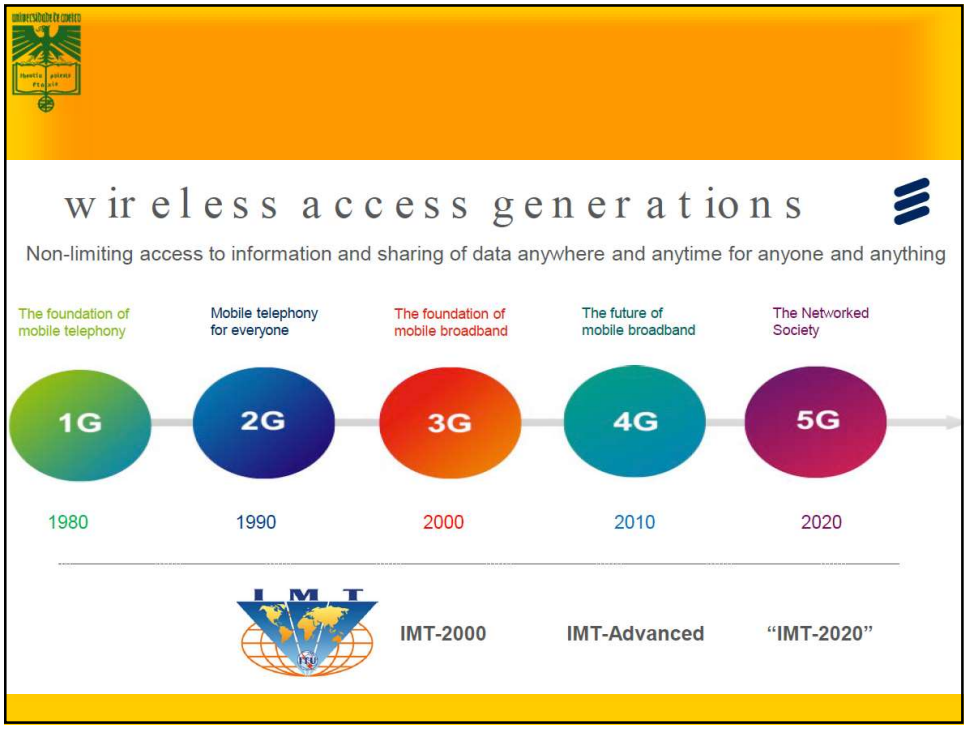
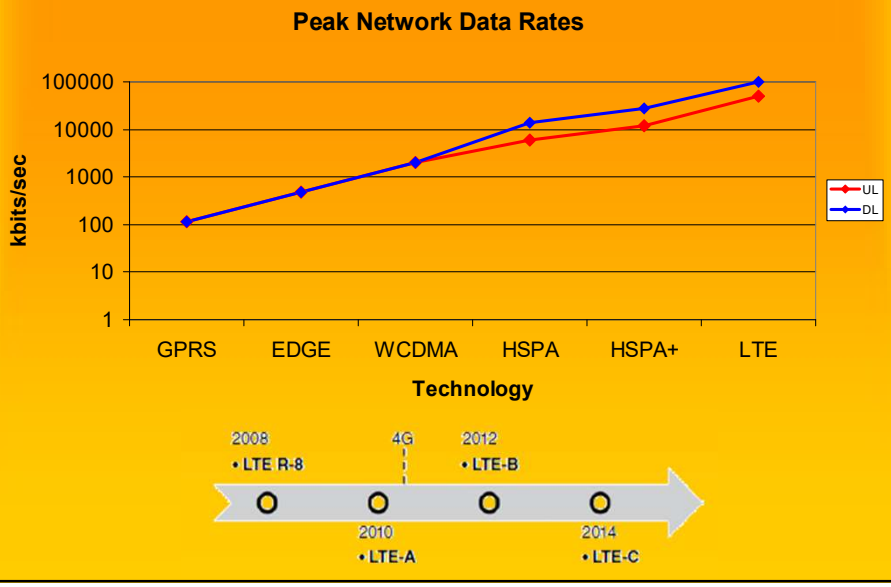
4G: LTE
Long-Term Evolution

the grown up child is no longer the same as his parents'



PHY: Evolution of 3GPP Radio Rates



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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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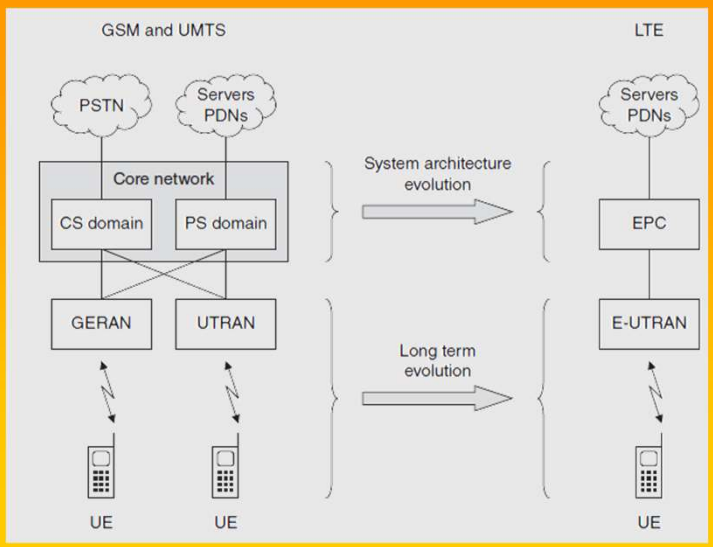
Network simplification



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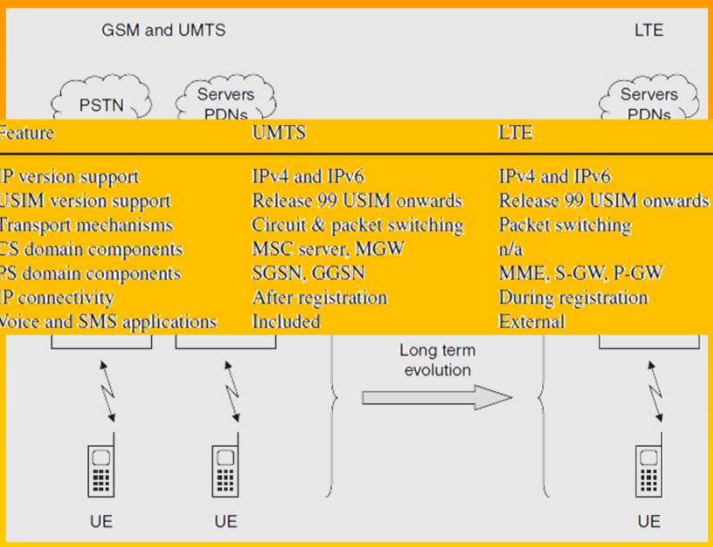
Network simplification



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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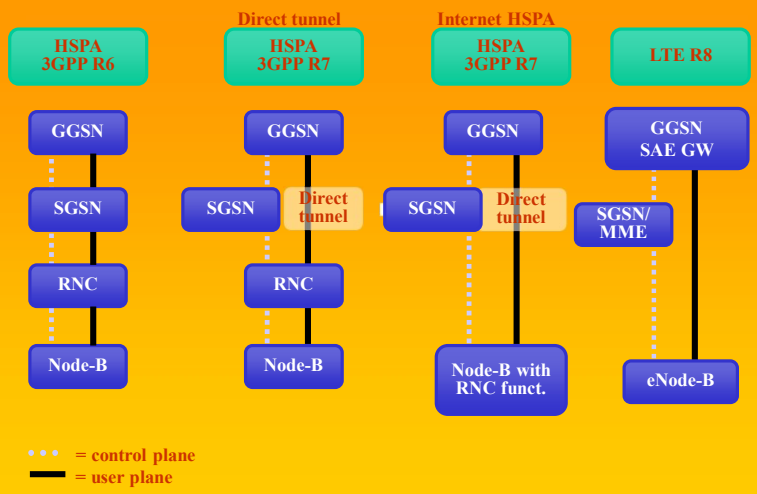
Network evolution towards 4G flat architecture



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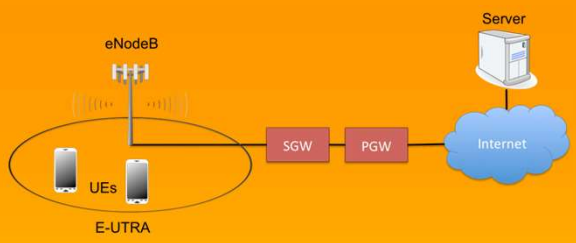
LTE Network elements



- **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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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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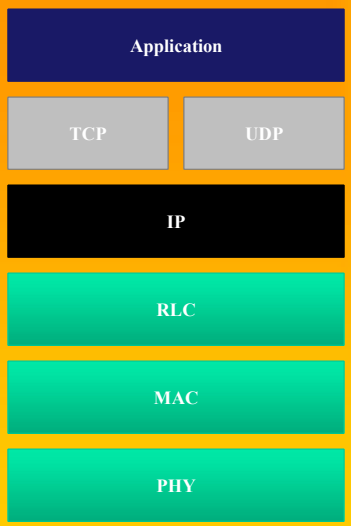
LTE Network Layers

- **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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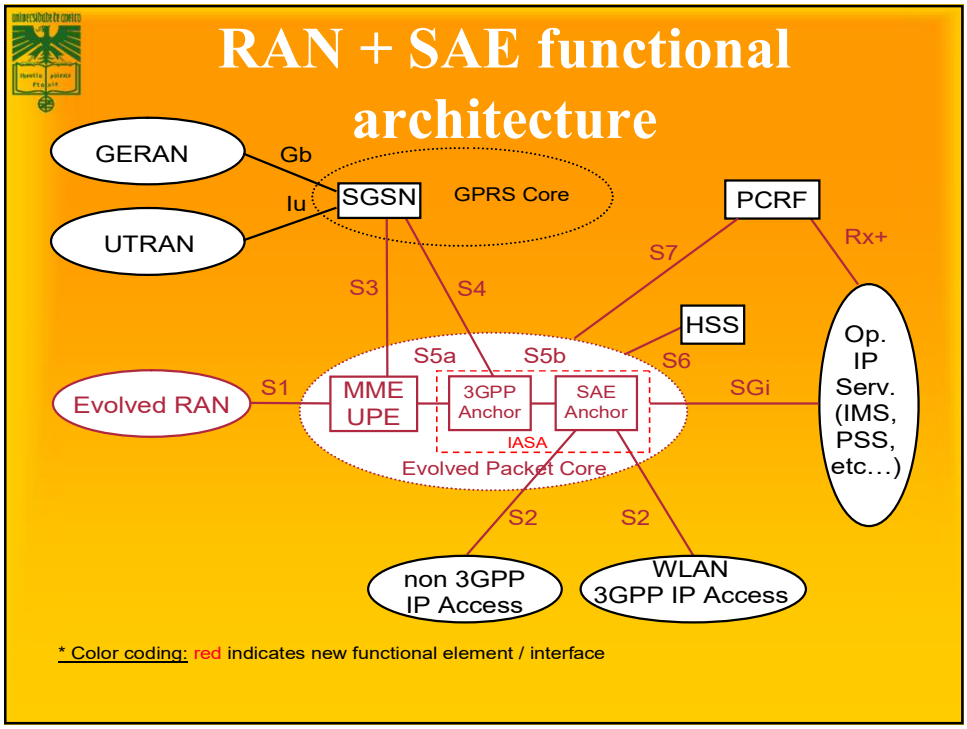
RAN + SAE functional architecture
GERAN
UTRAN
Gb
Iu
SGSN
GPRS Core
PCRF
Rx+
S7
S3
S4
HSS
S5a
S5b
S6
Op. IP Serv. (IMS, PSS, etc…)
Evolved RAN
S1
MME UPE
3GPP Anchor
SAE Anchor
SGi
IASA
Evolved Packet Core
S2
S2
non 3GPP IP Access
WLAN 3GPP IP Access
* Color coding: red indicates new functional element / interface

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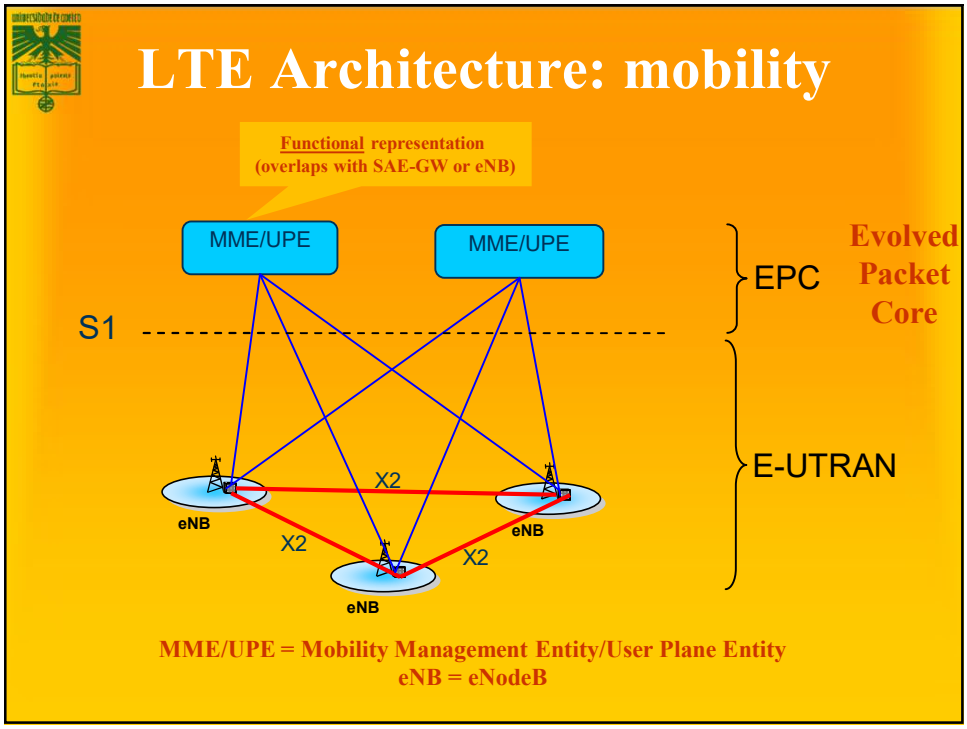
LTE Architecture: mobility
Functional representation
(overlaps with SAE-GW or eNB)
MME/UPE
MME/UPE
EPC
Evolved Packet Core
S1
E-UTRAN
X2
X2
X2
eNB
eNB
eNB
MME/UPE = Mobility Management Entity/User Plane Entity
eNB = eNodeB

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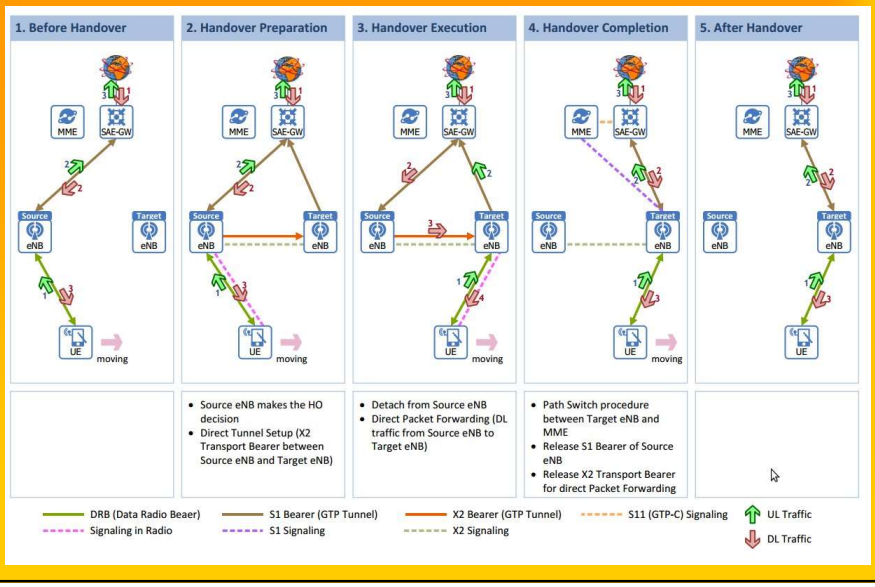
LTE handover(s)



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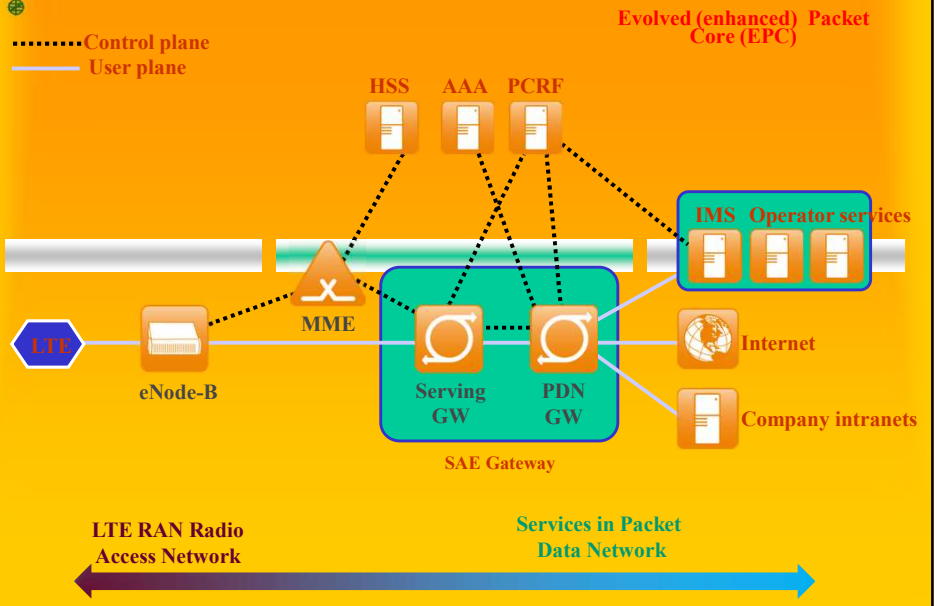
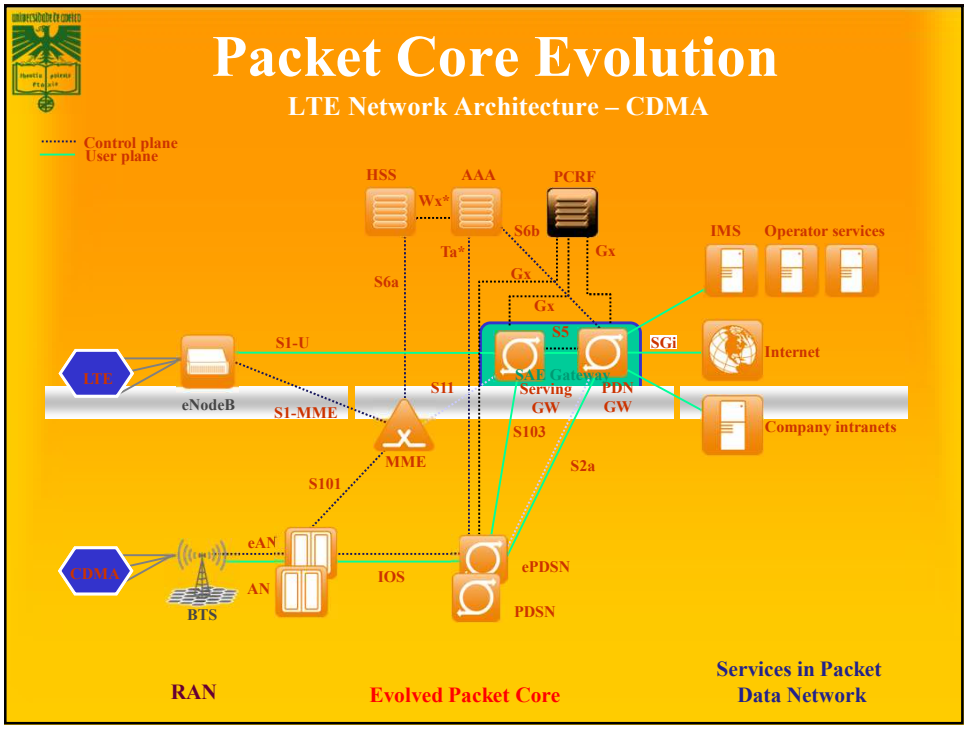
EPC architecture (simplified)



138



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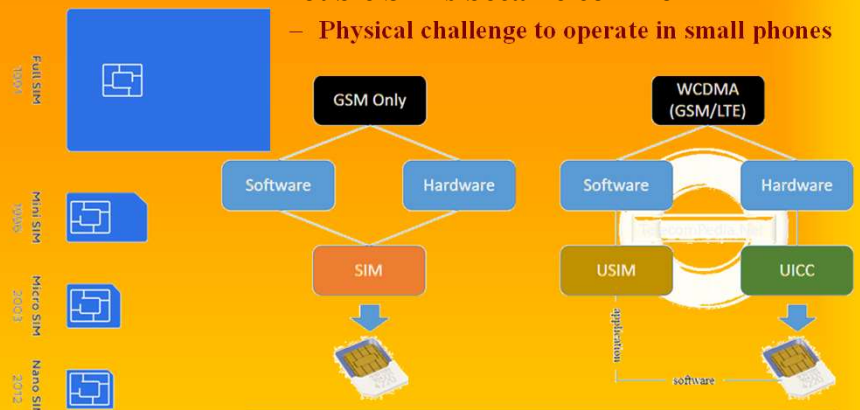
eSim/USIM evolution

- **Double SIMs became common**
  - **Physical challenge to operate in small phones**



SIM	USIM
Subscriber Identity Module	Universal Subscriber Identity Module
SIM is mainly used in mobile phones	USIM is a logical extension of the SIM card
Global Phone Book	Global Phone Book & Hidden Phone Book
·	APN settings can be written directly on the card
·	MMS can be stored on the card
Can store up to 255 contact numbers	Thousands of contacts, email addresses, extra numbers
Compatible with GSM & WCDMA	Compatible with backward technologies
A5, A3 and A8 algorithms are not very secured	More secured with Milenage and Kasumi Algorithms
3G Video Call is not supported in 3G network	3G Video Call is supported in 3G network

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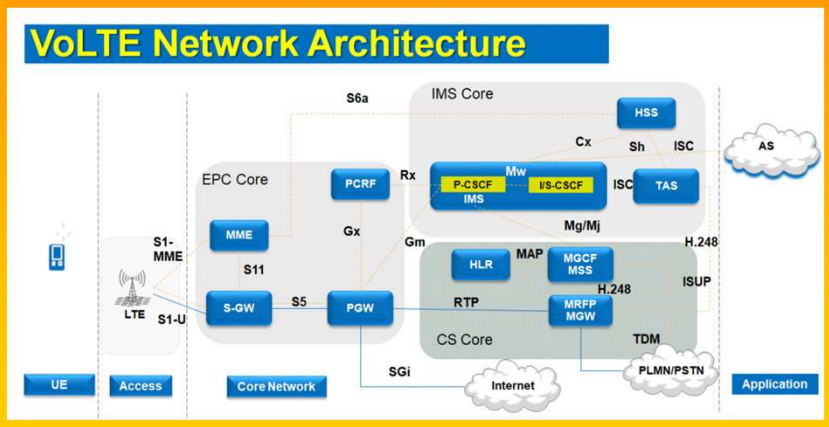
And Voice?

- Based in IMS!
  - Supports CSFB (Circuit Switch FallBack)



CSFB vs VoLTE

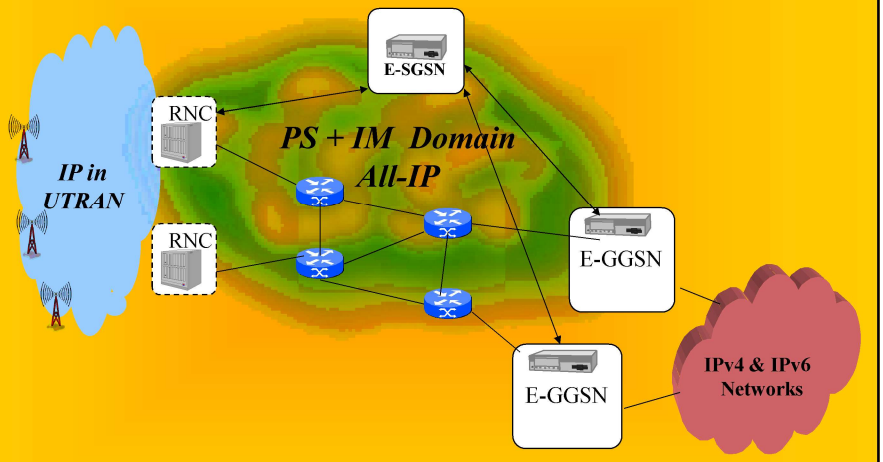
- CFSB supports voice and SMS services in 4G networks using the 2G/3G systems.

Feature	CSFB	VoLTE
Easy of Deployment	Challenging, but not as difficult as VoLTE	Numerous major challenges to overcome
Economic Considerations	Minor	Major
LTE Coverage Requirements	Low	High
Call Setup Time	Approx. 3-7 secs	Approx. 2-4 secs
Voice Quality	Acceptable	HD Voice
Lifespan	2G and 3G limited life	IMS forms basis for 5G voice and beyond

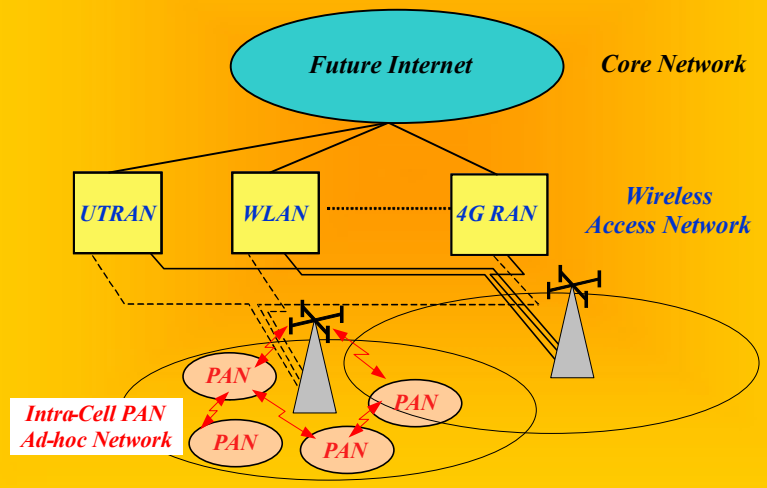
Evolution Driver:

INTEGRATION OF DIFFERENT NETWORKS

Roadmap to All-IP Networks - 3GPP R6+



Heterogeneous Network Architecture



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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**

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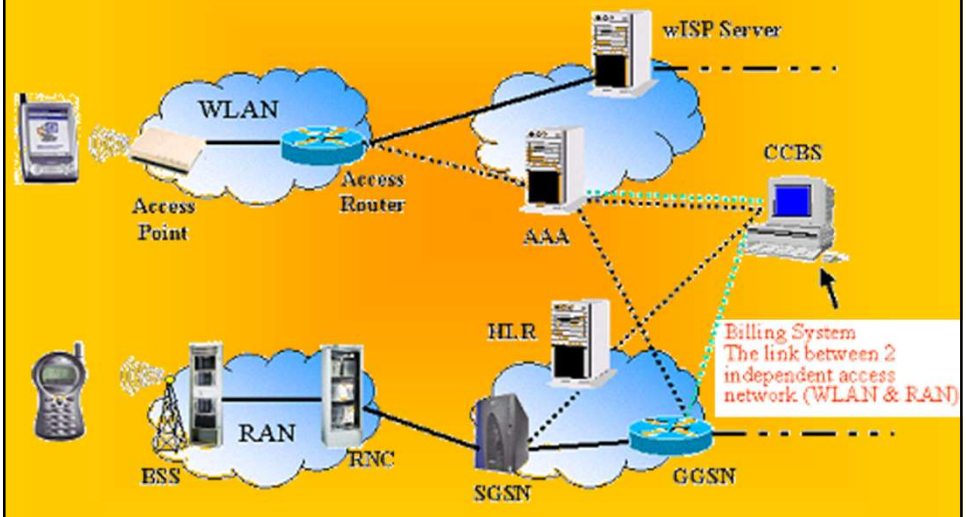
Open Coupling



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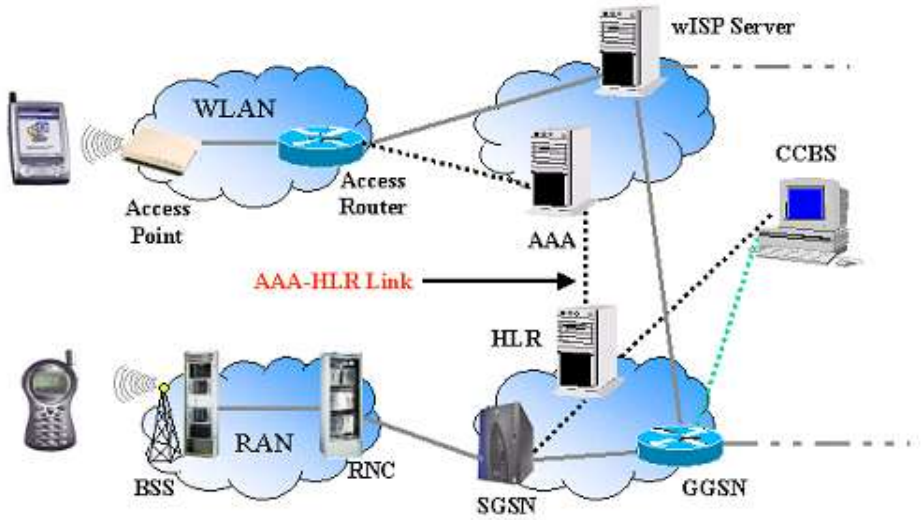
Loose Coupling



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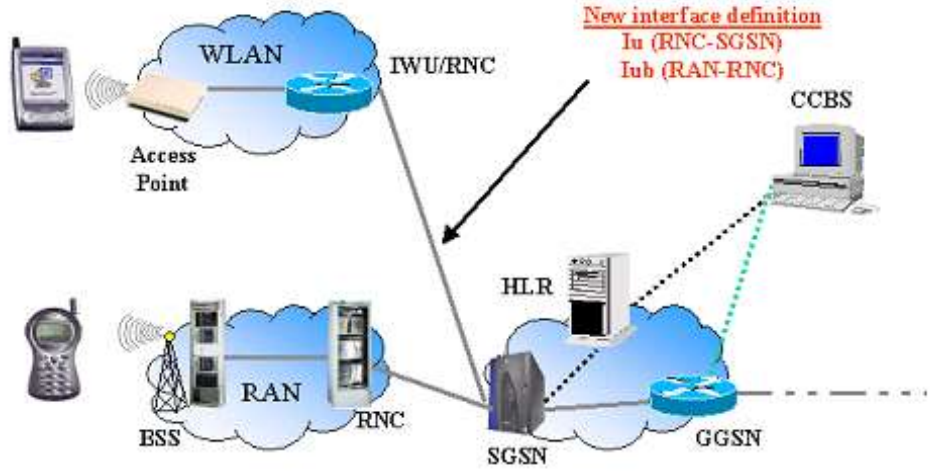
Tight Coupling



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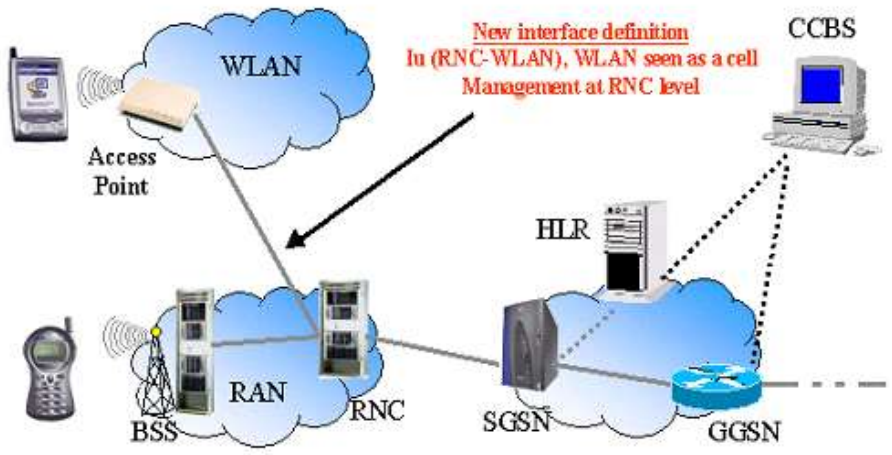
Very tight Coupling



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5G
How it became the current network

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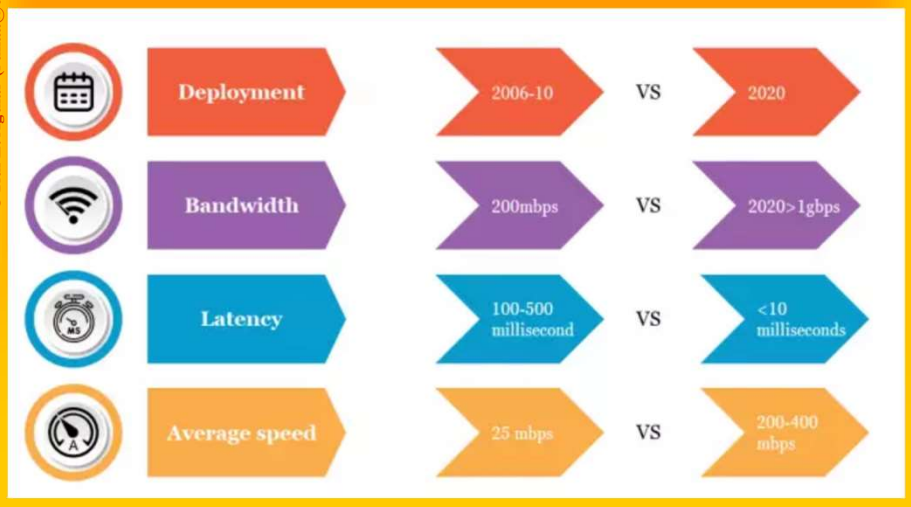
Expectations: 4G vs 5G



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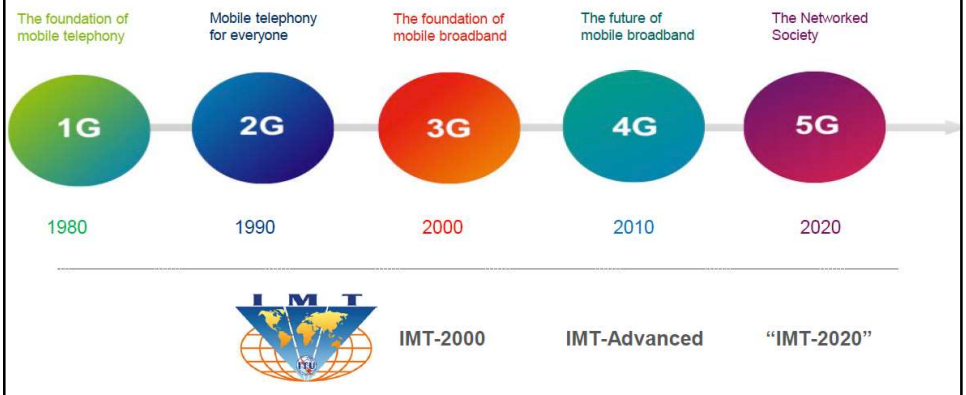
wireless access generations

Non-limiting access to information and sharing of data anywhere and anytime for anyone and anything



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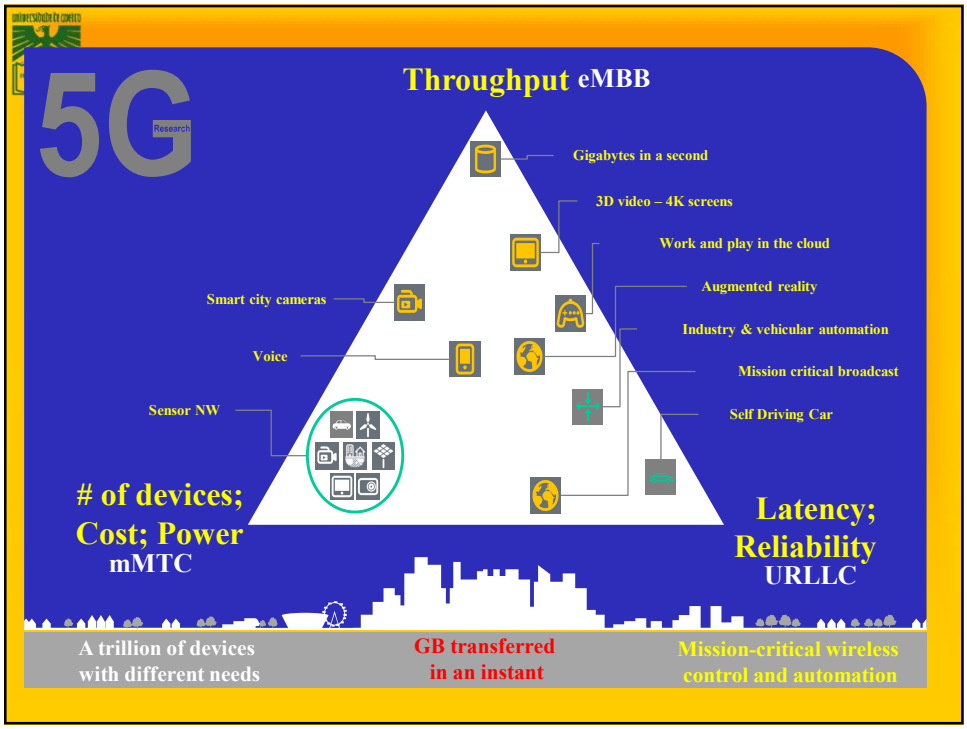
5G
Research
Throughput eMBB
Gigabytes in a second
3D video – 4K screens
Work and play in the cloud
Augmented reality
Industry & vehicular automation
Mission critical broadcast
Self Driving Car
Smart city cameras
Voice
Sensor NW
# of devices;
Cost; Power
mMTC
Latency;
Reliability
URLLC
A trillion of devices
with different needs
GB transferred
in an instant
Mission-critical wireless
control and automation

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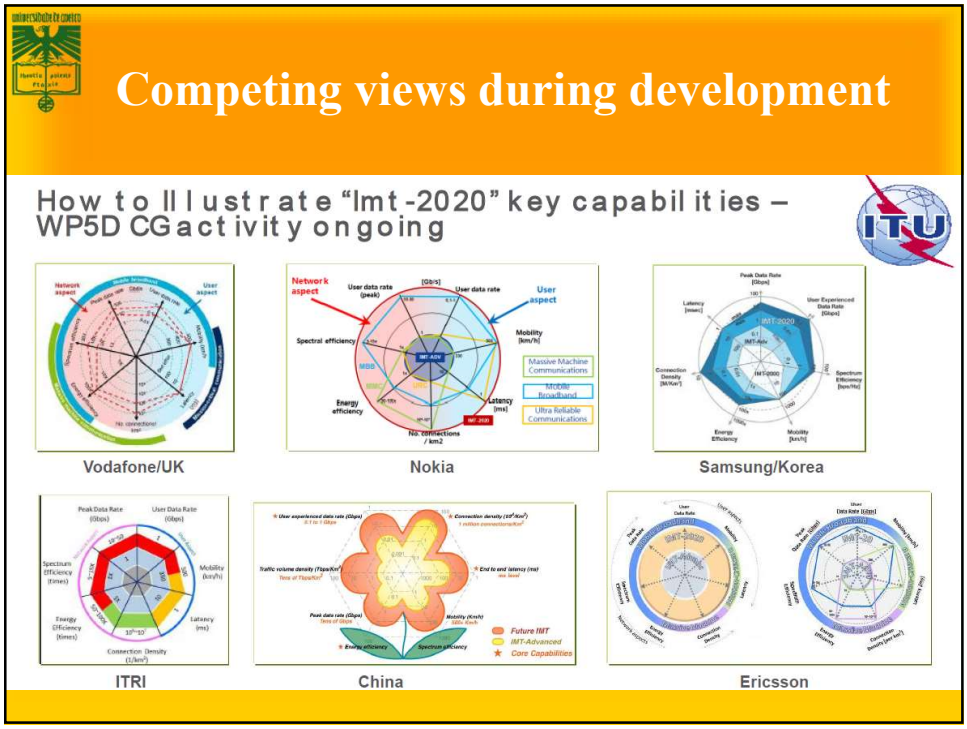
Competing views during development
How to Illustrate "Imt-2020" key capabilities –
WP5D CG activity ongoing
ITU
Vodafone/UK
Nokia
Samsung/Korea
ITRI
China
Ericsson

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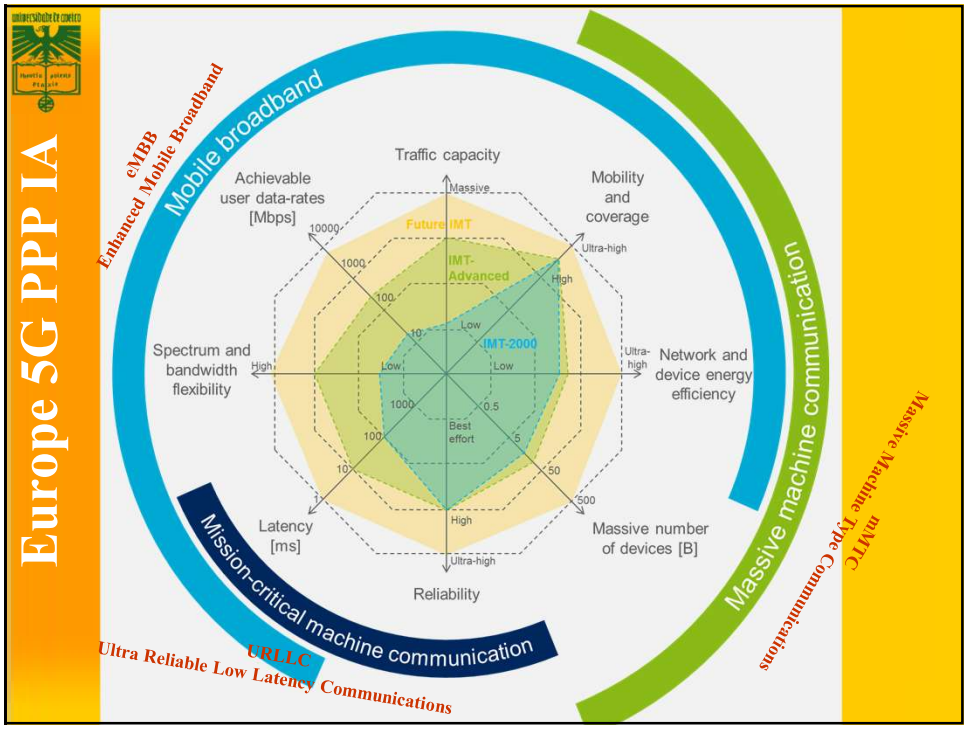
Europe 5G PPP IA
eMBB
Enhanced Mobile Broadband
Mobile broadband
Traffic capacity
Mobility and coverage
Network and device energy efficiency
Massive number of devices [B]
Reliability
Latency [ms]
Spectrum and bandwidth flexibility
Achievable user data-rates [Mbps]
Future IMT
IMT-Advanced
IMT-2000
Massive machine communication
mMTC
Massive Machine Type Communications
Mission-critical machine communication
URLLC
Ultra Reliable Low Latency Communications

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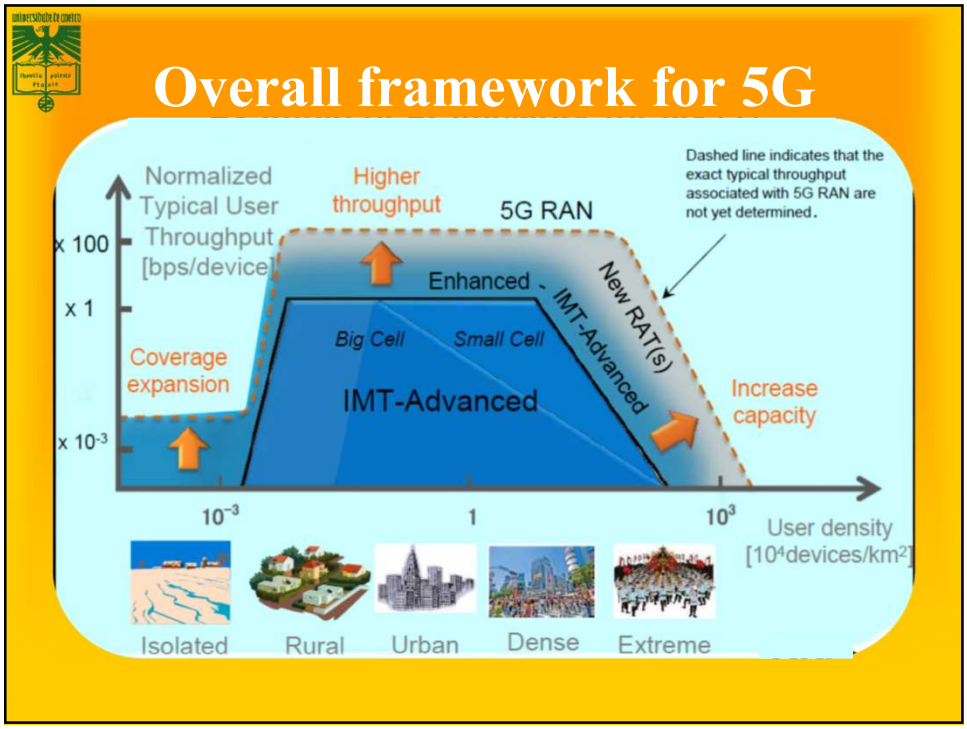
Overall framework for 5G
Normalized Typical User Throughput [bps/device]
x 100
x 1
x 10-3
Higher throughput
5G RAN
Dashed line indicates that the exact typical throughput associated with 5G RAN are not yet determined.
Enhanced - IMT-Advanced
New RAT(s)
Big Cell
Small Cell
IMT-Advanced
Coverage expansion
Increase capacity
10-3
1
103
User density [10⁴devices/km²]
Isolated
Rural
Urban
Dense
Extreme

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Example view on 5G

Next generation Wide Area

Scalable service experience anytime and everywhere

4G	*'massive mobile data'*
3G	*'voice, video and data'*
2G	*'high quality voice and SMS'*
Wi-Fi	*'best effort data'*
PAN	*'short range and low power'*

Architecture

5G Research

Ultra dense deployments

Zero latency and GB experience – when and where it matters

Integrated, harmonized and complementing each other

Source: Nokia.

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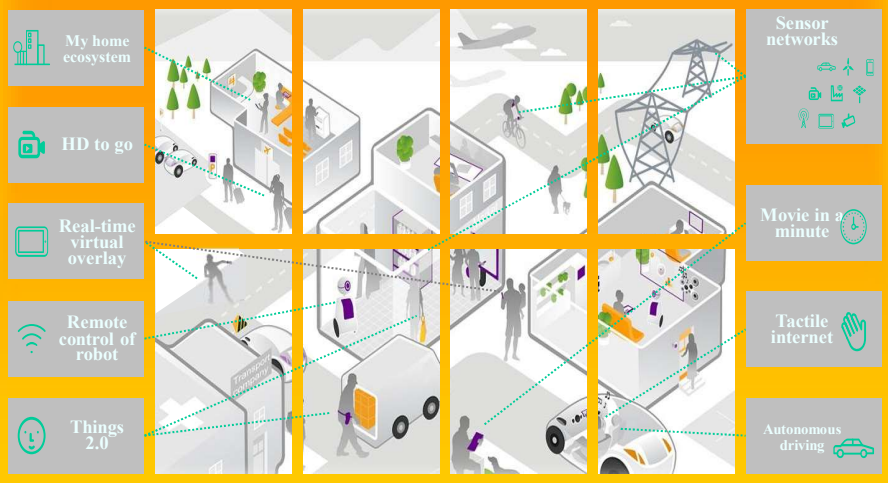
The 2020+ user experience



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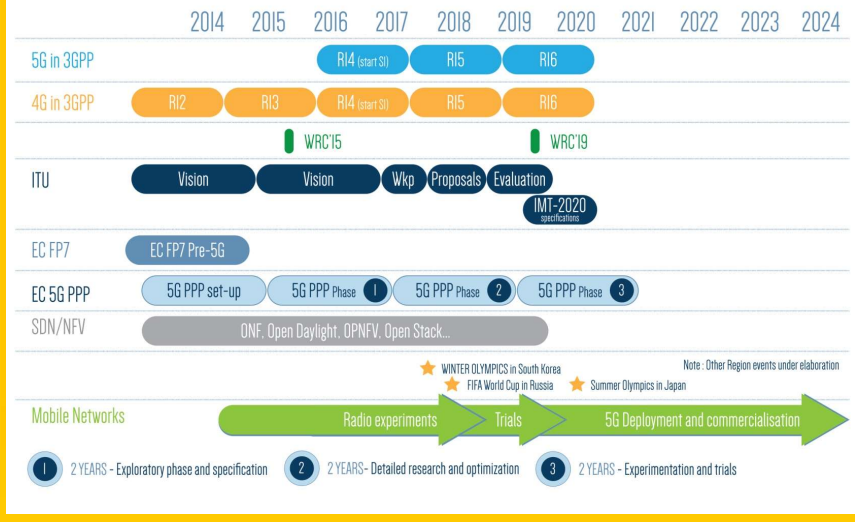
5G PPP Vision and Requirements
5G roadmap



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Source: 5G Infrastructure Association: Vision White Paper, February 2015.

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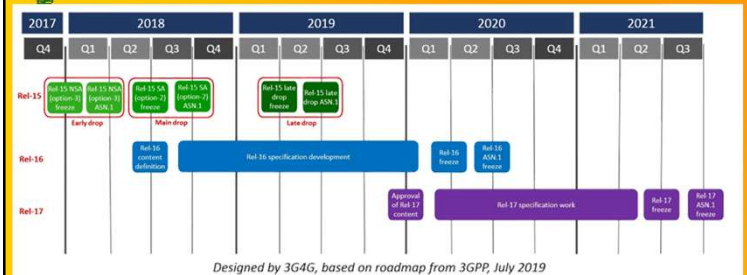
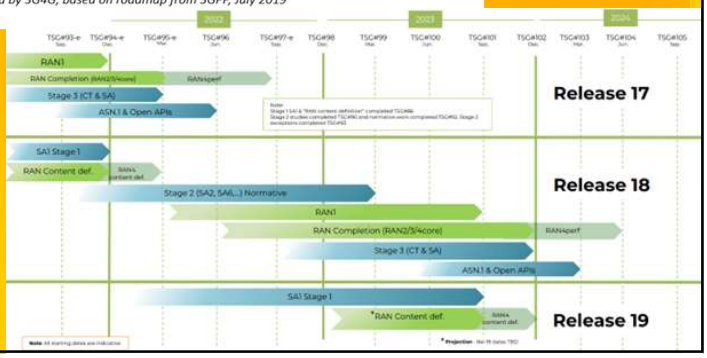
5G Evolutions



Designed by 3G4G, based on roadmap from 3GPP, July 2019



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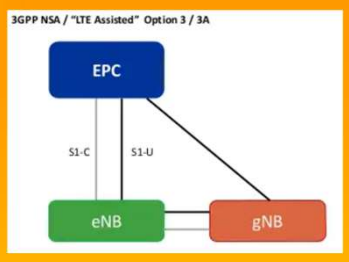
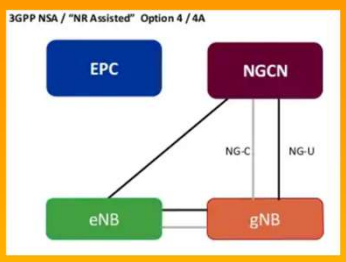
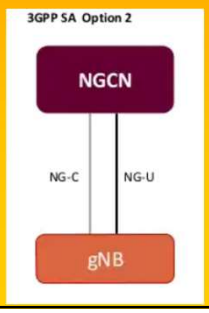
Implementation options







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Road to comercial 5G

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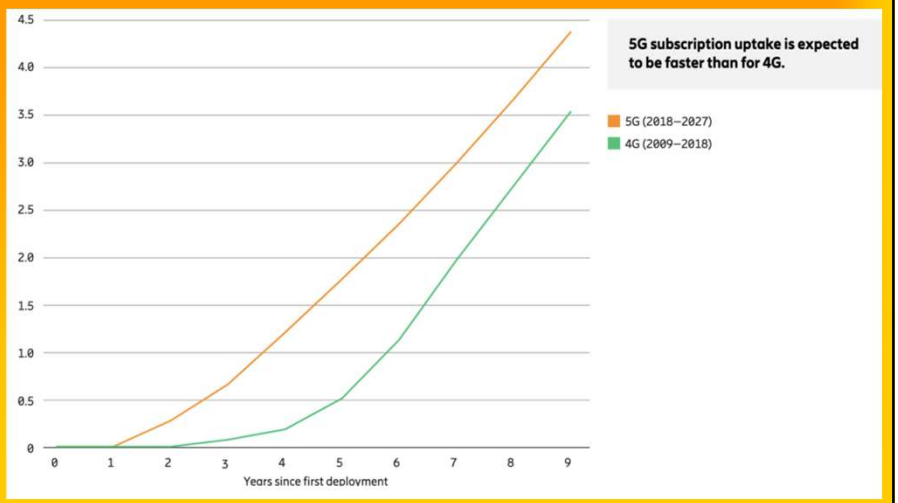
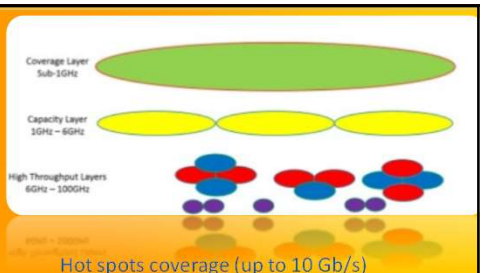
5G uptake



5G – TECHNOLOGIES

EU 5G "Pioneer" Frequency Bands



5G

4G + Wi-Fi

Hot Spot data speeds 26 GHz — Hot spots coverage (up to 10 Gb/s) e.g. fixed wireless access, railway stations, sport events, smart factories,

Urban mobile data speeds 3.6 GHz — **Urban coverage with dense small cells (1-3 Gb/s) e.g. mobile Gb/s society, smart cities, option for connected highways**

Reliable coverage 700 MHz — Universal coverage (10's of Mb/s) of reliable connectivity

Source: 5G-PPP

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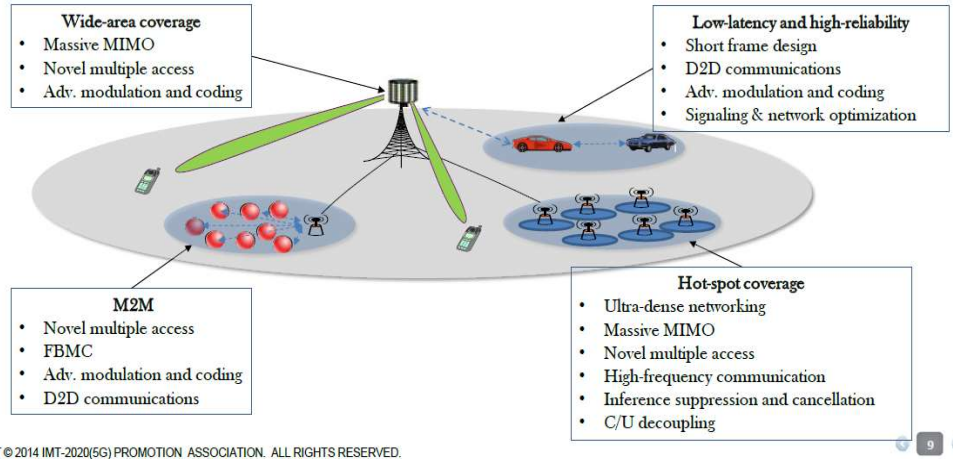
5G RAN Scenarios and Key Technologies

5G radio access networks need to meet diverse requirements of 5G typical scenarios including wide-area coverage, hot-spot coverage, low-latency and high-reliability and M2M.



9

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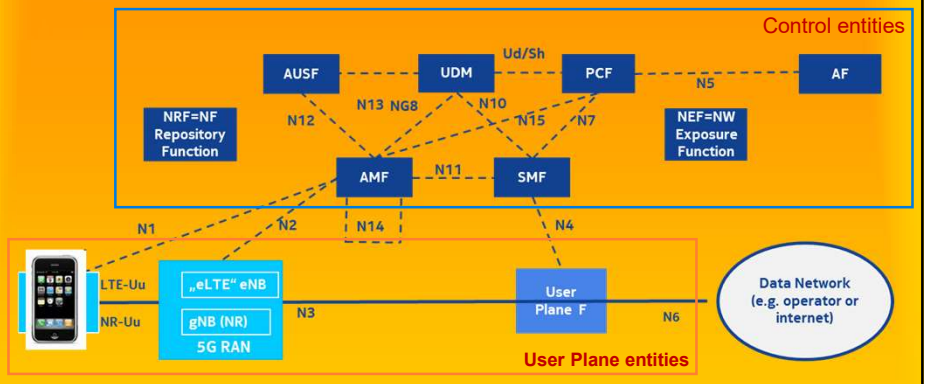
"5G Architecture"

- References points….



5G global architecture

- 5G System still separated in:
  - UEs
  - 5G RAN
  - 5G Core
- Control and user plane separation remains
- Core implementation oriented towards SBA (servisse base architecture, e.g. microservices)
- Multi-technologies in the access.
- Conceptual separation in multiple networks (slicing)

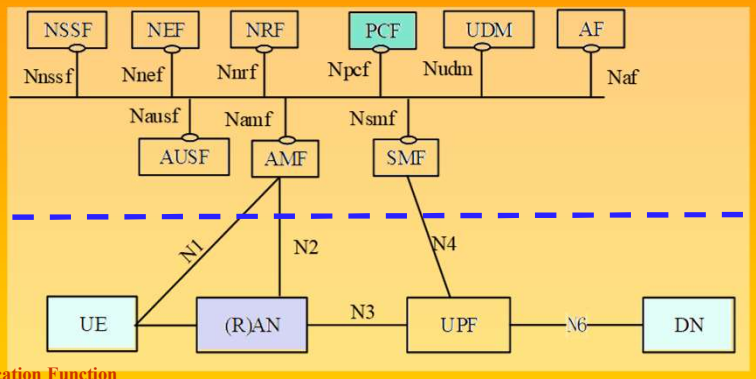
The (limited) 5G System architecture

(3GPP TS 23.501 Rel 15)

August

References points representation

shows the interaction that exist between the NF services in the network functions described by point-to-point reference point (e.g. N11) between any two network functions (e.g. AMF and SMF)



AF – Application Function
AUSF – Authentication Server Function,
AMF -Core Access and Mobility Management Function
SMF -Session Management Function
UPF -User plane Function
DN – Data Network
NSSF – network slice selection function
NEF – Network Exposure Function
NRF – Network Repository Function
PCF – Policy Control Function
UDM – User data management

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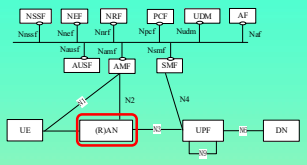
RAN



Radio Access Network (RAN)

- Radio Resources Management (RRM)
- Control, Dynamic allocation of resources to UEs in both uplink and downlink (scheduling)
- Selection of an AMF at UE attachment
- Routing of User Plane data towards UPF(s)
- Routing of Control Plane information towards AMF
- Connection setup and release
- Scheduling and transmission of paging messages and system broadcast information
- Measurement and measurement reporting configuration for mobility and scheduling
- Transport level packet marking in the uplink
- Session Management
- Support of Network Slicing
- QoS Flow management and mapping to data radio bearers

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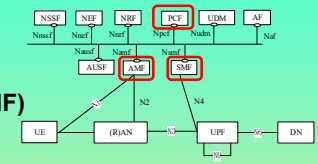
AMF, SMF and PCF

AMF, SMF and PCF



- **Access and Mobility Management Function (AMF)**
  - Termination of NAS (Non-Access Stratum) signalling
  - NAS ciphering & integrity protection
  - Registration management
  - Connection management
  - Mobility management
  - Access authentication and authorization
  - Security context management
- **Session Management Function (SMF)**
  - Session management (establishment, modification, release)
  - UE IP address allocation & management
  - UPF selection and configuration for QoS and traffic steering
  - DHCP functions
  - Lawful intercept functions
  - Charging data collection and support of charging interfaces
- **Policy Control Function (PCF)**
  - Supports unified policy framework to govern network behaviour
  - Provides policy rules to Control Plane function(s) to enforce them
  - Accesses subscription information relevant for policy decisions in a Unified Data Repository (UDR)

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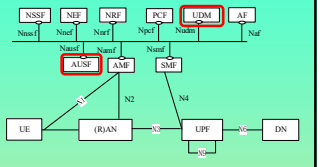
AUSF and UDM



AUSF and UDM

- **Authentication Server Function (AUSF)**
  - Acts as an authentication server for 3GPP access and untrusted non-3GPP access
- **Unified Data Management (UDM)**
  - Generation of 3GPP Authentication and Key Agreement (AKA) credentials
  - User Identification handling
  - Access authorization based on subscription data
  - Lawful Intercept functionality
  - Subscription management

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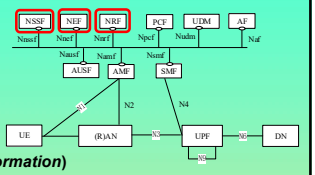
NEF, NRF and NSSF

NEF, NRF and NSSF



- **Network Slice Selection Function (NSSF)**
  - Selecting of the Network Slice instances serving the UE
  - Determining the Allowed NSSAI (*Network Slice Selection Assistance Information*)
  - Determining the AMF set to be used to serve the UE
- **Network Exposure function (NEF)**
  - Exposure of capabilities and events
  - Secure provision of information from external application to 3GPP network
  - Translation of internal/external information
- **NF Repository function (NRF)**
  - Supports service discovery function
  - Maintains the NF profile of available NF instances and their supported services

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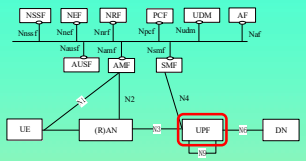
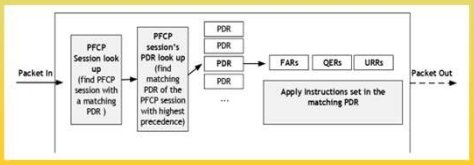
UPF



- **User Plane Function (UPF)**
  - Packet routing & forwarding
  - Anchor point for Intra-/Inter-RAT mobility
  - External PDU session point of interconnect to Data Network
  - Packet inspection and User plane part of Policy rule enforcement
  - Lawful intercept (UP collection)
  - Traffic usage reporting
  - Uplink classifier (ULCL) to support routing traffic flows to a data network
  - QoS handling for user plane, e.g. packet filtering, gating, UL/DL rate enforcement
  - Transport level packet marking in the uplink and downlink
  - Downlink packet buffering and downlink data notification triggering



Packet processing flow in the UP Function

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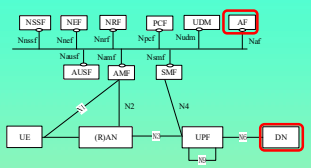
AF and DN



- **Application Function (AF)**
  - **Application influence on traffic routing**
  - **Accessing Network Exposure Function**
  - **Interacting with the Policy framework for policy control**

- **Data Network (DN)**
  - **Operator services**
  - **Internet access**
  - **3rd party services**
  - **May be a Local Area Data Network (LADN):**
    - a DN that is accessible by the UE only in specific locations, that provides connectivity to a specific **Data Network Name (DNN)**, and whose availability is provided to the UE.

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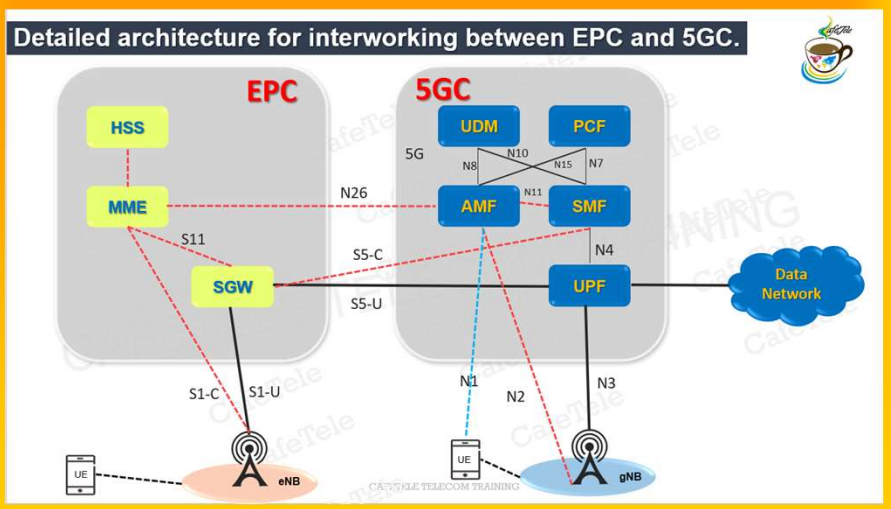
(implementations)



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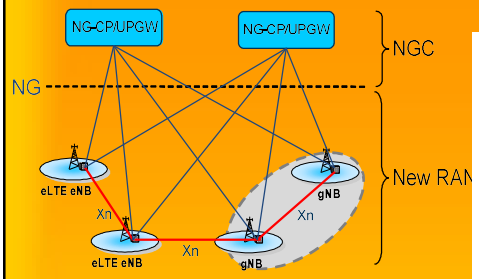
5G: the (new) RAN architecture



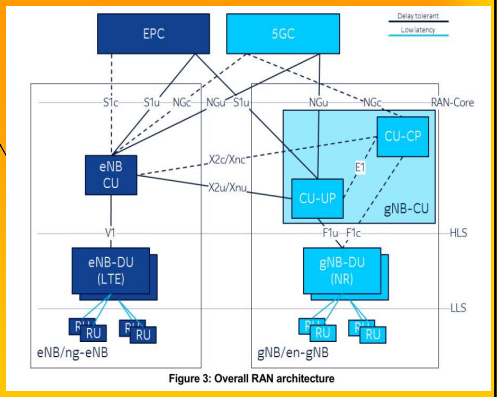


Figure 3: Overall RAN architecture

NGC: Next Generation Core
NG-CP: *Next Generation Control Plane*
UPGW: *User Plane GateWay*

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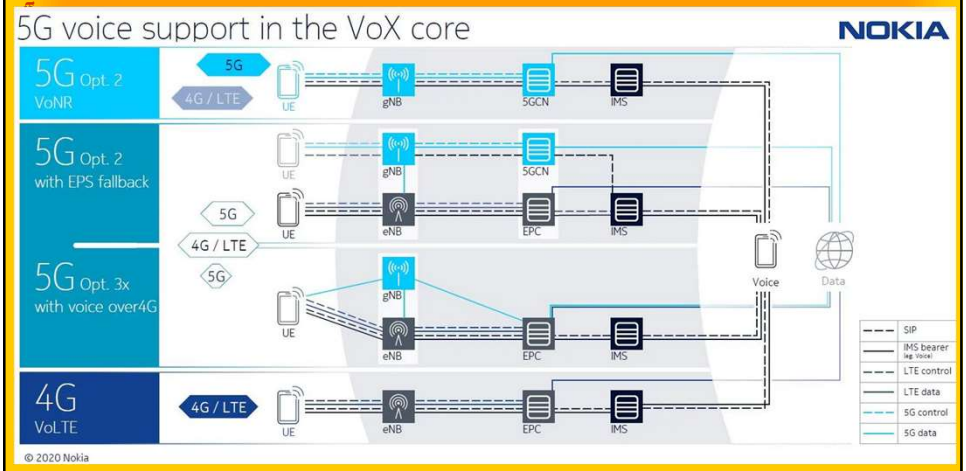
And voice?



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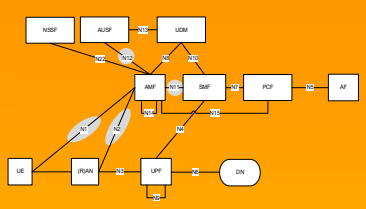
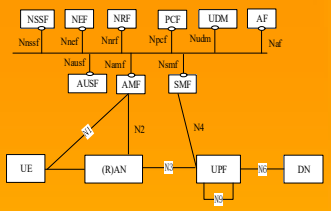
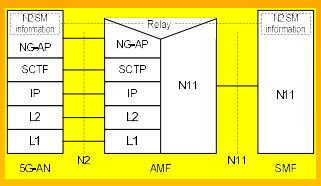
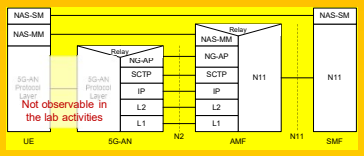
Protocol stacks: Control Plane

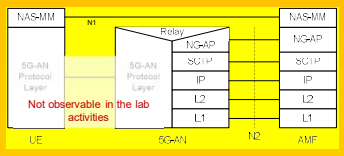






SCTP: Stream Control Transmission Protocol
PFCP: Packet Forwarding Control Protocol
NG-AP: NG Application Protocol
NAS-MM: NAS Mobility Management
NAS-SM: NAS Session Management
NAS: Non-Access-Stratum





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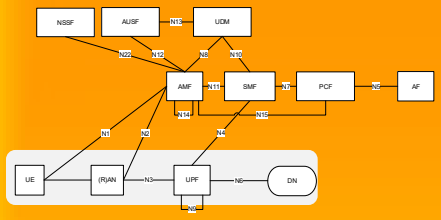
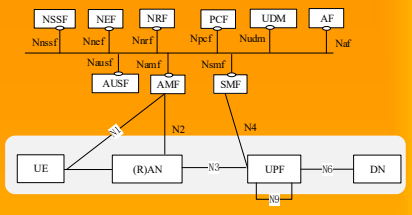
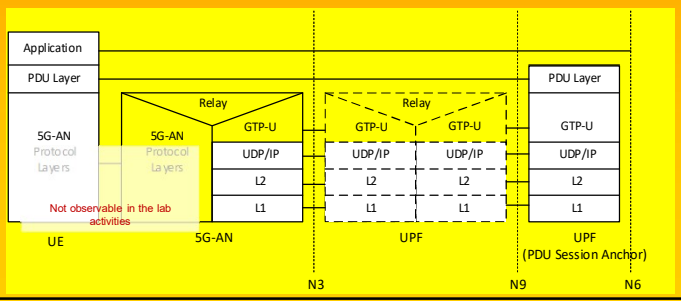
Protocol stacks: User Plane





GTP: GPRS Tunnelling Protocol



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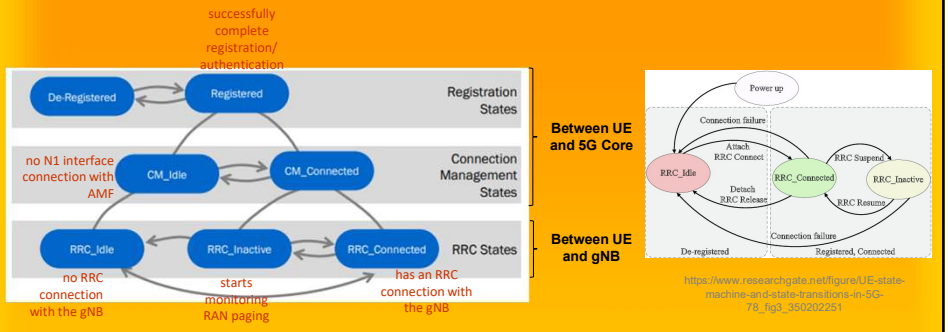
UE states in 5G



https://www.researchgate.net/figure/UE-state-machine-and-state-transitions-in-5G-78_fig3_350202251

https://www.linkedin.com/pulse/5g-ue-states-5g-myapekshatelecom/

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Expected Technology – trends besides radio layers

| August 2017

- Integration of different technologies (not only physical layer)
  - Following the current trends….
- Complex radio environment
  - CRAN, HCRAN, microcells, as now but device # explosion
- Separation between infrastructure, network, computation and service
  - Reconfigurable network and service provision (SDN, NFV, virtualization, cloud…)
  - Edge becoming an entity per se
- Multitenant environment
  - Different types of providers, different types of interrelations
  - Slicing of resources: deep virtualization (cloud and network)

Network Slicing (NGMN)

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Networks require (complex) infrastructure

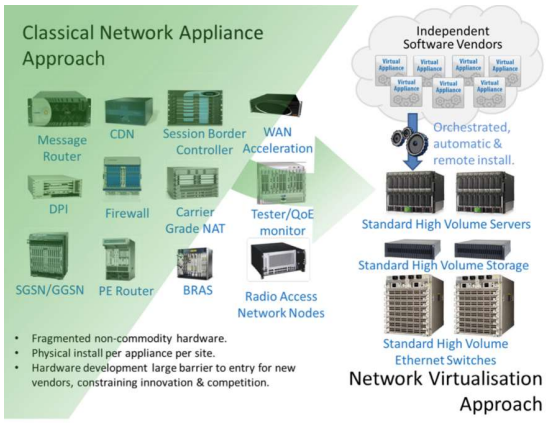
Well known figure …

–Current infrastructure.

- Current network equipment designed for special use case

–Software Defined Networking and Network function Virtualization:

- Special use cases as software release running on top of standard hardware
- Virtualization will become a key issue to reduce OPEX and CAPEX



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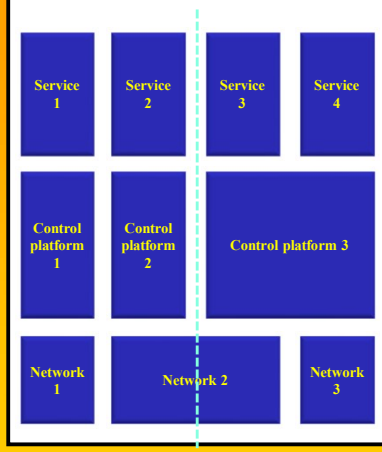
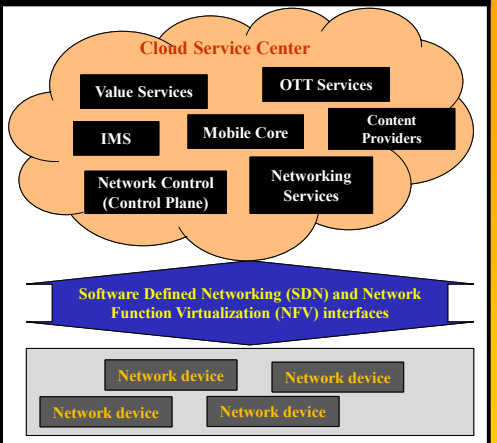
Evolving complex infrastructure

From here…



To here…



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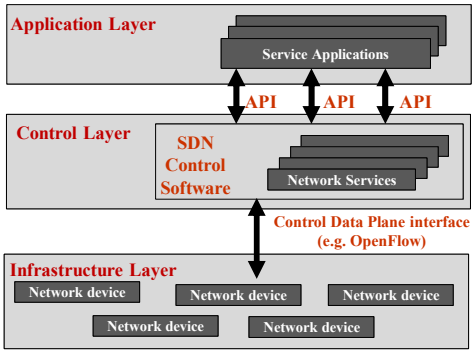
The "new" purpose of SDN and NFV

Split of the control plane from the user/data plane

- User/data plane implemented by standard (low-cost) equipment
  - Reduction on the HW cost
- Control plane implemented in the cloud – Network Function Virtualization – with standardized and open interfaces to services/business applications
  - Easy service development
- Software maintained by the operator
  - Change on the value and revenue model



Source: ONF (Open Network Foundation)

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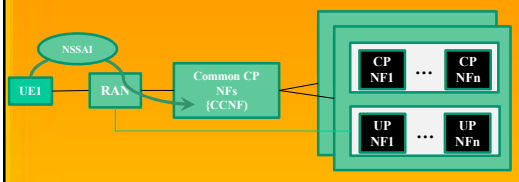
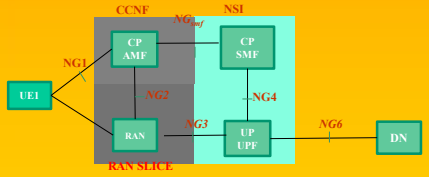
Network slicing (3GPP TR 23.799 view)

- A Network Slice is a complete logical network made up of Access and Core Network Components (…. missing computing side….)





- Slices are selected based on NSSAI provided by the UE
  - RAN selects a CCNF (AMF/NSSF) based on the NSSAI
  - An NSSAI can generate multiple Network Slices
  - An AN can be common to all slices
  - The NSSAI includes at least: SST and SD
- CCNF Redirection can be done at RAN or CCNF
- SMF Selection is based on:
  - NSSAI (Provided by the UE), UE Subscription Info, DNN and Local Operator policies
- SM-NSSAI can be associated to an application
  - Data is routed to the PDU sessions associated to the SM-NSSAI

Network Slice Selection Assistance Information (*NSSAI*)
Common Control Network Functions (*CCNF*)
Access and Mobility Function (AMF)
CP (control Plane)
(1) AMF, (2) Session Management Function (SMF), (3) Policy Control Function (PCF), (4) Application Function (AF), (5) Authentication Server Function (AUSF), (6) User Plane Function (UPF), and (7) User Data Management (UDM).

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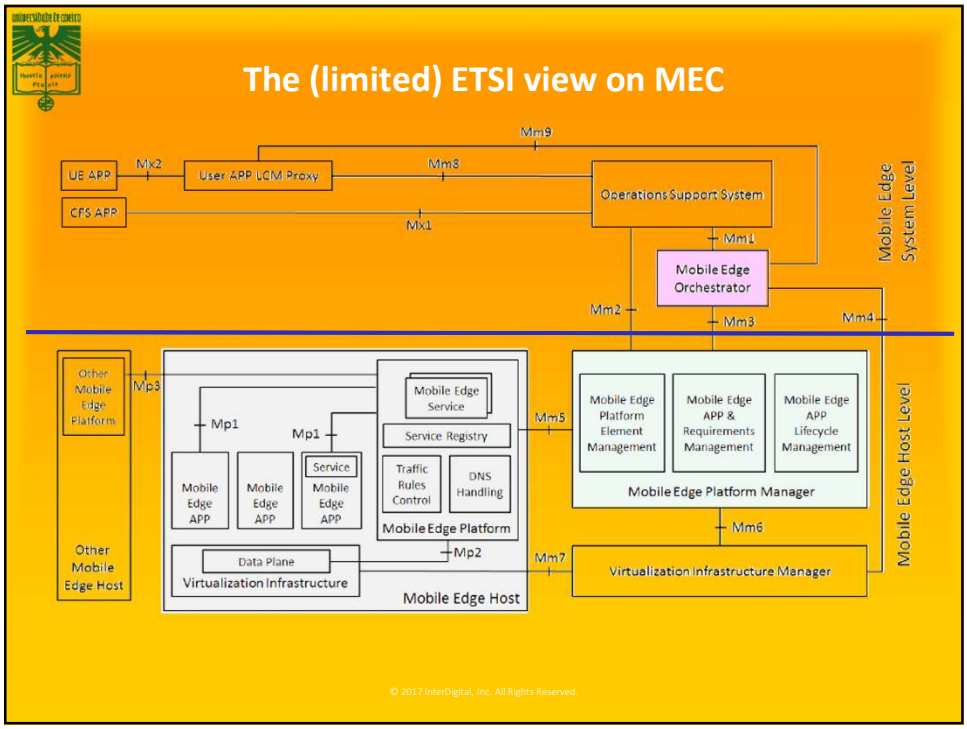
The (limited) ETSI view on MEC
Mm9
Mx2
UE APP
User APP LCM Proxy
Mm8
Operations Support System
CFS APP
Mx1
Mm1
Mobile Edge System Level
Mobile Edge Orchestrator
Mm2
Mm3
Mm4
Other Mobile Edge Platform
Mp3
Mp1
Mp1
Mobile Edge Service
Service Registry
Service
Mobile Edge APP
Mobile Edge APP
Mobile Edge APP
Traffic Rules Control
DNS Handling
Mobile Edge Platform
Mm5
Mobile Edge Platform Element Management
Mobile Edge APP & Requirements Management
Mobile Edge APP Lifecycle Management
Mobile Edge Platform Manager
Mm6
Other Mobile Edge Host
Data Plane
Virtualization Infrastructure
Mp2
Mm7
Virtualization Infrastructure Manager
Mobile Edge Host
Mobile Edge Host Level
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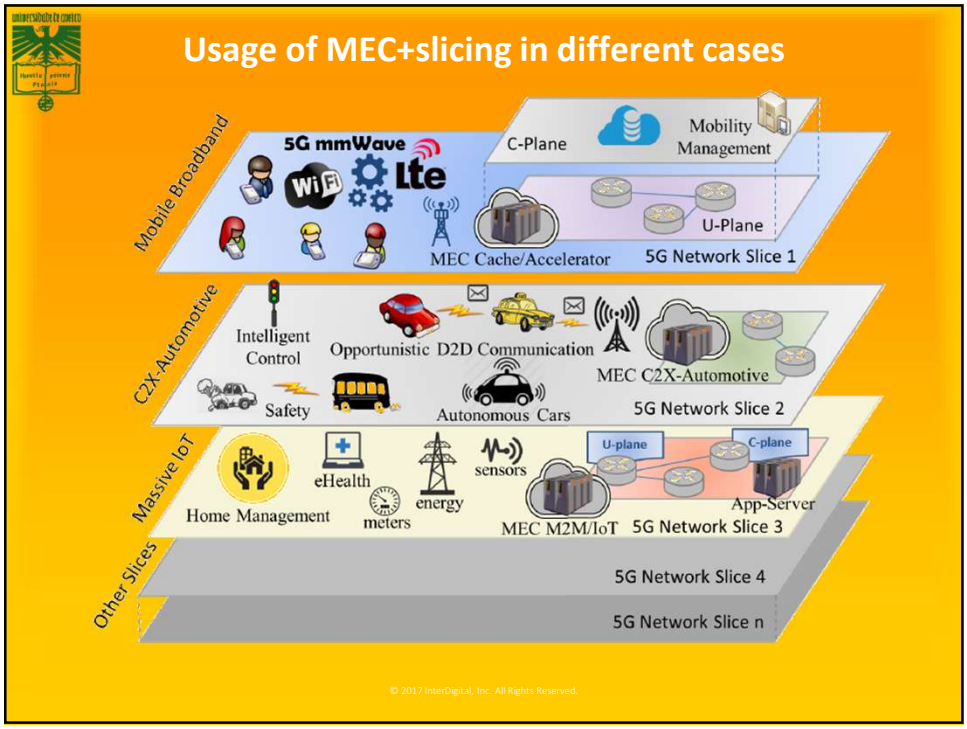
Usage of MEC+slicing in different cases
Mobile Broadband
5G mmWave
Wi Fi
lte
C-Plane
Mobility Management
U-Plane
MEC Cache/Accelerator
5G Network Slice 1
C2X-Automotive
Intelligent Control
Opportunistic D2D Communication
MEC C2X-Automotive
Safety
Autonomous Cars
5G Network Slice 2
Massive IoT
Home Management
eHealth
meters
energy
sensors
U-plane
C-plane
App-Server
MEC M2M/IoT
5G Network Slice 3
Other Slices
5G Network Slice 4
5G Network Slice n
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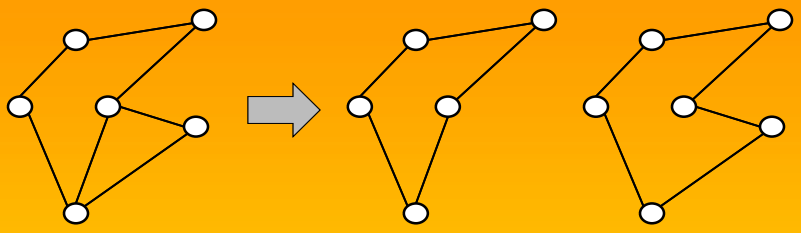
Network virtualization

- Making a physical network appear as multiple logical ones



- Network virtualization is tightly coupled with software defined capabilities (such as SDN and SDR)

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Change is needed for this world…

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