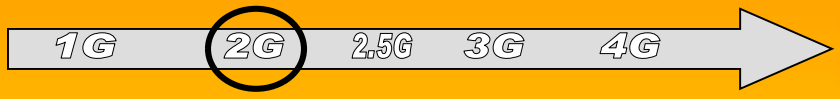
Evolution of Mobile Wireless

Global System for Mobile communications (GSM)

- TDMA
- Different frequency bands for cellular and PCS
- Developed in 1990, expected >1B subscriber by end of 2003



IS-95

- CDMA
- 800/1900 MHz – Cellular/PCS
- U.S., Europe, Asia

TDMA/CDMA for spectrum sharing; Circuit switching, primary voice
<56kbps data rates

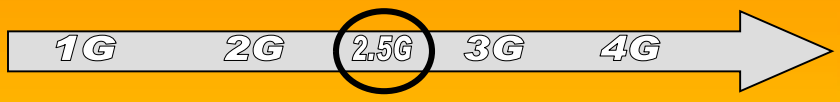
15

16

Evolution of Mobile Wireless

General Packet Radio Services (GPRS)

- Introduces packet switched data services for GSM
- Transmission rate up to 170 kbps
- Some support for QoS



Enhanced Data rates for GSM Evolution (EDGE)

- Circuit-switched voice (at up to 43.5 kbps/slot)
- Packet-switched data (at up to 59.2 kbps/slot)
- Can achieve on the order of 475 kbps on the downlink, by combining multiple slots

Digital: GSM to GPRS; Analog: AMPS to CDPD
Higher data rates (<192kbps), bridge to 3G

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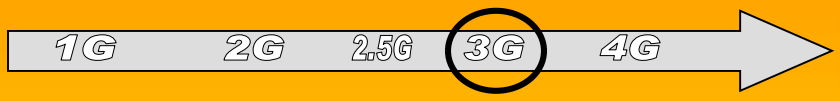
Evolution of Mobile Wireless

Universal Mobile Telecommunication Systems (UMTS)
- Wideband DS-CDMA
- Bandwidth-on-demand, up to 2 Mbps
- Supports handoff from GSM/GPRS



IS2000
- CDMA2000: Multicarrier DS-CDMA
- Bandwidth on demand (different flavors, up to a few Mbps)
- Supports handoff from/to IS-95

High speed, seamless integration of voice and data (Internet) services
< 7 Mbps data rates, packet switching

First-Generation Analog

- **Advanced Mobile Phone Service (AMPS)**
  - **In North America, two 25-MHz bands allocated to AMPS**
    - One for transmission from base to mobile unit
    - One for transmission from mobile unit to base
  - **Each band split in two to encourage competition**
  - **Frequency reuse exploited**
- **AMPS Operation**
  - **Subscriber initiates call by keying in phone number and presses send key**
  - **Network verifies number and authorizes user**
  - **Network issues message to user's cell phone indicating send and receive traffic channels**
  - **Network sends ringing signal to called party**
  - **Party answers; network establishes circuit and initiates billing information**
  - **Either party hangs up; network releases circuit, frees channels, completes billing**

Diferences Between First and Second Generation Systems

- Digital traffic channels
  - first-generation systems are almost purely analog; second-generation systems are digital
- Encryption
  - all second generation systems provide encryption to prevent eavesdropping
- Error detection and correction
  - second-generation digital traffic allows for detection and correction, giving clear voice reception
- Channel access
  - second-generation systems allow channels to be dynamically shared by a number of users

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2nd Generation: GSM

- Defined by CEPT/ETSI
- Requirements in terms of:
  - Services — Portability, =PSTN
  - QoS — = PSTN
  - Security — Low cost cipher
  - RF Usage — Efficiency
  - Network — Numbering ITU-T, SS-7
  - Cost — Low

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Basic Architecture

- Defines cells
- Defines a Mobile Terminal
  MobileEquipment+ SubscriberIdentityModule
  (etc…; e.g. International Mobile Station Equipment Identity (IMEI))
- Uses a Network Subsystem
  MSC; HLR, VLR
- Uses a Radio Subsystem
  BSS; BTransceiverS, BSController
- Defines a Operation Support Subsystem
  (security)

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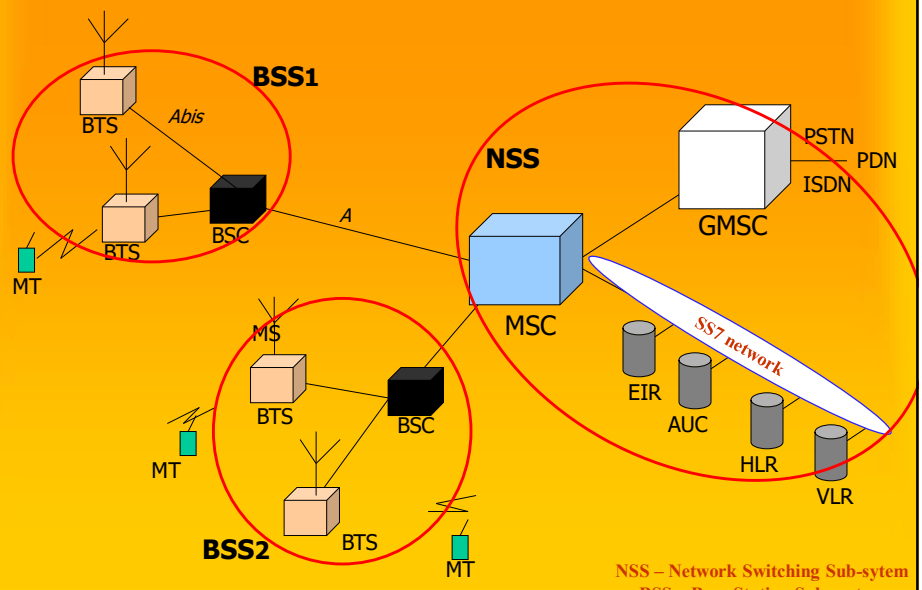
Basic Architecture

- Each cell is controlled by a base station (BS)
- The Base Station Subsystem (BSS) is structure as base station controllers (BSC) + base transceiver station (BTS)
- BSCs are connected to the mobile switching center (MSC) through physical lines
- MSCs are interconnected to each other
- There are MSCs connected to the public network (PSTN), the gateway mobile switching center (GMSC).

22

GSM Architecture



Mobile Switching Center

- **MSC = local switching center**
  Contains:
  - Home Location Register (HLR)
  - Visitor Location Register (VLR)
  - Autentication Center (Au)
  - Equipment Identity Registry (EIR)
- **Connects the BSS (base station subsystem)**
  (Master of the cell, define channels and access to them...)
- **Contains the registers for "their" mobile terminals**
- **Specific signalling channels**
  - **MT-BS (MSC): location, call setup, received call answer**
  - **BS (MSC)-MT: cell identification, location update, received call setup**

Network Subsystem DBs

- **HLR - Home Location Register**
  - **maintains permanent information about the subscribers of a GSM network (subscriber record)**
    - Subscription data: IMSI, MSISDN, subscription type (restrictions, supplementary services, ...)
  - **tracks the location and state of the mobile terminal within the network**
    - Location information: mobile VLR number.
- **VLR - Visitor Location Register**
  - **maintains temporary information about the subscribers registered on a GSM network (including subscribers in roaming)**
    - Data: IMSI, MSISDN, TMSI, MSRN, subscription type, location area, ...
  - **keeps up-to-date information about the location of the user within the network**

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Network Subsystem DBs

- **AuC – Authentication Center**
  - **service responsible for the authentication of the subscribers**
  - **maintains the encryption algorithms**
  - **maintains the secret key (k_i) for each subscriber**
  - **generates the session keys**
- **EiR – Equipment Identity Register**
  - **provides security mechanisms for the mobile equipments**
  - **keeps lists of mobile equipments**
    - white list (authorized)
    - gray list (under "observation")
    - black list (blocked)

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Mobile Station

- **Mobile station communicates across Um interface (air interface) with base station transceiver in same cell as mobile unit**
- **Mobile equipment (ME) – physical terminal, such as a telephone or PCS**
  - **ME includes radio transceiver, digital signal processors and subscriber identity module (SIM)**
- **GSM subscriber units are generic until SIM is inserted**
  - **SIMs roam, not necessarily the subscriber devices**

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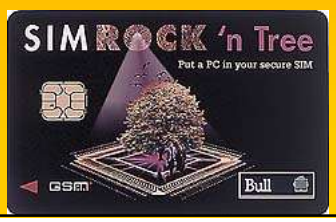
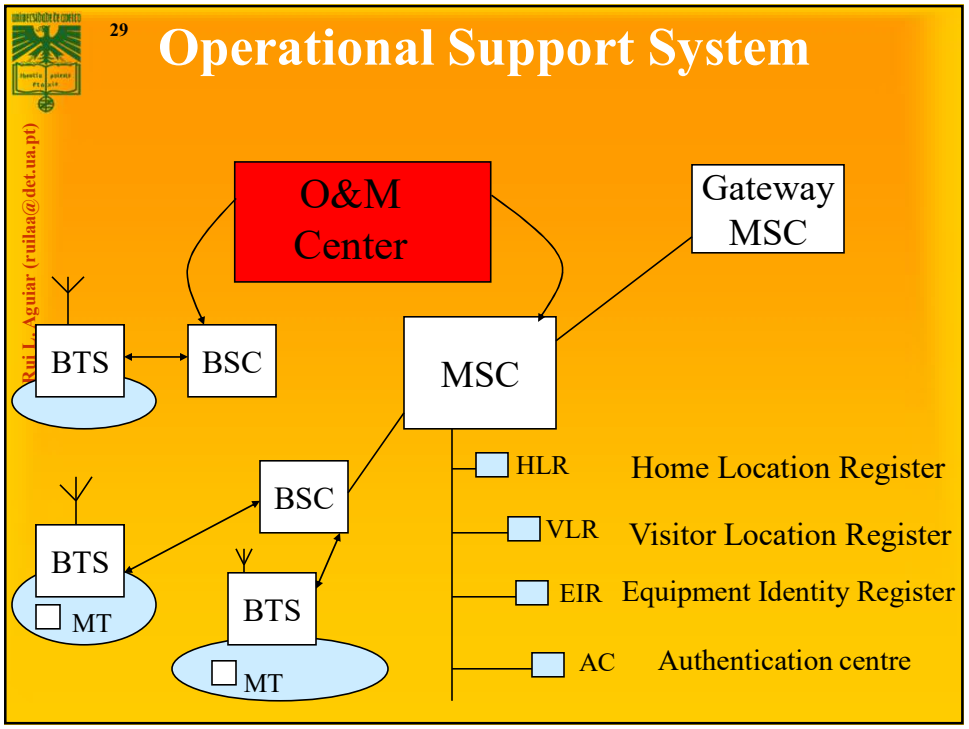
SIM: Suscriber Identity Module

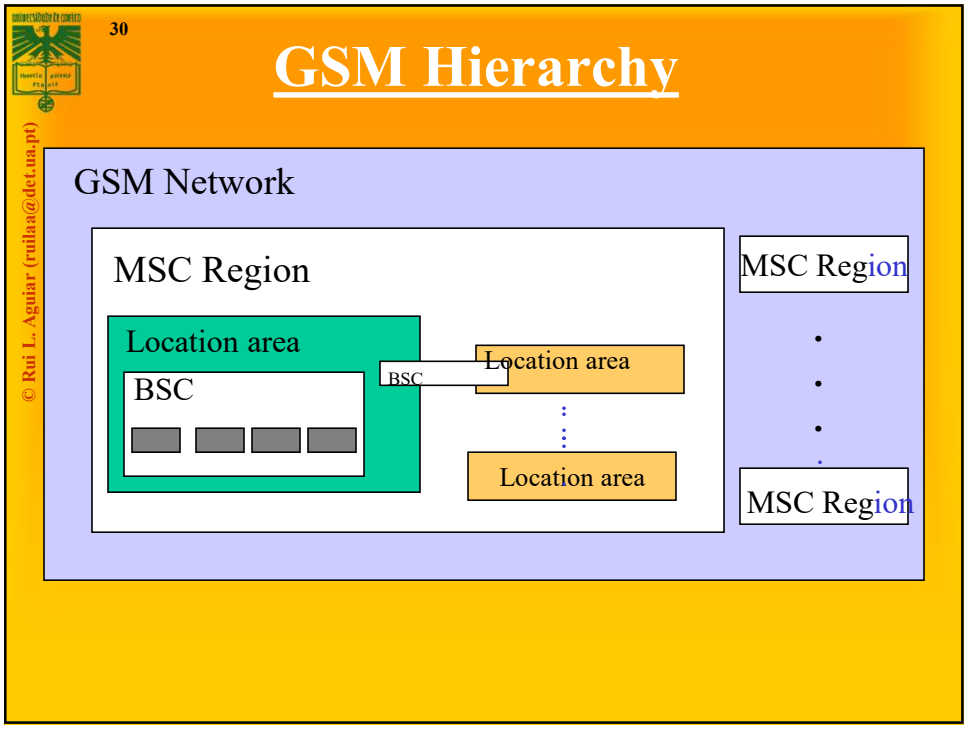
- *Informations*:
  - **subscriber identity, password (PIN), subscription information (authorized networks, call restrictions, …), security algorithms, short numbers, last received/dialed numbers, last visited location area, ...**
- **SIM card + GSM terminal = access to GSM services.**



28


29
Operational Support System
© Rui L. Aguiar (ruilaa@det.ua.pt)
O&M Center
Gateway MSC
BTS
BSC
MSC
BSC
BTS
MT
BTS
MT
HLR
Home Location Register
VLR
Visitor Location Register
EIR
Equipment Identity Register
AC
Authentication centre

29


30
GSM Hierarchy
© Rui L. Aguiar (ruilaa@det.ua.pt)
GSM Network
MSC Region
Location area
BSC
BSC
Location area
Location area
MSC Region
MSC Region

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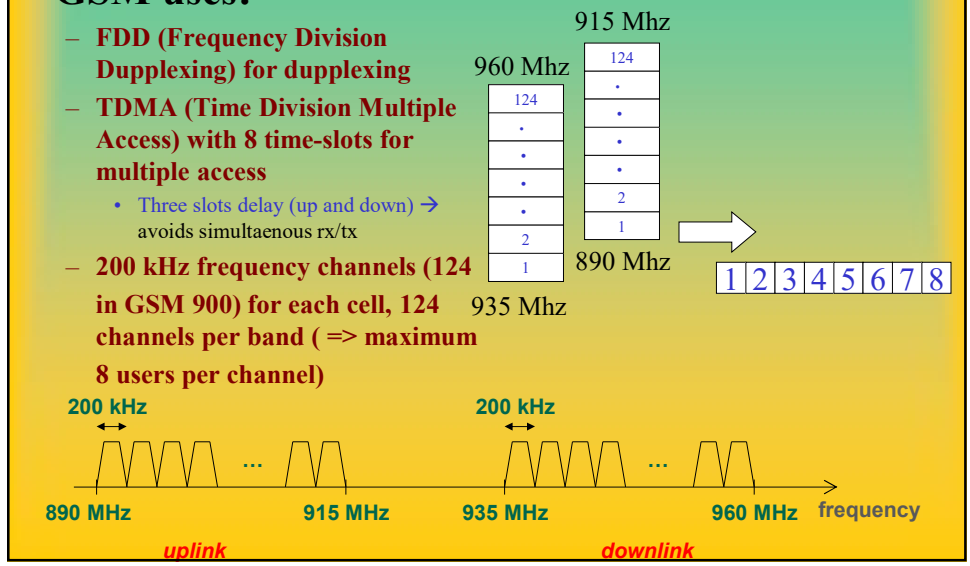
Air interface (Um) – channel allocation

- **GSM uses:**
  - **FDD (Frequency Division Dupplexing) for dupplexing**
  - **TDMA (Time Division Multiple Access) with 8 time-slots for multiple access**
    - Three slots delay (up and down) → avoids simultaenous rx/tx
  - **200 kHz frequency channels (124 in GSM 900) for each cell, 124 channels per band (=> maximum 8 users per channel)**



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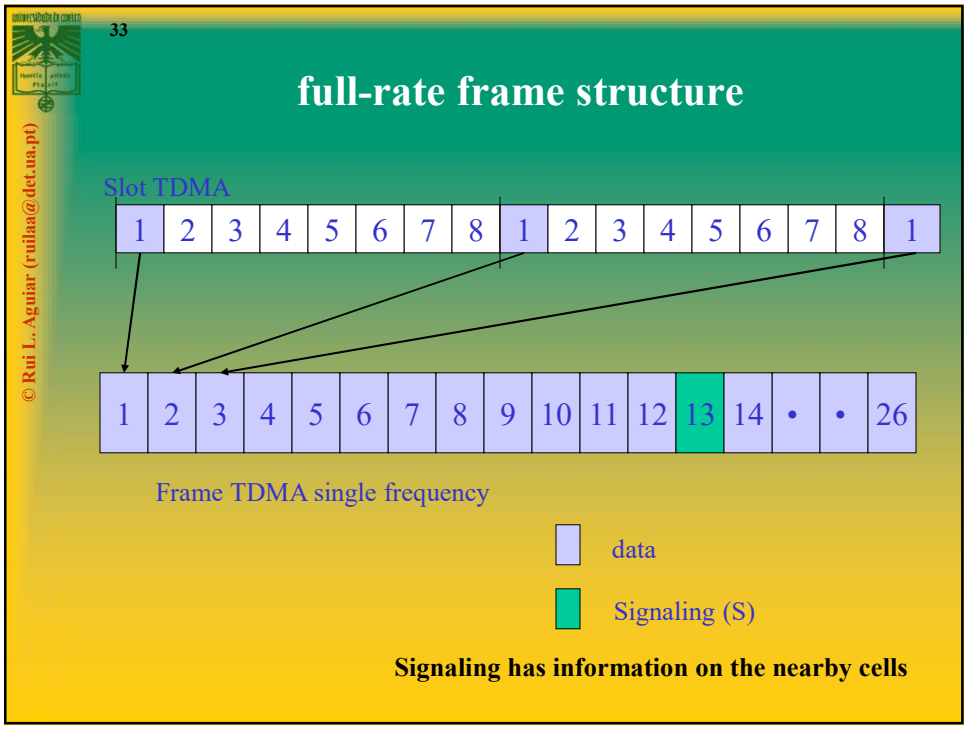
Logical channels

- **Logical channels are mapped in physical channels**
- **Physical channel is a timeslot, in a given frequency.**
- **Data channels:**
  - **TCH/FS - *full-rate speech* (13 kbps)**
  - **TCH/HS - *half-rate speech* (6,5 kbps)**
  - **TCH/F9.6 - *9.6 kbps full rate data***
  - **TCH/F4.8 – *4.8 kbps full rate data***
- **Signaling channels**
  - **BCH – Broadcast channels**
  - **CCH – common control channels**
  - **DCCH/ACCH – dedicated/associated control channels**

32


33
full-rate frame structure
Slot TDMA
1 2 3 4 5 6 7 8 1 2 3 4 5 6 7 8 1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 • • 26
Frame TDMA single frequency
data
Signaling (S)
Signaling has information on the nearby cells
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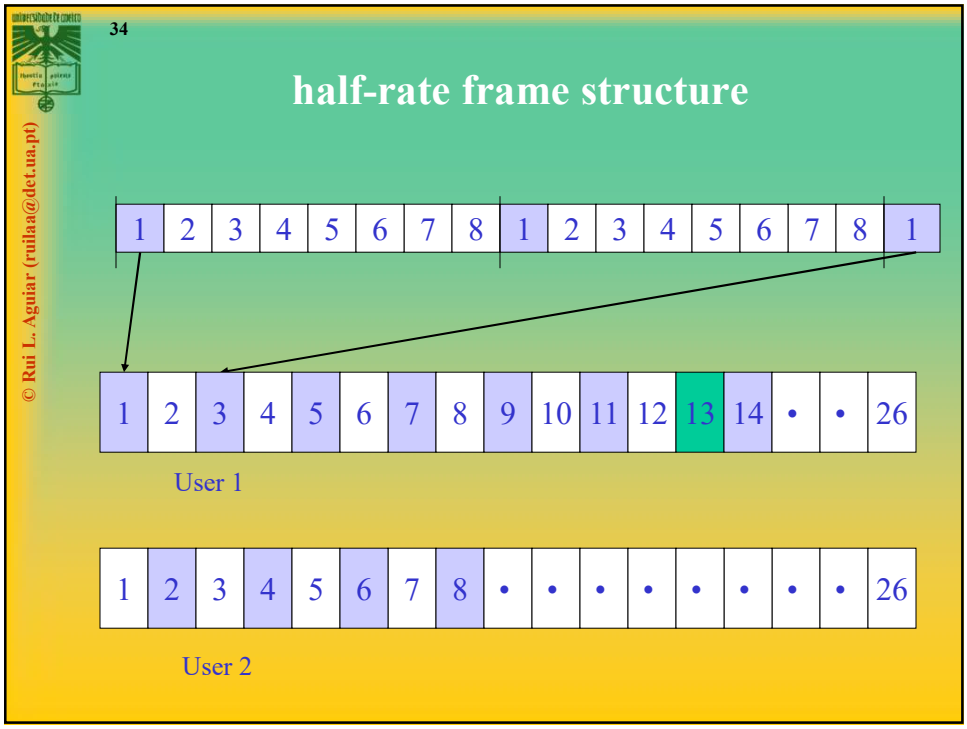
34
half-rate frame structure
1 2 3 4 5 6 7 8 1 2 3 4 5 6 7 8 1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 • • 26
User 1
1 2 3 4 5 6 7 8 • • • • • • • • 26
User 2
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Control channels

Used for:

- **Synchronizing MT with the cell**
- **Informing the MT about**
  - Cell parameters
  - Nearby cells
  - Channel information
- **Support paging**
  - Search for the MT when in low power mode
- **Allows the MT to access the network**
  - Shared (contention) access
  - Essential for the MT to request connections

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Signalling Channels

BCH :
- Broadcast Control Channel (BCCH)
- Frequency Correction Channel (FCCH)
- Synchronization Channel (SCH)

CCH :
- Random Access Channel (RACH)
- Paging Channel (PCH)

D/ACCH
- Stand-alone Dedicated Control Channel (SDCCH)
- Slow Associated Control Channel (SACCH)

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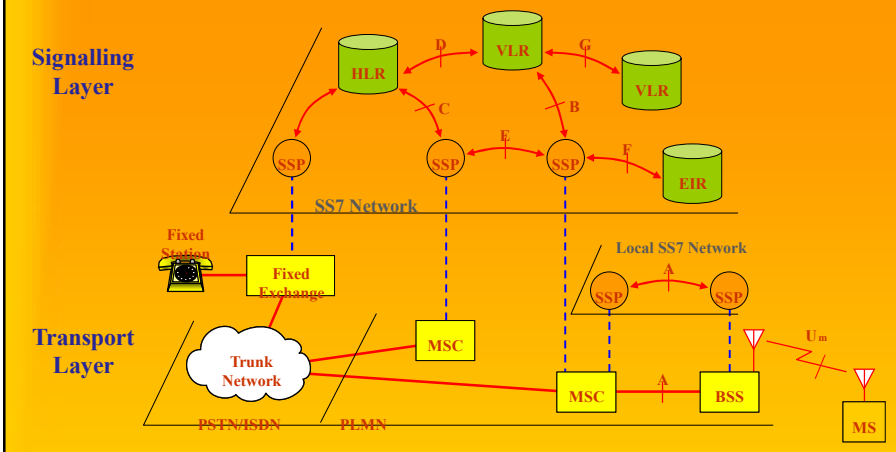
GSM Signalling and Transport Layers



MSC - Mobile Services Switching Centre
BSS - Base Station System
HLR - Home Location Register
VLR - Visitor Location Register
EIR - Equipment Identity Register
MS - Mobile Station
SSP - Service Signalling Point in SS7 Network

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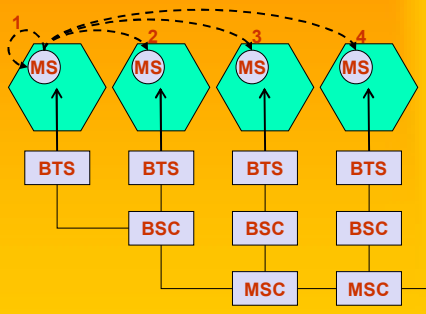
Types of handover (GSM)

1. Intra-cell: from a channel to another within the same cell
2. Inter-cell, Intra-BSC: from a channel in one cell to a channel in another cell, both controlled by the same BSC
3. Inter-BSC, Intra-MSC: from a channel in one cell to a channel in another cell, controlled by different BSCs, under the same MSC control
4. Inter-MSC: from a channel in one cell to a channel in another cell connected to different MSCs



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Functions Provided by Higher Protocols

- **Protocols above the link layer of the GSM signaling protocol architecture provide specific functions:**
  - **Radio resource management**
  - **Mobility management**
  - **Connection management**
  - **Mobile application part (MAP)**
  - **BTS management**

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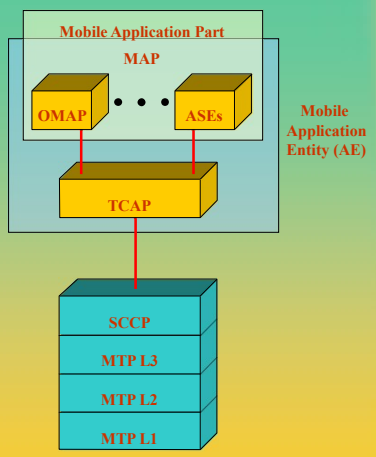
Mobile Application Part (MAP)

Information transfer between GSM PLMN entities uses the Mobile Application Part (MAP) of SS7.

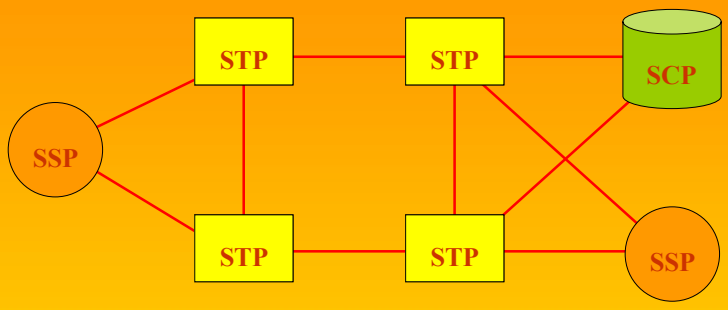
- **Location registration and cancellation**
- **Handover procedures**
- **Handling of supplementary services**
- **Retrieval of subscriber parameters during call set-up**
- **Authentication procedures**
- **OA&M**



40

Signalling System 7 (SS7)

SSP - Service Signalling Point
STP - Signal Transfer Point
SCP - Service Control Point



SS7 is a set of protocols governing mainly the transfer of call control information over a signalling network.
This signalling network is a packet switching network.

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The SS7 Architecture

OMAP - Operations Maintenance and Administration Part

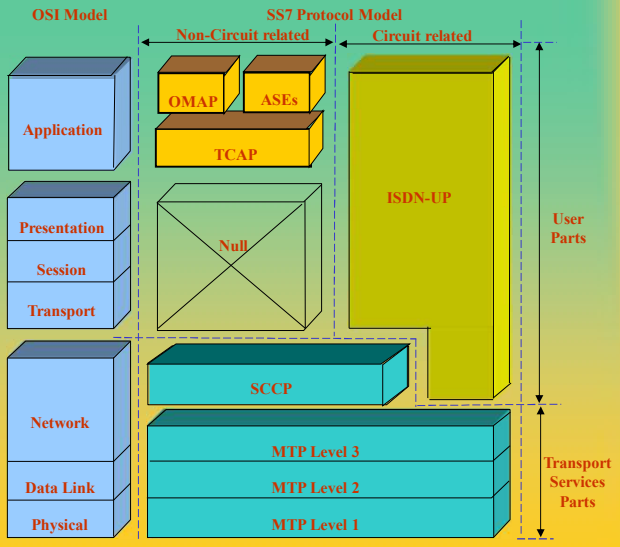
ASE - Application Service Element

TCAP - Transaction Capabilities Application Part

ISDN-UP - ISDN User Part

SCCP - Signalling Connection Control Part

MTP - Message Transfer Part



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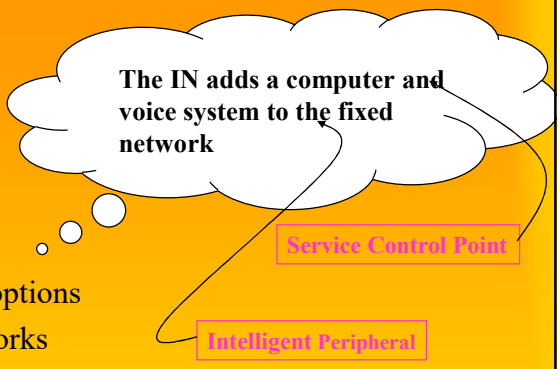
The Intelligent Network

- **Charging options**
  - **Freephone**
  - **Local rates**
  - **Premium rates**
- **Routing options**
  - **Group calls**
    - Network call centre options
    - Virtual Private Networks
  - **Personal calls**
    - one number
    - configurable routing



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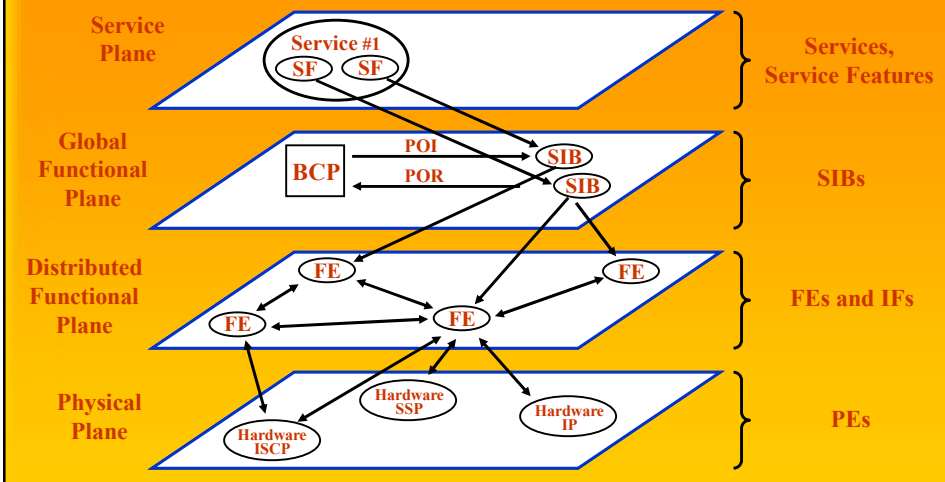
Intelligent Network Conceptual Model



PoI - Point of initiation
PoR – Point of Return
SIB Service Independent Block
BCP – Basic Call Processing

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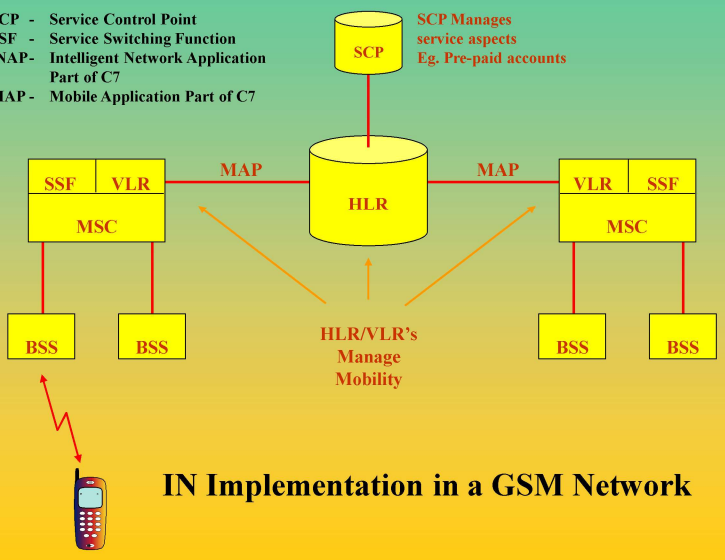
Intelligent Networks - CAMEL

SCP - Service Control Point
SSF - Service Switching Function
INAP- Intelligent Network Application Part of C7
MAP - Mobile Application Part of C7



IN Implementation in a GSM Network

45

Short Message Service - SMS

- supports the transmission of messages up to 160[1] characters, between mobile terminals
- messages are transmitted through the signaling channels
- is used for a variety of applications:
  - text messages between users (very popular)
  - broadcast of information by the network operator (e.g. promotions)
  - broadcast of location-dependent information (e.g. local restaurants)
  - access to computing applications (e.g. home banking and e-mail)
  - configuration of mobile terminals over the air

1 – When using (7 bits/charater); only 70 caracteres wehn using other codes (8 bits).

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SIM Toolkit

Principle: **The SIM card can initiate actions on the terminal.**

Objectives: **Allow exchanges between the network and the SIM through SMSs (without displaying them)**

➲ **Value-added services provision.**

Examples:

- *Reservation* in a restaurant (send a menu by the network, manages user choices and the SIM card sends back the reservation in an SMS).

- *Menus management* (kiosk services).

GPRS

- **Packet-oriented transport service, for data network connections (Internet). GPRS features:**
  - **Better transmission bit rates(max 150kbps).**
  - **Allows burst communications ("immediate": connections in <1s)**
  - **New network applications**
  - **New billing mechanisms (user-oriented: by traffic, p.ex.)**

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GPRS Architecture

- New entities are defined
  - SGSN – serving GPRS support node
  - GGSN – gateway GPRS support node
  - Interfaces between entities GPRS, GSM, core, e PSTN
- Transmission plane
  - Data packets are transmitted by a tunnel mechanisms
- Control plane
  - GTP: a protocol for tunnel management (create, remove, etc..)
- Radio interface
  - Changed the logical channels and how they are managed
  - Remains the concept of "master-slave"

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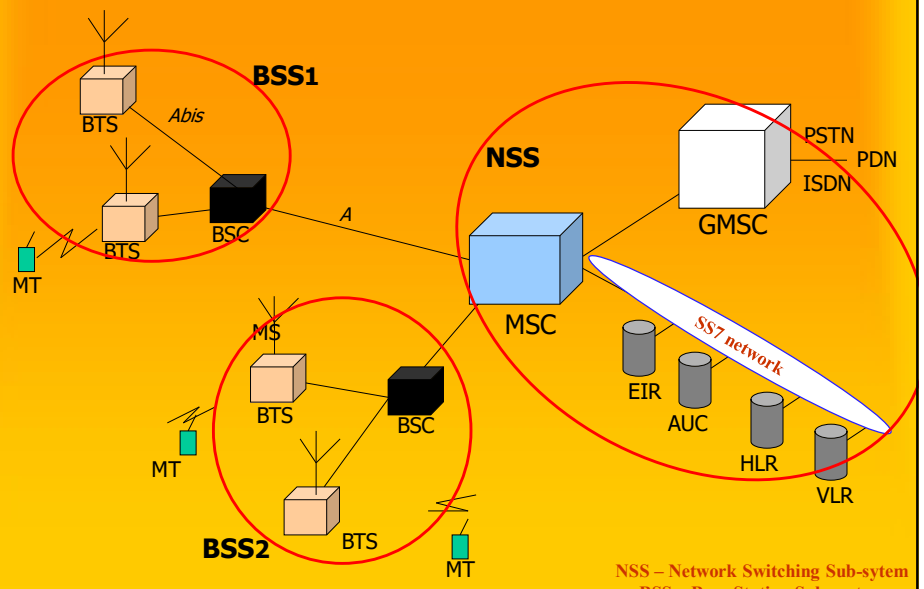
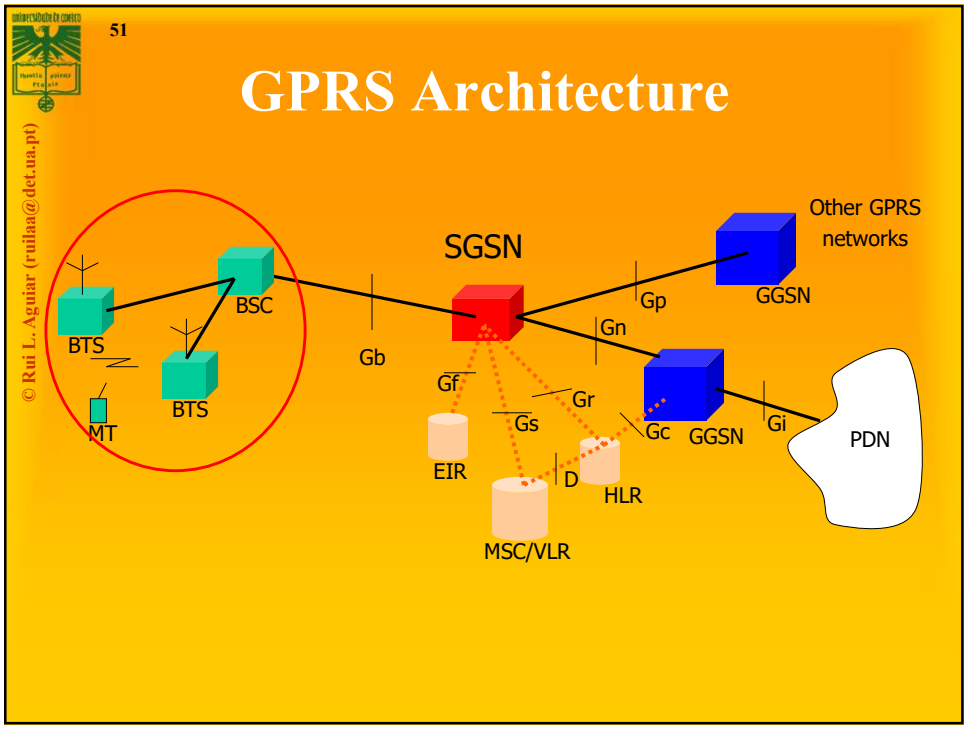
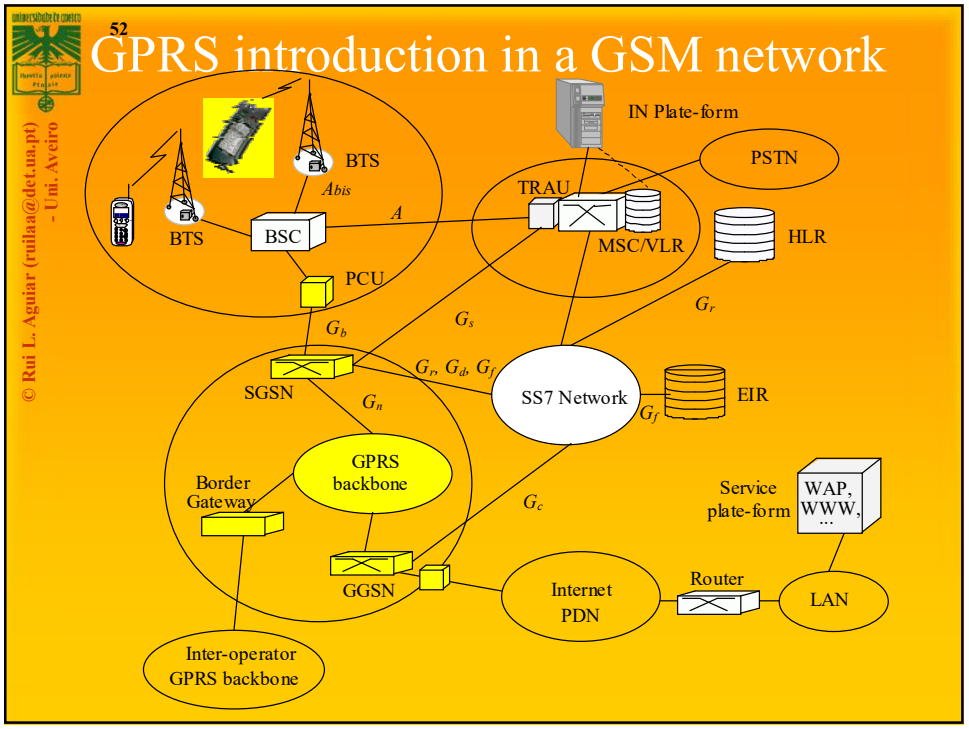
GSM Architecture



50


51
GPRS Architecture
© Rui L. Aguiar (ruilaa@det.ua.pt)
BTS
BSC
BTS
MT
Gb
SGSN
Gp
Other GPRS networks
GGSN
Gn
Gf
Gr
Gs
Gc
GGSN
Gi
PDN
EIR
D
HLR
MSC/VLR

51


52
GPRS introduction in a GSM network
© Rui L. Aguiar (ruilaa@det.ua.pt) - Uni. Aveiro
BTS
Abis
BTS
BSC
A
IN Plate-form
PSTN
TRAU
MSC/VLR
HLR
PCU
Gb
Gs
Gr
Gn, Gd, Gf
SGSN
Gn
SS7 Network
Gf
EIR
GPRS backbone
Border Gateway
Gc
Service plate-form
WAP, WWW, ...
GGSN
Internet PDN
Router
LAN
Inter-operator GPRS backbone

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GGSN (*Gateway GPRS Support Node*) Functions

- ***Gateway:***
  - **Allows the connection to other IP or GPRS networks.**
- ***Routing*:**
  - **IP router which supports dynamic or static routing,**
- ***Mobility management:***
  - **Use of *routing areas*.**
  - **Handover management between the BSCs and other SGSNs.**
  - **Allows the routing of the packets towards the users SGSNs, according to their mobility.**
- ***Sessions management:***
  - **At each session, the SGSN activates a PDP (*Packet Data Protocol*) context, and allocates an IP address to the MT.**

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GGSN (*Gateway GPRS Support Node*) Functions

- ***Security:***
  - **Ciphers the communications towards or from the mobiles.**
  - **Includes firewalls for filtering the packets coming from external IP networks.**
- ***Authentication:***
  - **At *Attach* and inter-SGSN RA updates.**
- ***Billing:***
  - **Production of the CDRs according to the quantity of information and the session duration (attachment, duration of active PDP context).**
- ***SMS:***
  - **Supports the Gd interface for the communications with the SMS-GMSC and the SMS-IWMSC.**

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Connection management

After attach: receive a packet with a PDP identifier

- **Acts as an address**

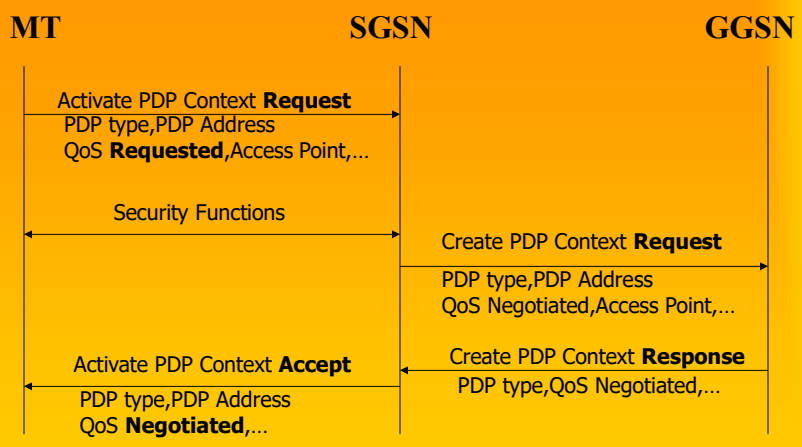
PDP identifier: per session.

- static: allocated by the MT home networks
- Dinamic: allocated by the GGSN

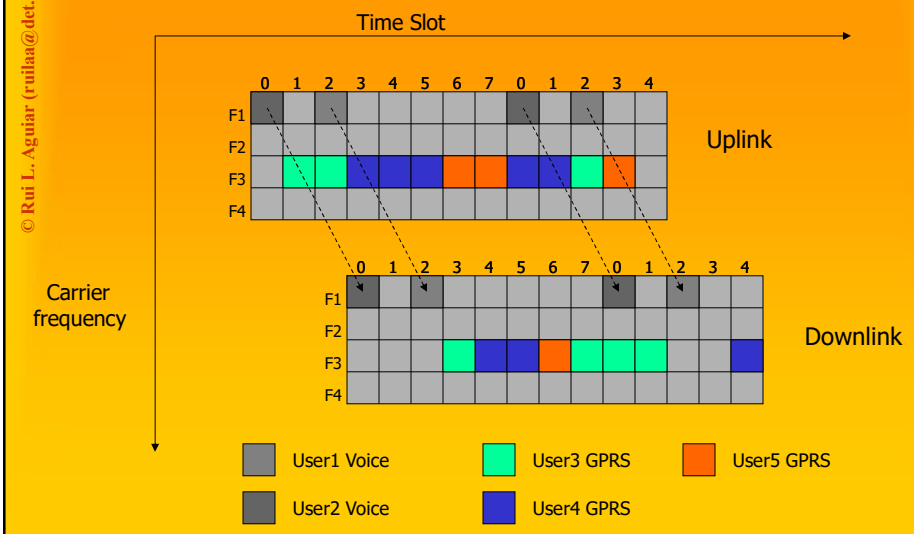
PDP profile:

- **Type**
- **PDP identifier**
- **Requested QoS**
- **correspondent GGSN address**

PDP context activation



GPRS Radio Interface



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GPRS: logical channels

Group	Channel	Function	Direction
Packet data Traffic channel	PDTCH	Data Traffic	MS ↔ BSS
Packet broadcast control channel	PBCCH	Broadcast Control	MS ← BSS
Packet common Control Channel (PCCCH)	PRACH	Random Access	MS → BSS
	PAGCH	Access Grant	MS ← BSS
	PPCH	Paging	MS ← BSS
	PNCH	Notification	MS ← BSS
Packet Dedicated Control Channels	PACCH	Associated Control	MS ↔ BSS
	PTCCH	Timing Advance Control	MS ↔ BSS

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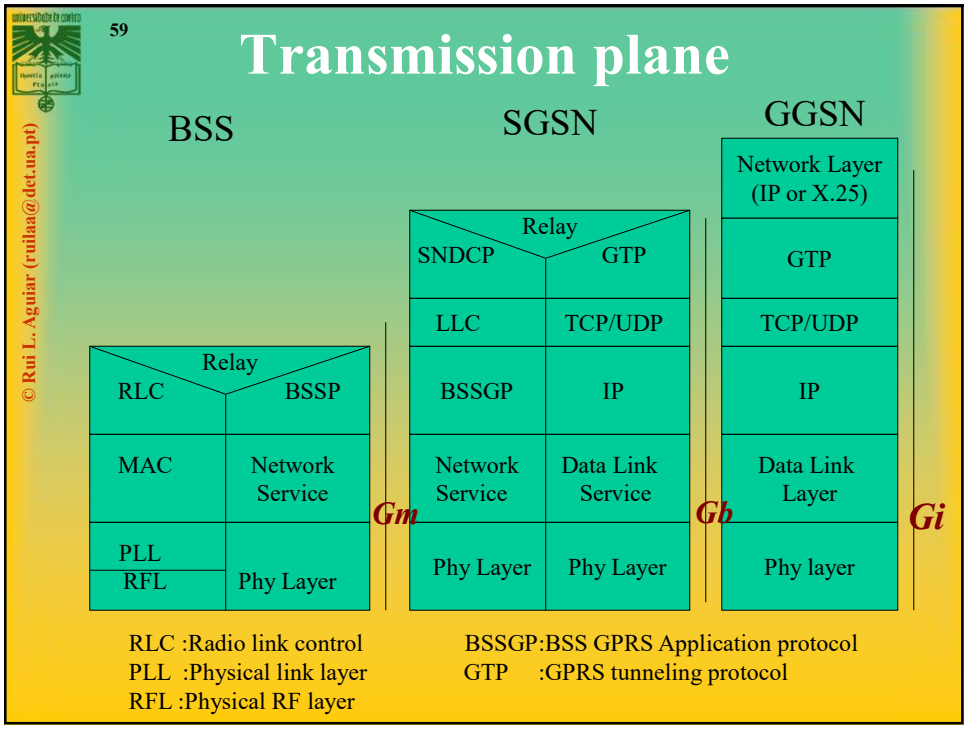
59
Transmission plane
BSS
SGSN
GGSN
Network Layer (IP or X.25)
Relay
SNDCP
GTP
GTP
LLC
TCP/UDP
TCP/UDP
Relay
RLC
BSSP
BSSGP
IP
IP
MAC
Network Service
Network Service
Data Link Service
Data Link Layer
Gm
Gb
Gi
PLL
RFL
Phy Layer
Phy Layer
Phy Layer
Phy layer
© Rui L. Aguiar (ruilaa@det.ua.pt)
RLC :Radio link control
PLL :Physical link layer
RFL :Physical RF layer
BSSGP:BSS GPRS Application protocol
GTP :GPRS tunneling protocol

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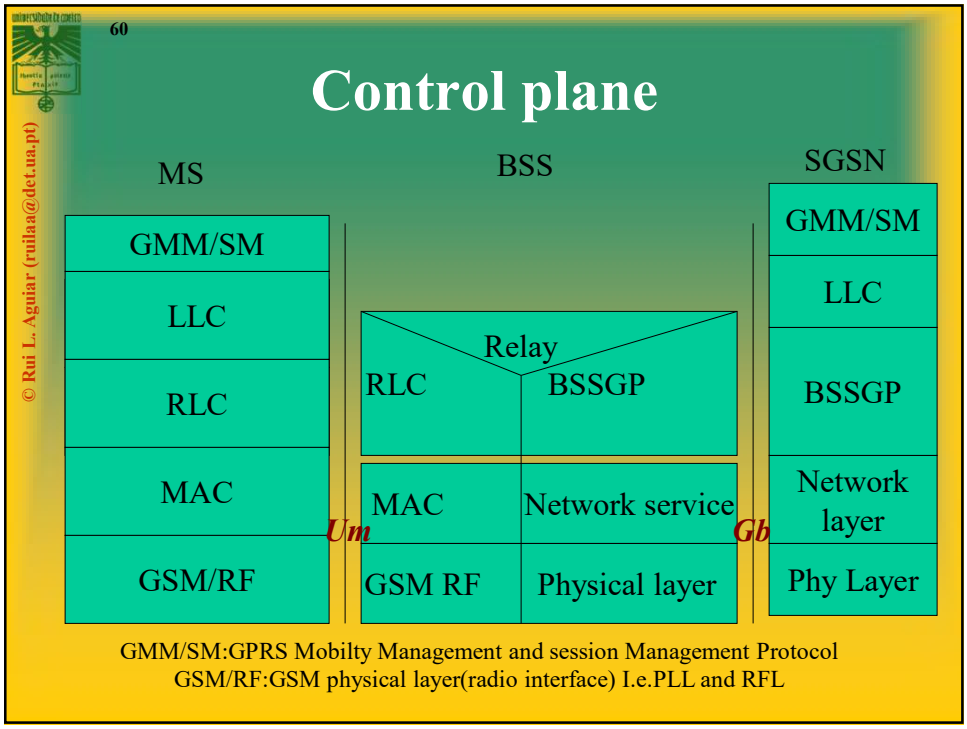
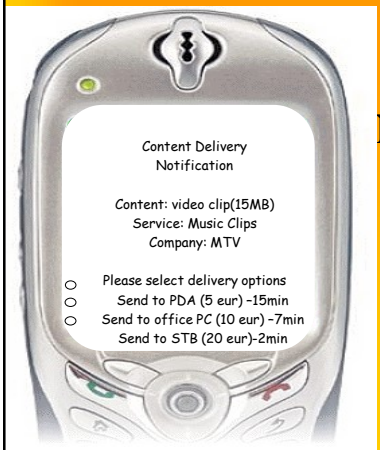

60
Control plane
MS
BSS
SGSN
GMM/SM
GMM/SM
LLC
LLC
Relay
RLC
BSSGP
RLC
BSSGP
MAC
MAC
Network service
Network layer
Um
Gb
GSM/RF
GSM RF
Physical layer
Phy Layer
© Rui L. Aguiar (ruilaa@det.ua.pt)
GMM/SM:GPRS Mobilty Management and session Management Protocol
GSM/RF:GSM physical layer(radio interface) I.e.PLL and RFL

60

3G: UMTS



New idea for new technology

The teenager wants to move on

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UMTS Abbreviations

AAL2	ATM adaptation layer 2
ANSI	American National Standards Institute
ARIB	Association of radio industries and businesses
ASN.1	Abstract Syntax Notation One
ATM	Asynchronous transfer mode
BER	Bit error rate
BS	Base station
BSAP	Base Station application part
BSC	Base station controller
BSSGP	Base Station Sub-System GPRS Protocol
CC	Call control
cdma	code division multiple access
CDPD	Cellular Digital Packet Data
CN	Core network
CS	Circuit switched
CSCF	Call services control function
EDGE	Enhanced data rates for GSM evolution
ETSI	European Telecommunication standardisation institute
FDD	Frequency division duplex
GERAN	Global system for mobile communications enhanced data rates for GSM evolution radio access network
GGSN	Gateway GPRS support node
GMM	GPRS MM
GMSC	Gateway MSC
GPRS	General packet access
GSM	Global system for mobile communication
GTP	GPRS tunneling protocol
HLR	Home location register
HSCSD	High speed circuit switched data
HSS	Home subscriber server
IETF	Internet engineering task force
IM	Internet multimedia
IP	Internet protocol
ISDN	Integrated services digital network
ITU	International telecommunications union
LLC	Link layer control
MAC	Medium access control
MAP	Mobile application part
MM	Mobility management
MGCF	Media gateway control function
MGW	Media gateway
MSC	Mobile services switching center
MMS	Multimedia messaging
OSA	Open services architecture
P-CSCF	Proxy-CSCF
PDC	Personal digital communication
PDCP	Packet data convergence protocol
PDP	Packet data protocol
PHB	Per hop behaviour
PLMN	Public land mobile network
PS	Packet switched
PSTN	Public switched telephony network
RAN	Radio access network
RANAP	RAN application part
RF	Radio frequency
RLC	Radio link control
RNC	Radio network controller
RRC	Radio resource control
RSVP	Resource reservation protocol
SCP	Services control point
SA	Services and System Aspects
SDL	Specification and description language
SDU	Serving data unit
SGSN	Serving GPRS support node
SGW	Signalling gateway
SM	Session managament
SMG	Special mobile group
SNDCP	Sub-network dependent convergence protocol
T	Terminal
TD-CDMA	Time division-CDMA
TDD	Time division duplex
TDMA	Time division multiple access
TFT	Traffic flow template
TIA	Telecommunications industry association
UMTS	Universal mobile telecommunication system
UWCC	Universal wireless communications consortium
UTRAN	UMTS terrestrial RAN
VHE	Virtual home environment
VLR	Visitor location register
VoIP	Voice over IP
WAP	Wireless application protocol
WLAN	Wireless local area network
WCDMA	Wideband CDMA
3GPP	3rd generation partnership project
3GPP2	3rd generation partnership project 2

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What is 3GPP?

3rd Generation Partnership Project - partnership of regional SDOs

SDOs take 3GPP specifications and transpose them to regional standards. Addresses:

3G (IMT-2000) systems based on the evolved GSM core network and the Universal Terrestrial Radio Access (UTRA), in FDD and TDD modes;

GSM, including GSM evolved radio access technologies (GPRS/EDGE/GERAN)

ITU references the regional standards

GSM
GPRS
EDGE
W-CDMA – FDD (Frequency Division Duplex)
TD-CDMA – TDD (Time Division Duplex)

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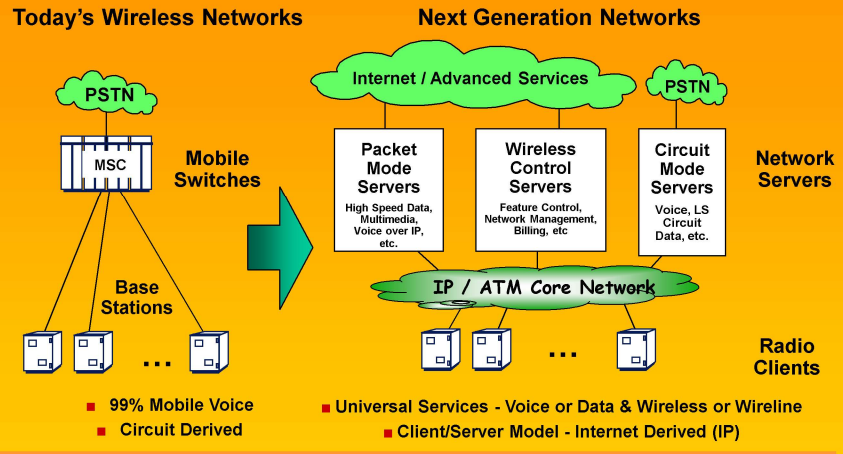
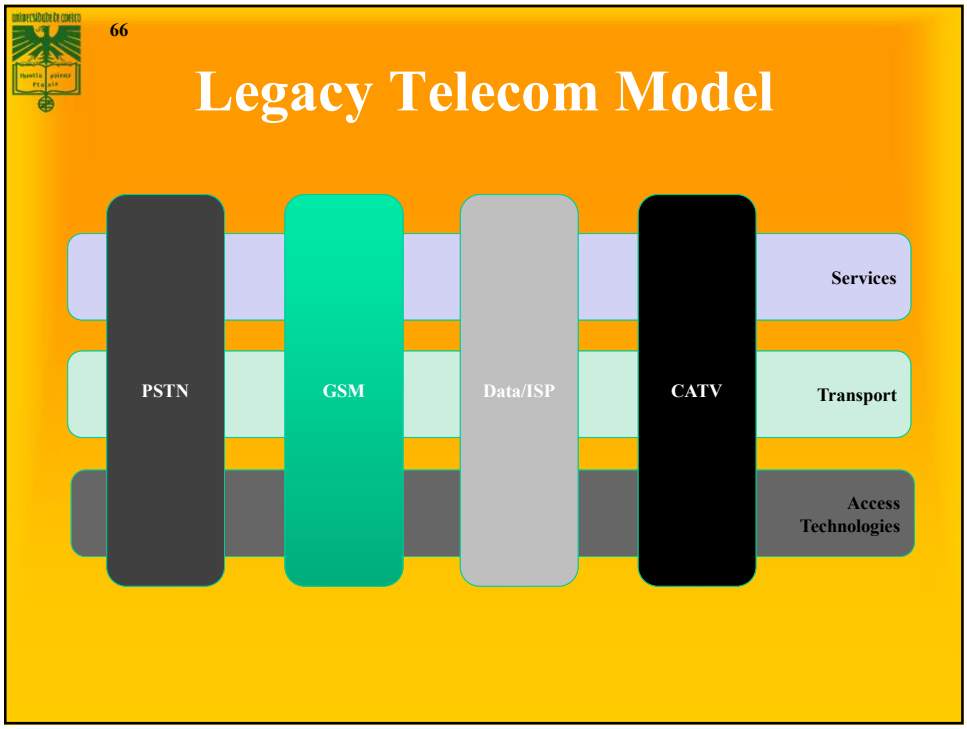
Transition to "Next Generation Networks"



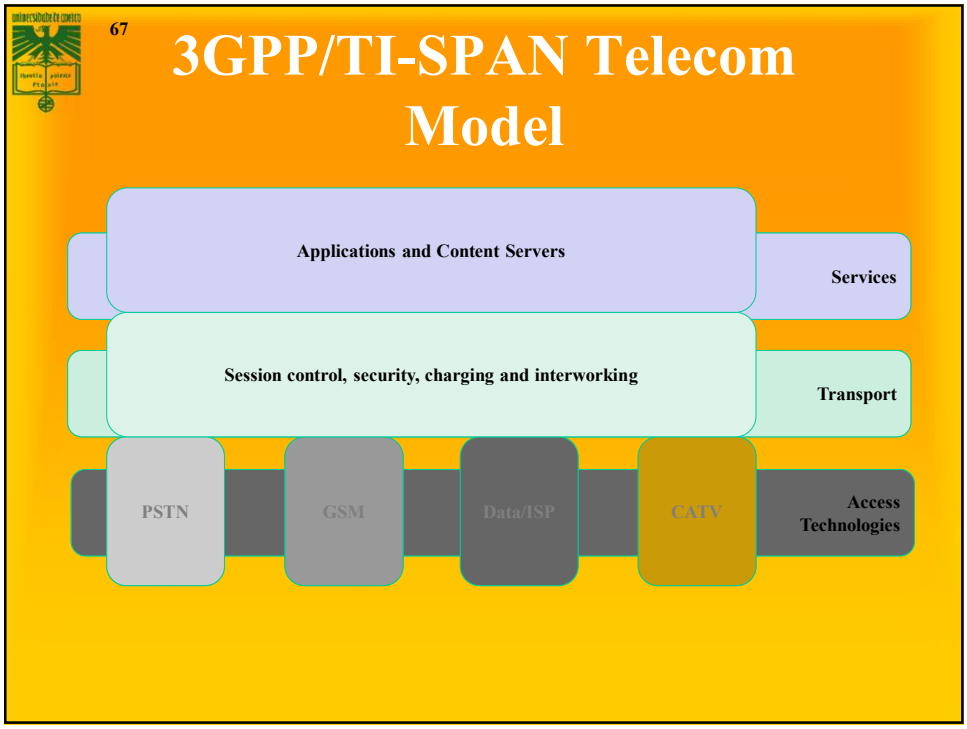
- 99% Mobile Voice
- Circuit Derived
- Universal Services - Voice or Data & Wireless or Wireline
- Client/Server Model - Internet Derived (IP)

The next generation architecture uses Internet based client-server platforms to enable universal services and reduce network cost structure.

65


66
Legacy Telecom Model
PSTN
GSM
Data/ISP
CATV
Services
Transport
Access Technologies

66


67
3GPP/TI-SPAN Telecom Model
Applications and Content Servers
Session control, security, charging and interworking
PSTN
GSM
Data/ISP
CATV
Services
Transport
Access Technologies

67

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3GPP and service provision

- 3GPP is much more than radio
- It contains a full service exploitation context
  - Under consideration and evolution for telecom operators
  - Future integrated networks following from these trends
- Service support trends are not new
  - 2G systems also had their architectures (CAMEL)
  - Web brought some changes to this (hey, java, hey)
- Business models are paramount here
  - Walled garden concepts

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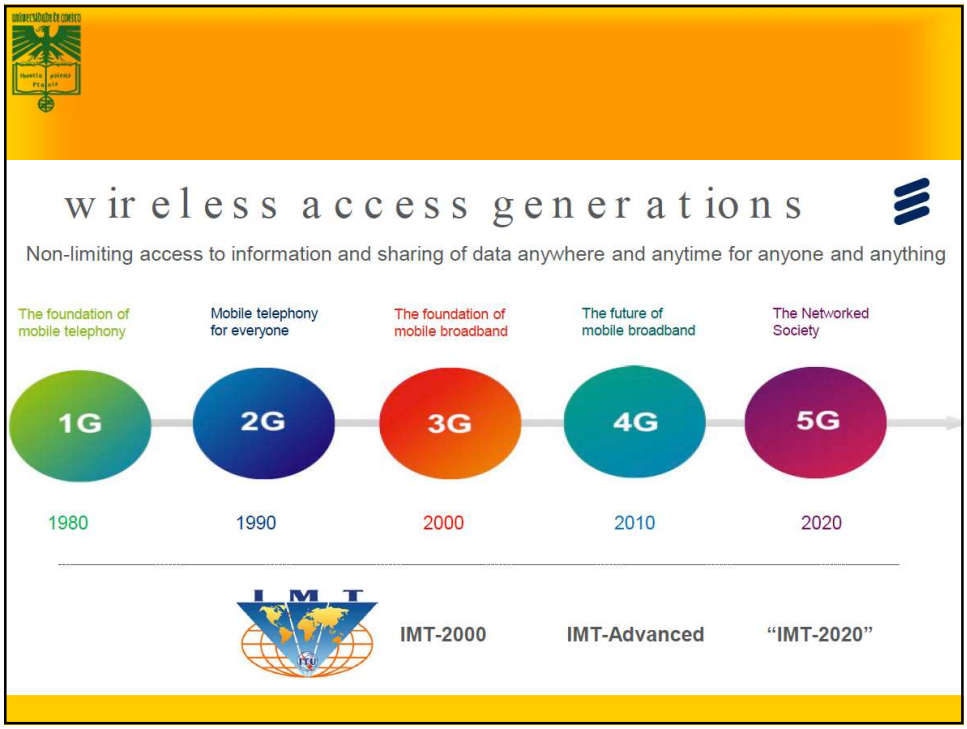
3G: Universal Mobile Telecommunication System

69



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UMTS

- **UMTS – Universal Mobile Telecommunication System –3G system**
- **Oriented towards generalized service diffusion, and future user trends: combines "cellular, "wireless", "internet", etc…**
- **"multimedia everywhere"**
- **Developed in order to have na evolutionary path from 2.5G systems; progressive evolution (GPRS-EDGE-UMTS)**

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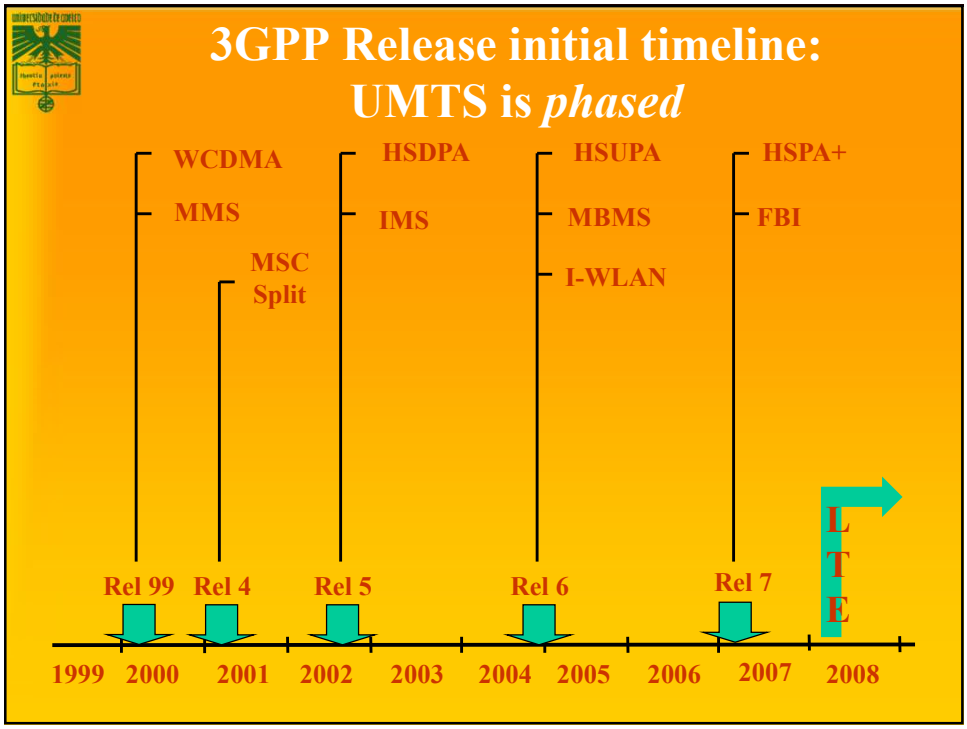

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Implications

- Any Device
- Any Access Technology
- Any Where

ALWAYS BEST CONNECTED

- One Network, multiple access technologies
- Common Session Control
- Generic Application Servers
- Single set of services that apply network wide
- Consistent user experience
- Operational efficiency
- New services/applications

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UMTS (Universal Mobile Transport Service)

Specification

- Flexible
  - **Handles multiple multimedia flows in a single connection.**
- Support to packet transport
- Flexible coding mechanisms (FDD/TDD WCDMA)
- Variable transmission rates
  - Max. 384 Kbps for global coverage (initially)
  - Max. 2Mbps for local coverage (initially)

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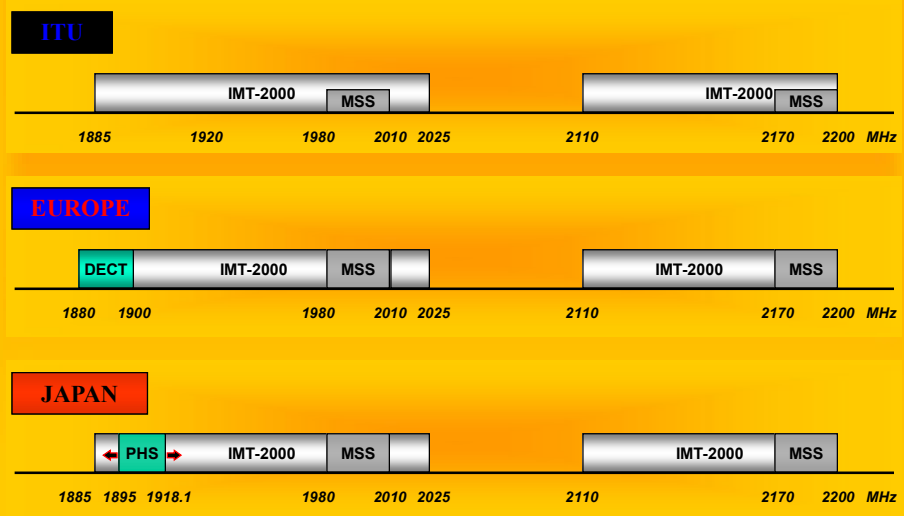
W-CDMA (Wide Band CDMA)

- **Larger capacity and coverage, keeping compatibility with 2G**
- **Supports the flexibility required, with multiple parallel connections**
- **Efficient packet access**
- **Advantages for the operator:**
  - **Interaction between asynchronous base stations (FDD)**
  - **Hierarchical cell structure**
  - **Adaptive antennas**
  - **TDD mode for asymmetric environments, and without coordination**

Spectrum usage



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Multiplexing modes

- **FDD – spectrum sharing based in the usage of different frequencies; good for symmetric services in large areas**
- **TDD – spectrum sharing based in timeslots; good for asymmetric services; require timing synchronism.**

- **Different modes licensed in different countries**
- **Different frequencies licensed for each mode**

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UMTS – air interface

- **UTRA-FDD:**
  - ***uplink*: 1920 – 1980 MHz (60 MHz)**
  - ***downlink*: 2110 – 2170 MHz (60 MHz)**
- **UTRA-TDD:**
  - **1900 – 1920 MHz (20 MHz)**
  - **2010 – 2025 MHz (15 MHz)**
- **In Portugal:**
  - **2x15 MHZ for UTRA-FDD**
  - **1x5 MHz for UTRA-TDD**

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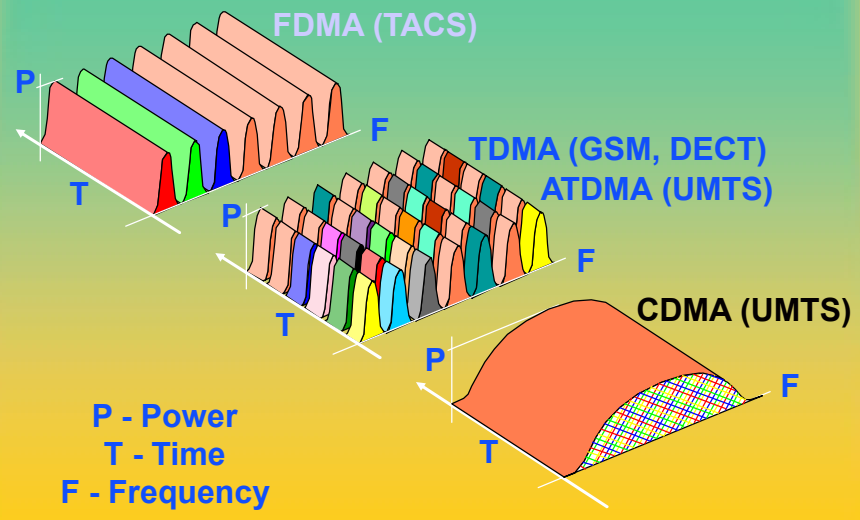
Multiplexing mechanisms



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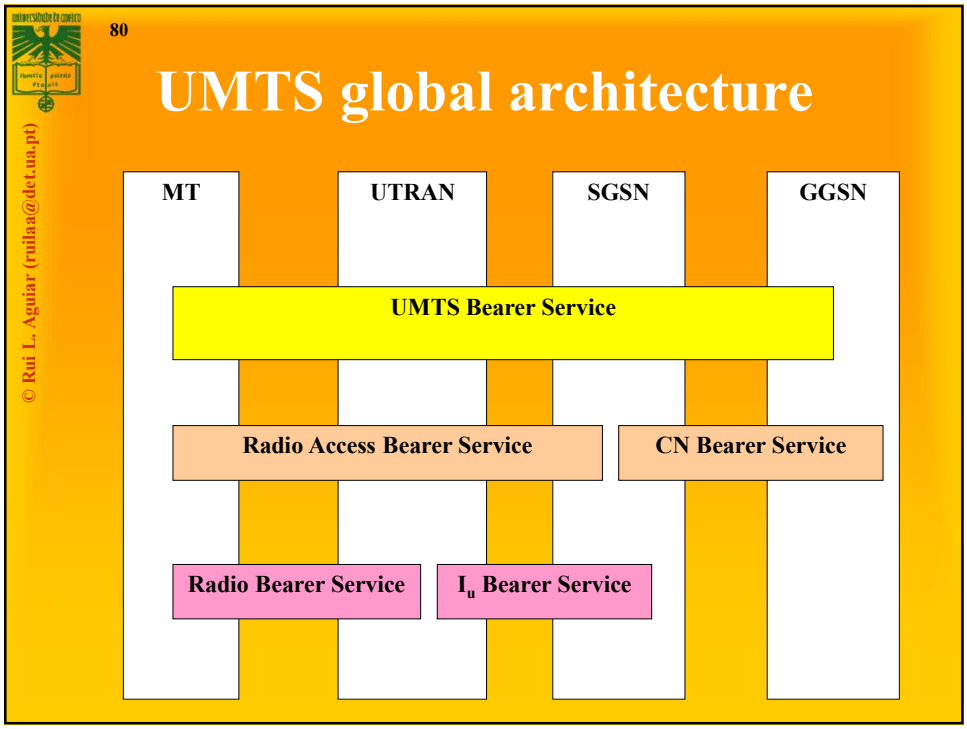
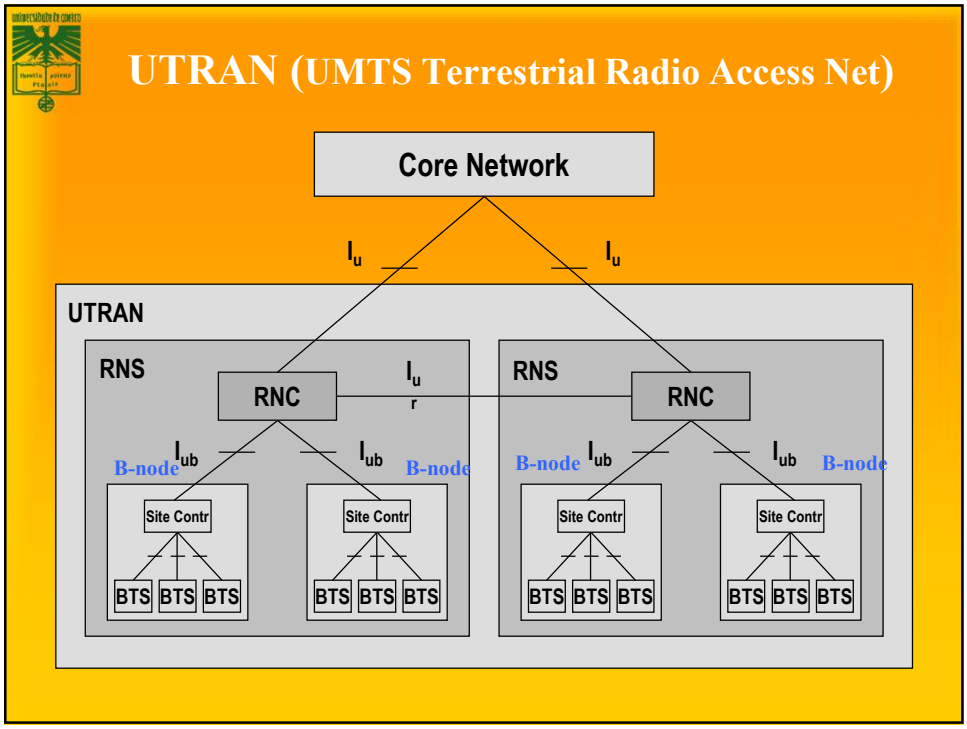

80
UMTS global architecture
© Rui L. Aguiar (ruilaa@det.ua.pt)
MT
UTRAN
SGSN
GGSN
UMTS Bearer Service
Radio Access Bearer Service
CN Bearer Service
Radio Bearer Service
I_u Bearer Service

80


UTRAN (UMTS Terrestrial Radio Access Net)
Core Network
I_u
I_u
UTRAN
RNS
RNC
I_u r
RNS
RNC
B-node
I_ub
I_ub
B-node
B-node
I_ub
I_ub
B-node
Site Contr
Site Contr
Site Contr
Site Contr
BTS BTS BTS
BTS BTS BTS
BTS BTS BTS
BTS BTS BTS

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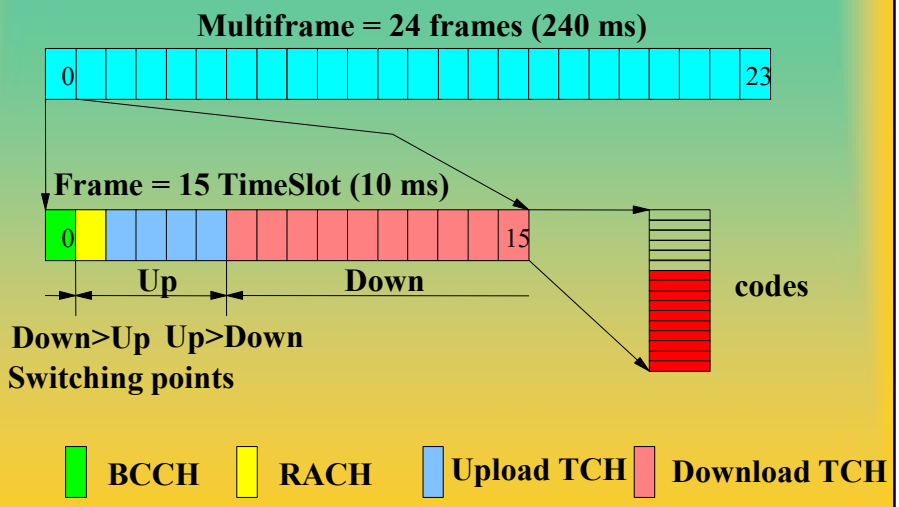
TDD: Frame structure



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Transport channels

- Dedicated Channel (DCH): fast bit rate changes (10ms); fast power control; inherent MS addressing
- Random Access Channel (RACH) - up link: colisions; open loop power control; explicit MS addressing
- Broadcast Control Channel (BCH) - down link
- Forward Access Channel (FACH) - down link: slow power control; explicit MS addressing
- Paging Channel (PCH) - down link: power saving modes

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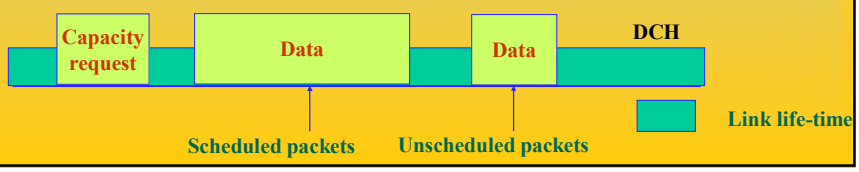
Data transport

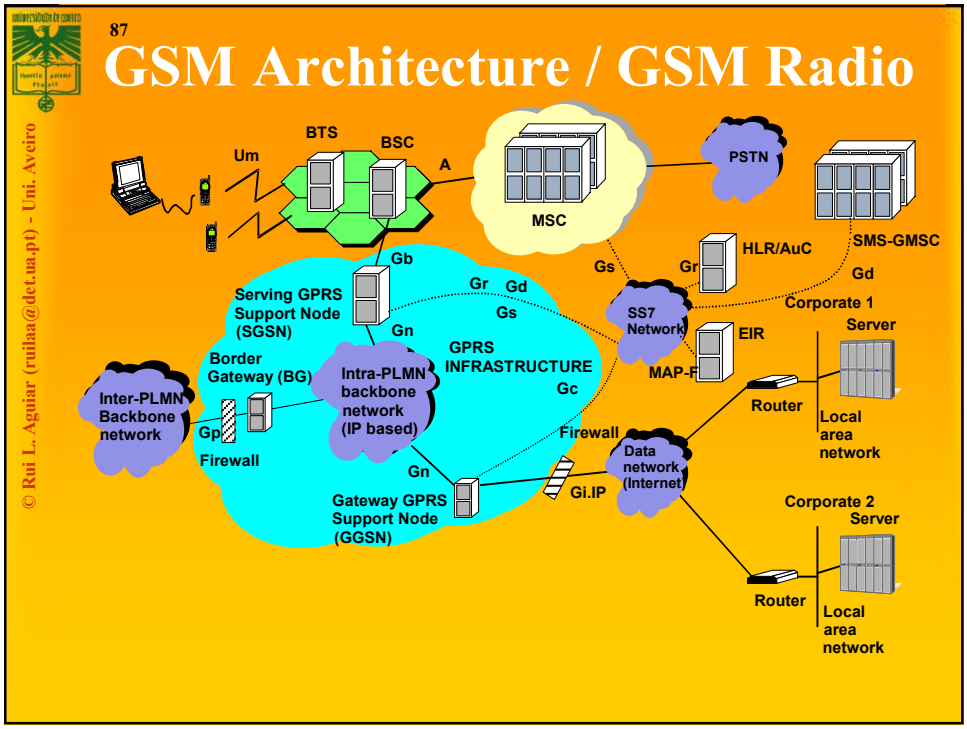
Data transport can be made using three different channels:

- **RACH (Random Access Channel):**
  - **Used for small data quantity**
  - **Low latency (no reserved used)**
    - **no power control, collisions may happen**
- **Dedicated channel requested (≈ VC setup):**
  - **o MS send a reservation request (in RACH), with a traffic spec; network returns a ReqAll + CapAll (with proper traffic formats) in FACH, if possible; CapAll may be delayed if network load is high; MS only transmit after CapAll.**
- **Using an existing dedicated channel (before expire):**
  - **If a DCH already exists, trnasmit the new packet in that channel; if the timer is expiring, transmit only the CapAll**

Real-time services

- **MS does a Res_Req in RACH**
  - **(or in an existing active DCH)**
- **Network transmits a Res All (with TF parameters)**
- **MS starts transmission immediately (without waiting by Cap_All)**
- **Network may change/reduce/restore TF according with load**




87
GSM Architecture / GSM Radio
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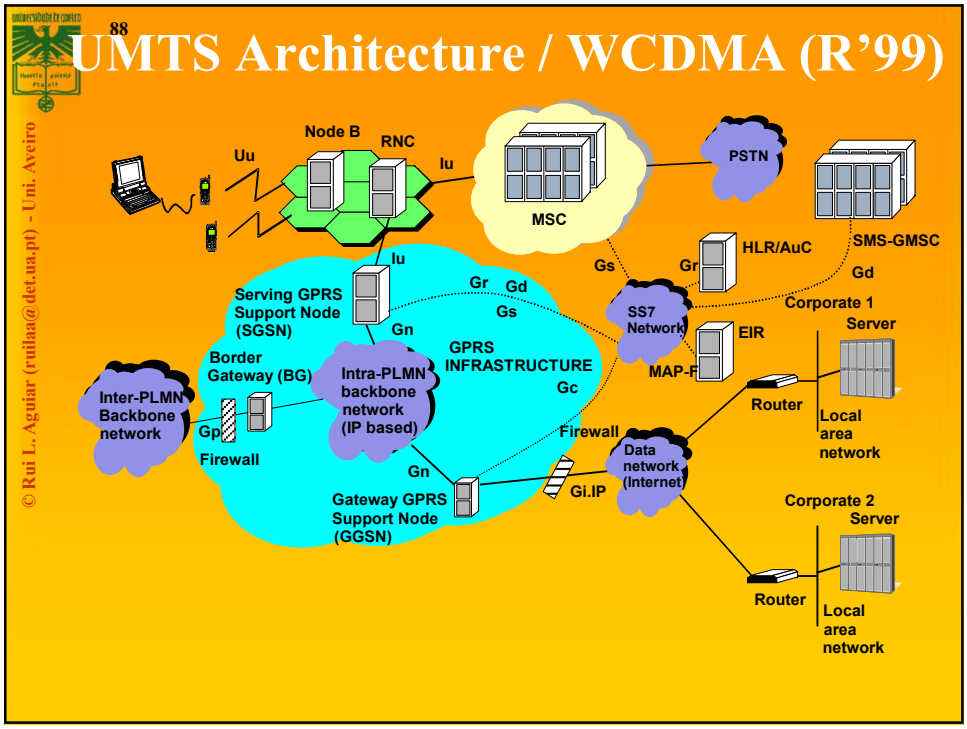
BTS
BSC
Um
A
MSC
PSTN
SMS-GMSC
HLR/AuC
Gb
Gs
Gr
Gd
Serving GPRS Support Node (SGSN)
Gn
SS7 Network
EIR
Corporate 1
Server
Border Gateway (BG)
GPRS INFRASTRUCTURE
Gc
MAP-F
Router
Inter-PLMN Backbone network
Intra-PLMN backbone network (IP based)
Gp
Firewall
Local area network
Data network (Internet)
Gi.IP
Gateway GPRS Support Node (GGSN)
Corporate 2
Server
Router
Local area network

87


88
UMTS Architecture / WCDMA (R'99)
© Rui L. Aguiar (ruilaa@det.ua.pt) - Uni. Aveiro
Node B
RNC
Uu
Iu
MSC
PSTN
SMS-GMSC
HLR/AuC
Gs
Gr
Gd
Serving GPRS Support Node (SGSN)
Gn
SS7 Network
EIR
Corporate 1
Server
Border Gateway (BG)
GPRS INFRASTRUCTURE
Gc
MAP-F
Router
Inter-PLMN Backbone network
Intra-PLMN backbone network (IP based)
Gp
Firewall
Local area network
Data network (Internet)
Gi.IP
Gateway GPRS Support Node (GGSN)
Corporate 2
Server
Router
Local area network

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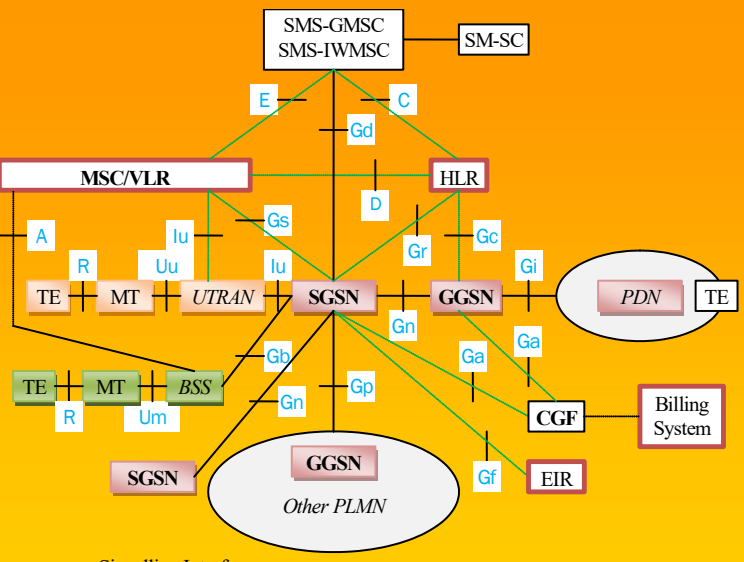
GPRS/UMTS R 99 Architecture



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Entities

- **The Serving GPRS Support Node (SGSN)**
  - **Mobility Management**
  - **Authentication**
  - **Gathers Charging Information**
- **Gateway GPRS Support Node (GGSN)**
  - **Gateway between UMTS Core Network and external networks**
  - **Address allocation for MS**
  - **Gathers Charging Information**
  - **Filtering**
- **Base Station Subsystem (BSS) / Radio Network Subsystem (RNS)**
  - **BSS**
    - BSC
    - BTS
  - **RNS**
    - RNC
    - Node-B

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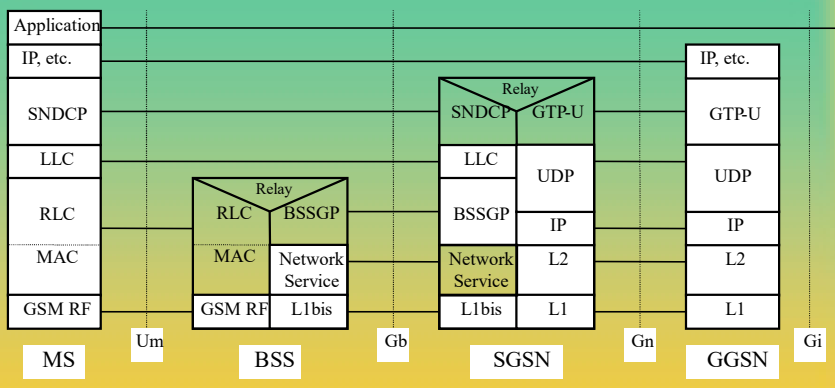
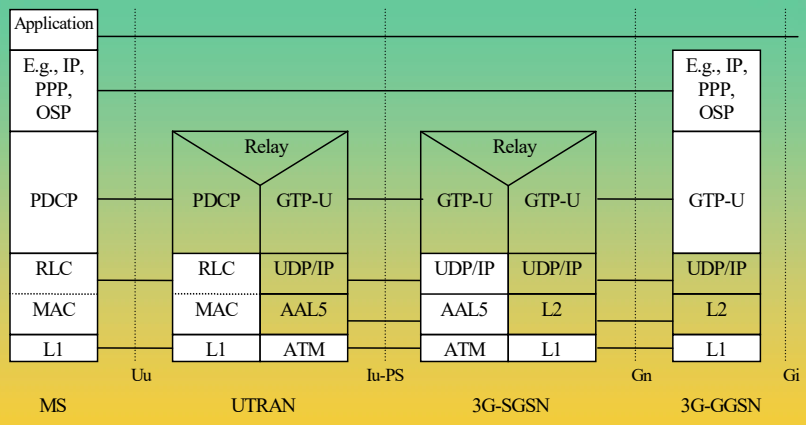
R99 Interfaces and Protocols GSM User Plane



92

93

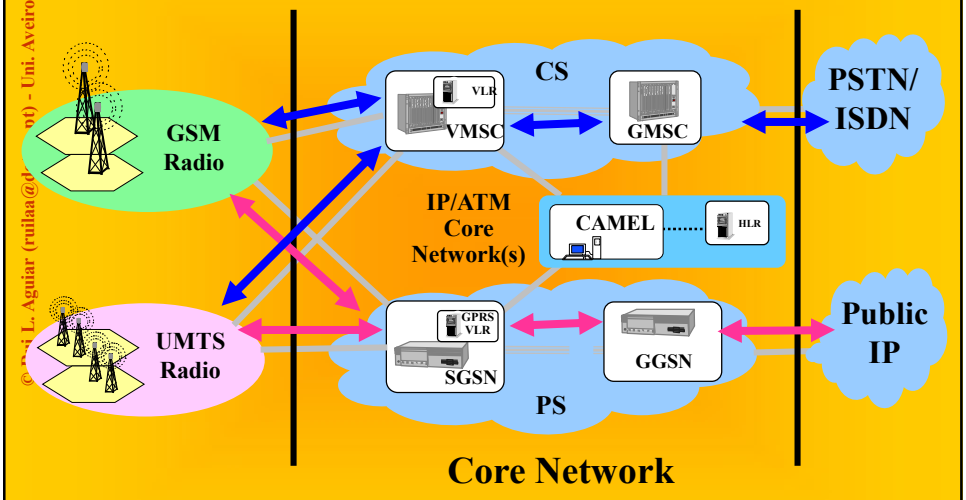
R99 Interfaces and Protocols UMTS User Plane



93

94

UMTS R99/R4 and GSM/GPRS

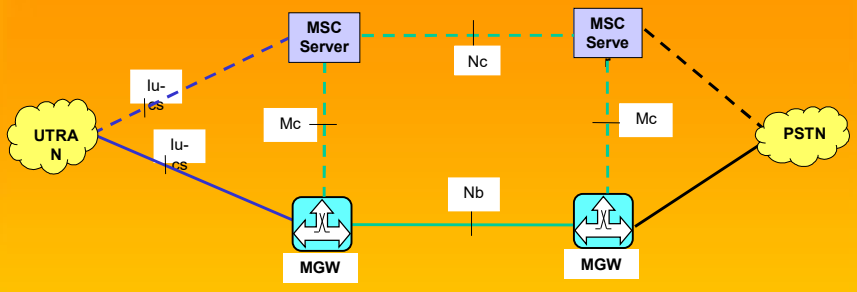


Databases migrated to a central entity (OSS)

94

95

CS Domain: Signaling & User Plane

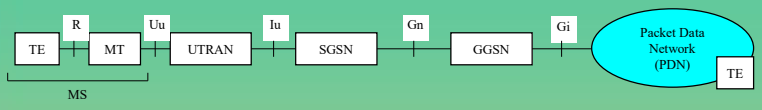


This bearer independent architecture makes possible the use of IP-based transport

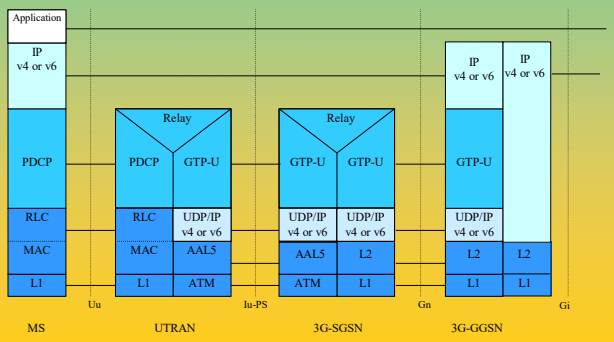
95

96

Simplified PS Domain Architecture



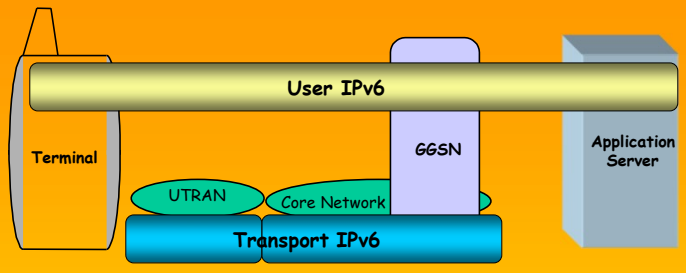
PS Domain User Plane protocol stack



96

97

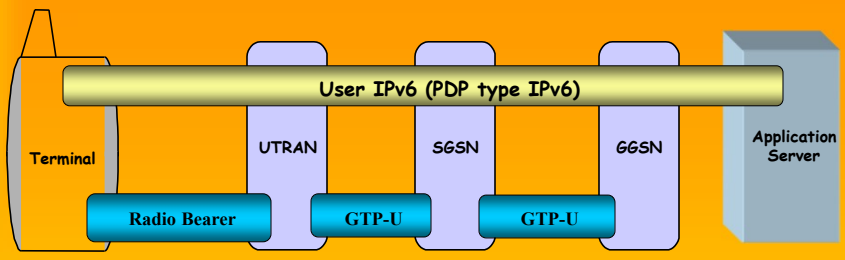
User plane vs transport plane



- User and transport planes are completely independent, i.e. the transport plane can run on a different IP version than the user plane
- UTRAN and Core Network transport can also run on different IP versions

97

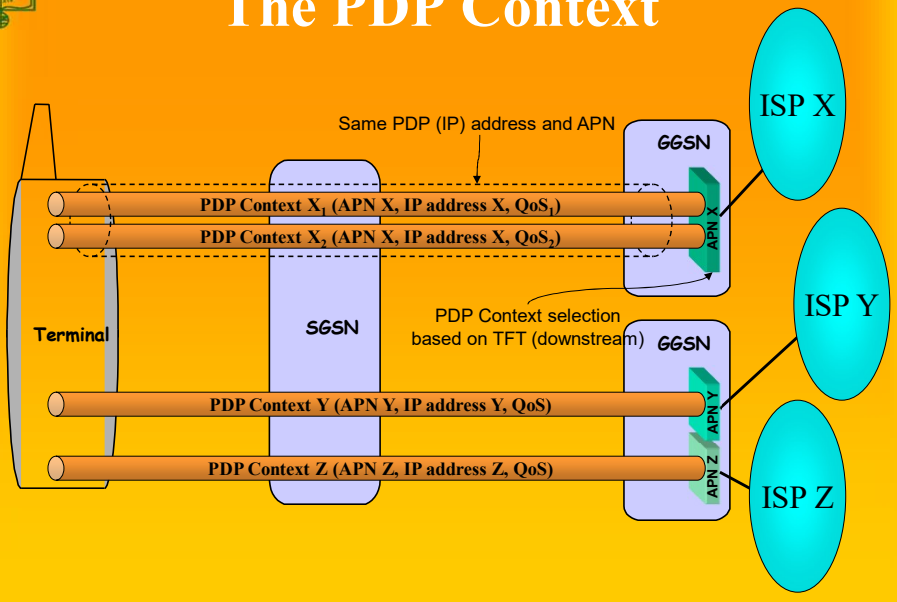
Transport of user IP packets in UMTS



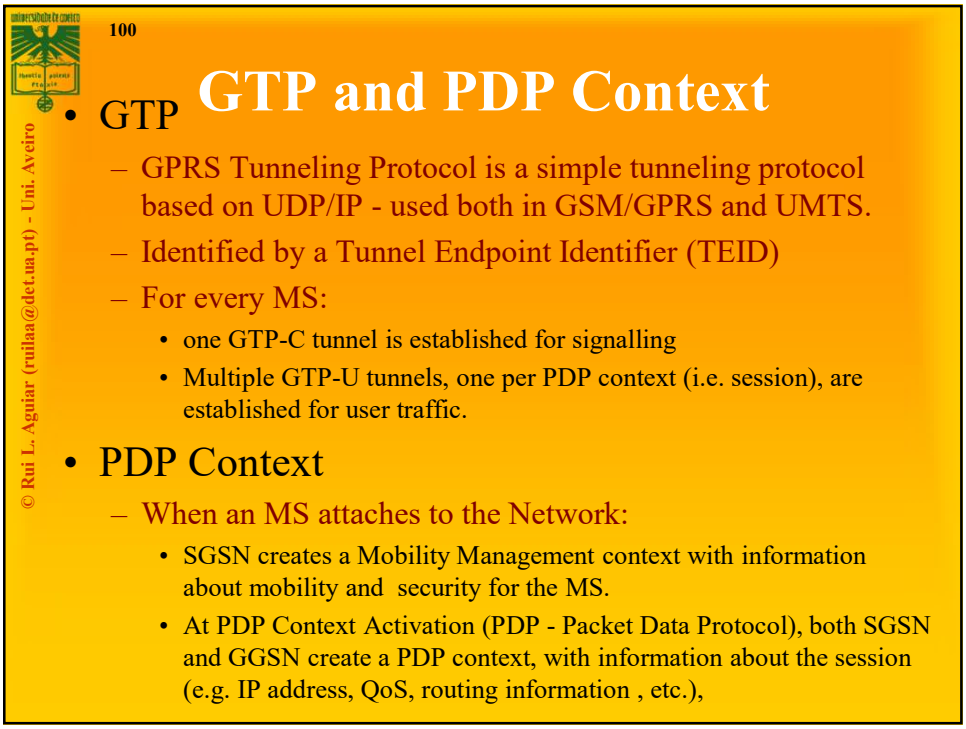
IP packets to/from the terminal are tunneled through the UMTS network, they are not routed directly at the IP level.

98

The PDP Context



99


100
GTP and PDP Context
• GTP
– GPRS Tunneling Protocol is a simple tunneling protocol based on UDP/IP - used both in GSM/GPRS and UMTS.
– Identified by a Tunnel Endpoint Identifier (TEID)
– For every MS:
• one GTP-C tunnel is established for signalling
• Multiple GTP-U tunnels, one per PDP context (i.e. session), are established for user traffic.
• PDP Context
– When an MS attaches to the Network:
• SGSN creates a Mobility Management context with information about mobility and security for the MS.
• At PDP Context Activation (PDP - Packet Data Protocol), both SGSN and GGSN create a PDP context, with information about the session (e.g. IP address, QoS, routing information , etc.),
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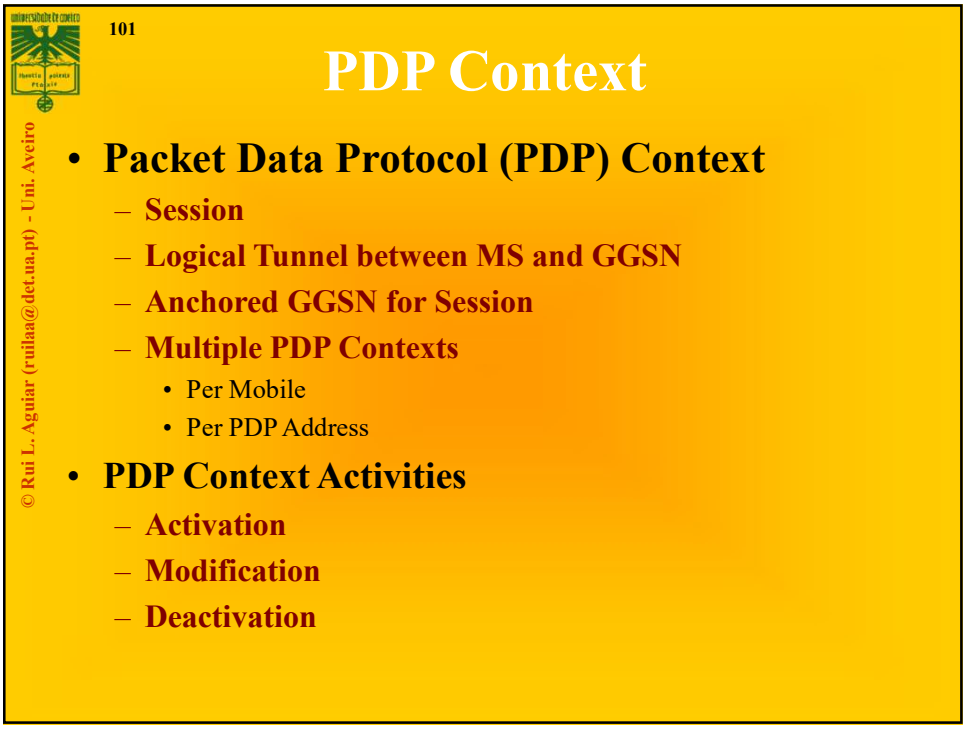
100


101
PDP Context
• Packet Data Protocol (PDP) Context
– Session
– Logical Tunnel between MS and GGSN
– Anchored GGSN for Session
– Multiple PDP Contexts
• Per Mobile
• Per PDP Address
• PDP Context Activities
– Activation
– Modification
– Deactivation
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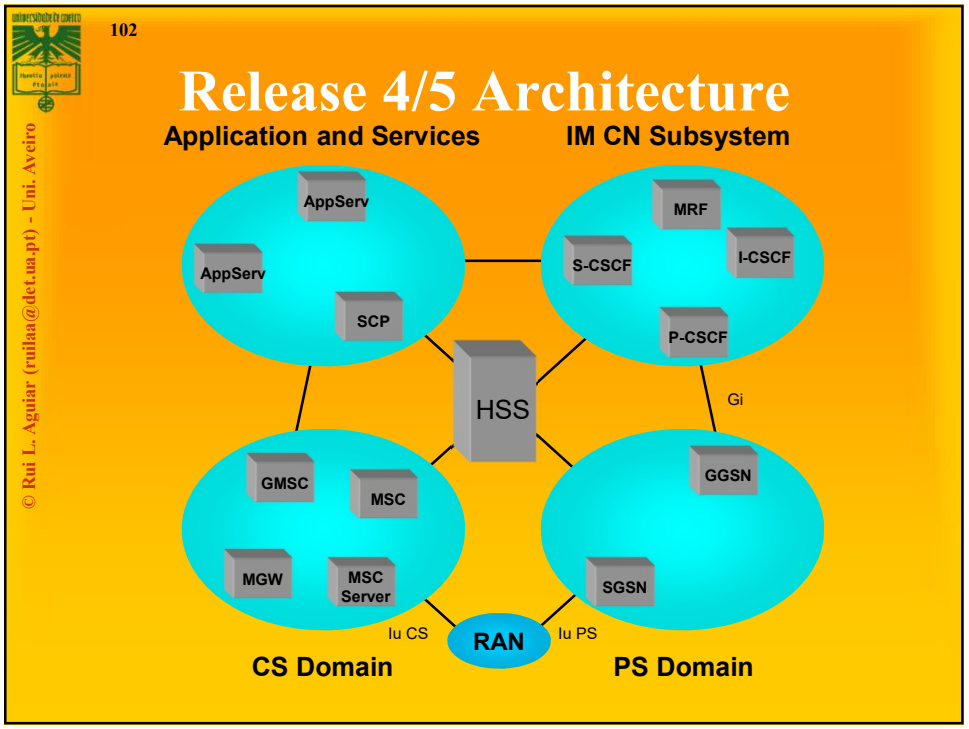
102
Release 4/5 Architecture
Application and Services
IM CN Subsystem
AppServ
AppServ
SCP
MRF
S-CSCF
I-CSCF
P-CSCF
HSS
Gi
GMSC
MSC
MGW
MSC Server
GGSN
SGSN
Iu CS
RAN
Iu PS
CS Domain
PS Domain
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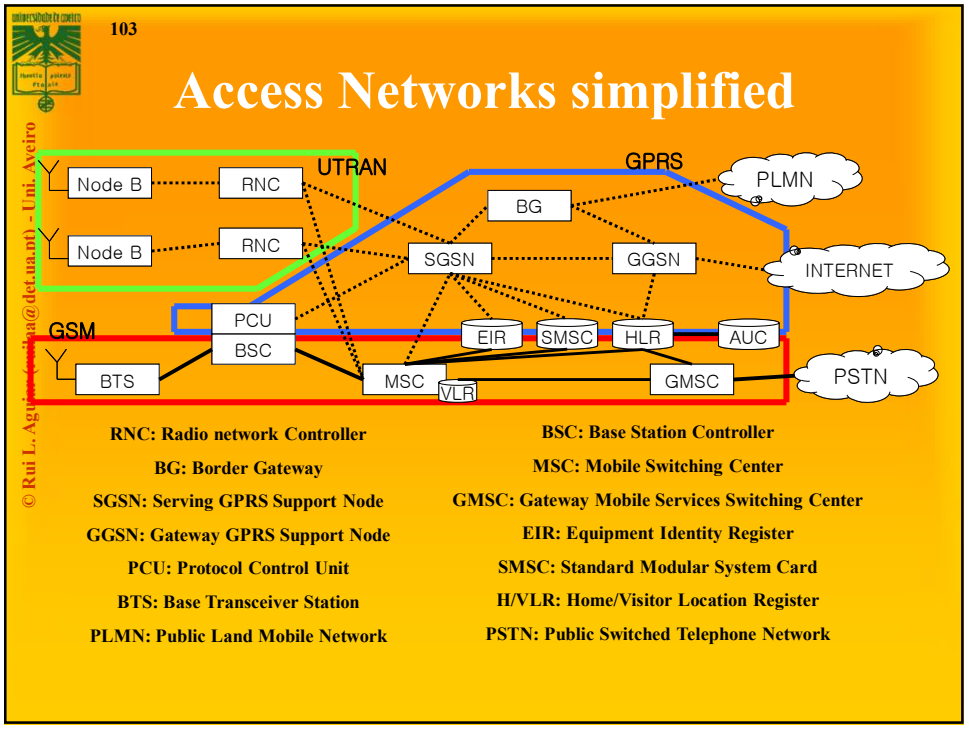
103
Access Networks simplified
Node B
Node B
RNC
RNC
UTRAN
GPRS
PLMN
BG
SGSN
GGSN
INTERNET
GSM
PCU
BSC
BTS
EIR
SMSC
HLR
AUC
MSC
VLR
GMSC
PSTN
RNC: Radio network Controller
BG: Border Gateway
SGSN: Serving GPRS Support Node
GGSN: Gateway GPRS Support Node
PCU: Protocol Control Unit
BTS: Base Transceiver Station
PLMN: Public Land Mobile Network
BSC: Base Station Controller
MSC: Mobile Switching Center
GMSC: Gateway Mobile Services Switching Center
EIR: Equipment Identity Register
SMSC: Standard Modular System Card
H/VLR: Home/Visitor Location Register
PSTN: Public Switched Telephone Network
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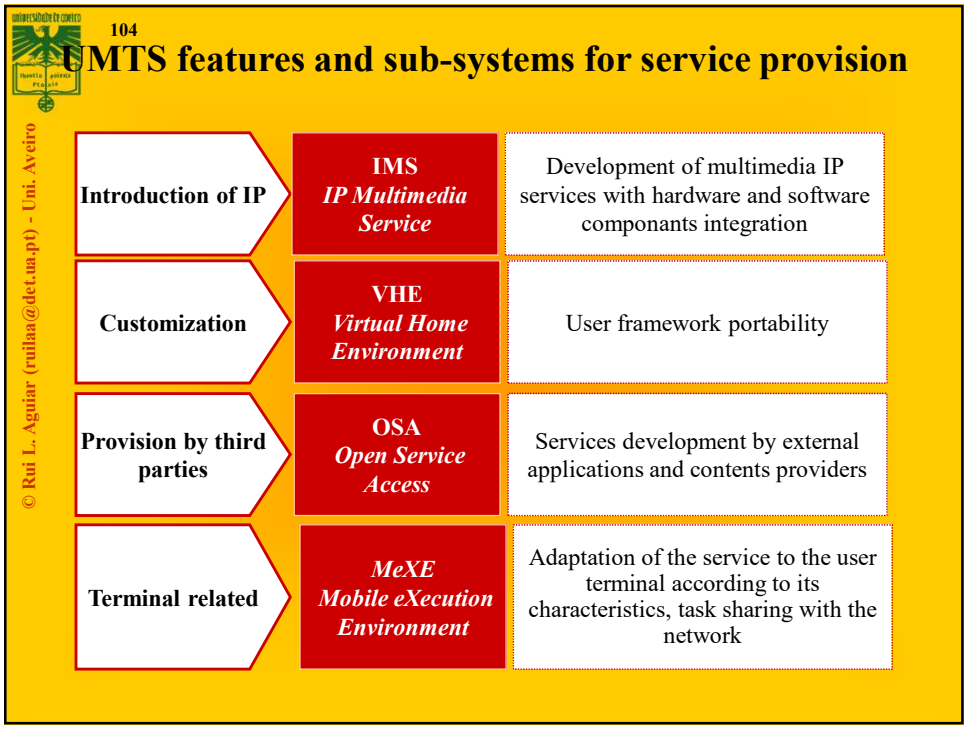
103


104
UMTS features and sub-systems for service provision
Introduction of IP
IMS
IP Multimedia Service
Development of multimedia IP services with hardware and software componants integration
Customization
VHE
Virtual Home Environment
User framework portability
Provision by third parties
OSA
Open Service Access
Services development by external applications and contents providers
Terminal related
MeXE
Mobile eXecution Environment
Adaptation of the service to the user terminal according to its characteristics, task sharing with the network
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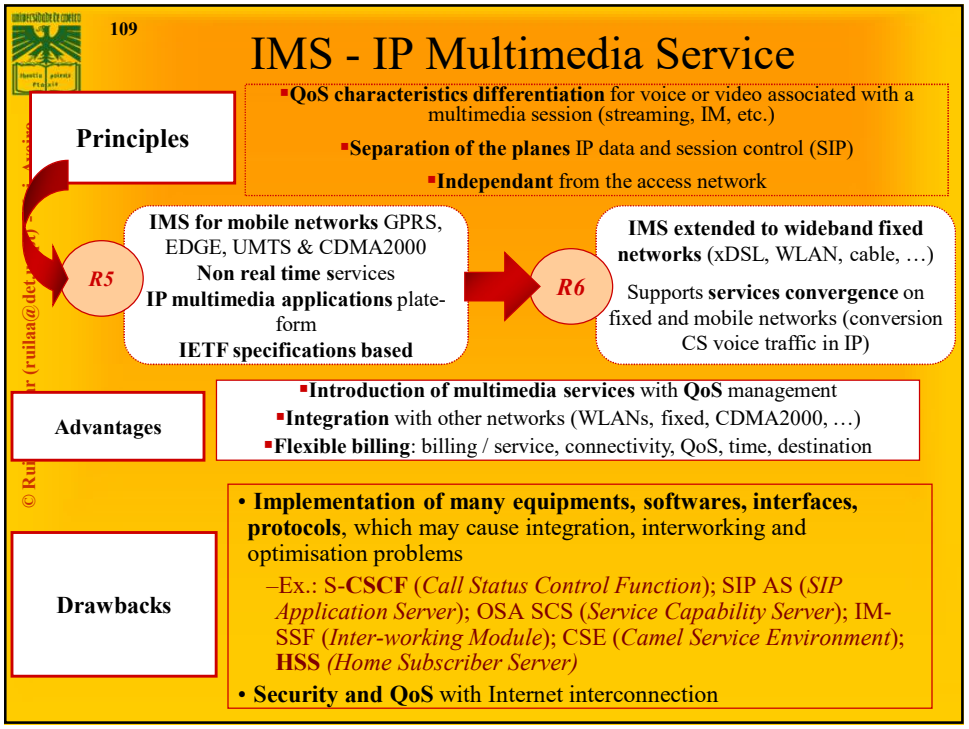
104


109
IMS - IP Multimedia Service
Principles
QoS characteristics differentiation for voice or video associated with a multimedia session (streaming, IM, etc.)
Separation of the planes IP data and session control (SIP)
Independant from the access network
R5
IMS for mobile networks GPRS, EDGE, UMTS & CDMA2000
Non real time services
IP multimedia applications plate-form
IETF specifications based
R6
IMS extended to wideband fixed networks (xDSL, WLAN, cable, …)
Supports services convergence on fixed and mobile networks (conversion CS voice traffic in IP)
Advantages
Introduction of multimedia services with QoS management
Integration with other networks (WLANs, fixed, CDMA2000, …)
Flexible billing: billing / service, connectivity, QoS, time, destination
Drawbacks
• Implementation of many equipments, softwares, interfaces, protocols, which may cause integration, interworking and optimisation problems
–Ex.: S-CSCF (Call Status Control Function); SIP AS (SIP Application Server); OSA SCS (Service Capability Server); IM-SSF (Inter-working Module); CSE (Camel Service Environment); HSS (Home Subscriber Server)
• Security and QoS with Internet interconnection

109

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IMS – Key Architectural Principals

- **Border Functions**
  - Access and Network Border Security
  - QoS and Admission Control
  - Media and Signaling Adaptation
- **Core Functions**
  - Subscriber Management – Registration
  - Session Switching – Set-up and tear-down of session legs, Session state maintenance, Application Server invocation
  - Session Routing – Breakout to external networks
  - Centralized Provisioning – Subscriber and Routing data
- **Application Functions**
  - Access to legacy applications
  - Native SIP Applications
  - Service Brokering

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SIP Protocol

- **Defined in IETF RFC 3261**
  - "… an application-layer control (signaling) protocol for creating, modifying, and terminating sessions with one or more participants. These sessions include Internet telephone calls, multimedia distribution, and multimedia conferences."
- **SIP is to the Internet what SS#7 is to telephony**
- **In IMS, SIP is extended to include extra functionality**
  - E.g. 3GPP TS 23.228
- **At the core of IMS there are several SIP proxies:**
  - I-CSCF, S-CSCF, P-CSCF
  - The Call Session Control function (CSCF) is the heart of the IMS architecture
  - The main functions of the CSCF:
    - provide session control for terminals and applications using the IMS network
    - secure routing of the SIP messages,
    - subsequent monitoring of the SIP sessions and communicating with the policy architecture to support media authorization.
    - responsibility for interacting with the HSS.

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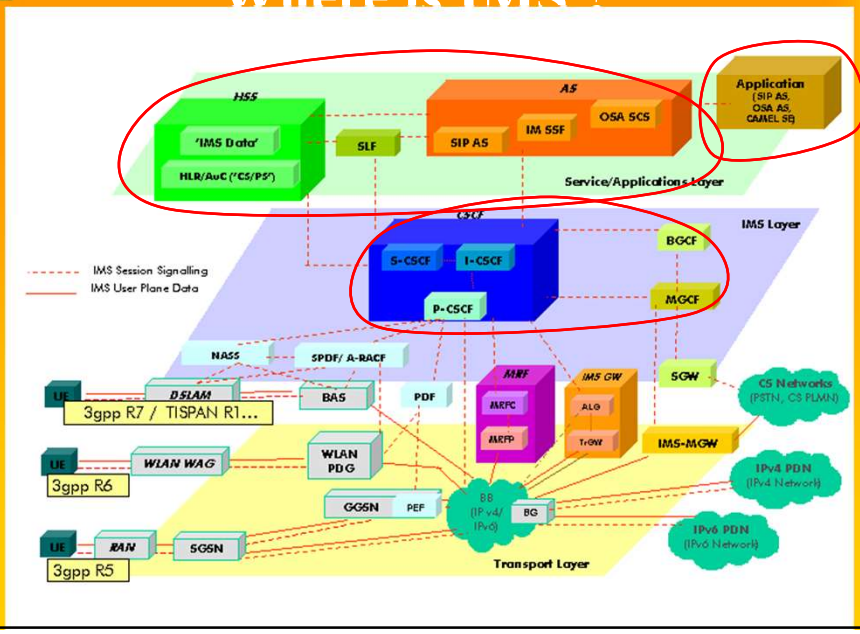
Services in IMS

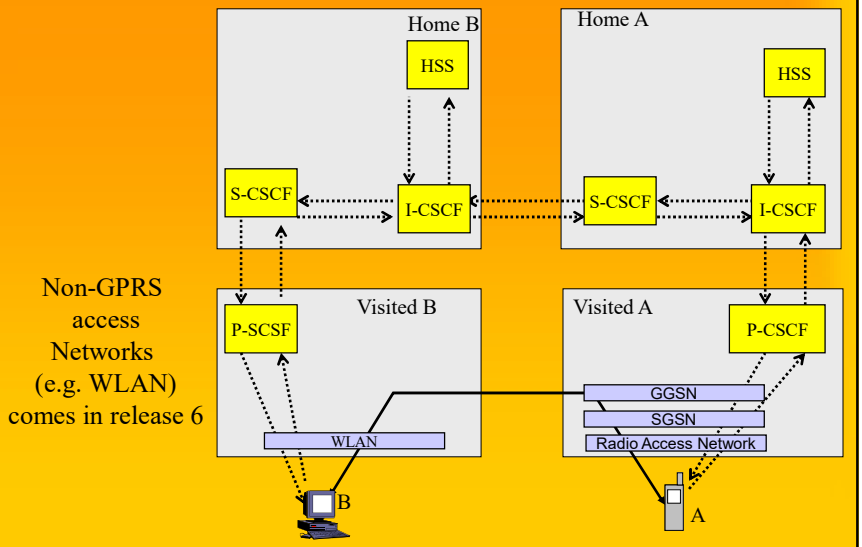
- IMS is an advanced infrastructure enabling services. But the services are in the end points or peers (calls, etc.), not in the IMS
- Application Servers (AS) are the key part to endow IMS with services
- AS are not owned by the network operator
  - (therefore not part of IMS)
- AS offered services enjoy all IMS advantages
- AS interact – using SIP - with the S-CSCF (which controls user's SIP session)
- AS can behave as another SIP proxy or as a SIP UA (terminal)
  - in this case they also receive and send media!

113

Where is IMS ?



UMTS IMS: basic call flow



S-CSCF

- **Serving - CSCF**
  - **Controls the user's SIP Session**
  - **very few per domain**
  - **Located in the home domain**
  - **Is a SIP registrar (and proxy)**

3GPP IMS - Eng. de Serviços - Rui Aguiar/Diogo Gomes <dgomes@ua.pt>

P-CSCF

- IMS contact point for the user's SIP signaling
- Several in a domain
- Located in the visited domain
- Terminals must know this proxy (e.g. DHCP used)
- Compresses and decompresses SIP messages
- Secures SIP messages
- Assures correctness of SIP messages

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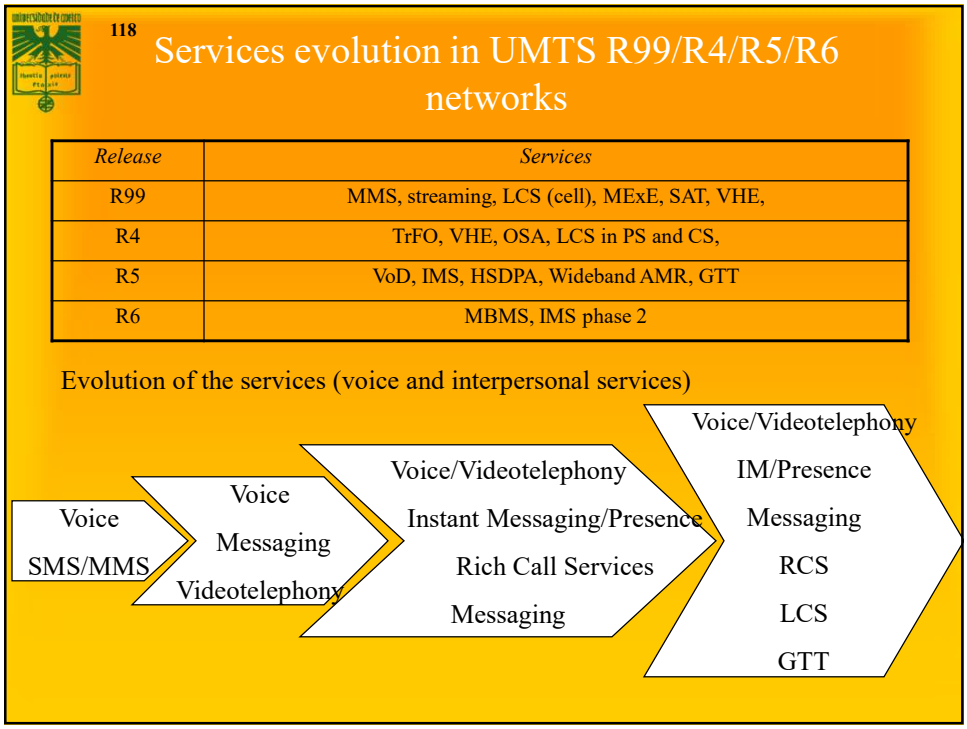
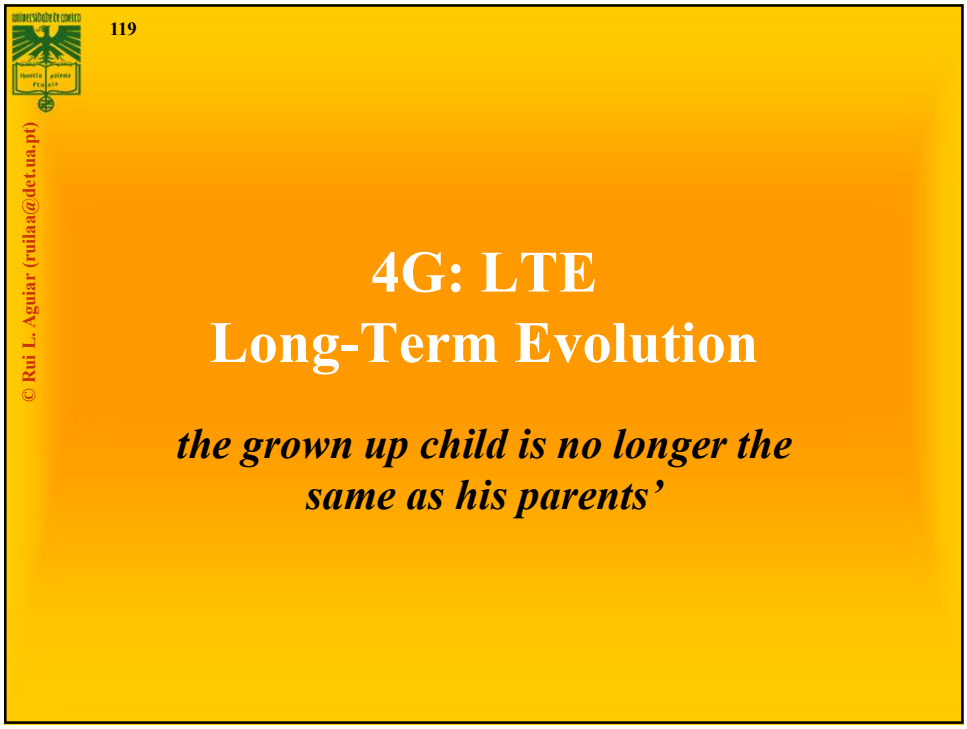
I-CSCF

- domain's contact point for inter-domain SIP signaling
- one or more per domain
- In case there are more than one S-CSCFs in the domain, locates which S-CSCF is serving a user


118
Services evolution in UMTS R99/R4/R5/R6 networks
Release
Services
R99
MMS, streaming, LCS (cell), MExE, SAT, VHE,
R4
TrFO, VHE, OSA, LCS in PS and CS,
R5
VoD, IMS, HSDPA, Wideband AMR, GTT
R6
MBMS, IMS phase 2
Evolution of the services (voice and interpersonal services)
Voice
SMS/MMS
Voice
Messaging
Videotelephony
Voice/Videotelephony
Instant Messaging/Presence
Rich Call Services
Messaging
Voice/Videotelephony
IM/Presence
Messaging
RCS
LCS
GTT

118


119
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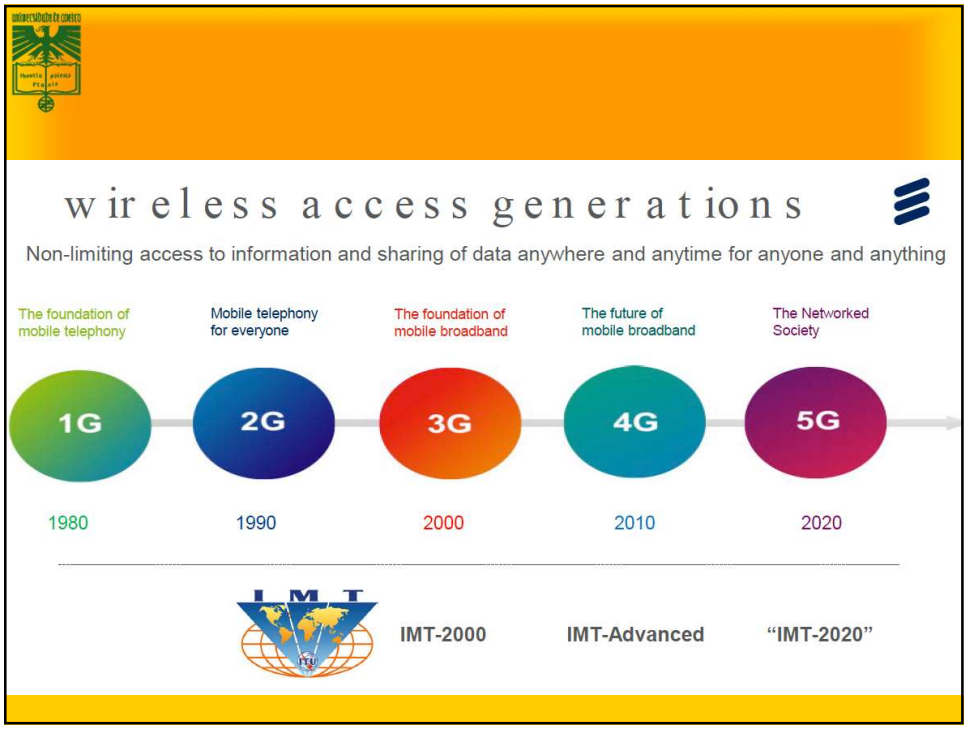
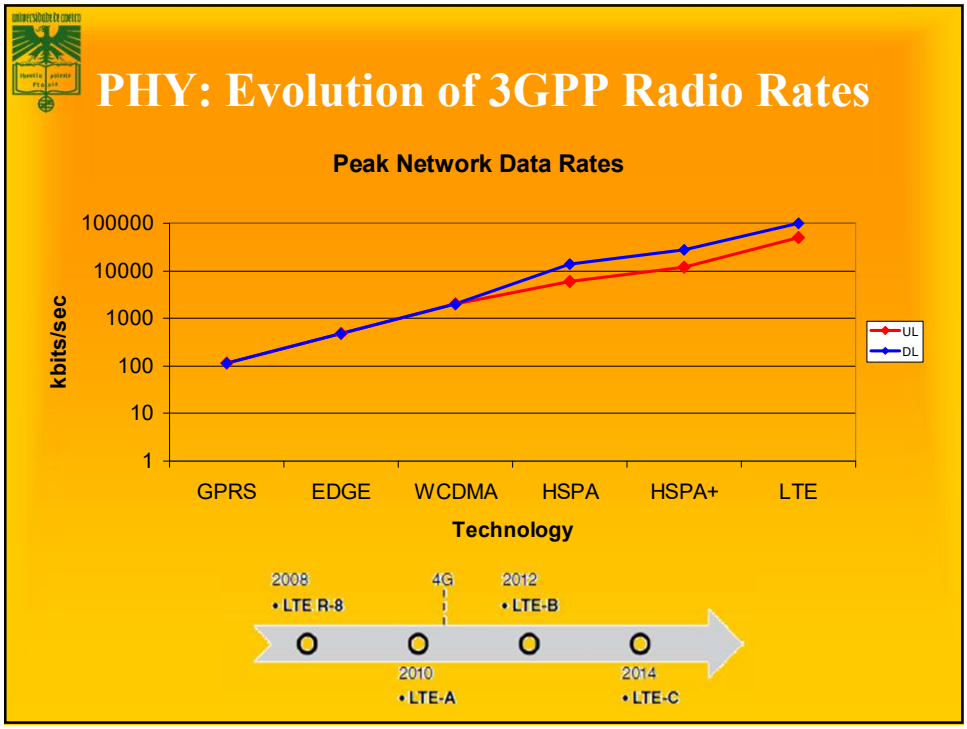
4G: LTE
Long-Term Evolution
the grown up child is no longer the same as his parents'

119


wireless access generations
Non-limiting access to information and sharing of data anywhere and anytime for anyone and anything
The foundation of mobile telephony
Mobile telephony for everyone
The foundation of mobile broadband
The future of mobile broadband
The Networked Society
1G
2G
3G
4G
5G
1980
1990
2000
2010
2020
IMT
IMT-2000
IMT-Advanced
"IMT-2020"

120


PHY: Evolution of 3GPP Radio Rates
Peak Network Data Rates
kbits/sec
100000
10000
1000
100
10
1
UL
DL
GPRS
EDGE
WCDMA
HSPA
HSPA+
LTE
Technology
2008
• LTE R-8
4G
2012
• LTE-B
2010
• LTE-A
2014
• LTE-C

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122

Network Growth

- **Worldwide Mobile networks in 2013**
  - ½ billion mobile devices added
  - 77% of this growth from smartphones
  - Mobile data traffic grew 81%
  - Mobile video traffic 51% of all mobile data
- **4G in 2013**
  - 2.9% of all connections (just starting)
  - BUT: account for 30% of all mobile traffic
  - Predicted to be ½ of all connections in 2018

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4G Long Term Evolution (LTE)

- **Long Term Evolution (LTE) – Standard created by the 3rd Generation Partnership Project**
  - Deployed globally
  - All packet switched network
  - High throughput and QoS considerations
  - Provides wireless retransmissions of lost data

Technology	3G	4G
Data Transfer Rate	3.1MB /sec	100MB/sec
Internet services	Broadband	Ultra Broadband
Mobile -TV Resolution	Low	High
Bandwidth	5 - 20 MHz	100 +MHz
Frequency	1.6- 2 GHZ	2 – 8 GHz
Network Architecture	Wide Area Network	Hybrid Network

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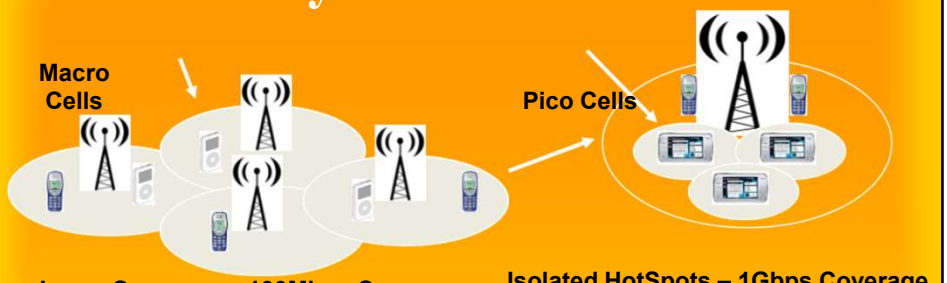
Hybrid network



Large Coverage – 100Mbps Coverage
Outdoor - High Mobility

Isolated HotSpots – 1Gbps Coverage
Indoor – Very Low Mobility

Needs

- Adaptive high performance transmission system
- (Great candidate for) Software Defined Radio

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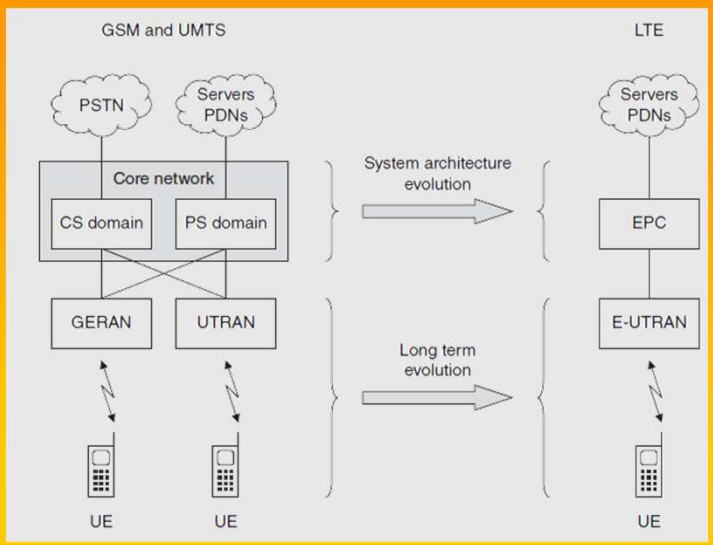
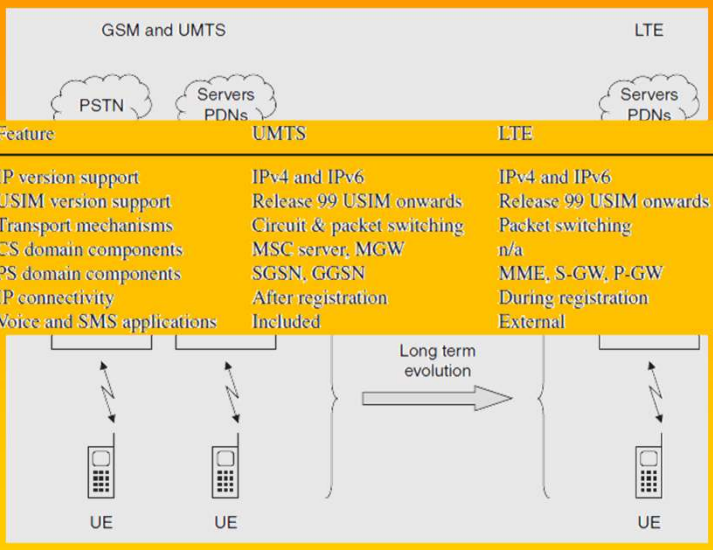
Network simplification



125

126

Network simplification



Feature	UMTS	LTE
IP version support	IPv4 and IPv6	IPv4 and IPv6
USIM version support	Release 99 USIM onwards	Release 99 USIM onwards
Transport mechanisms	Circuit & packet switching	Packet switching
CS domain components	MSC server, MGW	n/a
PS domain components	SGSN, GGSN	MME, S-GW, P-GW
IP connectivity	After registration	During registration
Voice and SMS applications	Included	External

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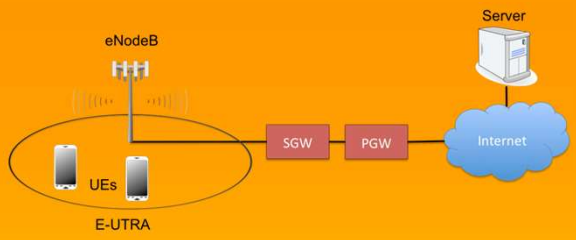
LTE Network



- **Packet Delivery Network Gateway (PGW)**
  - **Connects LTE network to IP networks**
- **Serving Gateway (SGW)**
  - **Route packets to and from wireless access points**
- **Enhanced Node B (eNodeB)**
  - **Wireless access point**
- **User Equipment (UE)**
  - **End user devices**

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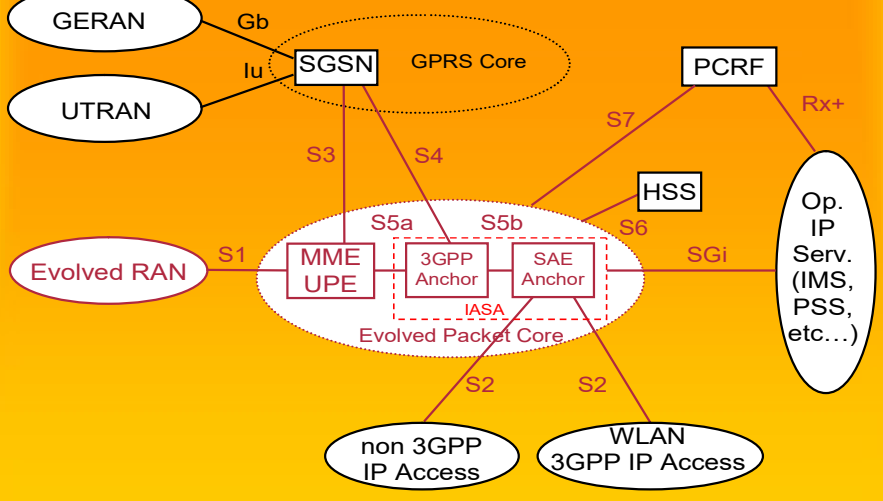
LTE e SAE architecture



* Color coding: red indicates new functional element / interface

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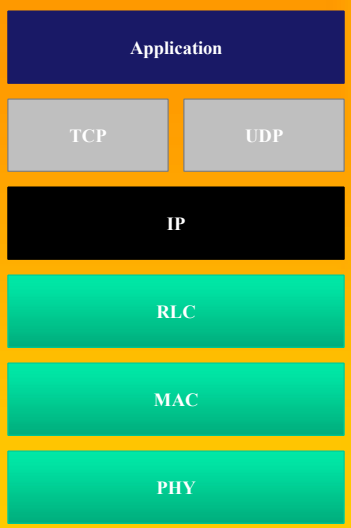
LTE Network Layers

- LTE wireless network has 6 layers PHY – RLC layers carry user and network control data
- LTE transmits collections of Physical Resource Blocks (PRB)s in transport blocks



5/5/2014

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PHY: Radio evolution

More flexible and resilient radio technology

Feature	WCDMA	LTE
Multiple access scheme	WCDMA	OFDMA and SC-FDMA
Frequency re-use	100%	Flexible
Use of MIMO antennas	From Release 7	Yes
Bandwidth	5 MHz	1.4, 3, 5, 10, 15 or 20 MHz
Frame duration	10 ms	10 ms
Transmission time interval	2 or 10 ms	1 ms
Modes of operation	FDD and TDD	FDD and TDD
Uplink timing advance	Not required	Required
Transport channels	Dedicated and shared	Shared
Uplink power control	Fast	Slow
Radio access network components	Node B, RNC	eNB
RRC protocol states	CELL_DCH, CELL_FACH, CELL_PCH, URA_PCH, RRC_IDLE	RRC_CONNECTED, RRC_IDLE
Handovers	Soft and hard	Hard
Neighbour lists	Always required	Not required

Wireless Loss and LTE

- LTE responds to poor signal quality by decreasing throughput
  - Retransmissions
- LTE has multiple configuration parameters for wireless retransmissions
  - E.g. 1 or 2 layers of retransmissions
- Network providers may not choose optimum settings
- Application developers have no knowledge on LTE retransmissions

5/5/2014

3GPP System Architecture Evolution (SAE) philosophy

- **SAE focus is on:**
  - **enhancement of Packet Switched technology to cope with rapid growth in IP traffic**
    - higher data rates
    - lower latency
    - packet optimised system
  - **through**
    - fully IP network
      - In addition to IMS services available in the current system, equivalent CS Services may be provided by IMS core since CS domain is not supported in LTE
    - simplified network architecture
      - Reduced number of nodes in the evolved packet core may be achieved compared to current architecture to provide connectivity to IMS
    - distributed control
      - Flexible accommodation and deployment of existing and new access technologies with mobility by a common IP-based network

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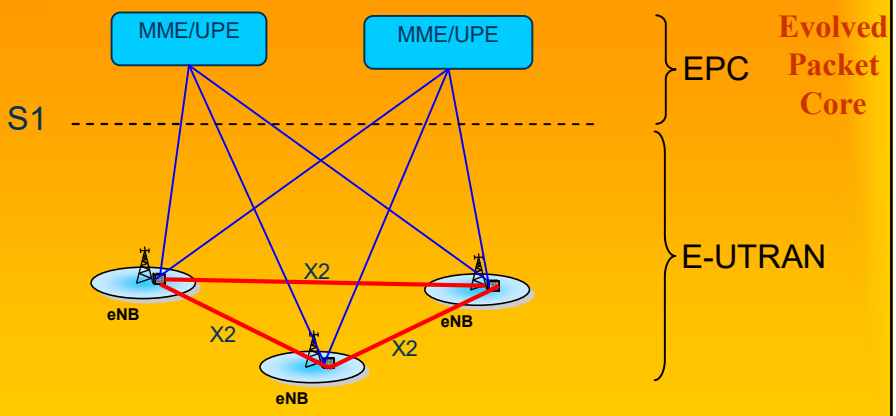
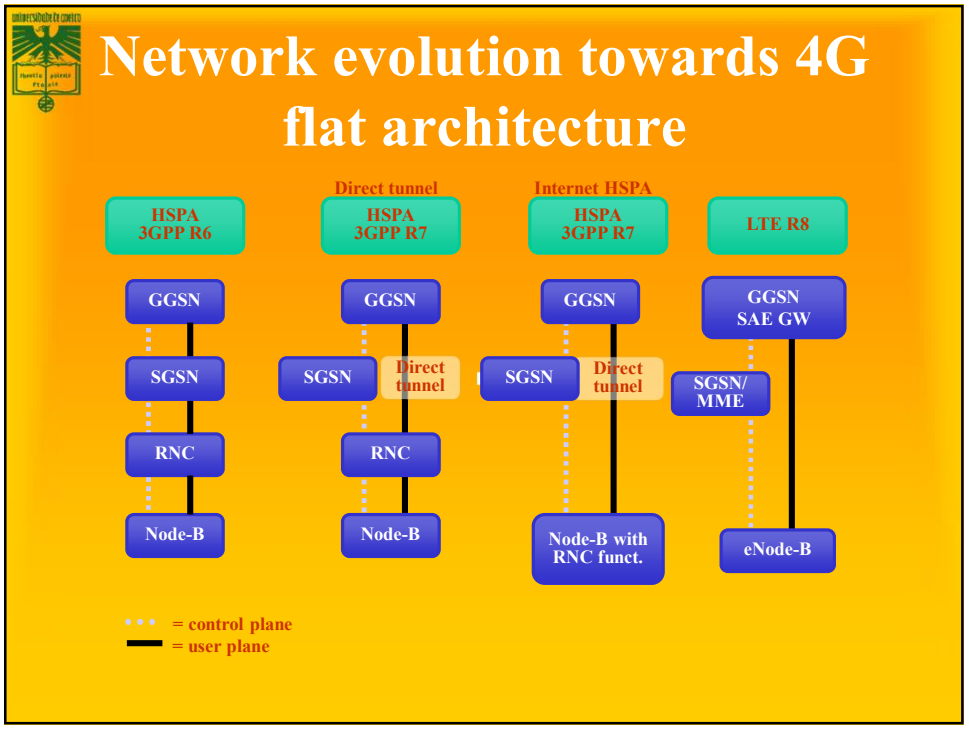
LTE Architecture: mobility

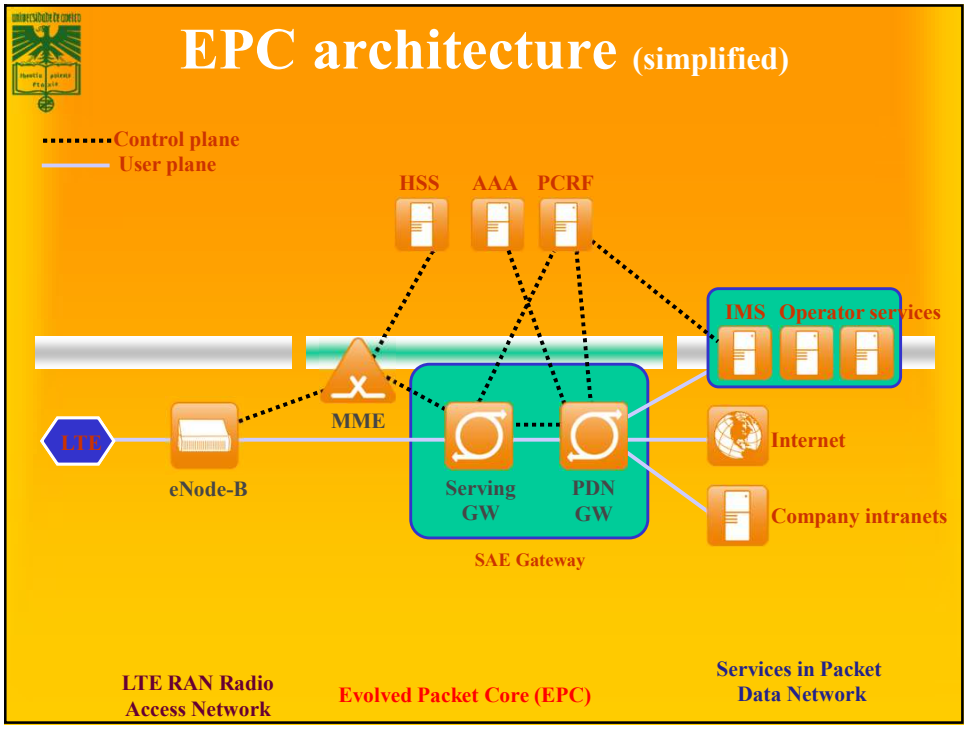


MME/UPE = Mobility Management Entity/User Plane Entity
eNB = eNodeB

135


Network evolution towards 4G flat architecture
Direct tunnel
Internet HSPA
HSPA 3GPP R6
HSPA 3GPP R7
HSPA 3GPP R7
LTE R8
GGSN
SGSN
RNC
Node-B
GGSN
SGSN
Direct tunnel
RNC
Node-B
GGSN
SGSN
Direct tunnel
Node-B with RNC funct.
GGSN SAE GW
SGSN/ MME
eNode-B
= control plane
= user plane

136


EPC architecture (simplified)
Control plane
User plane
HSS
AAA
PCRF
IMS
Operator services
MME
LTE
eNode-B
Serving GW
PDN GW
Internet
Company intranets
SAE Gateway
LTE RAN Radio Access Network
Evolved Packet Core (EPC)
Services in Packet Data Network

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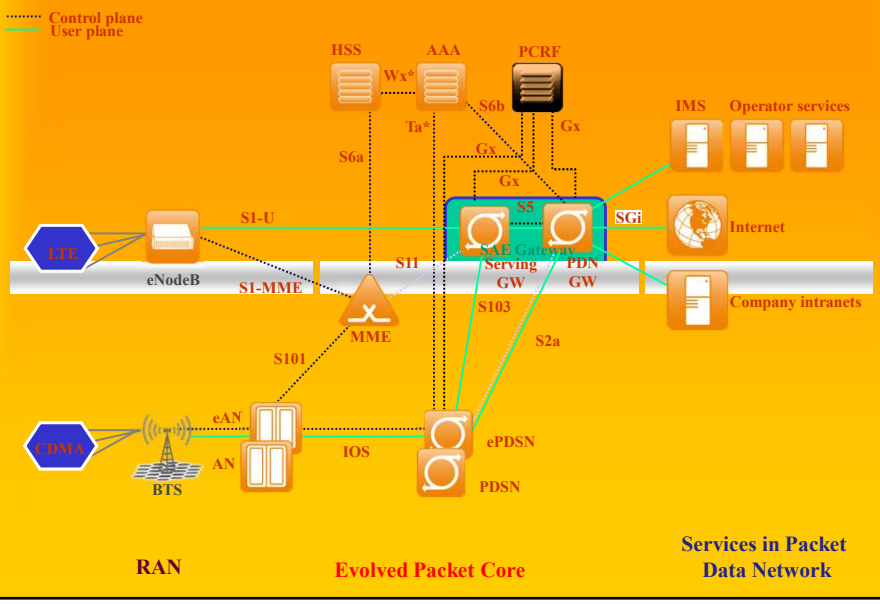
Packet Core Evolution

LTE Network Architecture – CDMA



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Evolution Driver:

INTEGRATION OF DIFFERENT NETWORKS

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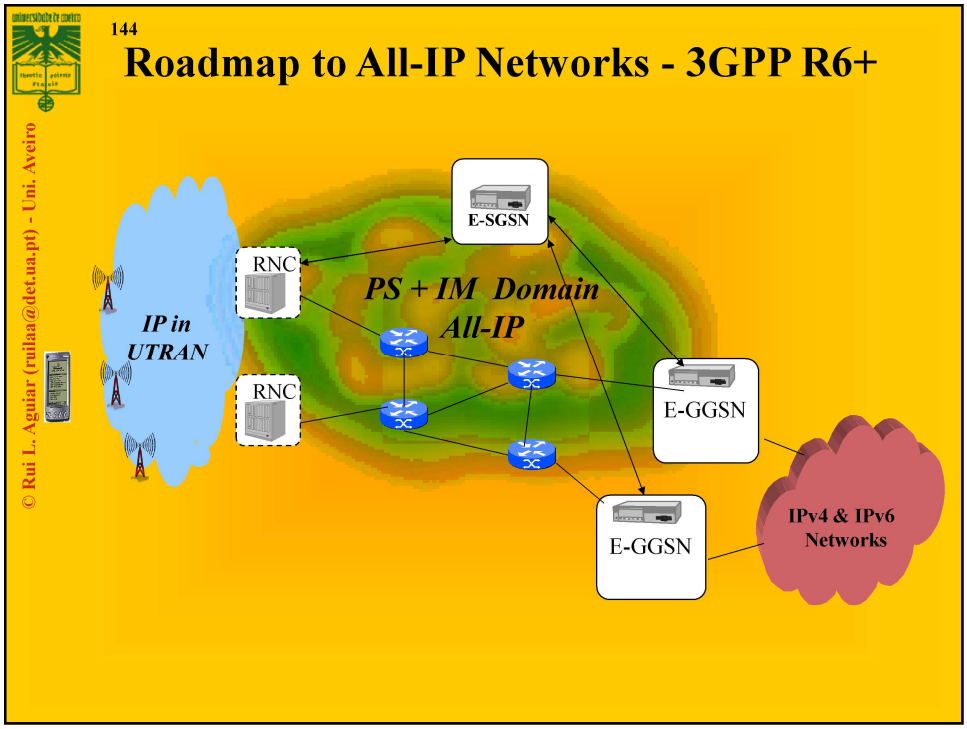
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Roadmap to All-IP Networks - 3GPP R6+
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E-SGSN
RNC
RNC
IP in
UTRAN
PS + IM Domain
All-IP
E-GGSN
E-GGSN
IPv4 & IPv6
Networks

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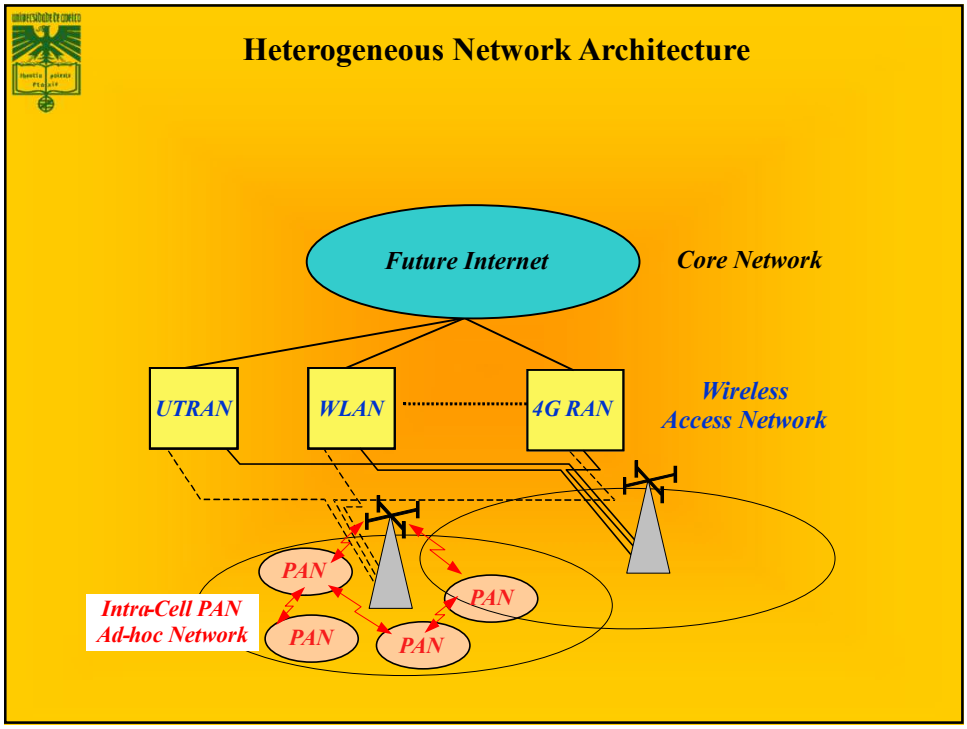
Heterogeneous Network Architecture
Future Internet
Core Network
UTRAN
WLAN
4G RAN
Wireless
Access Network
PAN
PAN
PAN
PAN
Intra-Cell PAN
Ad-hoc Network

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Inter-technology coupling

- Depending on the technical requirements, the integration of WLAN and cellular networks can occur at different coupling points
- There are four general approaches:
  - open coupling,
  - loose coupling,
  - tight coupling
  - very tight coupling
- Depending on the coupling approach, the mechanisms used could be different
  - This can be analyzed at all levels: AAA, QoS, handover, etc…

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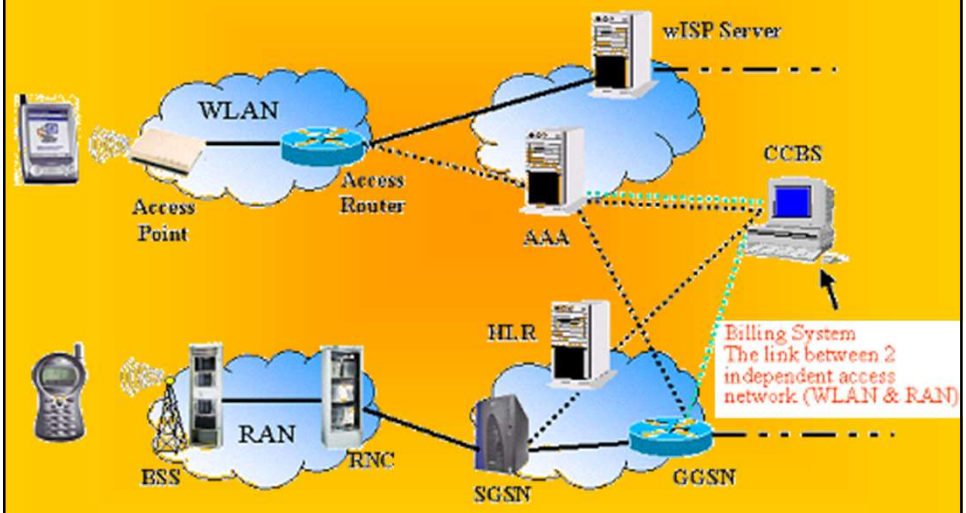
Coupling Options (WLAN/UMTS)

- Open coupling,
  - WLAN and cellular networks have complete disjoint operation in data and control paths
- loose coupling,
  - WLAN and cellular networks have complete disjoint operation in data path. The control protocols that handle authentication, billing and mobility management in the respective network need to be interoperable with each other
- Tight coupling,
  - the WLAN can be integrated into the cellular core network, and the cellular network treats the WLAN as part of the radio access network
- Very tight coupling,
  - the WLAN can be integrated into the cellular radio access network (BSC or BS), and the cellular network treats the WLAN as part of the BS

Open Coupling



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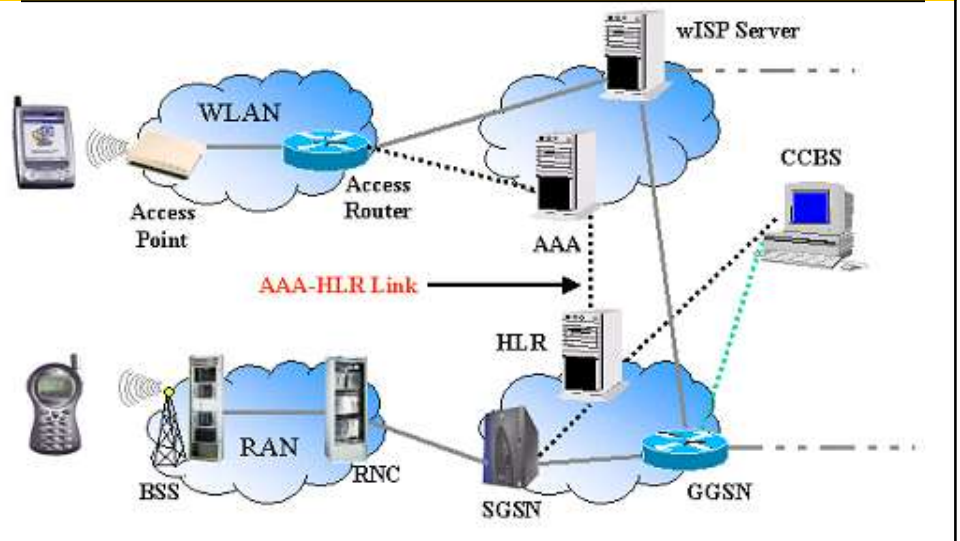
Loose Coupling



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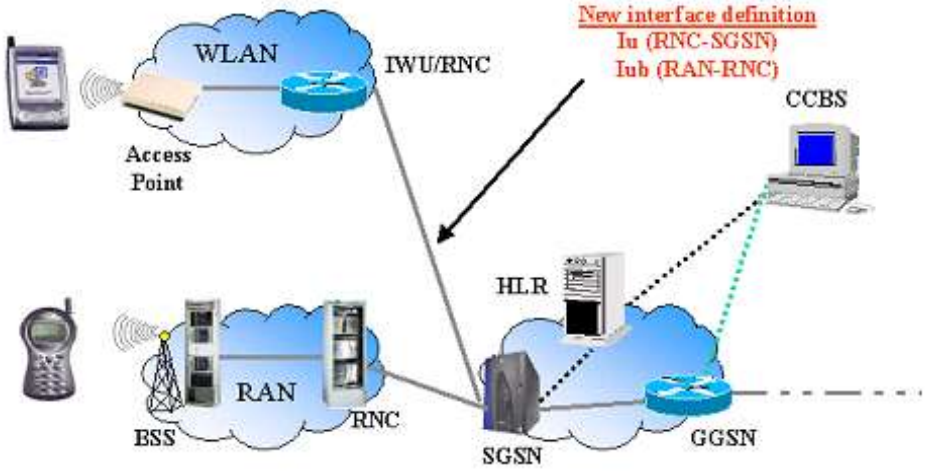
Tight Coupling



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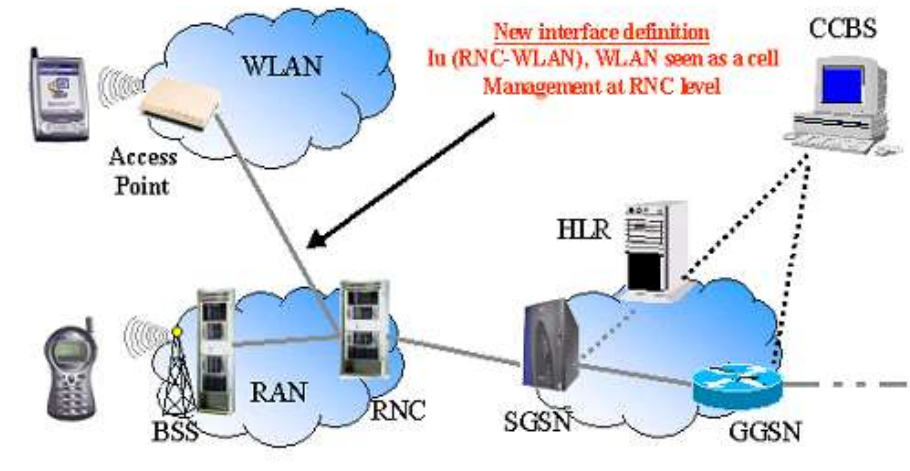
Very tight Coupling



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