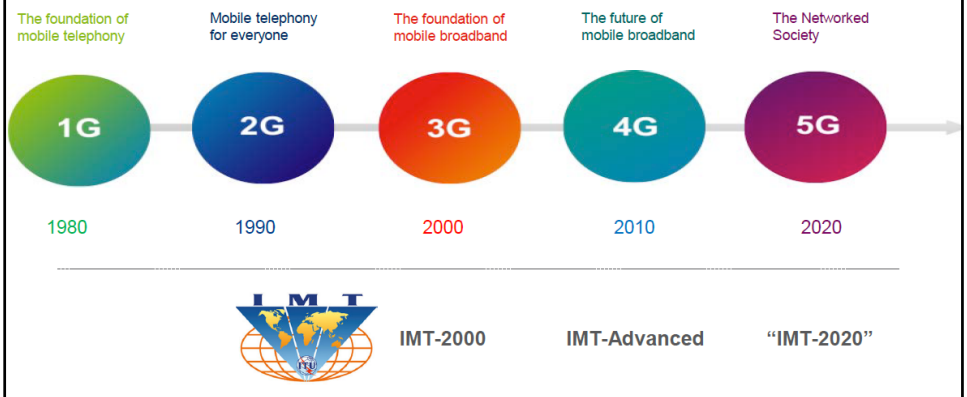
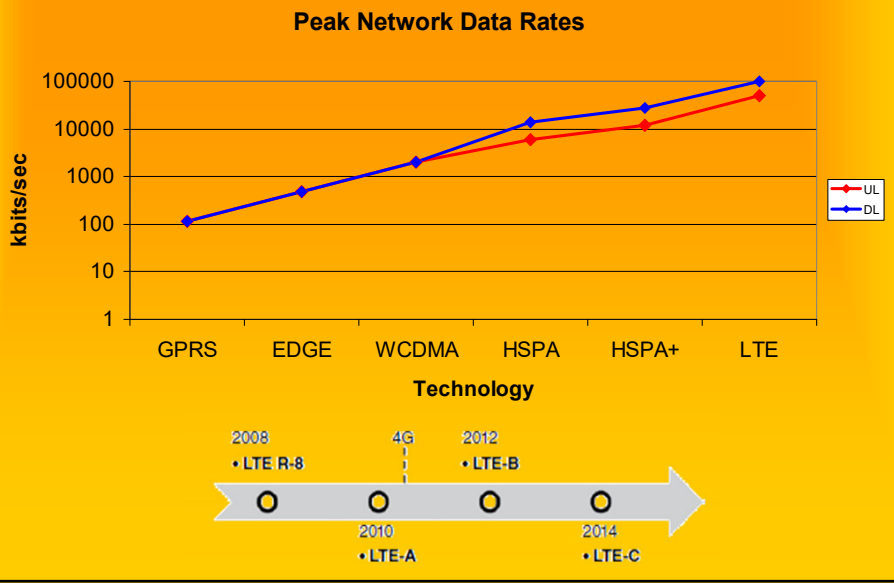
4G: Long-Term Evolution

wireless access generations

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



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**

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

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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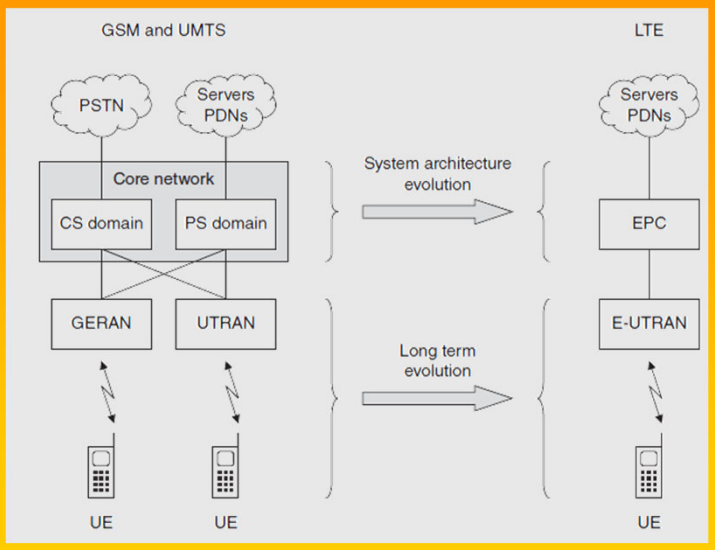
Network simplification



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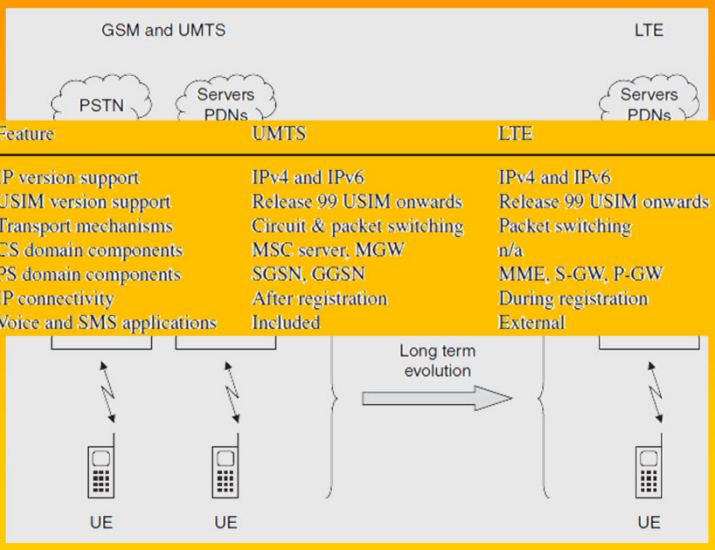
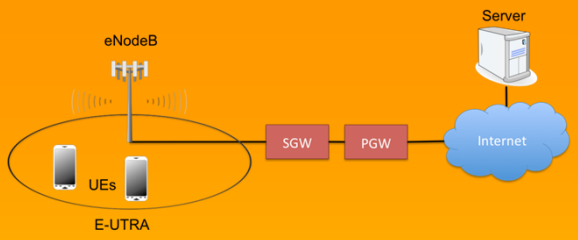
Network simplification



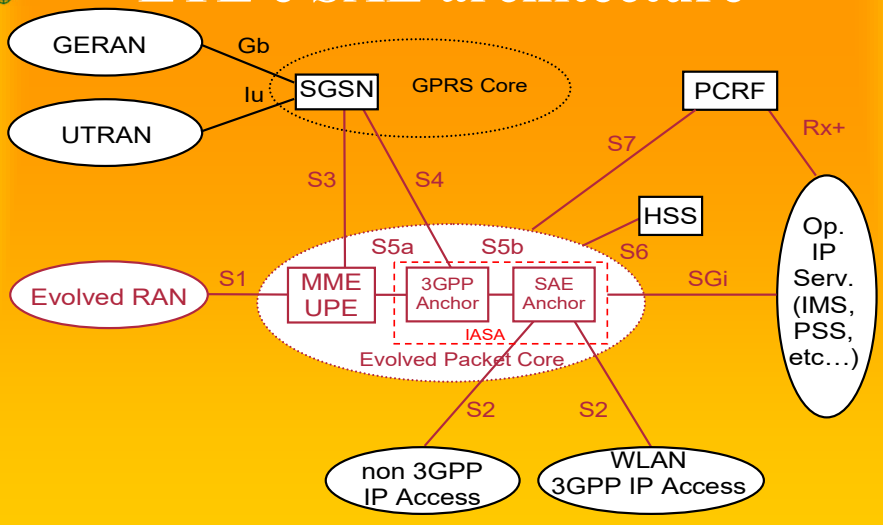
Feature	UMTS	LTE
IP version support	IPv4 and IPv6	IPv4 and IPv6
USIM version support	Release 99 USIM onwards	Release 99 USIM onwards
Transport mechanisms	Circuit & packet switching	Packet switching
CS domain components	MSC server, MGW	n/a
PS domain components	SGSN, GGSN	MME, S-GW, P-GW
IP connectivity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

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**

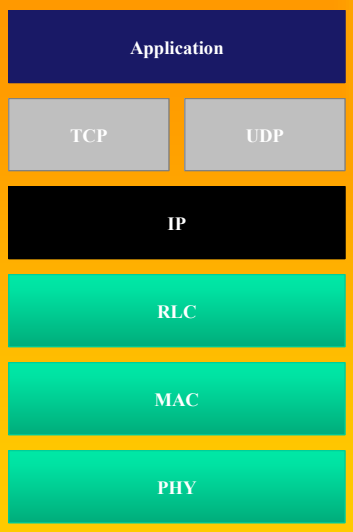
LTE e SAE architecture



* Color coding: red indicates new functional element / interface

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

Radio evolution

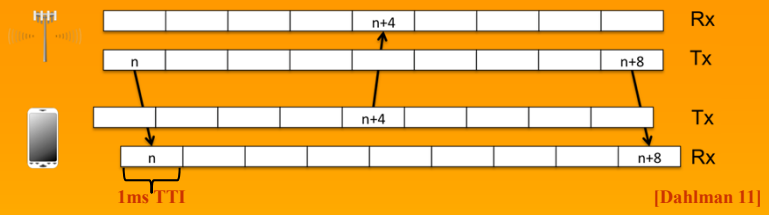
More flexible and resilient radio technology

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

LTE Retransmissions: MAC



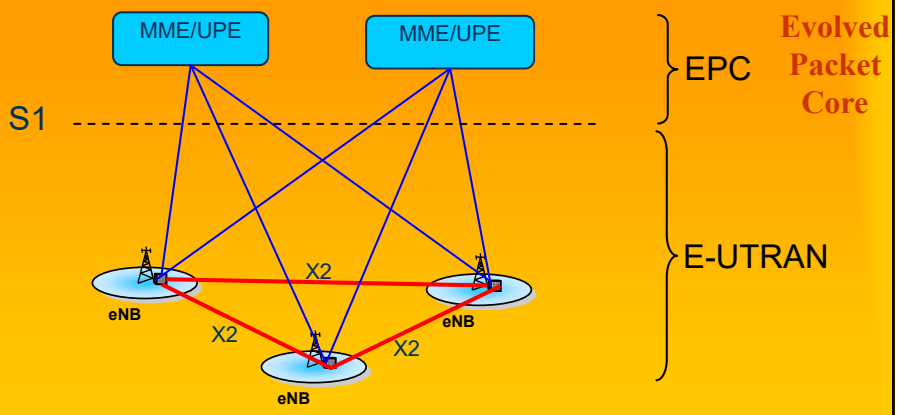
[Dahlman 11]

- Hybrid Automatic Request Reply (HARQ)
- Data sent at time n, arrives at time n
- 3ms taken to check if data arrived with errors
- n+4 ACK/NACK sent back
- n+8 if NACK, data can be retransmitted
  - Up to 3 retransmissions for downlink traffic

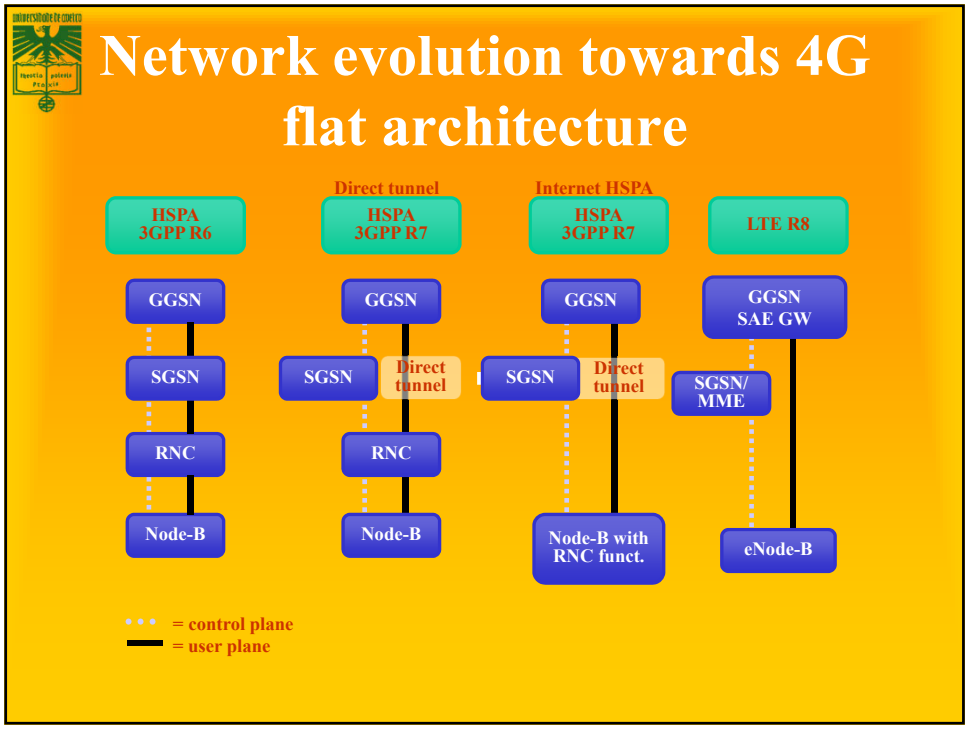
3GPP System Architecture Evolution (SAE) philosophy

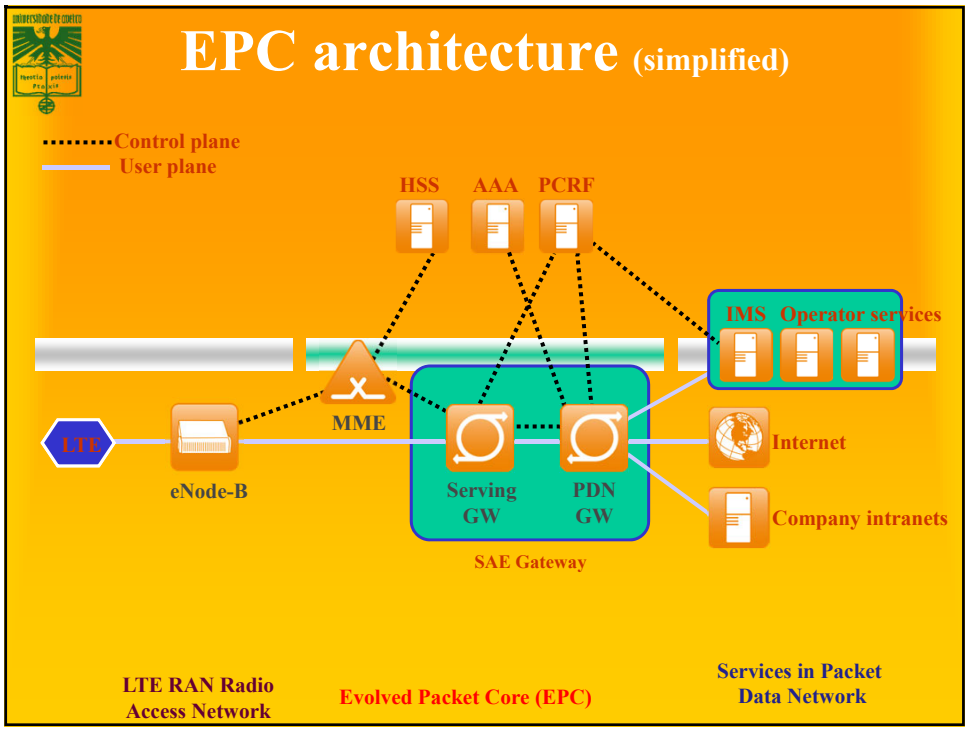
- **SAE focus is on:**
  - **enhancement of Packet Switched technology to cope with rapid growth in IP traffic**
    - higher data rates
    - lower latency
    - packet optimised system
  - **through**
    - fully IP network
      - In addition to IMS services available in the current system, equivalent 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

LTE Architecture: mobility



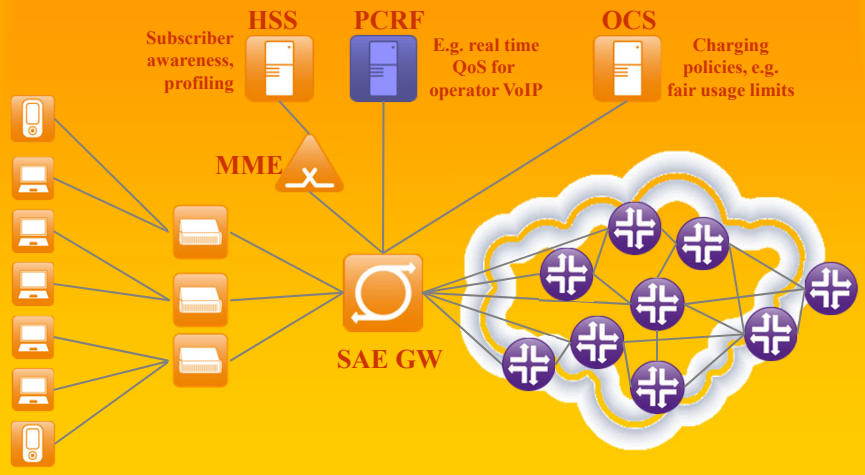
MME/UPE = Mobility Management Entity/User Plane Entity
eNB = eNodeB


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


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

Gateway role as policy enforcement point

- SAE Gateway holds a central position in the user plane – an aggregation point that cannot be bypassed



Quality of Service in LTE

- Substantially optimized bearer handling compared to 3G networks
- Reduced QoS parameter set for reduced implementation complexity compared to 3G
- Network centric QoS scheme reduces the complexity of terminal implementations

3G QoS relies on QoS aware terminals - terminal requests QoS level that is appropriate for the application:

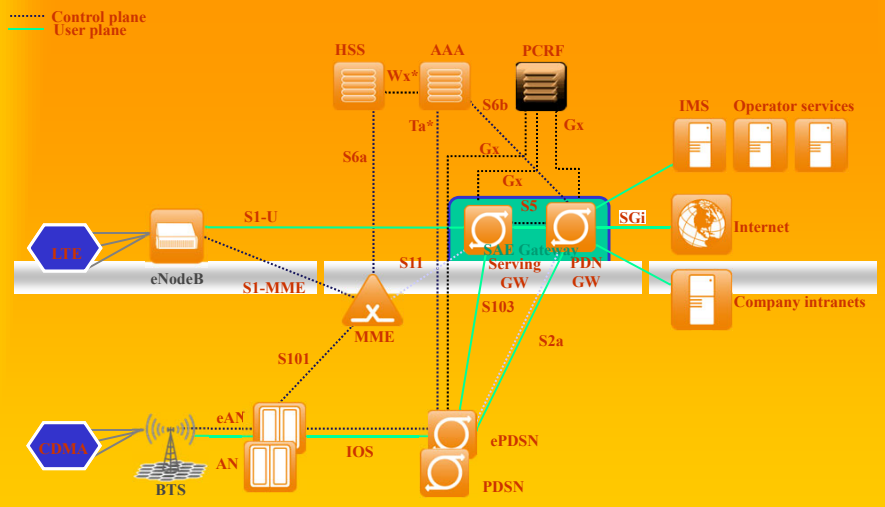
- Residual BER
- SDU error ratio
- Delivery of erroneous SDUs
- Maximum SDU size
- Delivery order
- Transfer delay
- ARP
- Traffic class
- THP
- Maximum bitrate UL/DL
- GBR (EL/DL)

LTE applies Network Centric QoS with a reduced set of parameters:

- Label
- Bearer type (Guaranteed or non-guaranteed Bit Rate)
- Packet Delay
- Packet Loss
- Guaranteed Bit Rate (uplink/downlink)
- Maximum Bit Rate (uplink/downlink)
- Allocation/Retention Priority (connection setup priority among subscribers when the network is congested)

Packet Core Evolution

LTE Network Architecture – CDMA



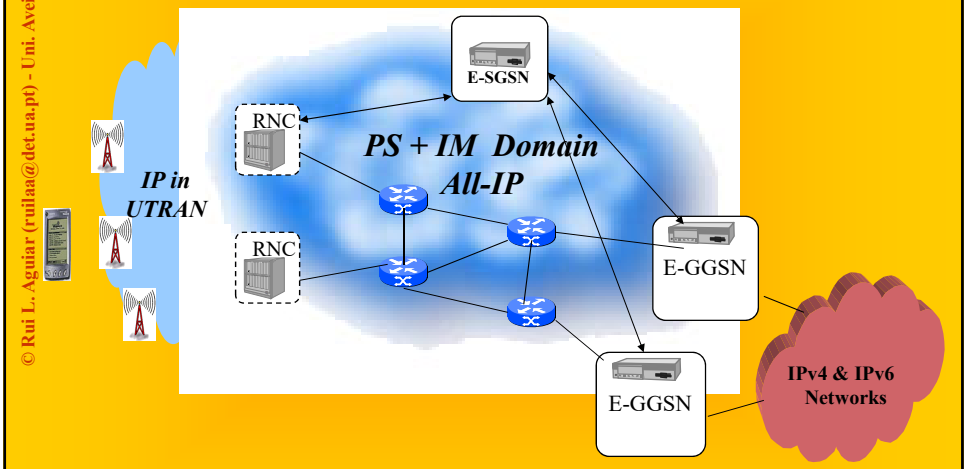
LTE-Advanced

- **Ambitions:**
  - **Greater (radio) flexibility**
    - Improved spectrum aggregation (*WiMax-alike*)
  - **Greater Bandwidths**
    - Better modulation schemes
  - **HetNets, and flexible deployment**
    - Coordinated n-cell deployments (n=macro, pico, femto, WiFi, relays)
  - **Improved Fairness**
    - Better interference management at cell edges
  - **Move into hyper-dense networks**
    - Hundreds of cells per Km2

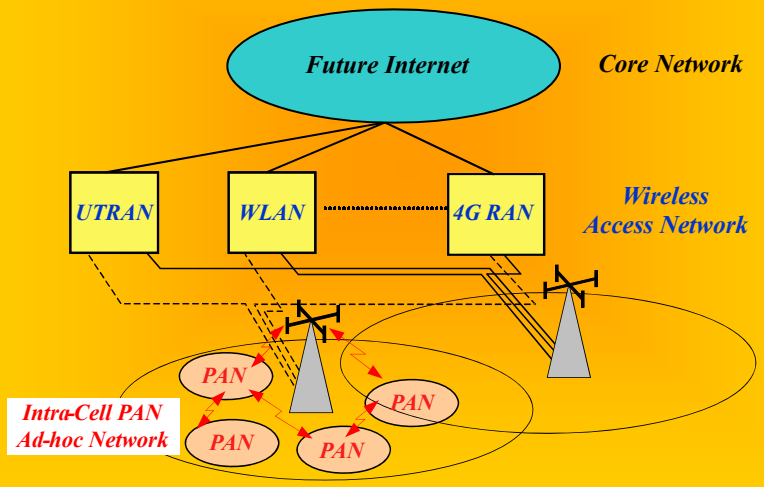
Evolution Driver:

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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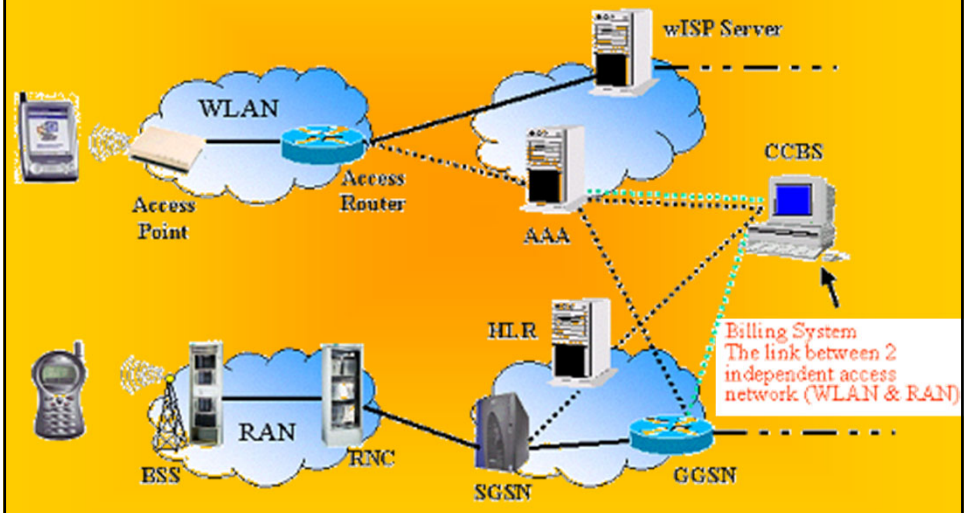
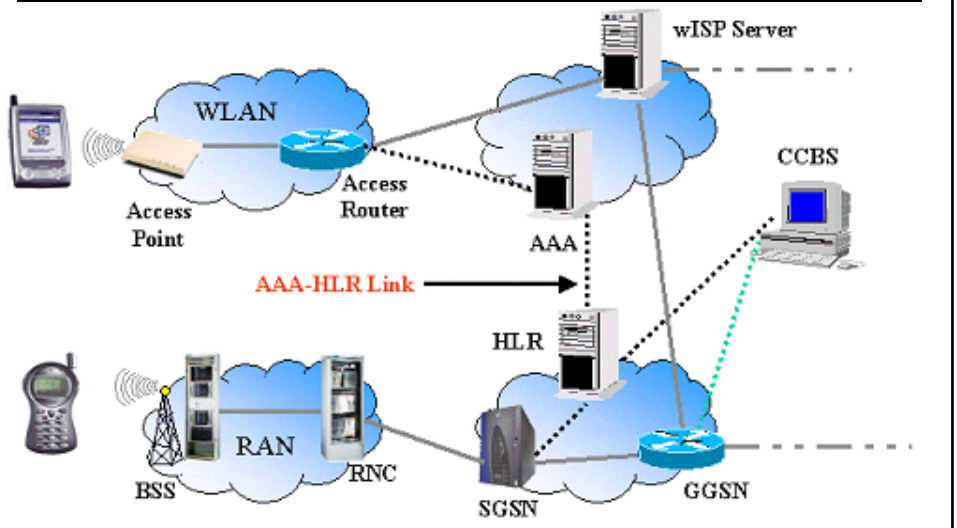
Coupling Options (WLAN/UMTS)

- **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

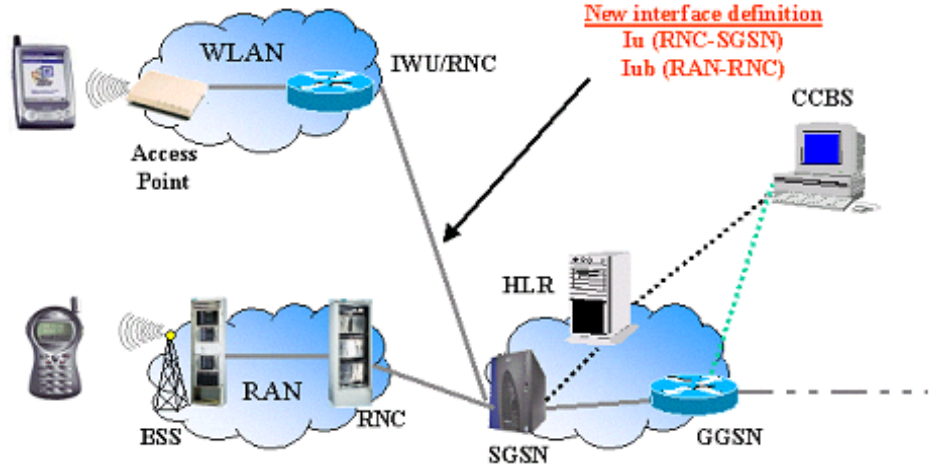
Open Coupling



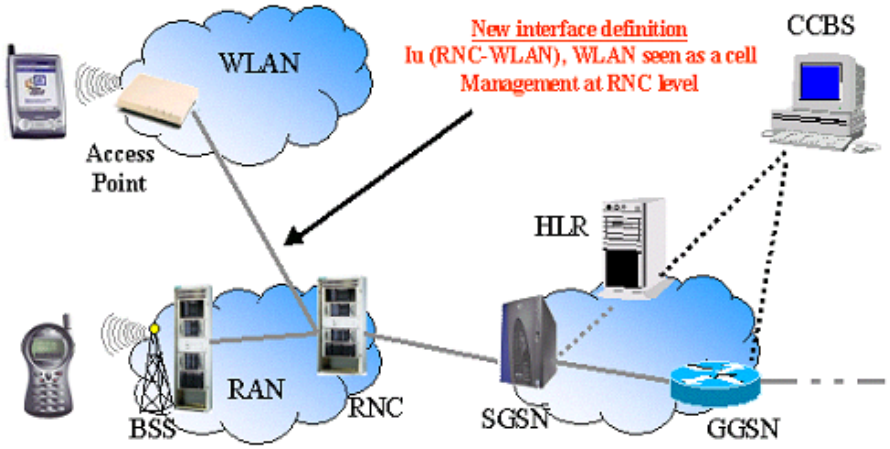
Loose Coupling



Tight Coupling



Very tight Coupling



5G – HOW IT CAME TO BE

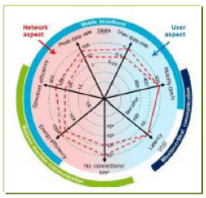
wireless access generations

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

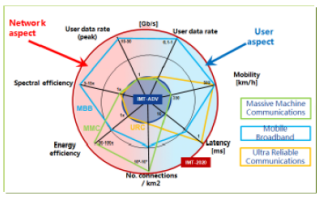
1G	2G	3G	4G	5G
The foundation of mobile telephony	Mobile telephony for everyone	The foundation of mobile broadband	The future of mobile broadband	The Networked Society
1980	1990	2000	2010	2020

IMT-2000 IMT-Advanced "IMT-2020"

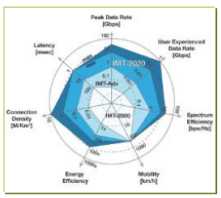
How to Illustrate "Imt-2020" key capabilities – WP5D CG activity ongoing



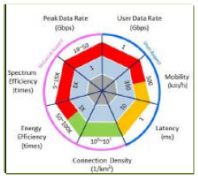
Vodafone/UK



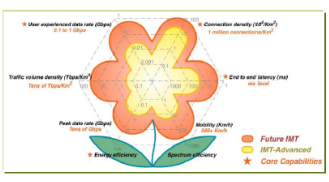
Nokia



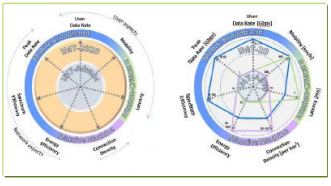
Samsung/Korea



ITRI



China



Ericsson

Socio-technical evolution requirements for beyond 2020

Broadband Internet connectivity widely available

Need for a strong limit on energy dissipation and CO_2 footprint per capita

More context-related information (e.g. augmented reality)

Increased amount of remote virtual collaboration

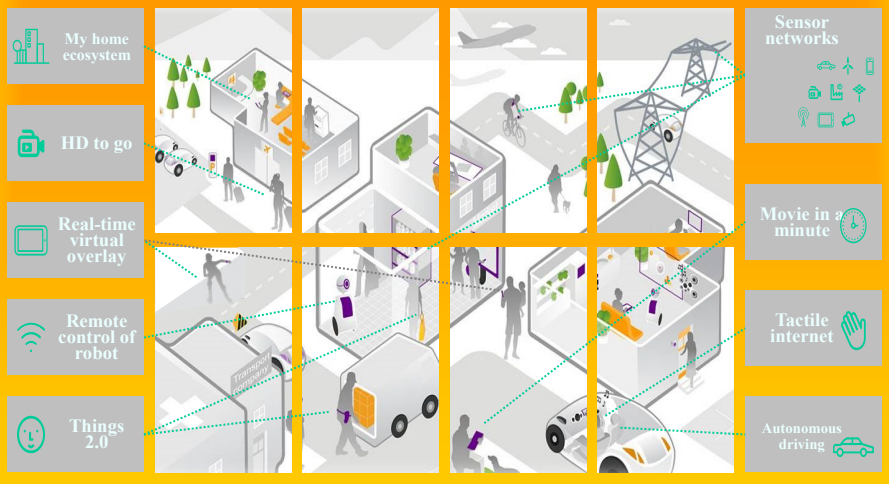
Increasing average age and higher importance of health care

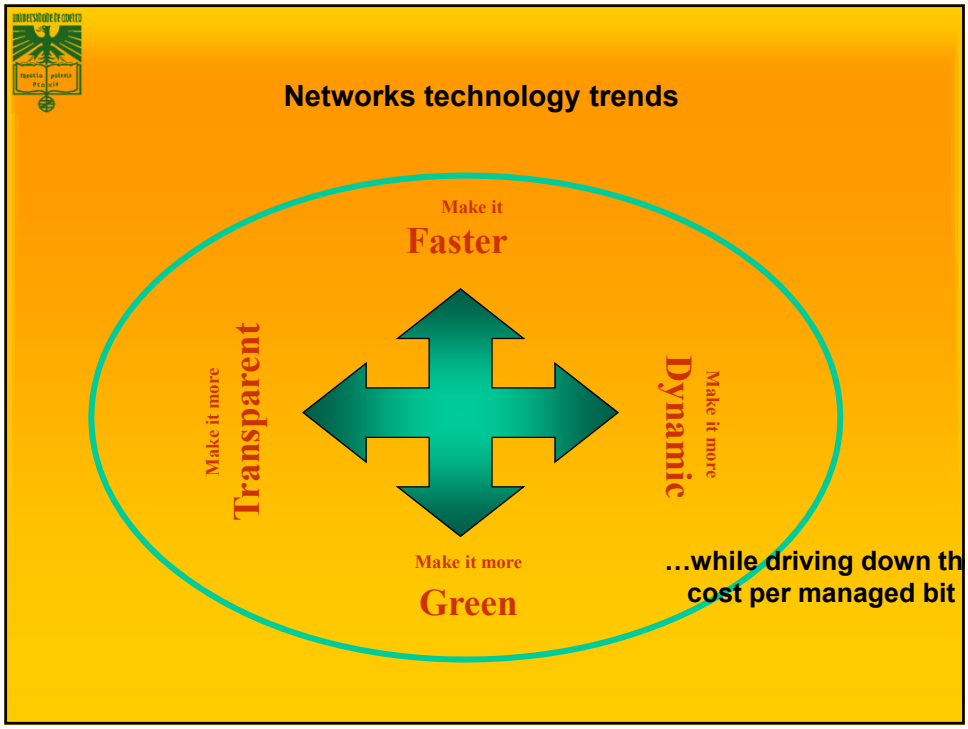
Need for more efficient and safer transportation means

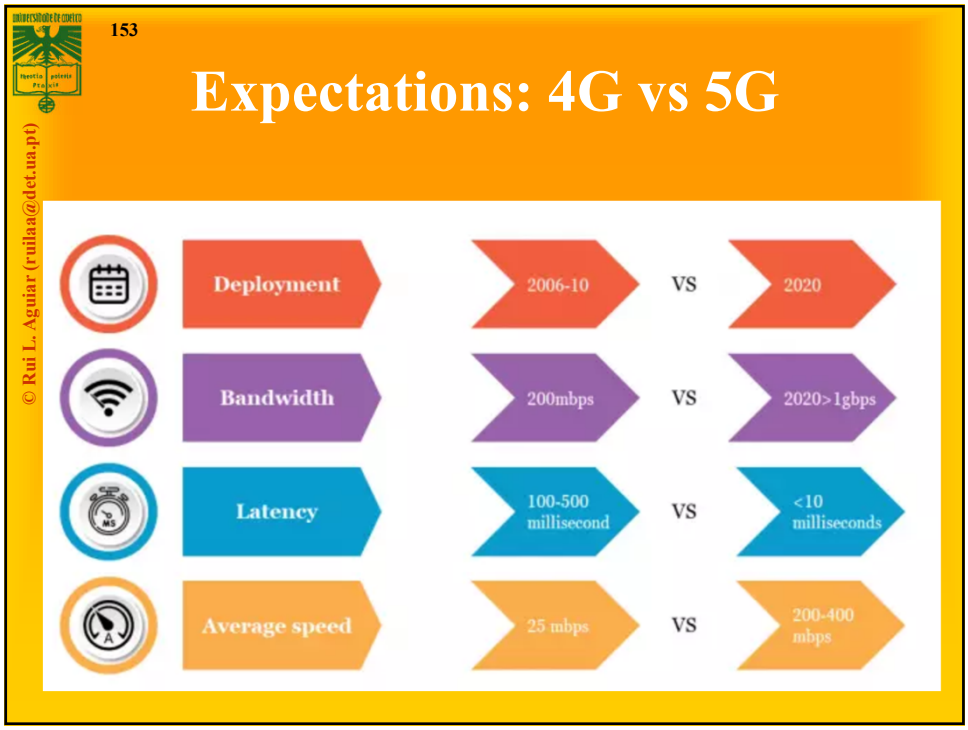
Personal data stored in the cloud and transmitted over wireless channels

'Internet of things': Smart Homes, Smart Cites, Smart Society

The 2020+ experience




Networks technology trends
Make it
Faster
Make it more
Transparent
Make it more
Dynamic
Make it more
Green
…while driving down th
cost per managed bit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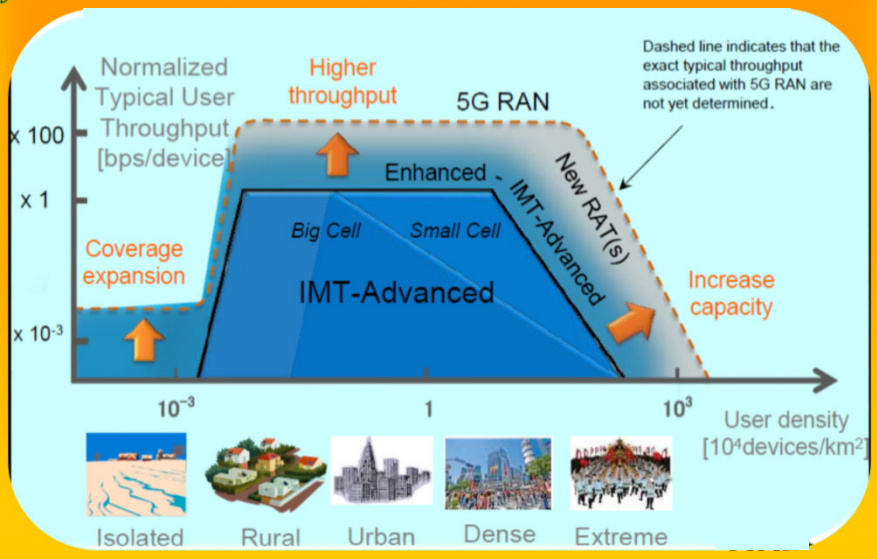
Expectations: 4G vs 5G
© Rui L. Aguiar (ruilaa@det.ua.pt)
Deployment
2006-10
VS
2020
Bandwidth
200mbps
VS
2020>1gbps
Latency
100-500 millisecond
VS
<10 milliseconds
Average speed
25 mbps
VS
200-400 mbps

Overall framework for 5G



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*
Wi-Fi	*'best effort data'*
PAN	*'short range and low power'*

Ultra dense deployments

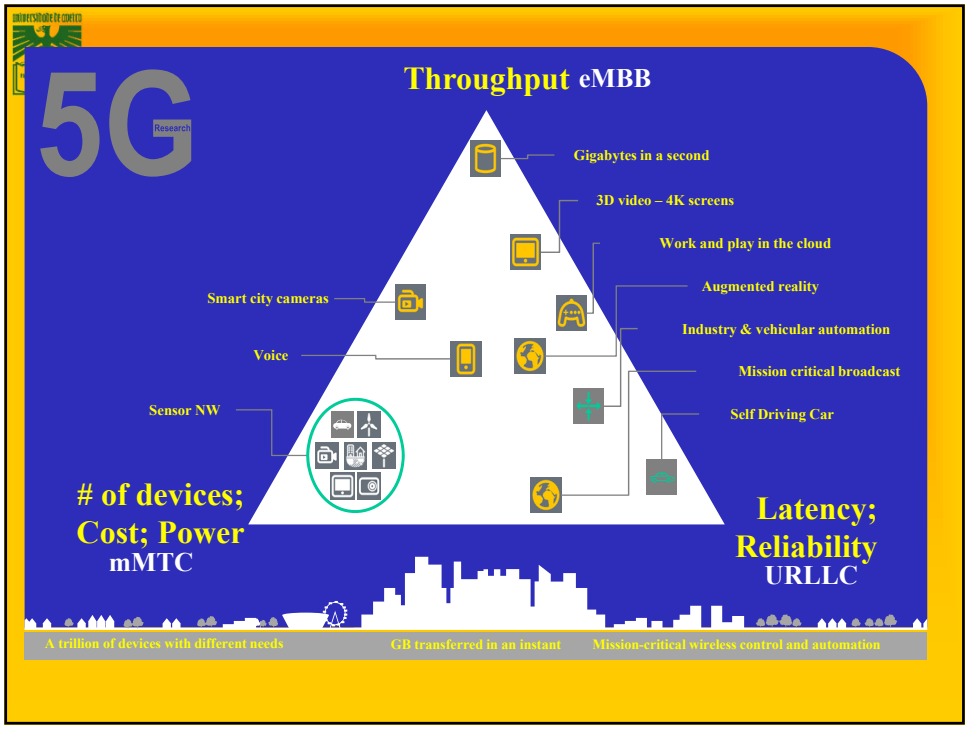
Zero latency and GB experience – when and where it matters

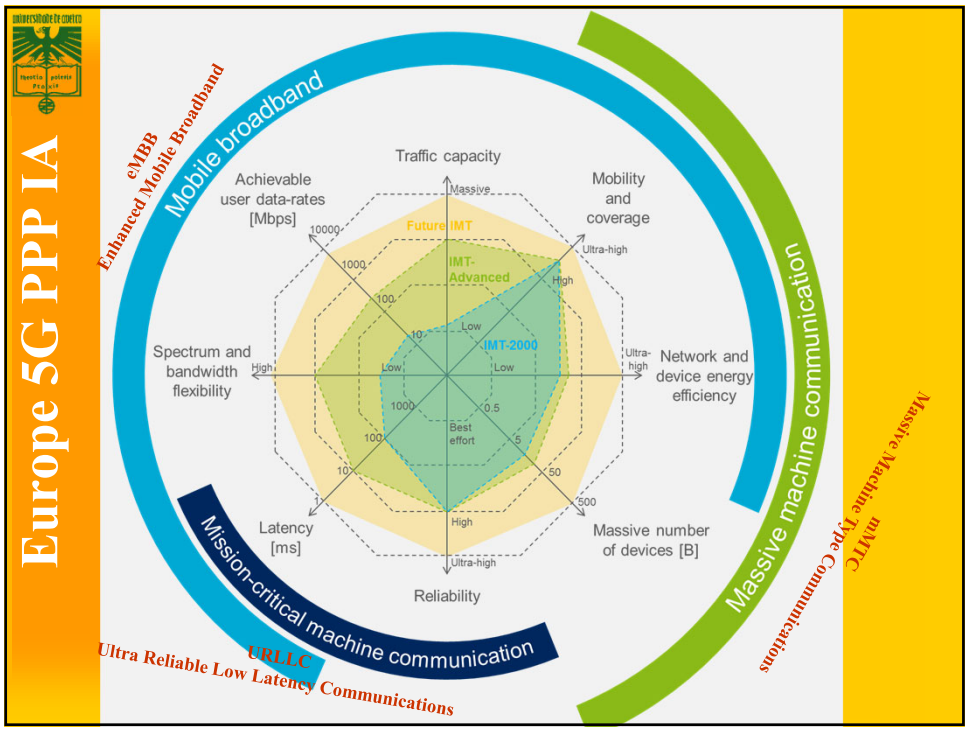
Architecture

5G Research

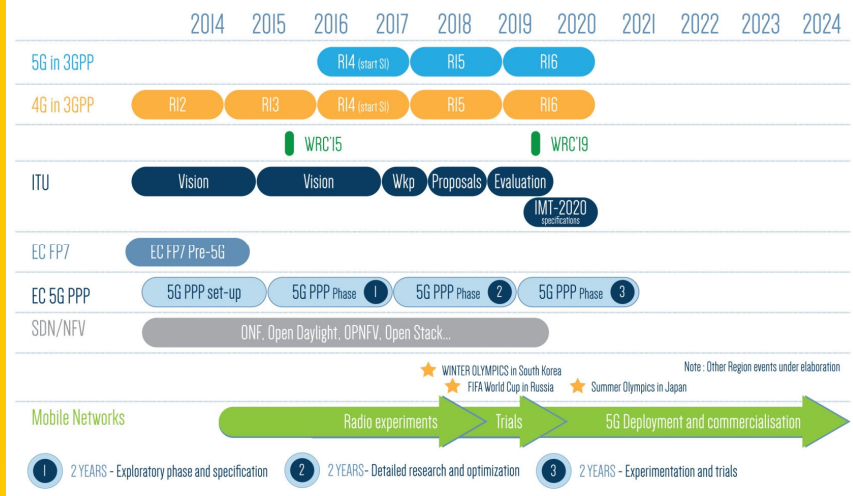
Integrated, harmonized and complementing each other

Source: Nokia.


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


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

5G PPP Vision and Requirements
5G roadmap



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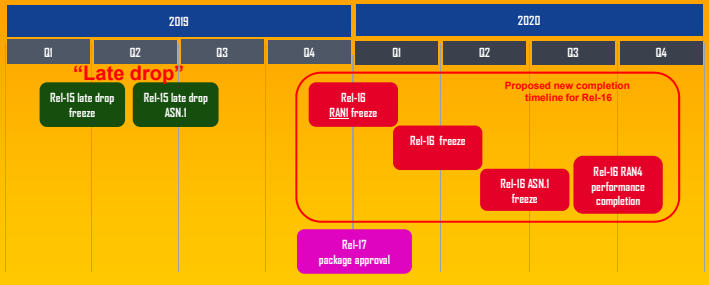
Source: 5G Infrastructure Association: Vision White Paper, February 2015.

Release 16 and 17 timeline

- RAN overall schedule to go back to the arrangement where RAN1 target completion is scheduled 3 months in advance of RAN2 completion and RAN4 core completion.
  - This ensures RAN1 stability for RAN2 protocol work and RAN4 requirements work to complete on time
- Rel-16 timeline is proposed to be aligned with the above scheduling
- Rel-17 package approval planned for December/2019



Road to comercial 5G

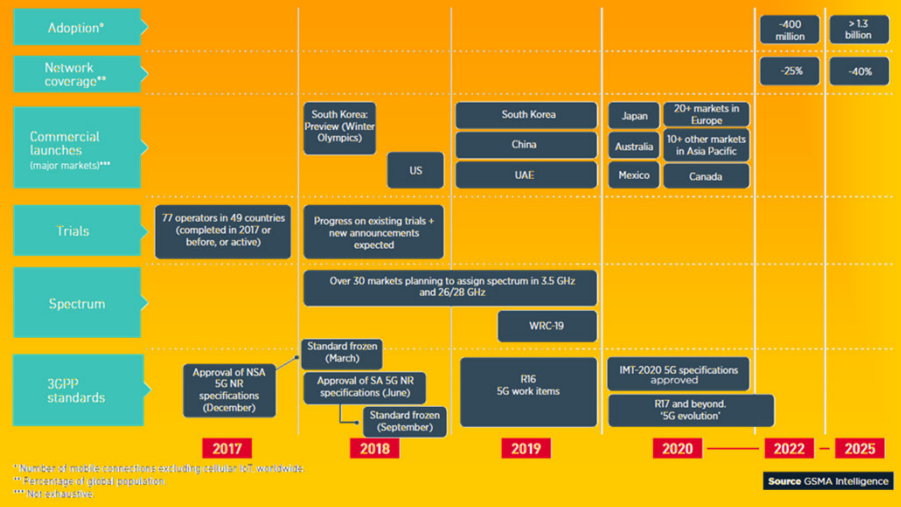


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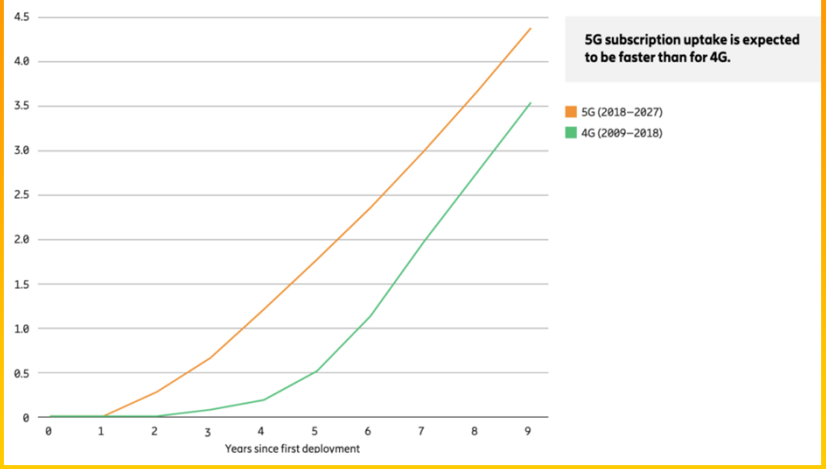
Figure 4: Comparison of 5G and 4G subscriptions uptake in the first years of deployment (billion)



5G introduction in Europe

Early 5G launch in selected areas

2018

Commercial launch of 5G services in at least one major city in all MS

2020

5G in all urban areas and along main transport paths

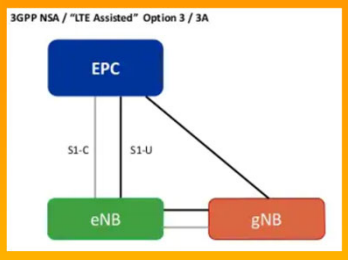
2025

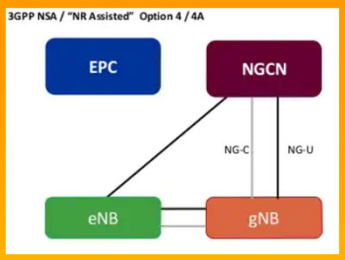
Consistent/quasi-simultaneous launch throughout single market

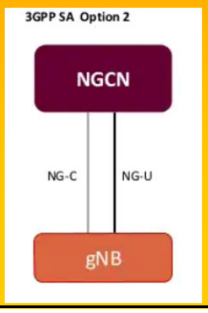
Roll-out with geographical and sectorial focus

Verticals "centre stage"

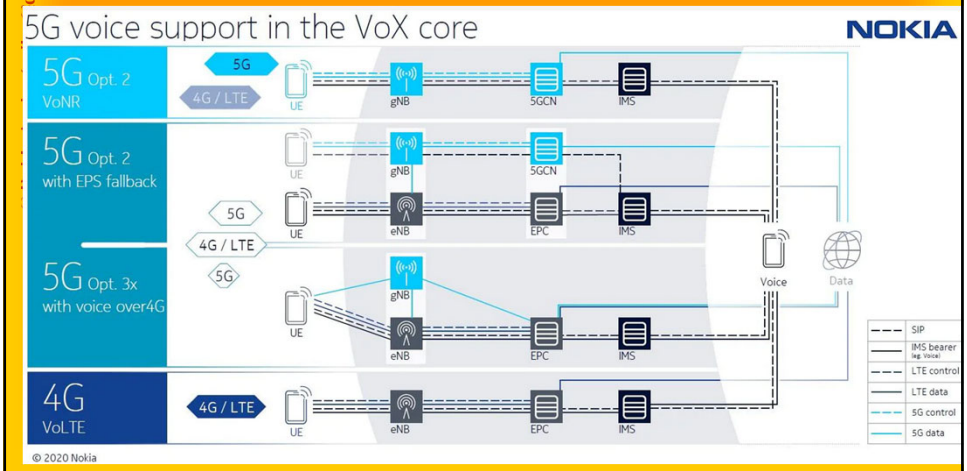
Implementation options





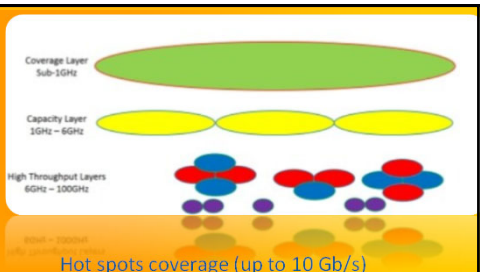


And voice?



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,

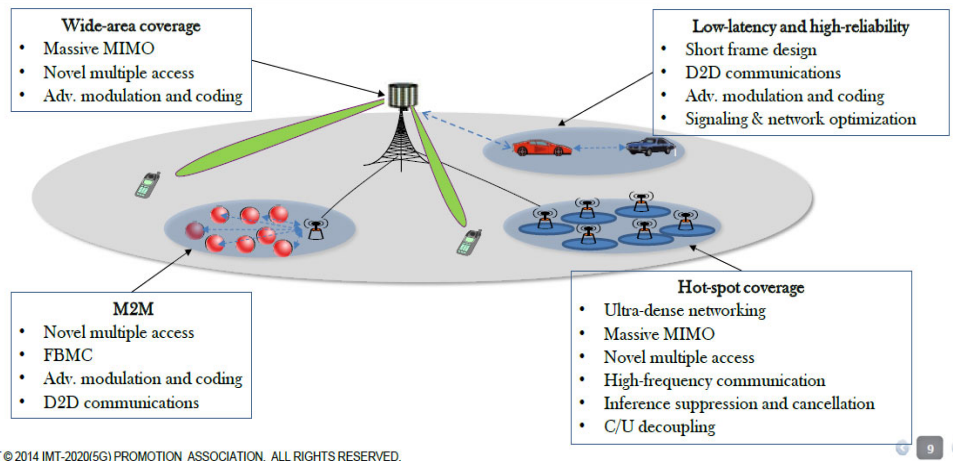
Urban mobile data speeds **3.6 GHz** — **Urban coverage with dense small cells (1-3 Gb/s) e.g. mobile Gb/s society, smart cities, option for connected highways**

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

Source: 5G-PPP

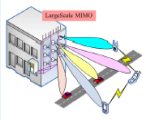
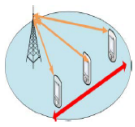
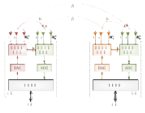
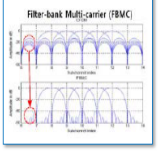
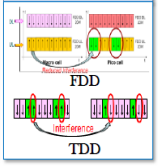
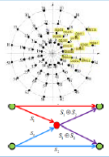
5G RAN Scenarios and Key Technologies

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.

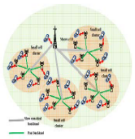
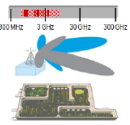


Key Wireless Technology Directions

Enabling wireless transmission technologies

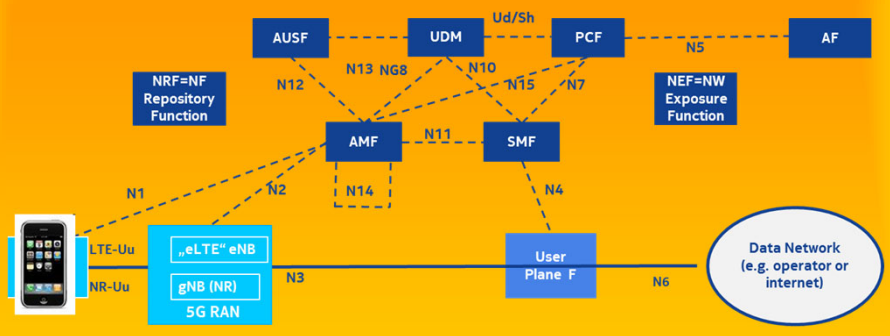
Massive MIMO + Beamforming	Novel Multiple Access	Full Duplex	FBMC	Flexible Duplex	Adv. Coding and Modulation
					

Key technical solutions

Ultra-dense networking	Low latency & high reliability	M2M	D2D	High frequency communications	Spectrum sharing
					

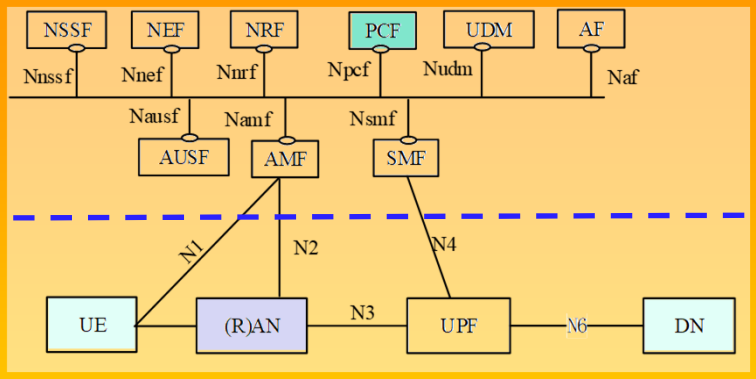
"5G Architecture"

- **References points….**



The (limited) 5G System architecture

(3GPP TS 23.501 Rel 15)



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

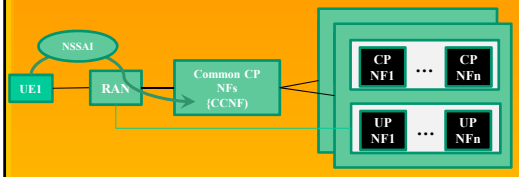
Expected Technology – trends besides radio layers

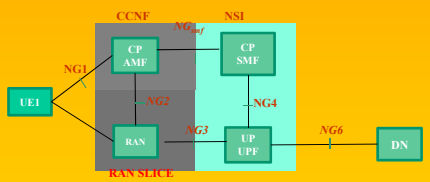
- Integration of different technologies (not only physical layer)
  - Following the current trends….
- Complex radio environment
  - CRAN, HCRAN, microcells, as now but device # explosion
- Separation between infrastructure, network, computation and service
  - Reconfigurable network and service provision (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)

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….)



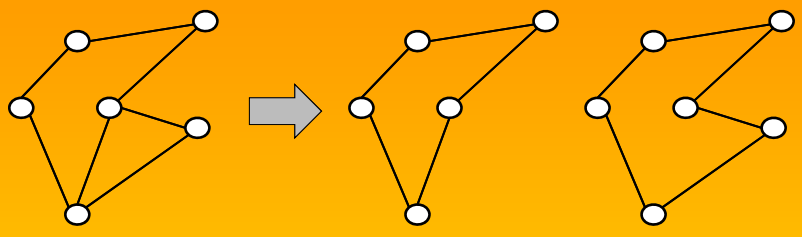


- Slices are selected based on NSSAI provided by the UE
  - RAN selects a CCNF (AMF/NSSF) based on the NSSAI
  - An NSSAI can generate multiple Network Slices
  - An AN can be common to all slices
  - The NSSAI includes at least: SST and SD
- CCNF Redirection can be done at RAN or CCNF
- SMF Selection 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).

Network virtualization

- Making a physical network appear as multiple logical ones



Physical Network | Virtualized Network - 1 | Virtualized Network - 2

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

6

Networks require (complex) infrastructure

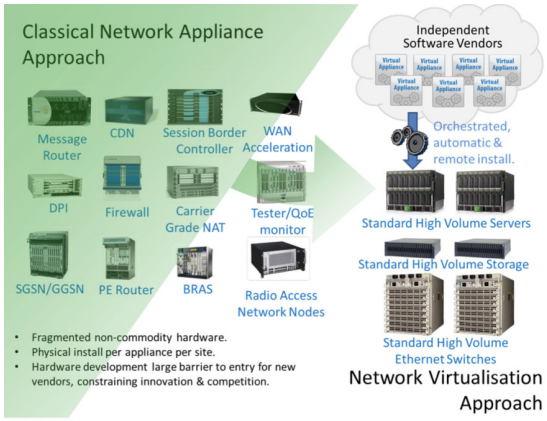
Well known figure …

–Current infrastructure.

- Current network equipment designed for special use case

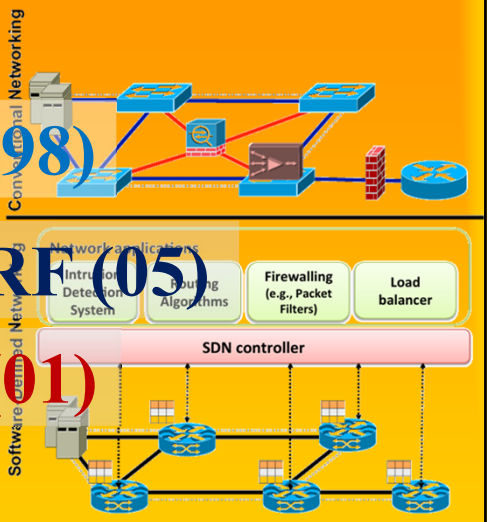
–Software Defined Networking and Network function Virtualization:

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



Software-Defined Networks

- Developed at Stanford in 2008
- Concept "new"
  - Although is hard to define what is the difference from previous telecom strategies.
- Decoupling data plane from control plane
- Overlay network



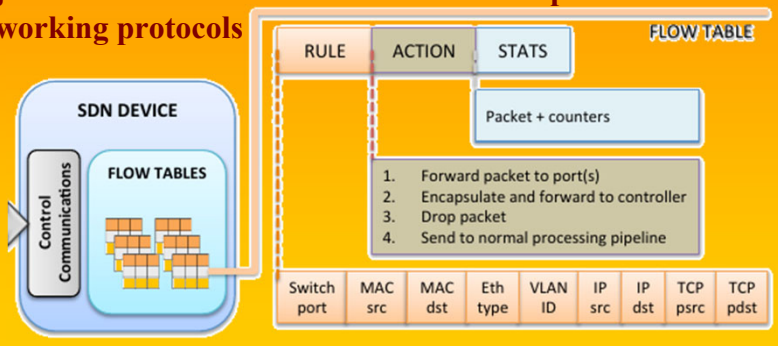
IETF COPS (98)

3GPP PCRF (05)

IETF Forces (01)

Software-Defined Network: OpenFlow

- **OpenFlow**
  - **Open-Source configuration and control protocol**
  - **Manufacturer-independent**
  - **Objective: enabler for researchers to develop new networking protocols**



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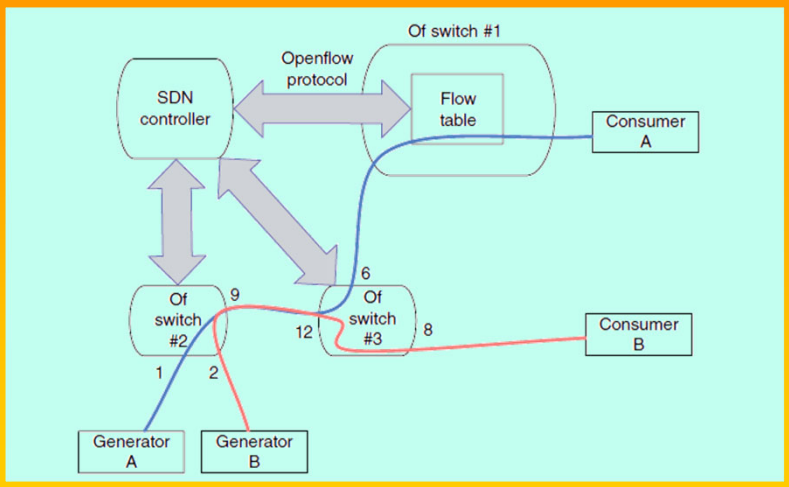
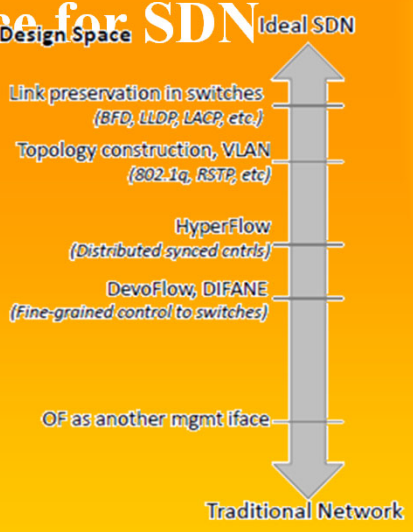
OpenFlow network operation



Design Space for SDN

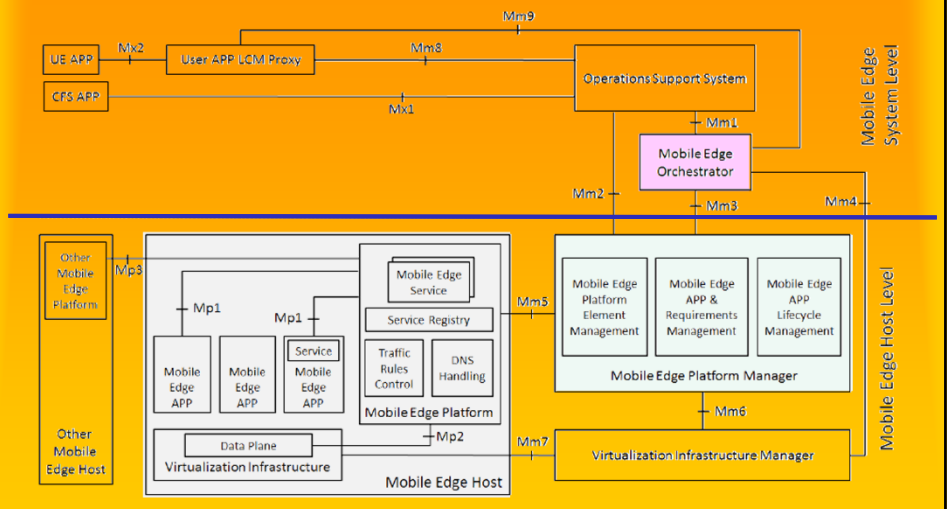
- **What have we found:**
  - **In reality: extremes will (do) not work**
  - **A trade-off will be required between Ideal SDN and network performance**
  - **Transition will be challenging:**
    - Green-field deployments (native) vs. Evolution (integration)
    - Operation of hybrid boxes (switches)



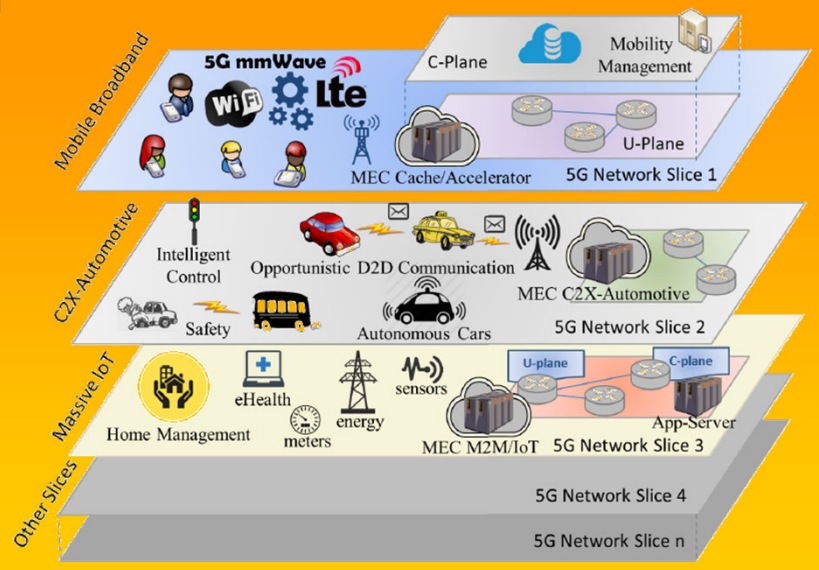
Observed Trends @Edge

- **Edge Solution appearing from needs coming new (5G) services**
  - **Low latency, 1000x throughput, traffic localization, …**
- **Possible by the usage of common converged Layer 2 transport infrastructure**
  - **Adoption of SDN principles with initial deployments**
  - **Work on L2-like overlays, such as BIER, SFC, …**
- **Adoption of SOA principles at the edge (3GPP SA2, ETSI MEC) brings:**
  - **Capacity at the edge through wider facility deployments**
    - Buildings ('MEC-enabled' rugged rack space) and street furniture (smart city initiatives)
    - Integration of other facilities like train, electricity, building management, …
  - **Capability to slice and dice resources through virtualization**
    - ETSI NFV MANO for orchestration of compute, storage and network resources

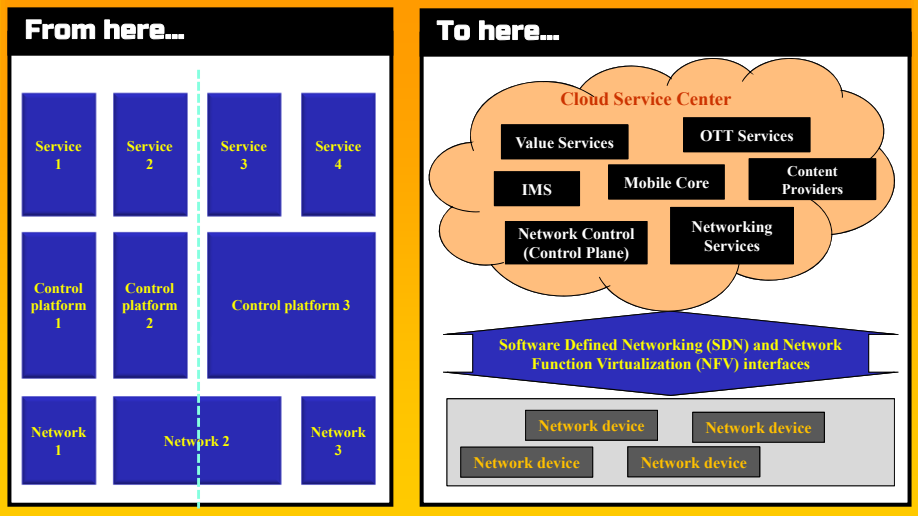
The (limited) ETSI view on MEC



Usage of MEC+slicing in different cases



Evolving complex infrastructure



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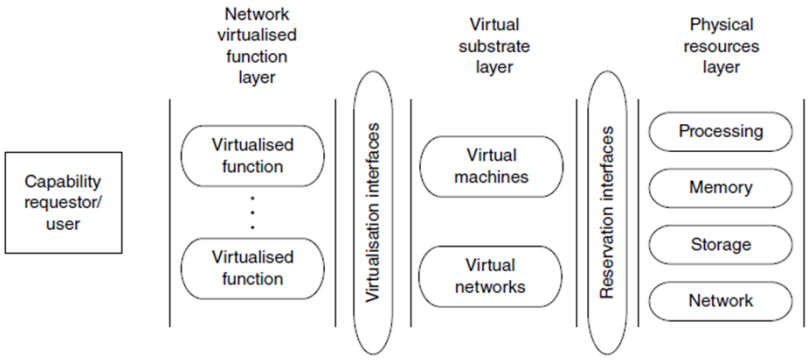
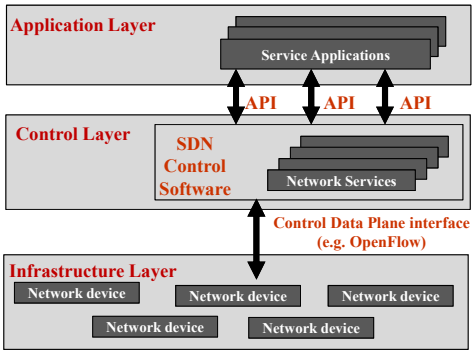
The NFV concept



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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In a reality that is …