Session 2

Wireless Broadband – Technology and Standards

Wireless Broadband Roadmap Development

ITU CENTRES OF EXCELLENCE NETWORK FOR ASIA PACIFIC REGION

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Objective of the presentation: Provide an overview of various technologies and standards driving wireless broadband including 3G, 4G and 5G (IMT 2000 and IMT 2020).

Present the challenges and disruptive technologies of 4G and 5G technologies.

Agenda

I. The evolving ICT environment
- A. Business pressure
- B. Technical pressure
- C. The challenges

II. 4G and 5G Technologies
- A. LTE and LTE-A basics
- B. Data rates
- C. E2E latency
- D. Capacity
- E. Energy
- F. Cost
- G. QoE

III. Conclusions

Agenda

I. The ICT evolving environment

Agenda

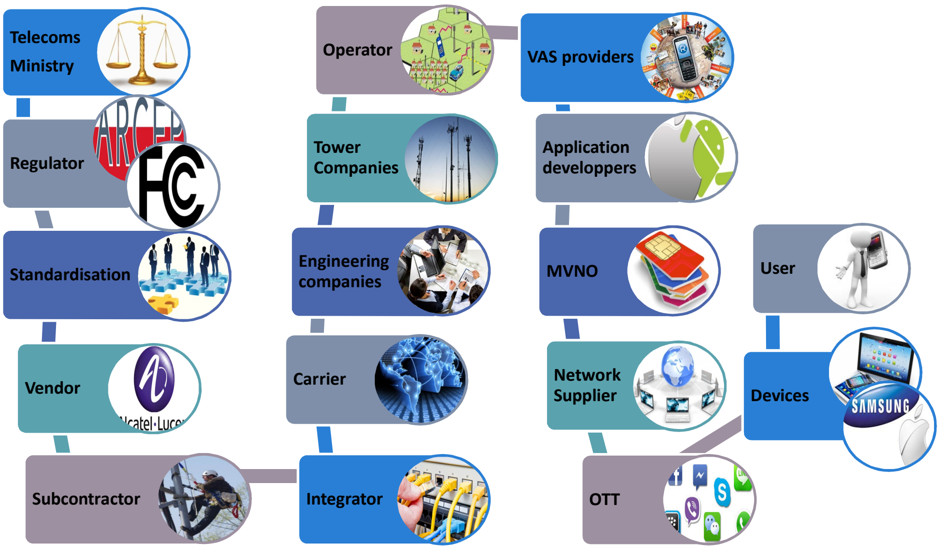
A. Business Pressure

Value chain evolution

In the 2000's

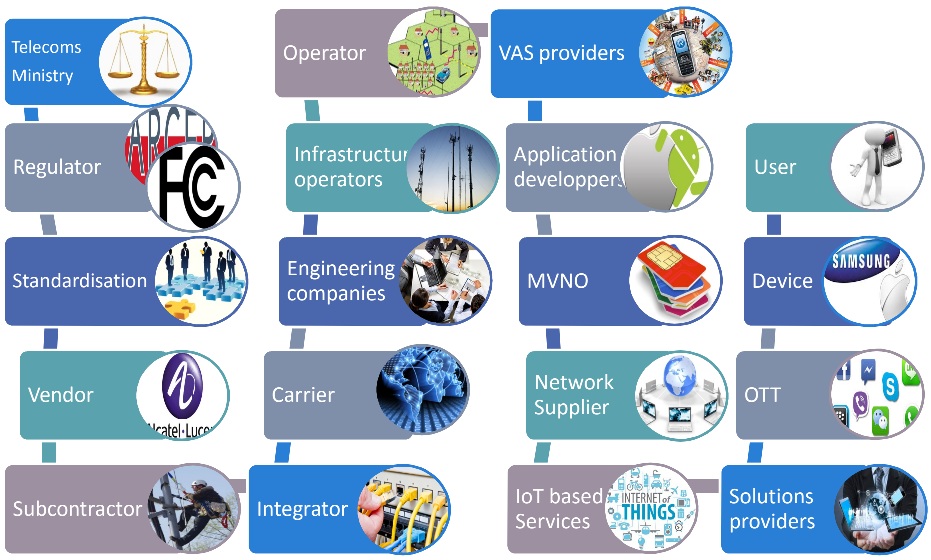
Value chain evolution

In 2015

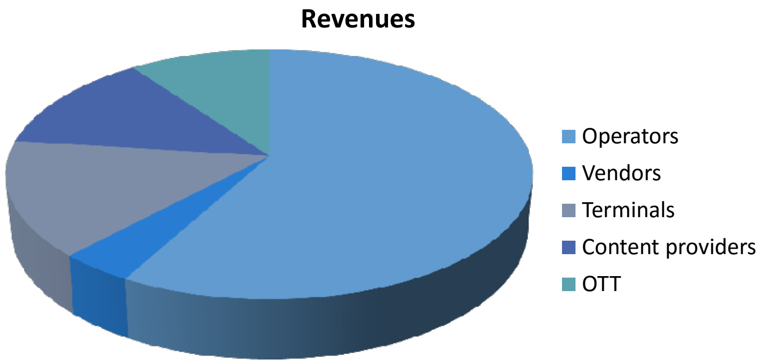


Value chain evolution

In 2020 (?)



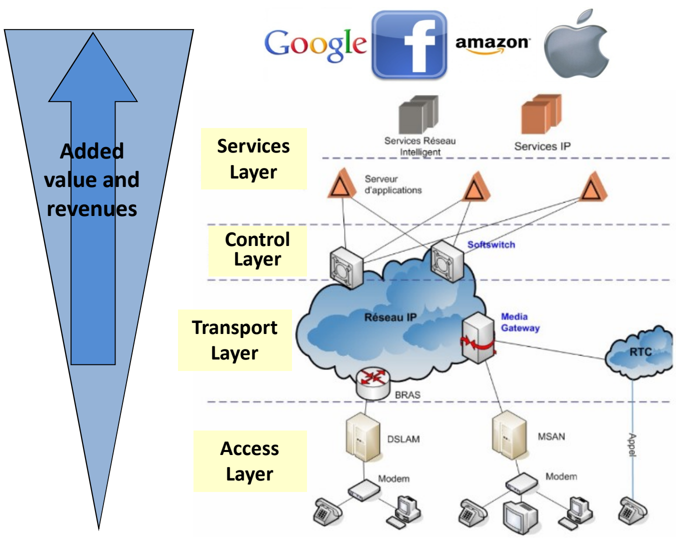
Shares of the stockholders in the value chain



Operators:	Orange, SFR, Bouygues Telecom, Iliad, Numericable
Vendors:	NSN, Cisco, ALU, E///, Huawei
Terminals:	Apple, Samsung, Nokia, LG, RIM
Content providers:	TF1, C+, M6, France Television, Radio France
OTT:	Google, FB, MS, Amazon, Yahoo!

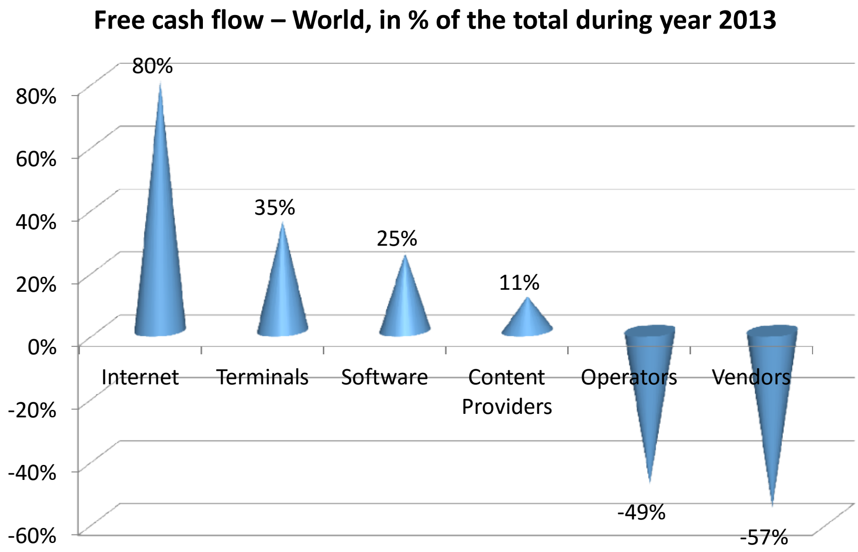
Business models changes

Revenues are taken by OTT players

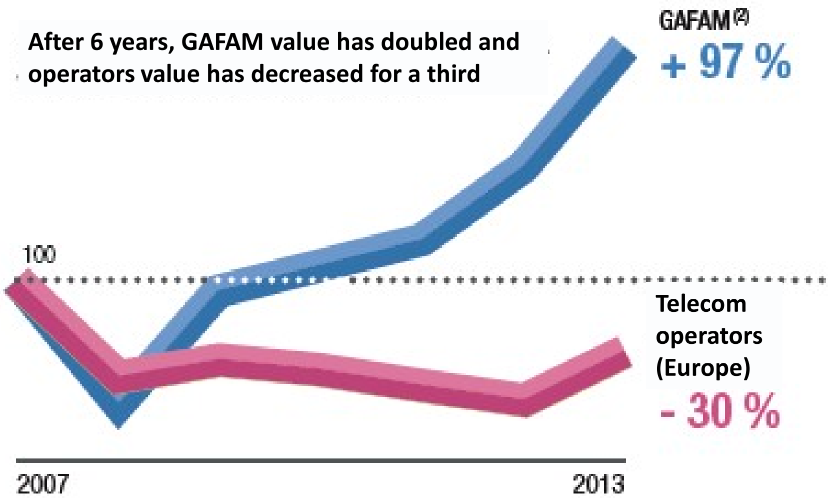


"OTT players are eating into operator revenues, and they benefit from operator investment at no cost to themselves". Wireless Intelligence 2013.

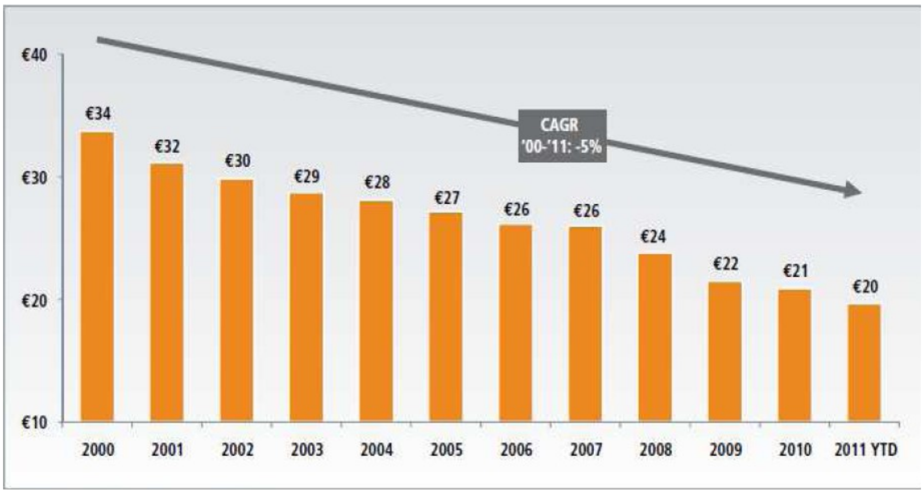
Evolution of the revenues and cash flow



FabFive value and evolution/operators value



Evolution of ARPU in Europe



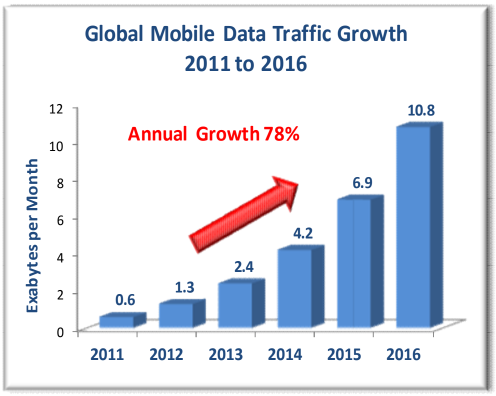
Source: Wireless Intelligence; EIU; A.T. Kearney analysis

Agenda

B. Technical Pressure

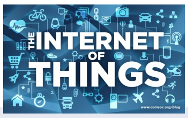
Traffic volume increase

- Global growth of mobile data traffic: **18 times** from 2011 to 2016
- ***AT&T network***:
  - 2007-2012: wireless data traffic has grown **20,000%**
  - At least **doubling** every year since 2007



Source: CISCO Visual Networking Index (VNI) Global Mobil Data Traffic Forecast 2011 to 2016

Connections numbers



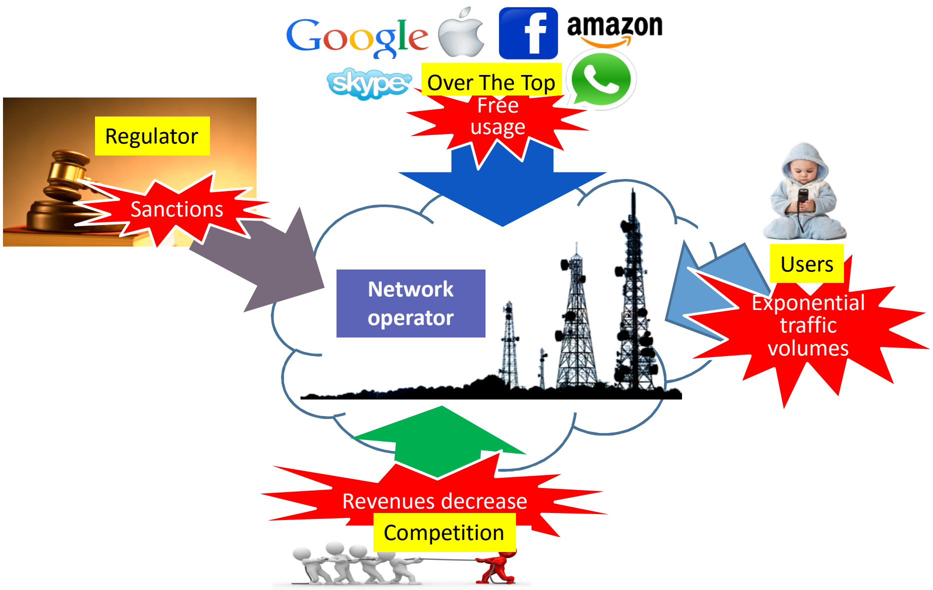
	2003	2010	2015	2020
World Population (Billion)	6.3	6.8	7.2	7.6
Connected Devices (Billion)	0.5	12.5	25	50
Connected Devices per Person	0.1	1.8	3.5	6.6

More Devices than People

3G → 4G → 5G

Source: Cisco

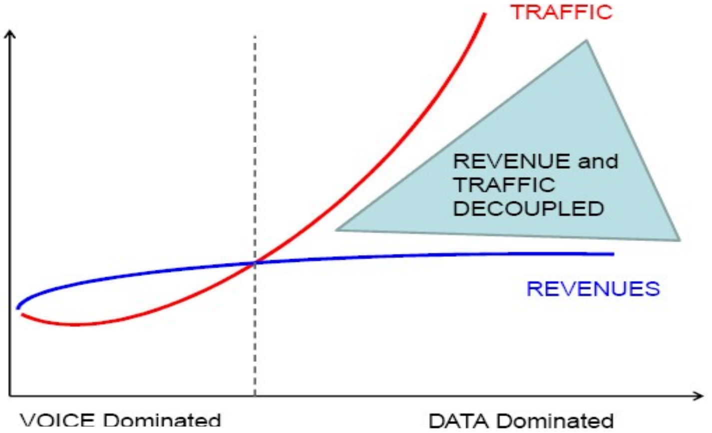
Operators under pressure



Agenda

C. Challenges

Traffic and revenues decoupled



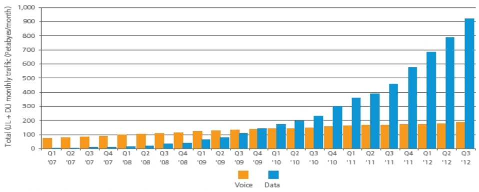
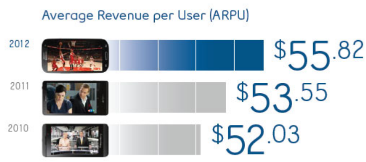
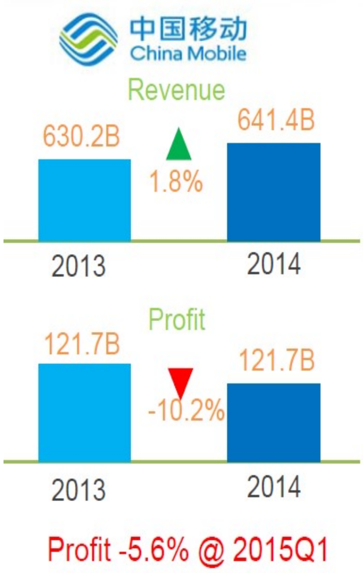


Figure 28: Total Monthly Mobile Voice and Data as Measured by Ericsson

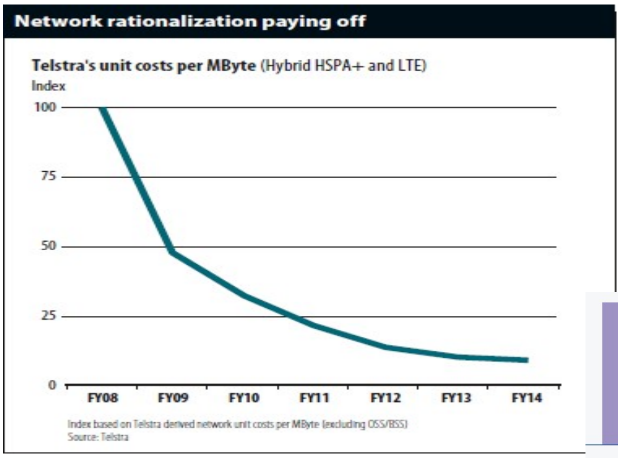


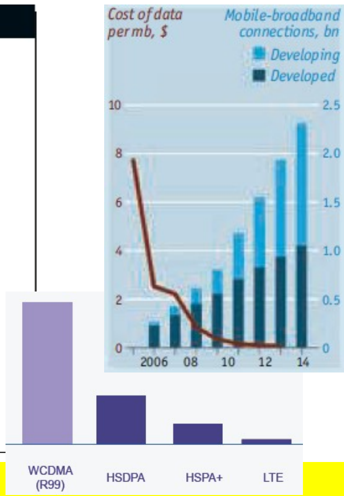
Flattened revenues for the operators



Company	Revenue 2013	Revenue 2014	Revenue IR	Profit 2013	Profit 2014	Profit IR
China Telecom (RMB)	321.6 B	324.4 B	0.90%	17.55 B	17.7 B	0.80%
China Unicom (RMB)	295.04 B	284.7 B	-3.50%	10.41 B	12.06 B	15.80%
DoCoMo (Yen)	4461.203 B	4383.397 B	-1.70%	464.729 B	410.093 B	-11.80%
SKT (WON)	16602 B	17164 B	3.40%	1610 B	1799 B	11.80%
AT&T (USD)	128.752 B	132.447 B	2.87%	18.553 B	6.518 B	-64.90%
Verizon (USD)	120.550 B	127.079 B	5.41%	11.497 B	9.625 B	-16.30%
DEUTSCHE TELEKOM (EURO)	60.1 B	60.7 B	1.00%	2.8 B	2.4 B	-14.30%
Telefónica (EURO)	45.1 B	50.377 B	11.70%	2.23 B	3.001 B	34.70%

Cost per Mbyte reduction with Telstra (Australia)





Bell Labs study results:

•1 GB of incremental capacity in ***a 2G/3G network*** costs about **USD 20-25**.

•Implementing ***LTE*** reduces this cost to about **USD 12-15** per GB.

•***Small cells*** can reduce costs to about **USD 9-11** per GB.

Transport cost per gigabyte

1990	$10,000
1995	$500
2000	$10
2005	$1
2010	$0.1

Technical needs to fulfill these requirements

- Main objective: "***Reduce the cost of bit/second carried by the network***"
- Efficiency
- Adaptability
- Simplicity
- Sharing
- Massive connectivity and capacity
- Energy efficient

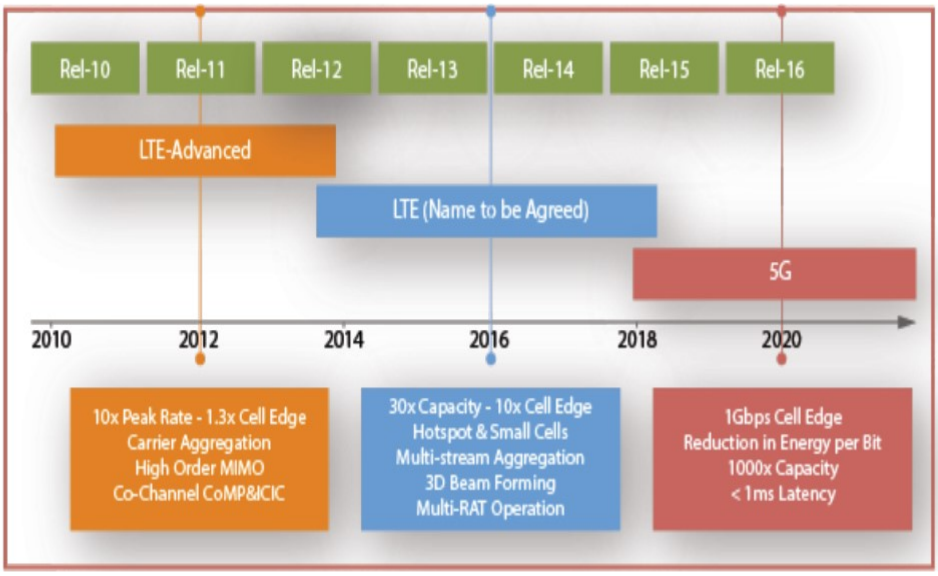
Gap analysis and recommendations (ITU SG13)

- Various bandwidth/data-rates demands
- Complex connectivity model
- Application-aware and distributed network architecture
- Signalling complexity in massive MTC
- Increasing service availability
- Signalling to reduce end-to-end complexity
- End-to-end network latency model
- Mobile network optimized softwarization architecture
- Data plane programmability
- End-to-end QoS framework
- Energy efficiency
- Enhancement of privacy and security
- Enhancement identity management
- Multi-RAT connectivity
- Fixed mobile convergence
- Flexible mobility
- Mobility management for distributed flat network
- End-to-end network management in a multi-domain environment
- OAM protocols

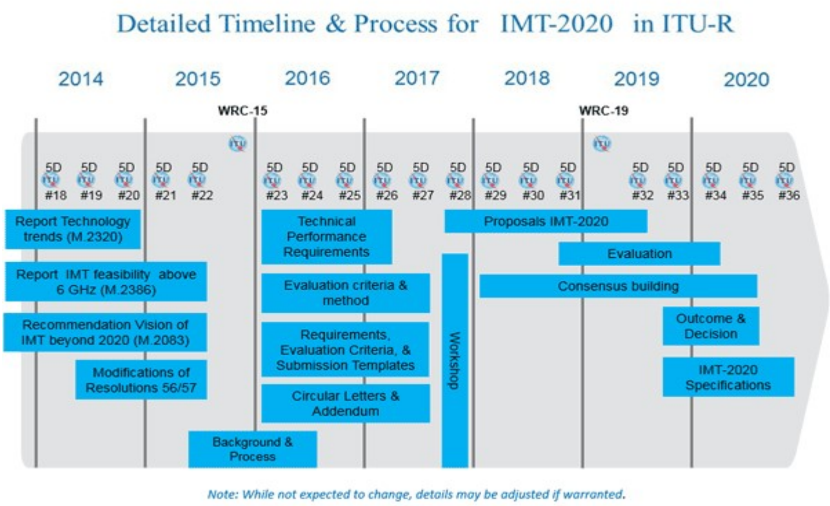
Agenda

II. 4G and 5G Technologies

5G and 3GPP Releases evolution



ITU-R WP5D

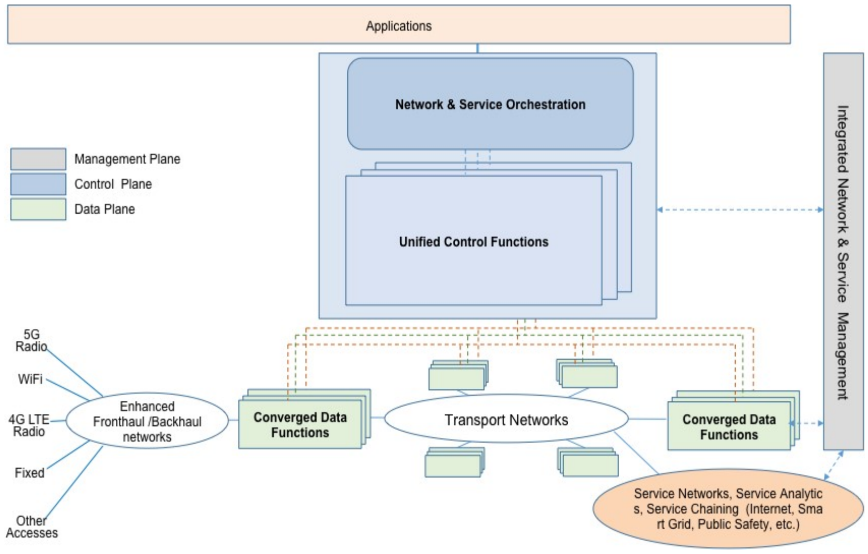


- Initial technology submission: Meeting 32 (**June 2019**)
- Detailed specification submission: Meeting 36 (**October 2020**)

5G Networks Fundamental RAN Technologies

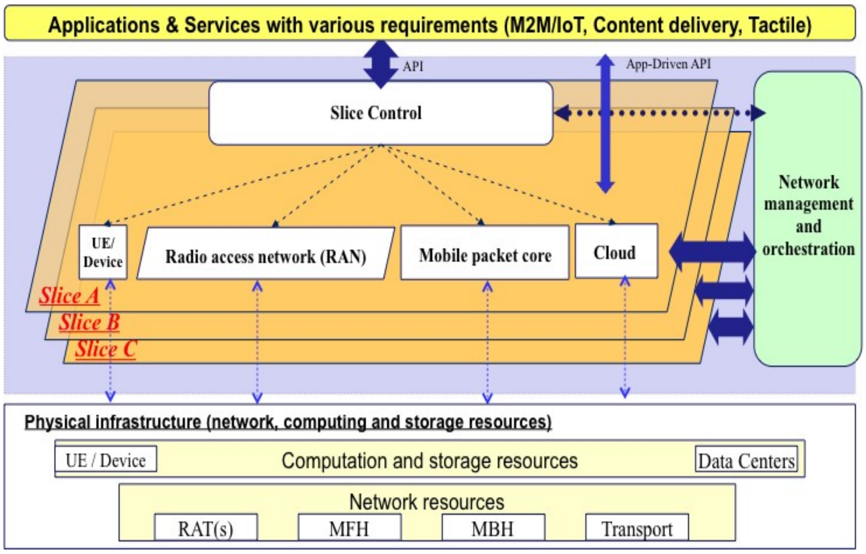
- Multiple access and advanced waveform technologies combined with coding and modulation algorithms
- Interference management
- Access protocols
- *Authorized Shared Access* (ASA) or *Licensed Shared Access* (LSA)
- Service delivery architecture
- Mass-scale MIMO
- Single frequency full duplex radio technologies
- 5G devices
- Virtualized and cloud-based radio access infrastructure

Network architecture for IMT-2020 networks



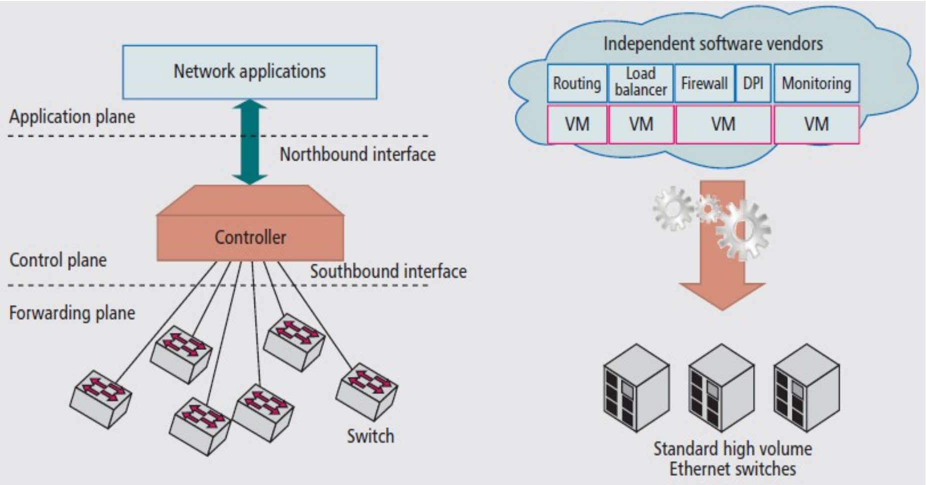
Source: ITU FG IMT-2020: *Report on Standards Gap Analysis*

Network softwarization view of IMT-2020 mobile networks



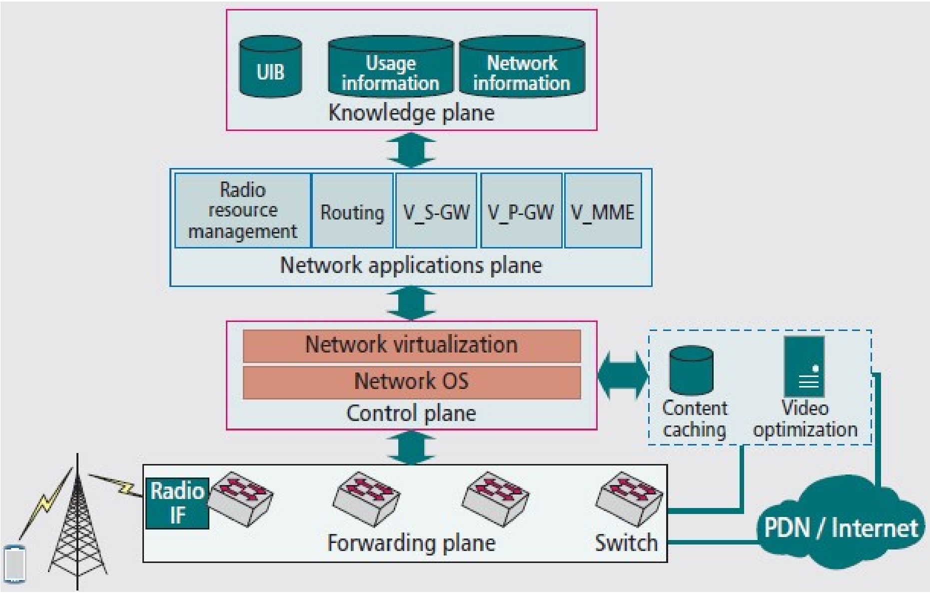
Source: ITU FG IMT-2020: *Report on Standards Gap Analysis*

SDN and NFV principles

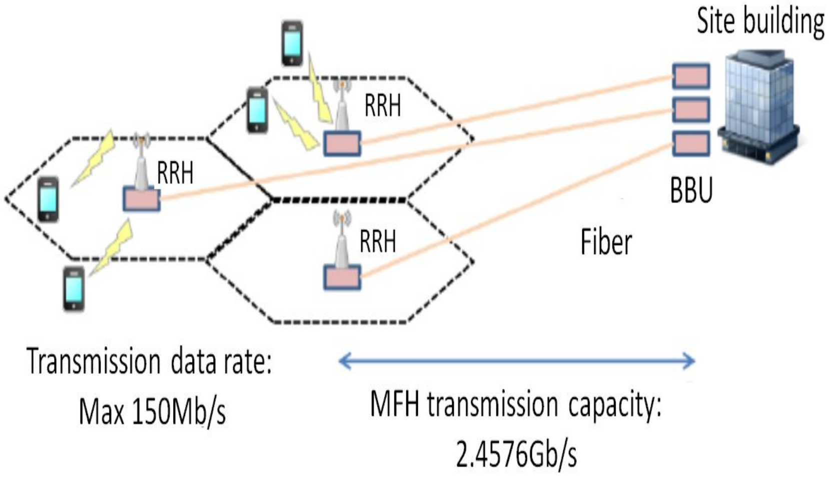


SDN Architecture ***Network Function Virtualization***

Cellular Software Defined Network

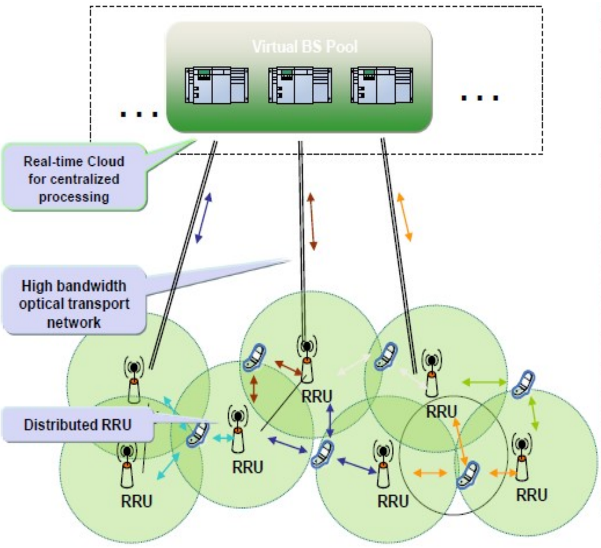


IMT-2020 front haul



Source: ITU FG IMT-2020: *Report on Standards Gap Analysis*

C-RAN: Centralized, Collaborative, Cloud and Clean System



Centralized Control and/or Processing

- Centralized processing resource pool that can support 10~1000 cells

Collaborative Radio

- Multi-cell Joint scheduling and processing

Real-Time Cloud

- Target to Open IT platform
- Consolidate the processing resource into a Cloud
- Flexible multi-standard operation and migration

Clean System Target

- Less power consuming
- Lower OPEX
- Fast system roll-out

Agenda

A. LTE and LTE-A Basics

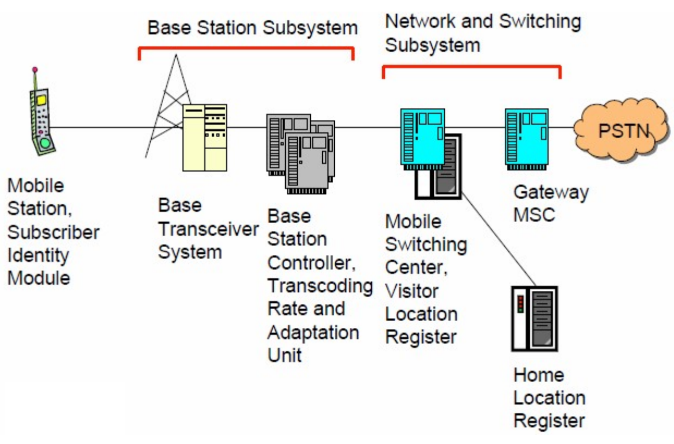
Needs for IMT-Advanced systems

- Need for **higher data rates** and greater spectral efficiency
- Need for a **Packet Switched only** optimized system
- Use of **licensed frequencies** to guarantee quality of services
- **Always-on experience** (reduce control plane latency significantly and reduce round trip delay)
- Need for **cheaper infrastructure**
- **Simplify architecture** of all network elements

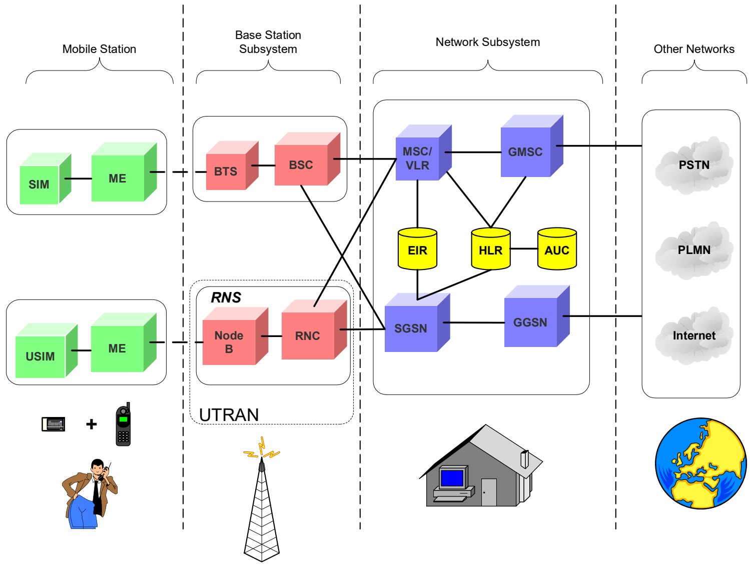
Impact and requirements on LTE characteristics

- Architecture (flat)
- Frequencies (flexibility)
- Bitrates (higher)
- Latencies (lower)
- Cooperation with other technologies (all 3GPP and non-3GPP)
- Network sharing (part or full)
- Full-IP (QoS issues, protocols integration, lower costs)
- OFDMA
- Broadcast services
- Intelligent radio schemes

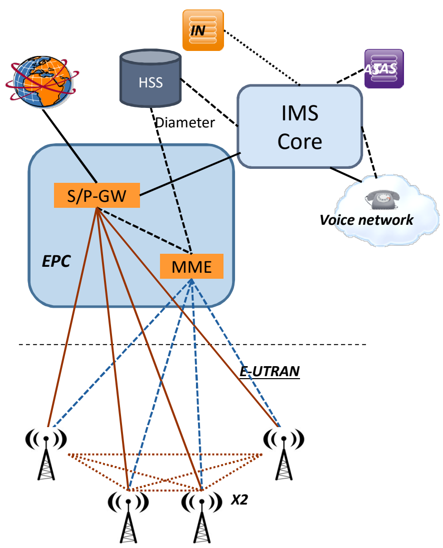
GSM Network Architecture



UMTS Network Architecture



LTE Network Architecture



Agenda

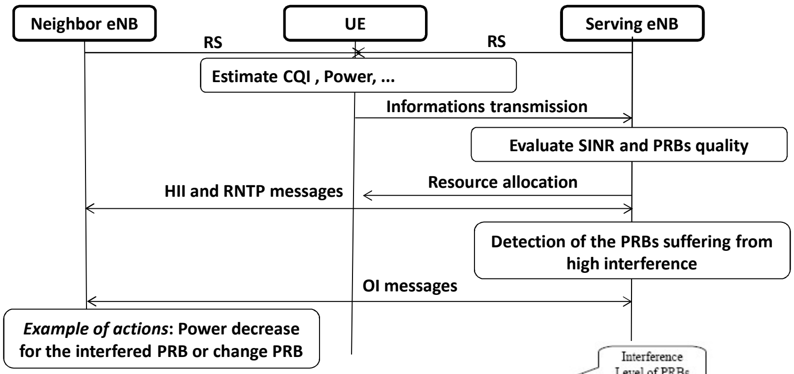
B. Data rates

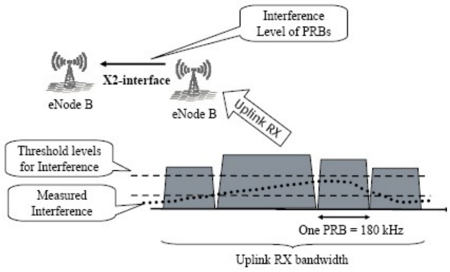
Data rates

The new environment	*Objectives*	*Related domain*	*4G means and techniques*	*5G means and techniques*
Video, 3D, massive connections	▪ Peak data rates exceeding 10 Gbps and 100 Mbps whenever needed. ▪ Tens of Gb/s/km² (2020). ▪ Cell data rate of 10 Gb/s. ▪ Signaling loads less than 1%	➢Radio interface features ➢Frequency allocation ➢RAN elements	**eICIC**, **Relaying**, **256-QAM**, **Dual connectivity** (R12): enables aggregation of component carriers from different eNBs and the ability to support CA between FDD and TDD component carriers, **Licensed Assisted Access** for LTE (LAA-LTE) with LTE in unlicensed spectrum, **LTE Wireless LAN Aggregation** (LWA) where WiFi can be supported by a radio bearer and aggregated with an LTE radio bearer, **D2D communication**, **DL Multi-User Superposition Transmission** (MUST): transmit more than one data layer to multiple users without time, frequency or spatial separation,	**Spectrum aggregation** (up to 1 GHz of aggregated spectrum in 2030), **Small cells** in 6-30 GHz band (cmWave) with 500 MHz carrier BW to provide hundreds of Gb/s/km² (2025), **Small cells** in up to 100 GHz band (mmWave) with 500 MHz carrier BW to provide a Tb/s/km² (2030), **Millimeter wavelength spectrum**, **Spectrum reuse and use of different bands** (mmWave using 28 GH and 38 GHz bands), **Multi-tier network**, **C-RAN**, **Massive MIMO**,

Radio interface features: ICIC technique

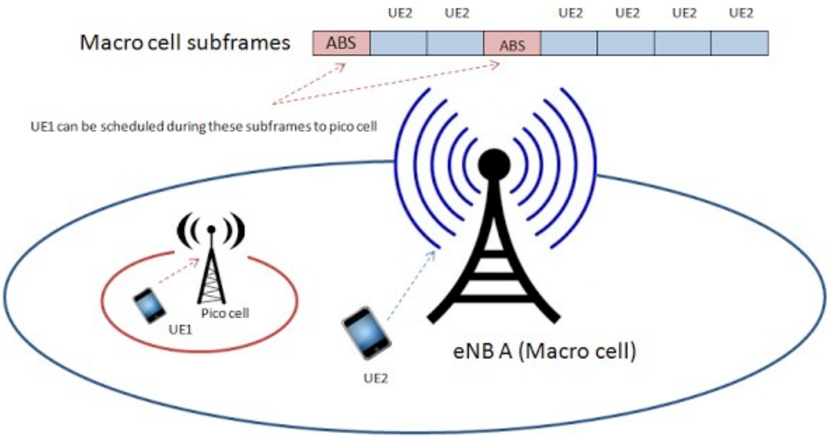
❖ICIC signaling messages over X2 interface





RNTP: Relative Narrowband Transmit Power
HII: High Interference Indicator
OI: Interference Overload Indicator,

Radio interface features: eICIC (enhanced ICIC)



Radio interface features: Higher Order Modulation (256QAM)

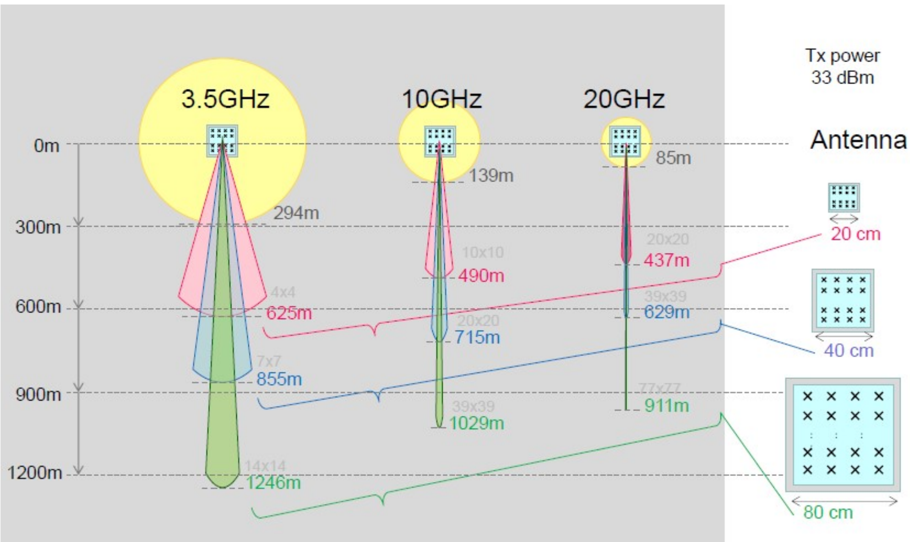
MCS Index	Modulation Order	TBS Index
0	2	0
1	2	1
2	2	2
3	2	3
4	2	4
5	2	5
6	2	6
7	2	7
8	2	8
9	2	9
10	4	9
11	4	10
12	4	11
13	4	12
14	4	13
15	4	14
16	4	15
17	6	15
18	6	16
19	6	17
20	6	18
21	6	19
22	6	20
23	6	21
24	6	22
25	6	23
26	6	24
27	6	25
28	6	26
29	2	reserved
30	4	
31	6	

MCS Index	Modulation Order	TBS Index
0	2	0
1	2	2
2	2	4
3	2	6
4	2	8
5	4	10
6	4	11
7	4	12
8	4	13
9	4	14
10	4	15
11	6	16
12	6	17
13	6	18
14	6	19
15	6	20
16	6	21
17	6	22
18	6	23
19	6	24
20	8	25
21	8	27
22	8	28
23	8	29
24	8	30
25	8	31
26	8	32
27	8	33
28	2	reserved
29	4	
30	6	
31	8	

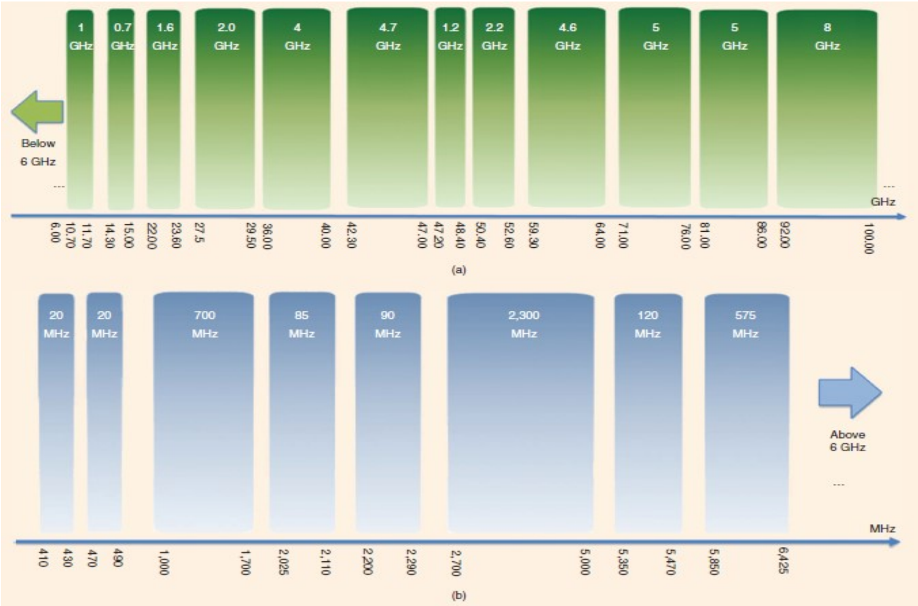
CQI Index	Modulation	Code rate x 1024
0	Out of range	
1	QPSK	78
2	QPSK	120
3	QPSK	193
4	QPSK	308
5	QPSK	449
6	QPSK	602
7	16QAM	378
8	16QAM	490
9	16QAM	616
10	64QAM	466
11	64QAM	567
12	64QAM	666
13	64QAM	772
14	64QAM	873
15	64QAM	948

CQI Index	Modulation	Code rate x 1024
0	Out of range	
1	QPSK	78
2	QPSK	193
3	QPSK	449
4	16QAM	378
5	16QAM	490
6	16QAM	616
7	64QAM	466
8	64QAM	567
9	64QAM	666
10	64QAM	772
11	64QAM	873
12	256QAM	711
13	256QAM	797
14	256QAM	885
15	256QAM	948

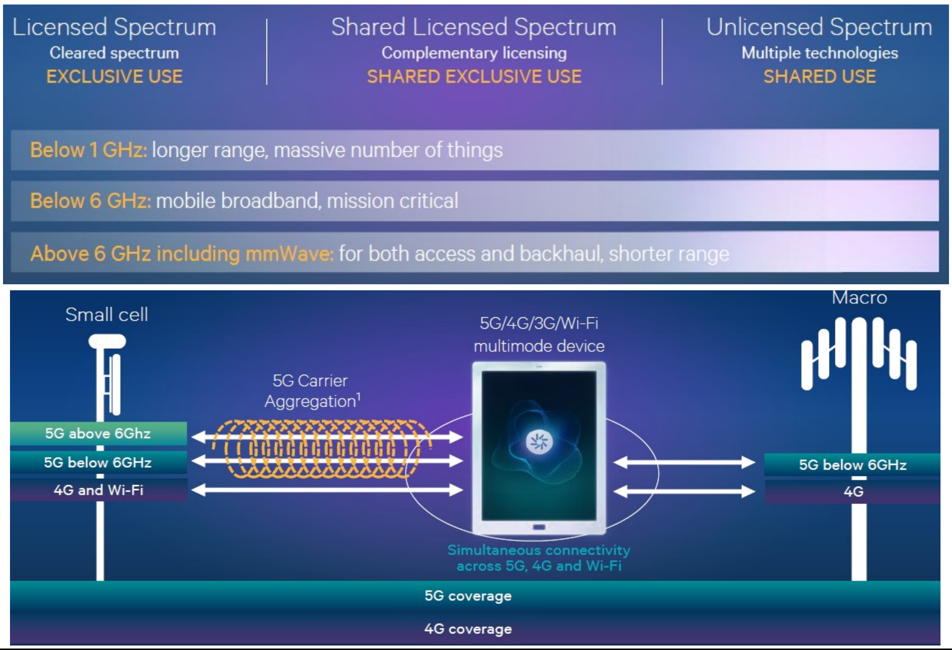
Radio interface features: Massive MIMO for coverage extension



Frequency Allocation: Candidate frequency bands for 5G



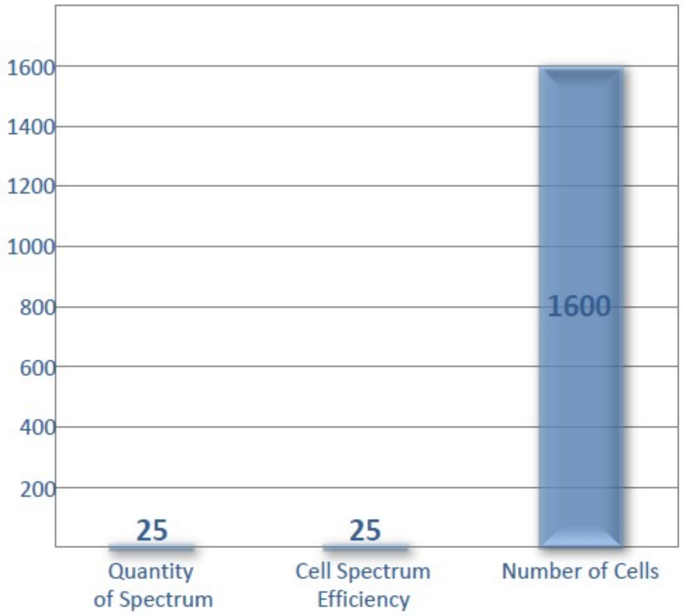
Frequency Allocation: Unified 5G design across spectrum types and bands



RAN elements: Small cells

- 2020: carry a majority of traffic with overall data volumes expected to grow up to 1,000 times (compared to 2010).
- Use traditional frequencies (< 6 GHz) or 6-30 GHz band (cmWave) with a 500 MHz carrier BW
- Enable **ultra-low latency** (< 1 ms for time critical *Machine Type Communications*), **higher data rates** (peak rates ***> 10 Gbps*** with user data rates ***> 100 Mbps***).

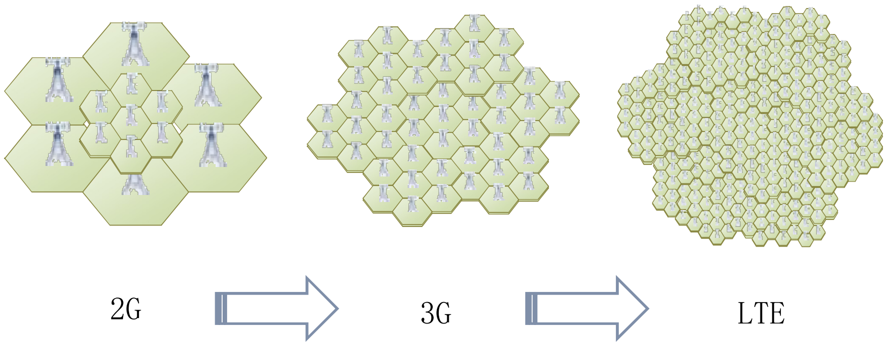
RAN elements: The need for small cells



The quantity of spectrum is not expected to increase significantly, increase in spectrum efficiency and the number of cells (smaller cells) are the only real way to increase network capacity.

RAN elements: Small cells

80 % data consumption occurs indoors in homes, offices, malls, train stations, and other Public places.

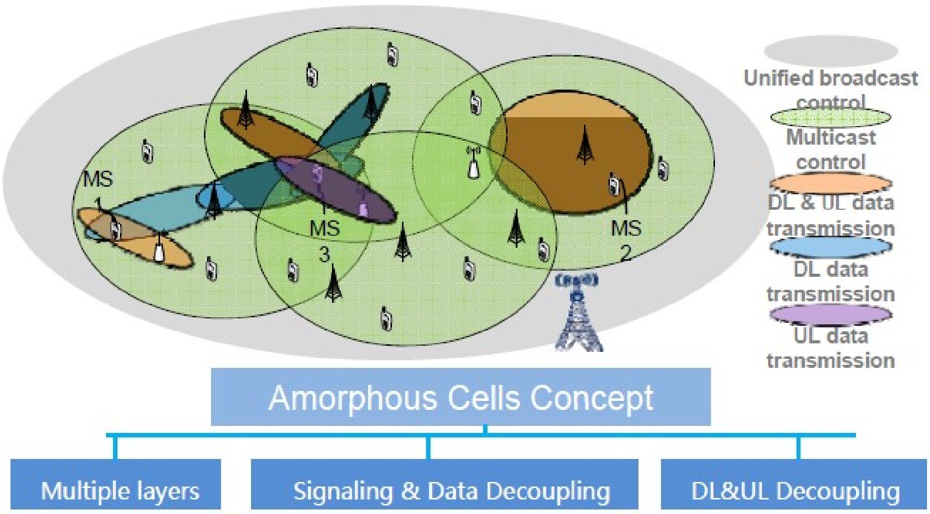


Network densification includes densification over space (small cells) and frequency (large portions of radio spectrum in diverse bands). Small cells: 150 m / Large cells: > 30 km.

Challenges:
- Construction Cost
- Inter-cell Interference
- Indoor propagation

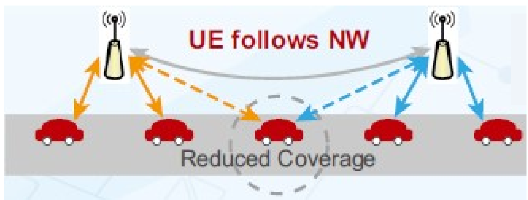
RAN elements: 3D Beamforming

RAN elements: Cell concept changes

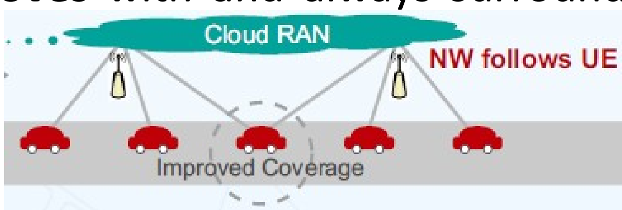


RAN elements: Elimination of cell boundaries

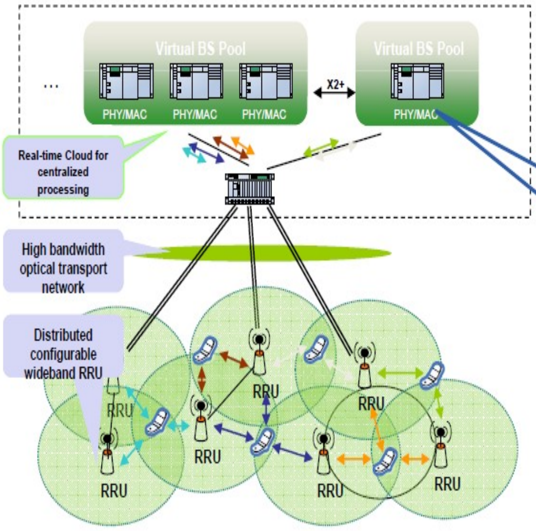
- *Classical networks*: devices associate with a cell.



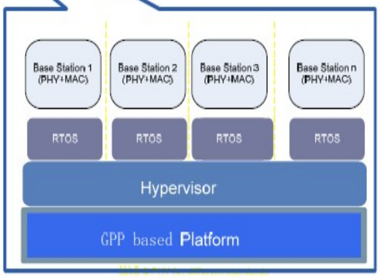
- *5G = virtualized device centric network*: access point(s) associated with the device. The cell **moves** with and always surrounds the device.



RAN elements: C-RAN



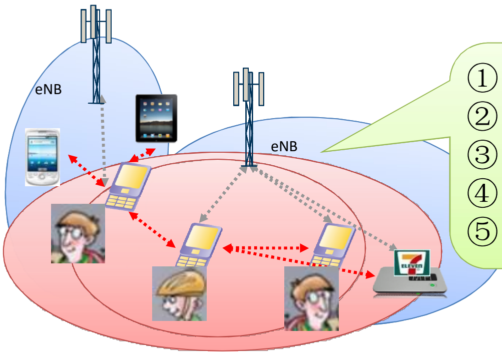
- Common platform, software based solution
- Live (soft) computation resource transition
- Inherent cooperation



BS virtualization

RAN elements: Device-to-Device (D2D) Communications

Enable devices to communicate directly without an infrastructure of access points or base stations.



① Increase network capacity
② Extend coverage
③ Offload data
④ Improve energy efficiency
⑤ Create new applications

Agenda

B. E2E latency

E2E Latency

The new environment	*Objectives*	*Related domain*	*4G/5G means and techniques*
M2M, Mission Critical Applications, games	▪ Network latency under 1 millisecond	➢ **Network architecture**	**D2D**, **Content caching close to users**, **Full-duplex communication**, **C-RAN**, **High-speed backhaul/fronthaul**, **Minimize access specific nodes**, **Separation of user and control planes**.

Latency definitions

- *Latency* = time a message takes to traverse a system.
- In a computer network =time for a data packet data to get from one point to another.
- Depends on:
  - Speed of the transmission medium (e.g., copper wire, optical fiber or radio waves)
  - Delays in the transmission by devices (e.g., routers and modems).
- Latency and bandwidth determine the network connection speed.
- A **low latency** = **high network efficiency**.
- Low enough latency ➔ no need for **local storage or computing** in a wireless device.
- ***Latency increase = grow of local processing.***

Web: 1 sec.

Voice: 150 ms

Traffic safety: 100 ms

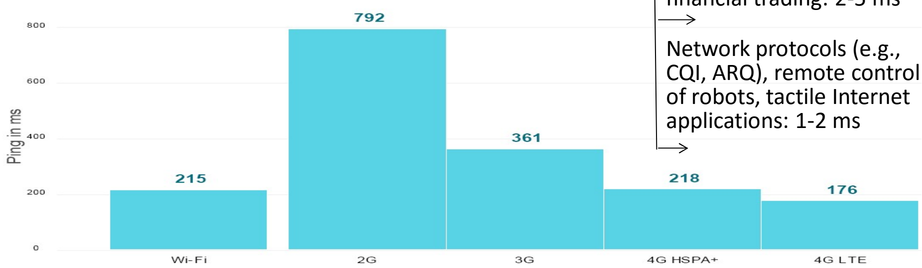
Online gaming: 50 ms

Cloud computing: 5 ms

Security (airplanes, …): < 5 ms

Health devices, safety or control mechanisms, electrical-distribution grid, financial trading: 2-5 ms

Network protocols (e.g., CQI, ARQ), remote control of robots, tactile Internet applications: 1-2 ms



Latency importance

- End-to-end latency is critical to enable new real time applications.
  - **Remote controlled robots** for medical, first response,
  - **Industrial applications** require rapid feedback control cycles in order to function well.
  - **Safety critical applications** for cars and humans, built around vehicle-to-vehicle (V2V) and vehicle-to infrastructure (V2I) communication, require very quick request-response and feedback control cycles with high availability and reliability.
  - **Augmented and virtual reality** applications (e.g., immersive displays and environments) require very fast request-response cycles to mitigate cyber sickness.

In order to realize these applications, networks must be able to support a target of **1 ms E2E latency** with high reliability.

Latency importance

Google Maps home page: shrunk from 100K to 70K-80K → traffic grows up 10% the first week and 25% more in the following 3 weeks.

Google: moving from a 10-result page loading in 0.4 sec. to a 30-result page loading in 0.9 sec. decreases traffic and ad revenues by 20% (a page with 10 results is 0.5 sec. faster than the page with 30 results).

↳ There really a difference between results that come back in 0.05 sec. and results that take 0.25 sec.

Amazon : every 100 ms ↗ in *load time* of Amazon.com ↘ *sales* by 1%.

Microsoft on Live Search: when search results pages were slowed by 1 sec.:

- Queries per user declined by 1.0%,
- Ad clicks per user declined by 1.5%

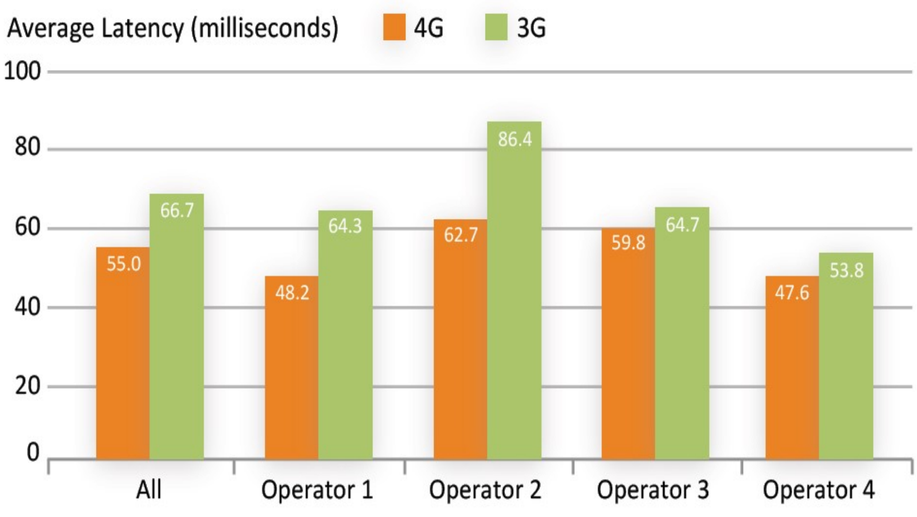
After slowing the search results page by two seconds:

- Queries per user declined by 2.5%,
- Ad clicks per user declined by 4.4%.

High Frequency Trading: a transaction can occur in a few tens of microseconds. Below 10 msec, High Frequency Trading is inefficient.

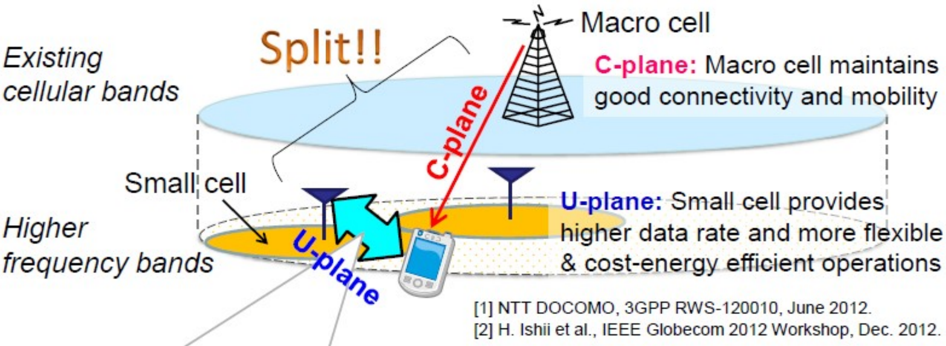
- May 17th, 2013: Anadarko Petroleum Corp. stock (in NYSE) falls from US$ 90 to 0.01 in 45 msec. Loss of US$ Billion / msec.

Average latency between 3G and 4G networks in the UK



Phantom cell in Release 12

“Phantom cell” – Split of C-plane & U-plane between macro and small cells in different frequency bands



New RAT to exploit higher frequency bands for “5G” (e.g. > 10GHz)

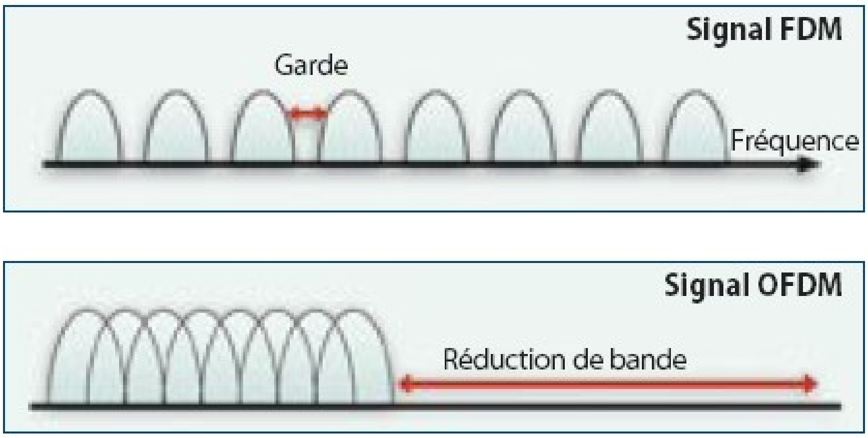
Agenda

C. Capacity

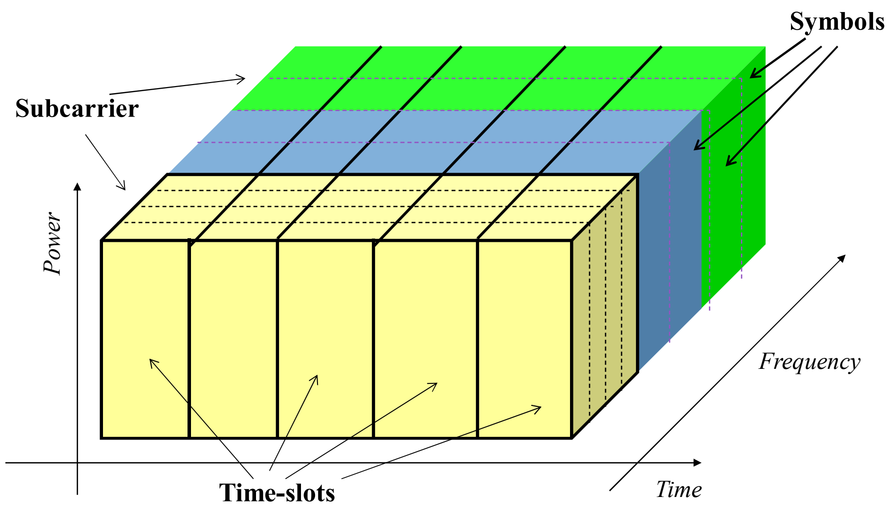
Capacity

The new environment	*Objectives*	*Related domain*	*4G means and techniques*	*5G means and techniques*
IoT	▪ Capacity expansion (10 000 more traffic) and device density by a factor of 1 000 (from 7 in 2013 to 10.28 billion mobile connections in 2O18 and 12.58 in 2010 to 50 billion things connected in 2020) ▪ Data Processing (4G: 0.1 Mb/s/m² and 5G: 10 Mb/s/m²) ▪ M2M, Internet of Things	➢Network architecture ➢Radio interface ➢Operation and management ➢architecture ➢Frequency spectrum ➢Architecture ➢Operation and maintenance	**Self-organization** (autonomous load balancing, interference minimization, spectrum allocation, power adaptation, …), **Active Antenna Systems** (AAS) with beamforming MIMO, **User Place Congestion Management** (UPCON): identification of cells and users in congestion situation to use policy decisions to mitigate congestion and the Application Specific Congestion Control for Data Communication (ACDC) can manage access attempts on a per application basis, SON,	**mmWave** to provide backhaul to the small cells in a mesh configuration with a maximum of 2 hops, Very large antenna arrays used to compensate higher pathloss at higher frequency bands, **cmWave and mmWave** deployments inter-site distance of 75-100 m can provide full coverage and satisfy the required capacity, Indoor small cell deployment needed for indoor capacity (2020), **Multi connectivity between LTE-A, cmWave and mmWave** for cell edge performance and lower small cell density, **Scalability** (scale well to handle signaling traffic such as authentication/authorization for large numbers of IoT devices, scale well to handle in(frequent) and small data transmissions from large number of devices), **D2D**, **Small cells**, **HetNets and multi-tier network**, **Network flexibility**: RAN and Core network evolve and scale independently of each other, **Supports use of specific core via network virtualization and service specific network slicing**, **Plug and play capability** with new RAT attached to the packet core without any modification, **RAN virtualization**, **M2M communication**, **Cognitive network**,

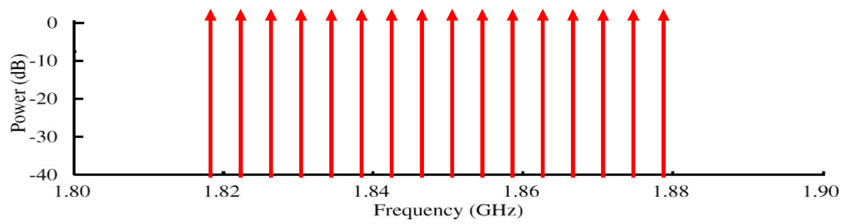
OFDM Basics

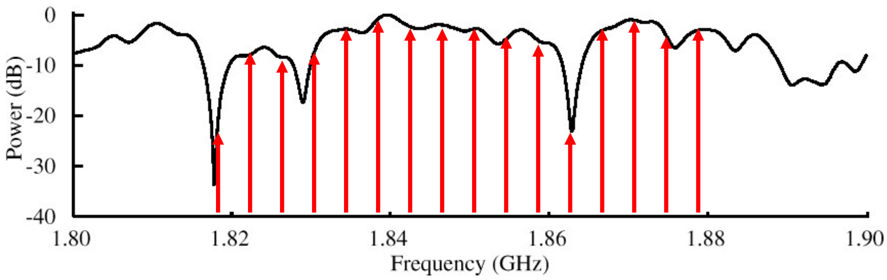


OFDM



OFDM Transmission – Robustness against fast fading





Radio channel effects

OFDM

Principle:

- ***Multicarrier modulation form***: the message to transit is divided into parts (e.g. symbols).
- Available spectrum divided into several carriers with low bitrates.
- Message parts transmitted simultaneously on a large number of channels (subcarriers).
- Different symbols transmitted on different subcarriers.
- Coding and modulation adapted to propagation conditions and the same on all subcarriers.

Advantage:

- Increased link capacity and multipath resistance.

FFT reminder

- FFT is derived from the discrete Fourier transform (DFT).
- Fourier discovered that any ***complex signal*** could be represented by a ***series of harmonically related sine waves*** all added together. He developed the math which early computers couldn't perform quickly.
- Cooley/Tukey developed the ***fast Fourier transform*** in the 1960s to greatly speed up the math to make Fourier analysis more practical.
- Any analog signal can be digitized in an analog-to-digital converter (ADC), the resulting samples are put through the FFT process. The result is a digital version of a spectrum analysis of the signal.
- The FFT sorts all the signal components out into the ***individual sine-wave elements*** of specific frequencies and amplitudes—a kind of mathematical spectrum analyzer. FFT is a good way to ***separate out all the carriers of an OFDM signal***.
- The IFFT just reverses the FFT process. All the individual carriers with modulation are in digital form and then subjected to an IFFT mathematical process, creating a single composite signal that can be transmitted. The FFT at the receiver sorts all the signals to recreate the original data stream.

The Theory Behind Radio Technology: Fourier Series

Jean Baptiste Joseph Fourier (1768-1830)
French mathematician and physicist

Idea:
"any" periodic function can be decomposed
into an (infinite) sum of sines and cosines

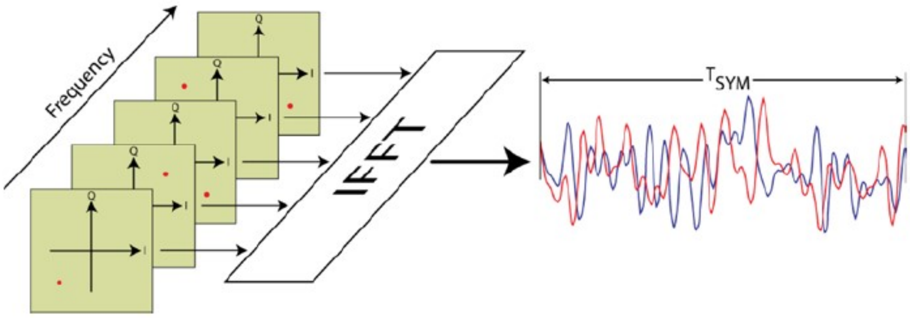
Fourier applied it to to problems of heat flow.

1824: gases in the atmosphere increase the surface temperature of the Earth.
Fourier described the greenhouse effect!

FFT reminder

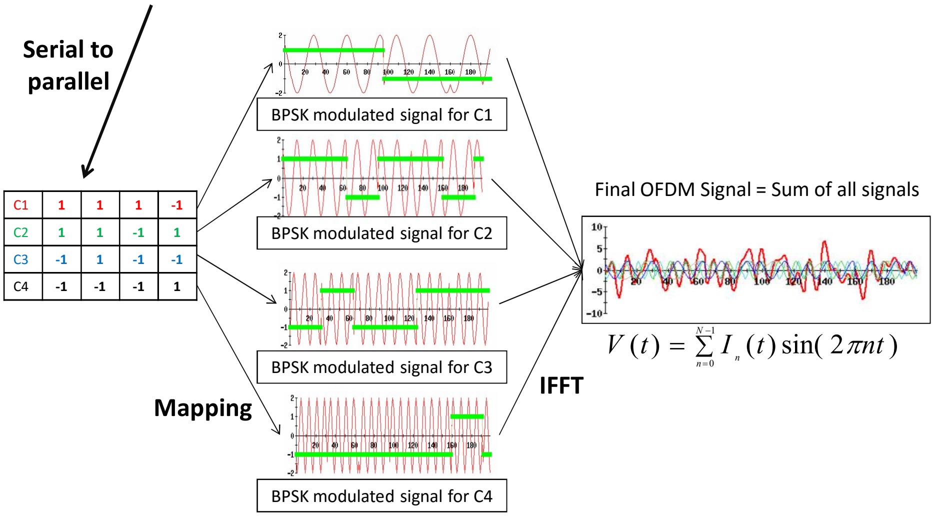
- FFT process keeps the individual modulated carriers from interfering with one another ("***orthogonal***").
- Orthogonal subcarriers all have an ***integer number of cycles*** within the symbol period. Therefore, the modulation on one channel does not produce intersymbol interference (ISI) in the adjacent channels.
- ***OFDM implementation in the real world***: with digital signal processing (DSP). IFFT and FFT math functions can be programmed on any fast PC, but it is usually done with a DSP IC or an appropriately programmed FPGA or some hardwired digital logic.

The IFFT converts input signals into parallel output sine wave modulated



OFDM operation

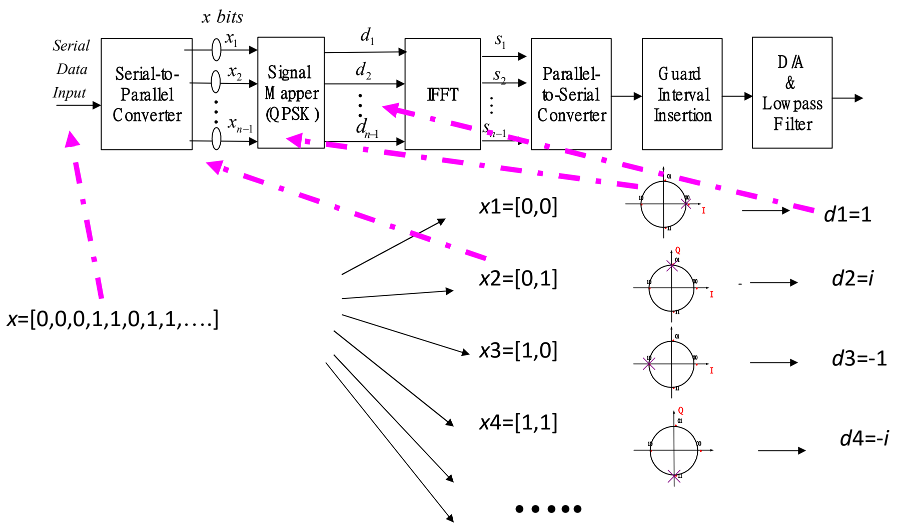
Input data flow: 1, 1, -1, -1, 1, 1, 1, -1, 1, -1, -1, -1, -1, 1, -1, -1, …



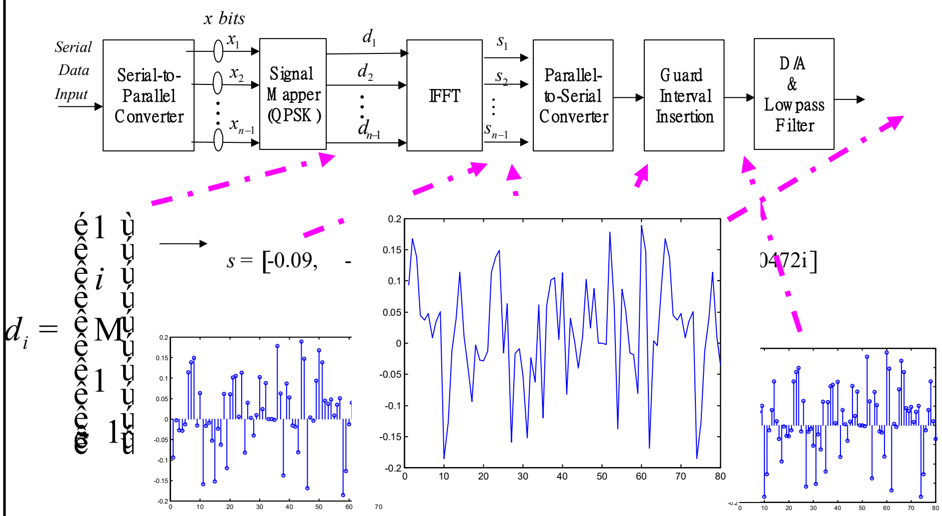
C1	1	1	1	-1
C2	1	1	-1	1
C3	-1	1	-1	-1
C4	-1	-1	-1	1

$$V(t) = \sum_{n=0}^{N-1} I_n(t)\sin(2\pi nt)$$

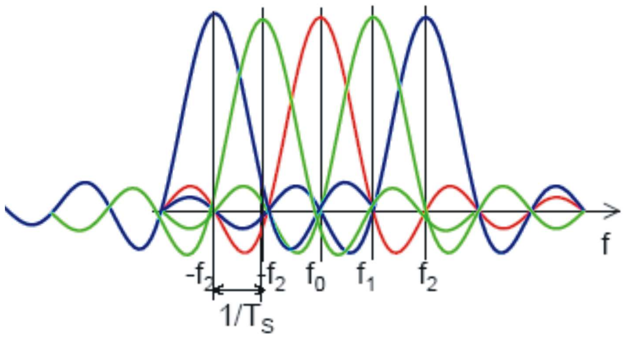
FFT-based OFDM System - OFDM Transmitter



FFT-based OFDM System - OFDM Transmitter

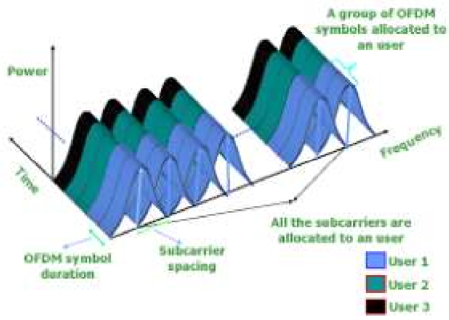


OFDM

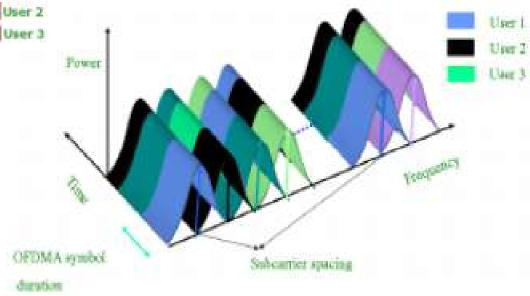


- Centers on orthogonal frequency carriers.
- Orthogonality: low = peak signal from other signals ➲ orthogonality in the frequency domain.
- Subcarriers spaced 1/Ts.

OFDM



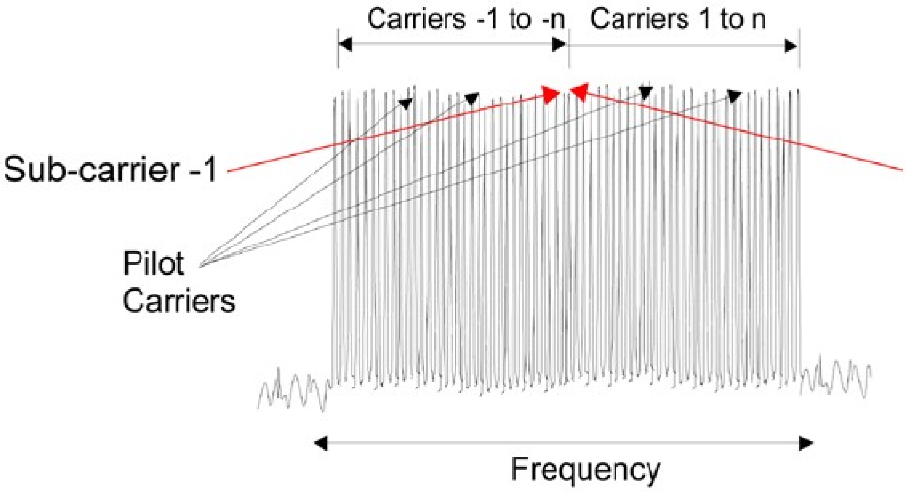
OFDM-TDMA Signal



OFDMA Signal

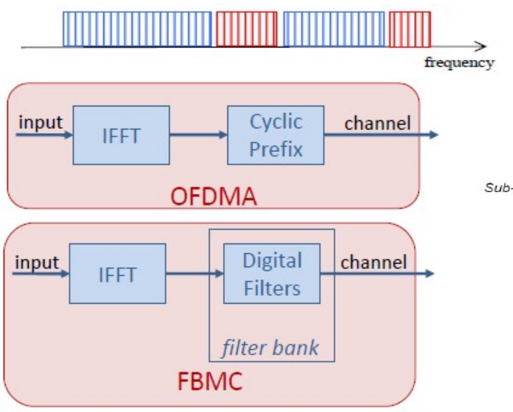
Pilot channels

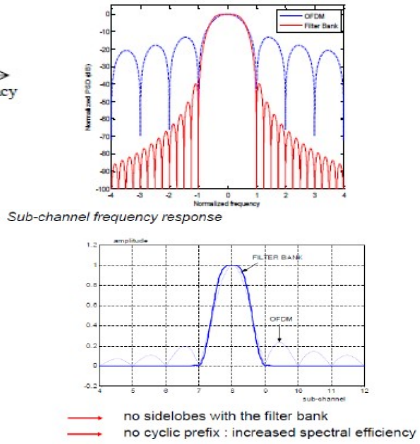
Reference phase and amplitude to demodulate the remaining sub-carriers.



Filter Bank Multicarrier (FBMC)

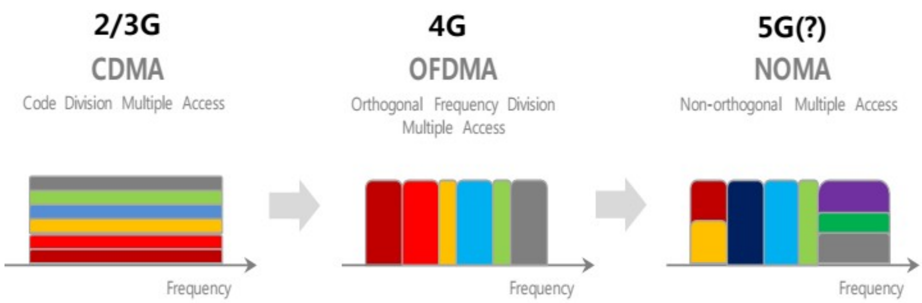
- Alternative approach to OFDMA with a higher spectral efficiency.
- Uses common FDMA ***without subcarrier overlap***.
- Almost perfect separation of frequency sub-bands without strict synchronization.
- Eliminates the guard bands between the different systems.
- No cyclic prefix.
- Facilitates simultaneous transmission and reception (in-band FDD, full duplex).
- Simplifies carrier aggregation.





NOMA principle

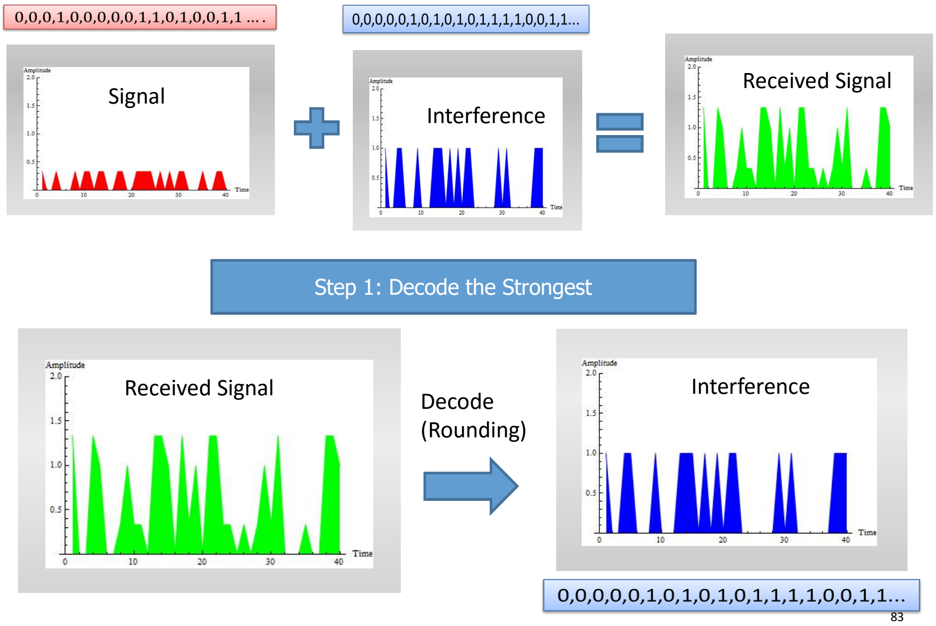
- NOMA provides multiple access utilizing power control in the frequency domain.
- Receiver can eliminate interference between terminals utilizing SIC (*Successive Interference Cancellation*) with varying transmission power of several terminals' signals.



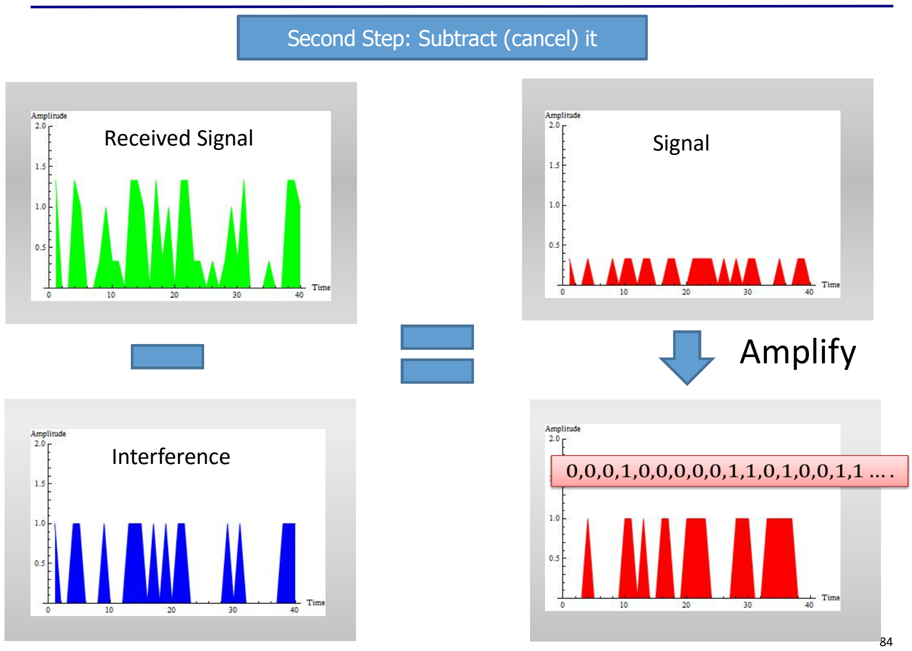
SIC (Successive Interference Cancellation)

- SIC ➔ Ability of a receiver to receive two or more signals concurrently (that otherwise collide).
- Process:
  1. The receiver decodes the strongest signal,
  2. It subtracts it from the combined signal,
  3. It extracts the weaker one from the residue.
- Facilitates recovery of the weakest signal:
  a) The bits of the strongest signal are decoded as before.
  b) The original (strongest) signal is then reconstructed from these bits, and subtracted (i.e., *cancelled*) from the combined signal.
  c) The bits of the weakest packet are then decoded from this residue.
  d) This can be an iterative process to recover multiple packets → ***successive interference cancellation***.

Successive Interference Cancelation (SIC) – Operating principle



Successive Interference Cancelation (SIC) – Operating principle



The Self Organizing Networks (SON)

SON can improve both the efficiency of network deployment and operation and user experience:

- Self-configuration,
- Self-optimization,
- Self-healing.

Important SON features include:

❖ Automatic Neighbor Relation (ANR),

❖ Coverage and Capacity Optimization (CCO),

❖ Mobility Load Balancing (MLB),

❖ Mobility Robustness Optimization (MRO).

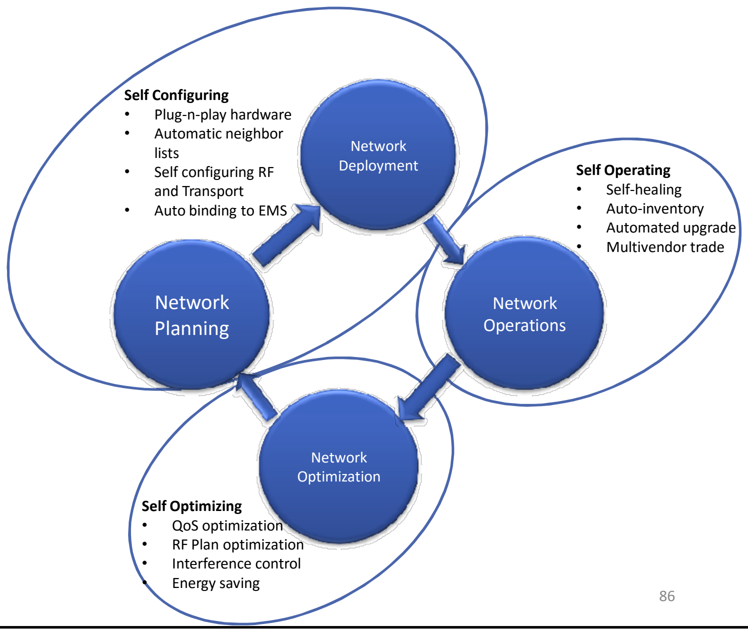
➢ **Interference management: eICIC + CCO.**

➢ **Mobility Management: MRO.**

➢ **Traffic Management: MLB.**

85

The Self Organizing Networks (SON)



86

Agenda

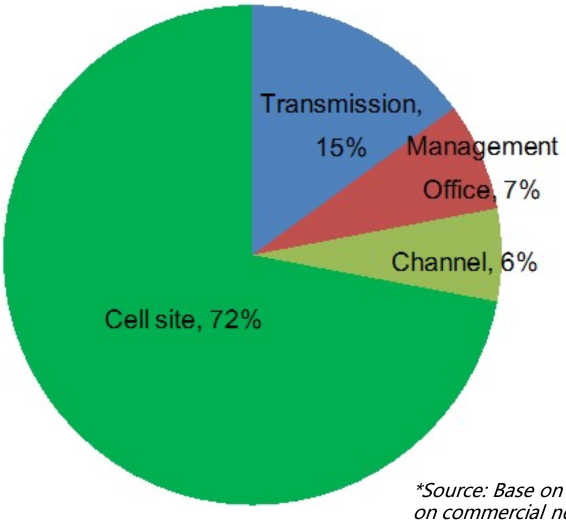
D. Energy

Energy

The new environment	*Objectives*	*Related domain*	*4G means and techniques*	*5G means and techniques*
Green Networking	▪ Energy efficiency gains by a factor of 1 000 per transported bit, Lower battery consumption, 10 years of battery	▪Radio interface ▪Green networking ▪RAN elements	**eDRX**, **Device Power Saving Mode**,	**Massive MIMO**, **Wireless charging**, **Energy harvesting**, A UE can have **simultaneous active connections to more than one BS or AP with the same or different RATs**, **Large number of RRH** (*remote radio head*) connected to central processing nodes (e.g., clouds),

Energy reduction

BS cell site is the major source of power consumption.



**Source: Base on China Mobile survey on commercial networks*

Low-Power Wide-Area (LPWA) networks

Key requirements for LPWA networks to successfully support massive M2M deployment:

- Long battery life (10 years of battery operation)
- Low device cost (module cost of less than 5 USD)
- Low deployment cost
- Full coverage (IoT connectivity link budget is an enhancement of 15-20 dB)
- Support for a massive number of devices (by 2025 there will be seven billion connected devices)

	SIGFOX	LoRa	clean slate cIoT	NB LTE-M Rel. 13	LTE-M Rel. 12/13	EC-GSM Rel. 13	5G (targets)
Range (outdoor) MCL	<13km 160 dB	<11km 157 dB	<15km 164 dB	<15km 164 dB	<11km 156 dB	<15km 164 dB	<15km 164 dB
Spectrum Bandwidth	Unlicensed 900MHz 100Hz	Unlicensed 900MHz <500kHz	Licensed 7-900MHz 200kHz or dedicated	Licensed 7-900MHz 200kHz or shared	Licensed 7-900MHz 1.4 MHz or shared	Licensed 8-900MHz 2.4 MHz or shared	Licensed 7-900MHz shared
Data rate	<100bps	<10 kbps	<50kbps	<150kbps	<1 Mbps	10kbps	<1 Mbps
Battery life	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years
Availability	Today	Today	2016	2016	2016	2016	beyond 2020

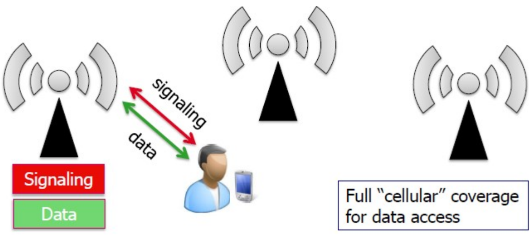
Long battery life

- **Rel. 12**: ***Device power saving mode*** (PSM)

Rel-12 Power Saving Mode (PSM)   Rel-13 extended DRX

- **Rel. 13**: ***enhanced DRX*** (eDRX) used when DL traffic is not delay-tolerant (and a long TAU cycle cannot be used) or in extreme coverage scenarios (when physical channels are repeated many times).

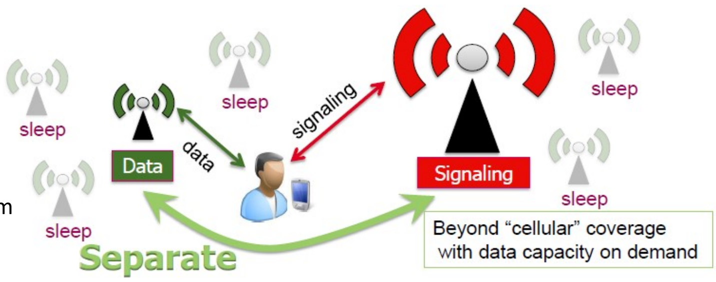
New architectures for green networking



Limitation of traditional cellular architecture:
- Continuous and full coverage for data access
- Limited flexibility for energy management
- High energy consumption also at low traffic load

Classical and Alternative Architectures

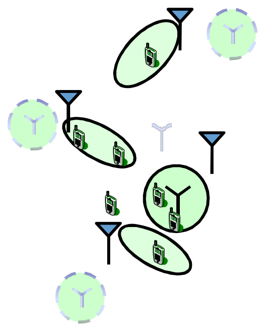
- System designed for energy efficiency
- Separate capacity from coverage
- Optimise signalling transmission
- Lean access to system
- Cope with massive amount of low data rate services



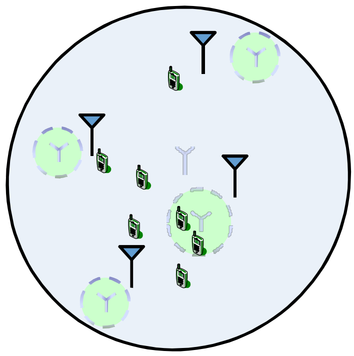
Separating Data Network from Signaling Network

Separating Data Network from Signaling Network

Data Network

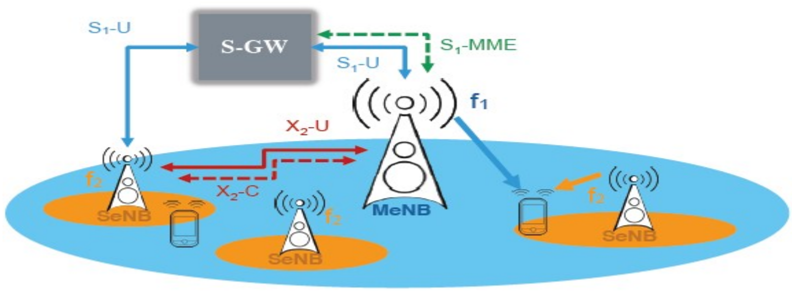


Signaling Network



Dual Connectivity: Principle

- UE connected to 2 different network nodes
- UE has 2 MAC entities and uses radio resources provided by 2 distinct schedulers



- **Master eNB** (MeNB)
- **Secondary eNB** (SeNB)
- **Master Cell Group** (MCG)
- **Secondary Cell Group** (SCG): group of serving cells associated with the MeNB/SeNB, comprising the **Primary Cell** (PCell) / **Primary SCell** (PSCell) and optionally one or more **Secondary Cells** (SCells).
- **In DC a UE is connected to one MeNB and one SeNB**

Agenda

E. Cost

Cost

The new environment	*Objectives*	*Related domain*	*4G means and techniques*	*5G means and techniques*
Decreasing ARPU	▪Ultra low cost M2M ▪Lower operating costs ▪Spectrum efficiency	▪Architecture ▪Operation and maintenance ▪Operation and management ▪Architecture ▪Radio interface ▪RAN elements	**Minimization of Drive Tests,** **SDN,** **NFV,** **Cloud,** **SON** **Network sharing**	**D2D communication**, **Full-Duplex system**, **Massive MIMO**, **CoMP joint transmission and reception**, **Network-assisted interference cancellation and suppression**, **Spectrum reuse** (NOMA, …), **3-dimensional or full-dimensional MIMO**

Enhanced ComP mechanism

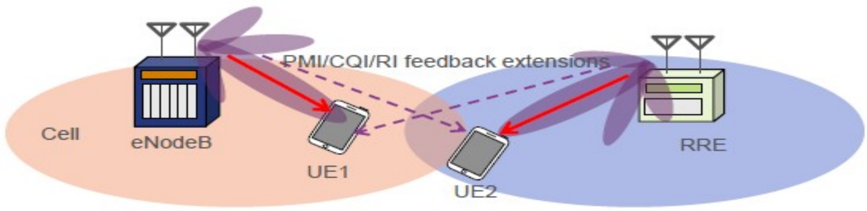


Figure. Coordinated beamforming / scheduling

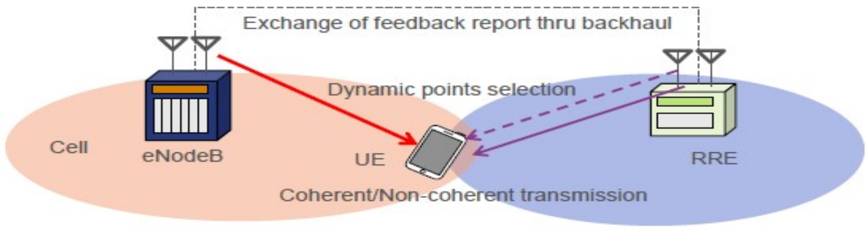


Figure. Joint Processing or Dynamic cell selection

SDN and NFV

SDN = the network layers are programmable by separating the data plane from the control plan

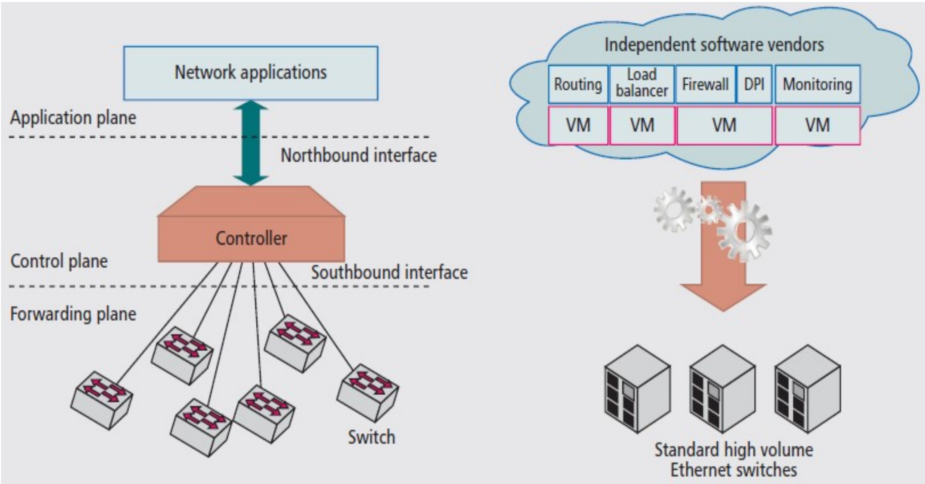
NFV = the capability of flexible networking service placement.

Together, SDN and NFV can enable MSPs to:

- make their network services dynamic,
- optimize their network resources,
- increase the agility of network,
- implement novel services,
- hasten the process from service design to service production,
- enable easy upgrading and network capacity expansion to support resource sharing between multiple-tenants and support for multi-cell collaborative signal processing.

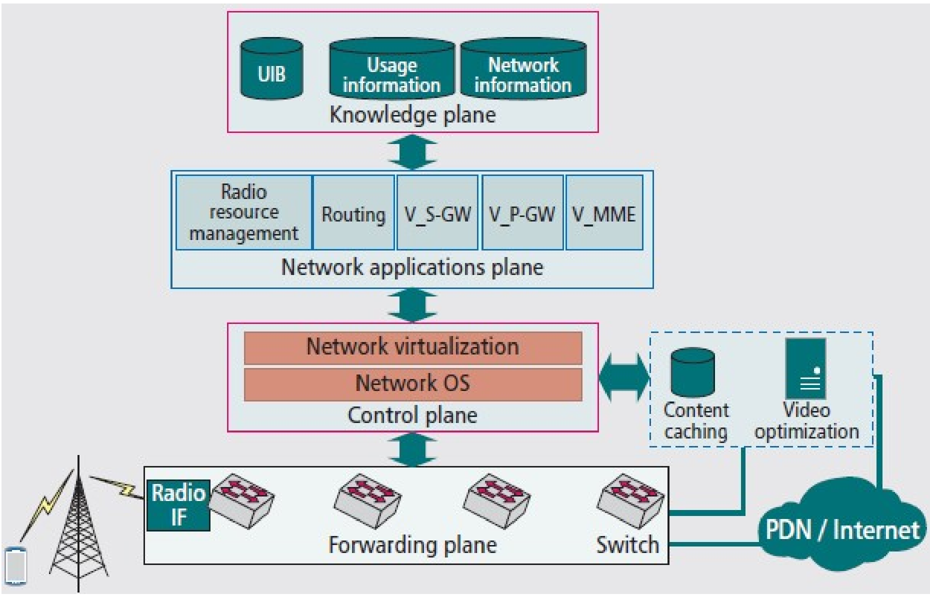
98

SDN and NFV principles

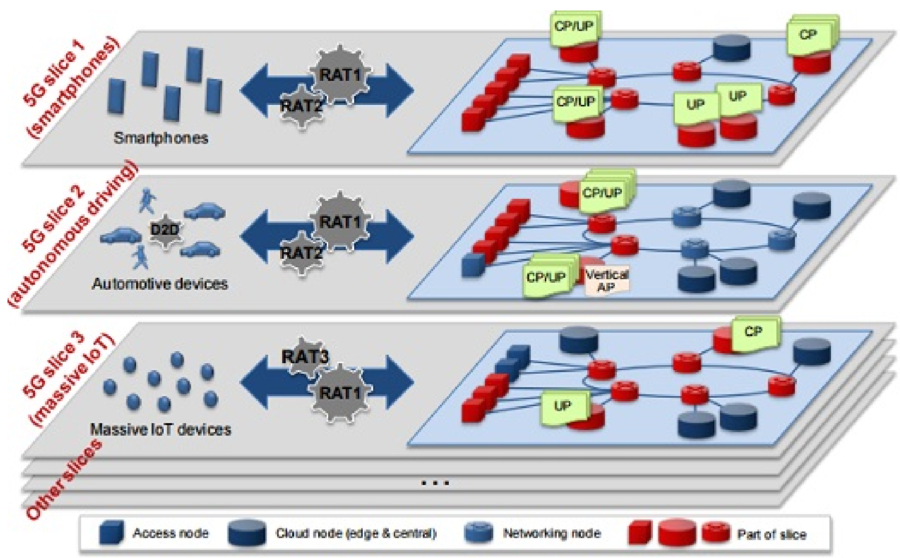


SDN Architecture ***Network Function Virtualization***

Cellular Software Defined Network



Resources slicing principle in 5G



Agenda

F. QoE

Quality of Experience

The new environment	*Objectives*	*Related domain*	*4G means and techniques*	*5G means and techniques*
Multiplicity of services	▪ Realistic applied services ▪ User friendly and context-aware network (the network to dynamically adapt to the needs of devices and applications rather than have applications adapt to today's one-size-fits-all set of access characteristics) ▪ Personalized: advanced services and applications (smart city, service-oriented communication, …) ▪ High secured: ensure the ability to defend against security attacks such as denial of service (DoS) for mission-critical applications (public safety, smart grids and natural gas and water distribution networks), Highly reliable ▪ Mobility (from no mobility to future high speed trains and even possibly aircraft)	▪ Architecture ▪ Network features	➢**Proximity services** (ProSe) with Group Call System Enablers for LTE (GCSE_LTE), ➢**WiFi integration with Access Network Discovery and Selection Function** (ANDSF) policy and RAN rules: network selection and traffic steering between WiFi and cellular, ➢**Machine Type Communications** (MTC), ➢**Full Coverage**: Power Spectral Density Boosting, ➢**Web Real Time Communication** (Web RTC), ➢**Enhanced Voice Services** (EVS), ➢**Network-Based IP Flow Mobility** (NBIFOM): GPRS tunneling in WLAN, ➢**Mission Critical Push-to-Talk** (MCPTT) over LTE for public safety, ➢**Dedicated Core** (DECOR), ➢**Monitoring Enhancement** (MONTE) for MTC services,	**Implementation of AAA** (*Authentication, Authorization and Accounting*) in an access agnostic manner, **Access agnostic packet core** across multiple RAT to support uniform authentication, session continuity and security, **C-RAN**, **Network virtualization**, **M2M communication**, Implementation of operator policies via **SDNs**, Implementation of QoS in an access agnostic manner, **Cloud system based service** (mobile cloud traffic from 35% to 70%), **Heterogeneous network architectures** (UEs, BSs, smart machines, wearable devices, …), **Mobility on-demand**, **Architecture Enhancements** for Service Capability Exposure (AESE) for third party application providers,

Radio interface features: Device to Device communication (D2D)

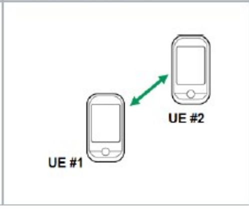
- Several governmental authorities consider LTE as a candidate for critical communications.
- In June 2009 the *National Public Safety Telecommunications Council* (NPTSC), the *Association of Public Safety Communication Officials* (APCO) and the *National Emergency Number Association* (NENA) in the US decided to endorse LTE as a the platform for the next-generation public safety network with broadband capabilities. 10 MHz of paired spectrum was set aside by the FCC for public safety purposes during the 700 MHz auction of February 2008. In 2012 President Obama signed a law in that mandates to transfer this spectrum to an authority called ***First Responder Network Authority*** (FirstNet).
- Technical specifications of the LTE support requirements for critical communications:
  - ➢ Reliability and Resilience. Functioning satisfactorily over periods and under adverse circumstances
  - ➢ Direct Communication between terminals
  - ➢ Group Communication
  - ➢ Off network communication
  - ➢ Mission Critical Push-To-Talk (MCPTT) including group call communication with low call setup time.
- *Release 12:* LTE **Device-to-Device** (D2D), **Proximity Services** and **Group Call System Enablers** (GCSE).
- *Release 13:* **Off network communication** and **MCPTT**.
- ***Proximity Services*** (ProSe): allow devices in close proximity to detect each other and to communicate directly with the goal to reduce the network load, increase capacity in a given bandwidth and allow communication in areas without network coverage.

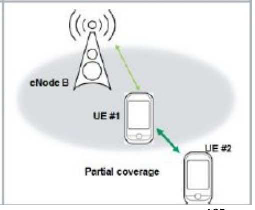
Radio interface features: LTE D2D Proximity Services (ProSe) scenarios

2 main elements:

- Network-assisted discovery of users in close proximity to each other,
- Direct communication between these users with, or without supervision from the network (only applicable for the public safety use case).

	Within network coverage (Intra-/Inter-cell)	Outside network coverage	Partial network coverage
Non-public safety use case	Discovery	-	-
Public safety use case	Discovery, Communication	Communication	Communication

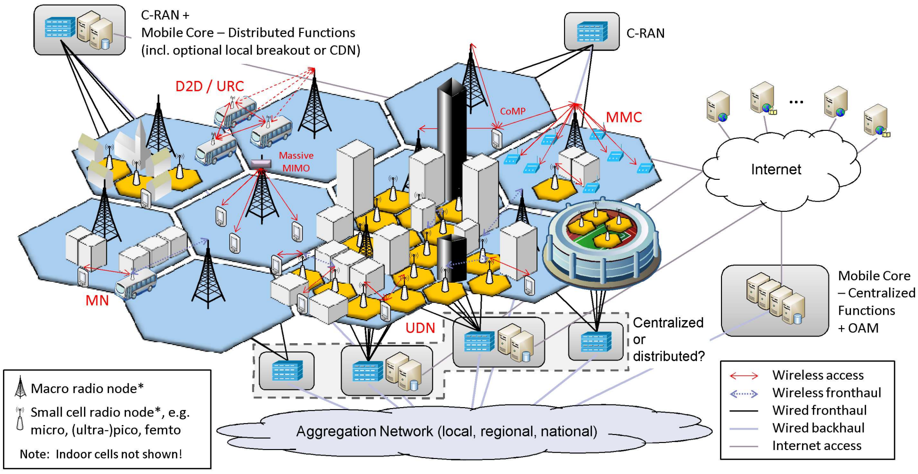




Agenda

III. Conclusions

METIS 5G Architecture



* Only Remote Radio Units (RRUs) assumed.

- Amazingly Fast scenario
  - high data rates & network capacities
- Ultra-Dense Networks (UDN)
  - ISD about 10 m
  - >= 1 radio nodes per room
- Local break out & Distributed mobile core functions
- Accelerated content delivery
- Tech. Dependent
  - D2D, MMC (Massive Machine Comm.), Moving Networks (MN), UDN Ultra-reliable Comm. (URC)

Thank you