5G Overview and Opportunities

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Topics of Discussion

- IET series of lectures

- The journey to 5G
  - Radio
  - Network

- The stakeholders
  - Vendors
  - Operators
  - & Now… Gov. Cities, Industries

- Standardisation
  - 5G-PPP
  - NGMN
  - 3GPP

- The opportunities
  - Technology Enablers for 5G
  - Users of 5G networks

IET series of lectures

This is the first of three presentation on 5G networks & Solutions

- Overview   Sep. 2017
- Standards   Jan. 2018
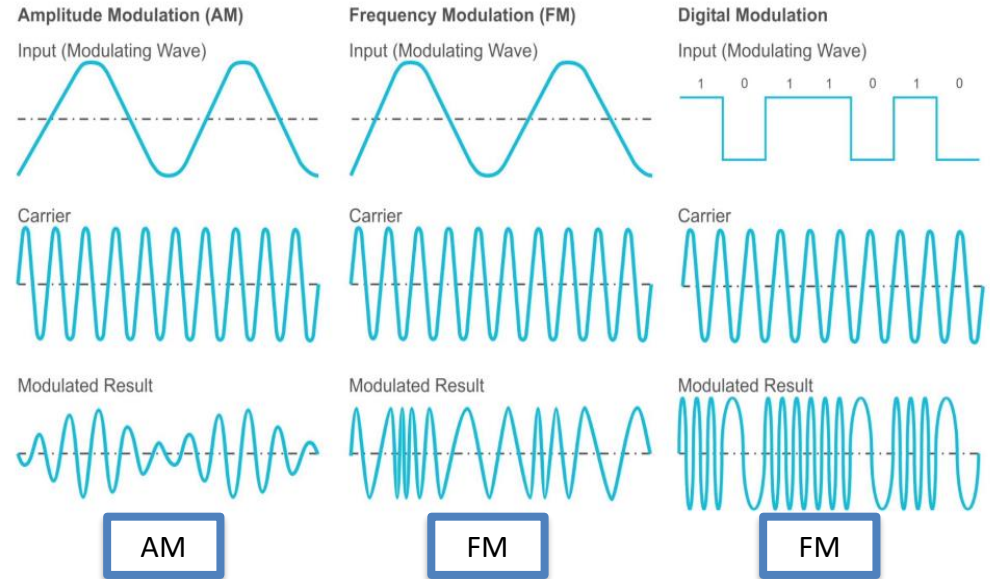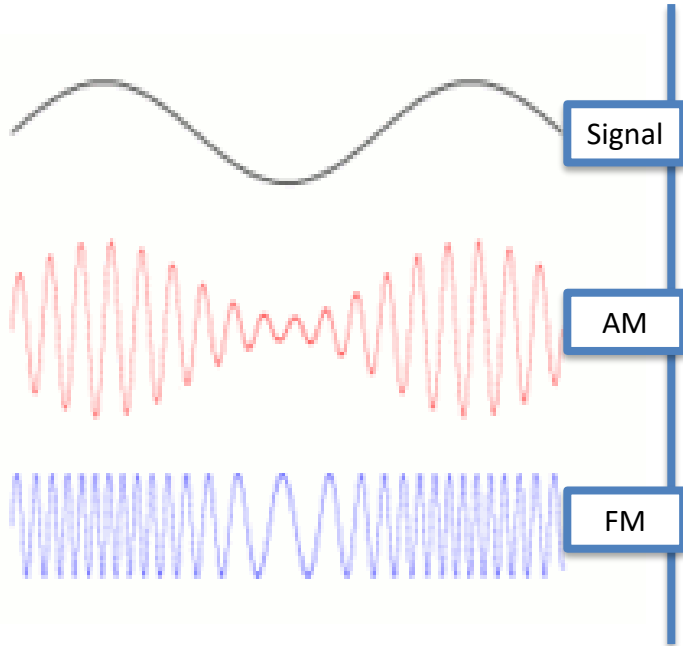- Deployment   Apr. 2018

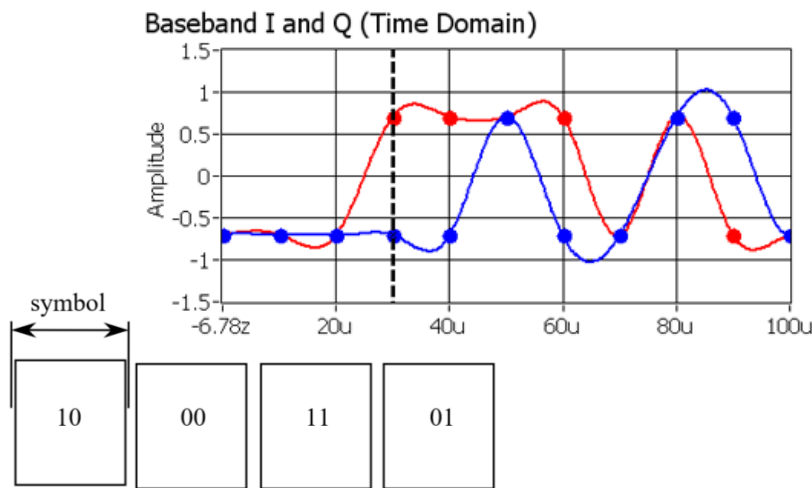Radio

Network

The journey to 5G

Radio

Signal

AM

FM

Amplitude Modulation (AM)

Input (Modulating Wave)

Carrier

Modulated Result

AM

Frequency Modulation (FM)

Input (Modulating Wave)

Carrier

Modulated Result

FM

Digital Modulation

Input (Modulating Wave)

1 0 1 1 0 1 0

Carrier

Modulated Result

FM

Radio

PSK - Phase Shift Keying

Baseband I and Q (Time Domain)

symbol

| 10 | 00 | 11 | 01 |

Constellation Graph
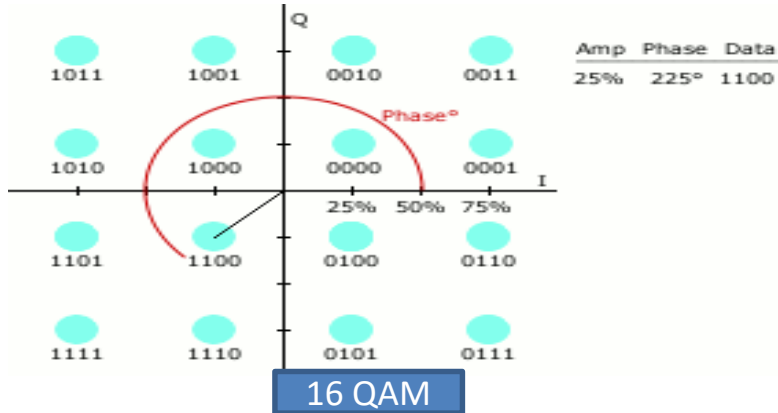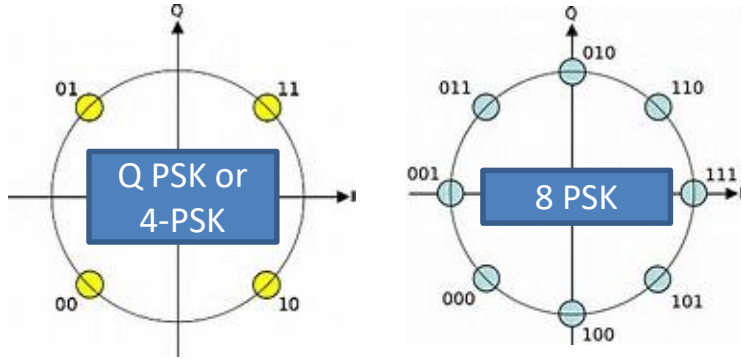
Cursor
Constellation
Transitions

REF: https://electronics.stackexchange.com/questions/26586/qam-modulation-how-data-in-different-frequencies-are-laid-out
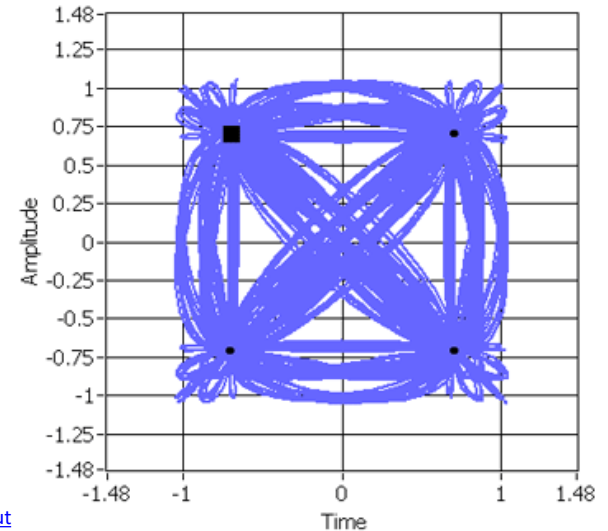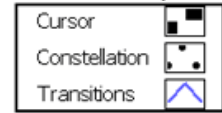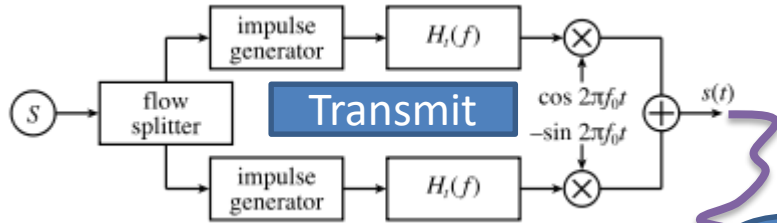
Radio

Higher Order Digital Modulation

Q PSK or 4-PSK

8 PSK

16 QAM

QAM Level	Number of Bits Per Symbol	Efficiency over Previous QAM Level
4 QAM	2	
8 QAM	3	50.00%
16 QAM	4	33.33%
32 QAM	5	25.00%
64 QAM	6	20.00%
128 QAM	7	16.67%
256 QAM	8	14.29%
512 QAM	9	12.50%
1024 QAM	10	11.11%

Number of bits represented by one symbol at all QAM levels

Radio

QAM – Quadrature Amplitude Modulation
Fundamental modulation scheme in
… 5G, LTE, 3G, 2G, Wi-Fi, …

16-QAM

RF Channel

Transmit

Receiver

Rectangular   Circular
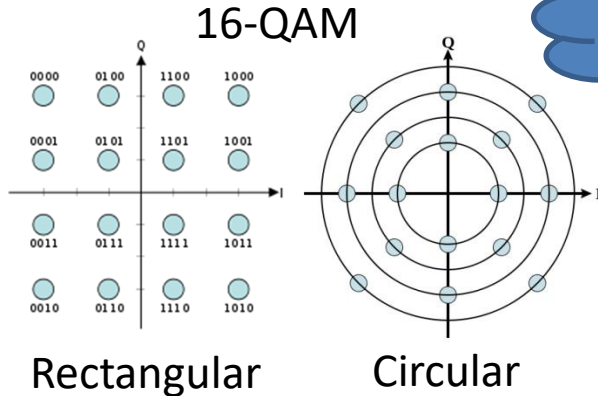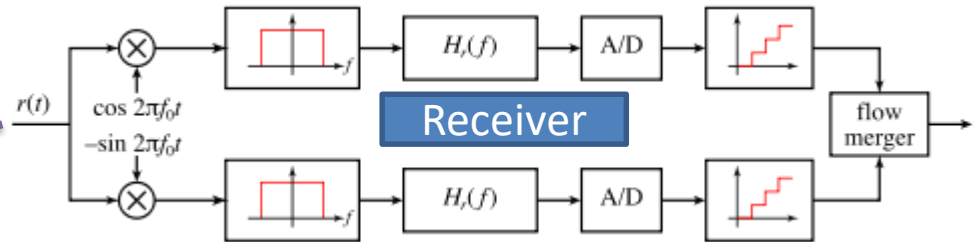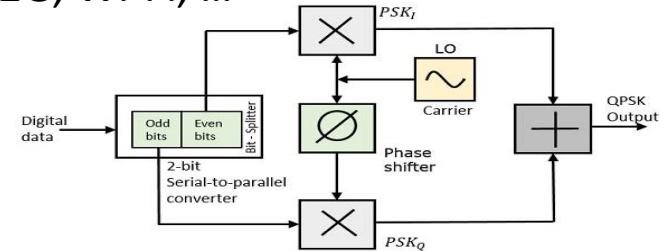
Ref: https://en.wikipedia.org/wiki/Quadrature_amplitude_modulation

Radio – Frequency / Time / Code

- TDMA – Time Division Multiple Access
- FDMA – Frequency Division Multiple Access
- CDMA – Code Division Multiple Access
- OFDM – Orthogonal Frequency Division Multiplexing
- OFDMA – Orthogonal Frequency Division Multiple Access

Radio OFDMA in LTE & 5G

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Radio – TDD / FDD

TDD - Time Division Duplex

FDD - Frequency Division Duplex
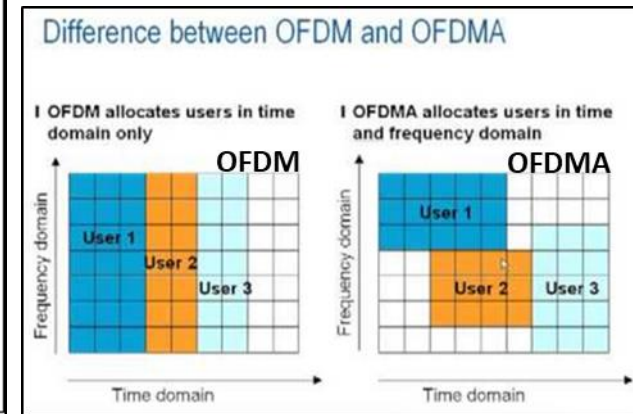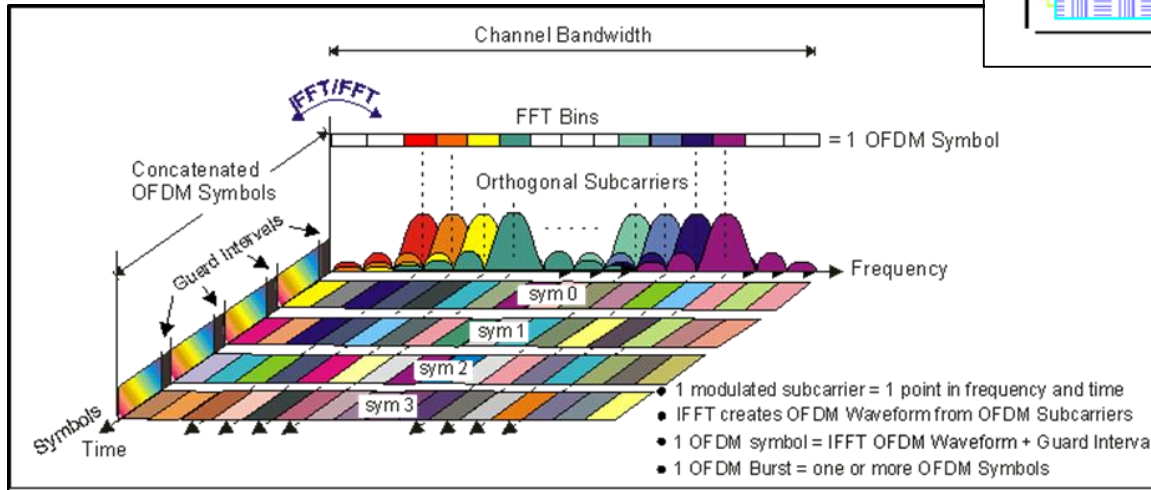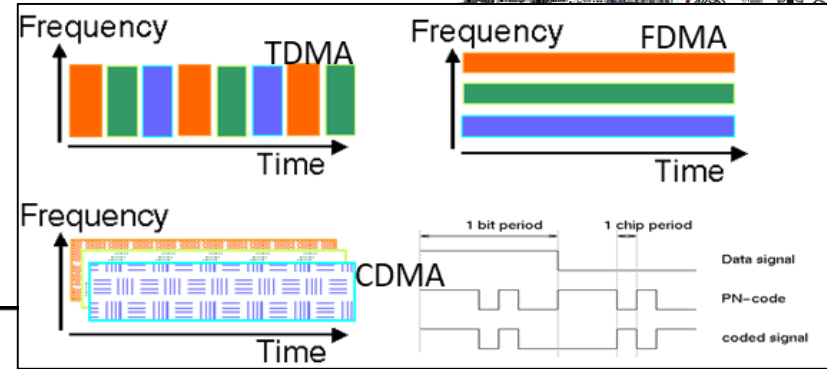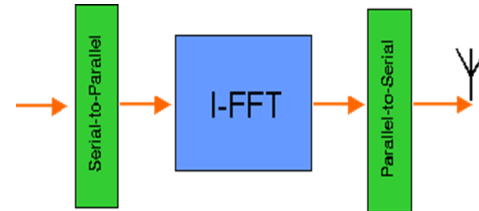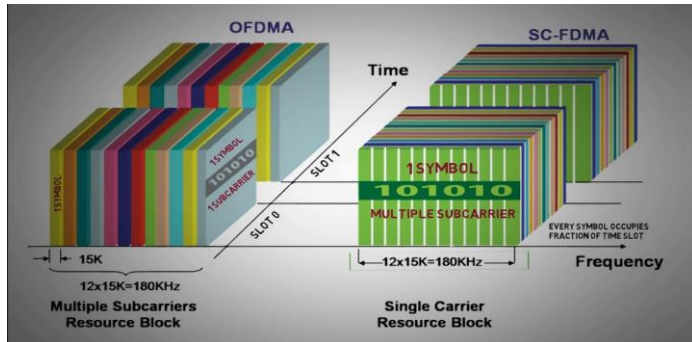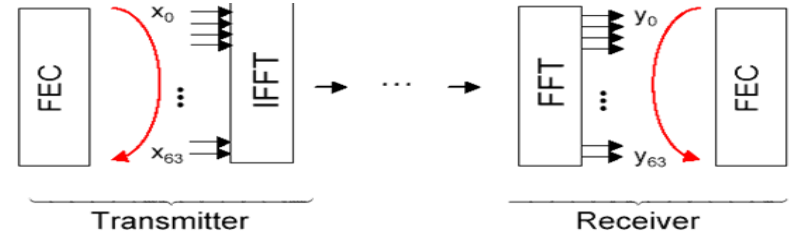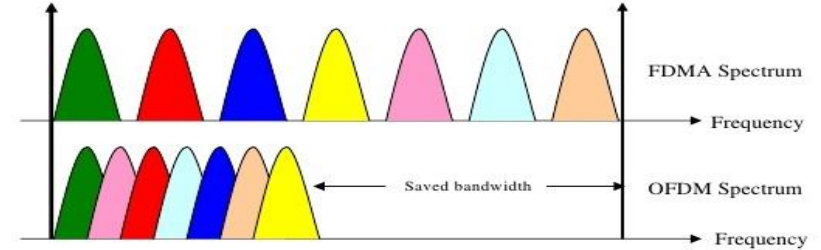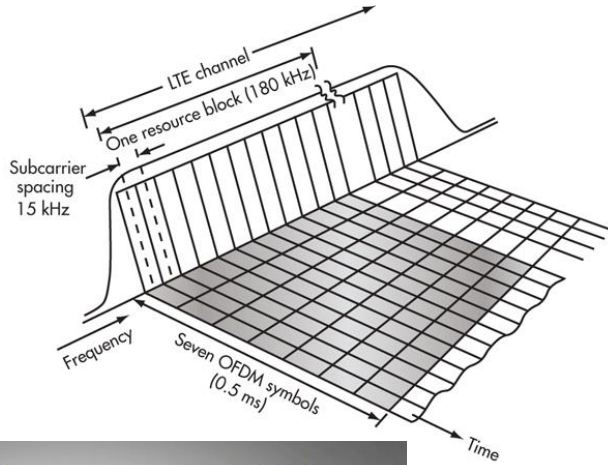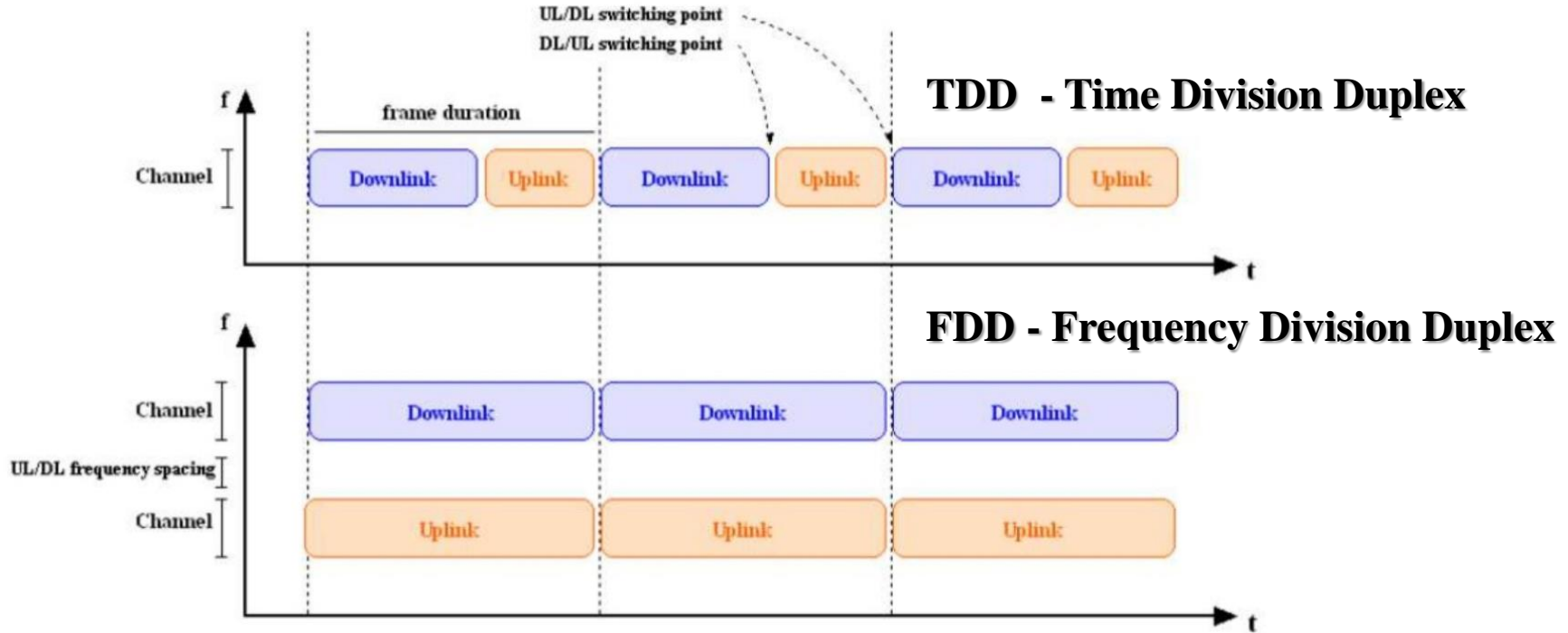
Radio – Environment

RF Channel modelling impacted by

- Fast fading

- Slow fading

- Diffraction

- Reflection

- Scattering

- Doppler
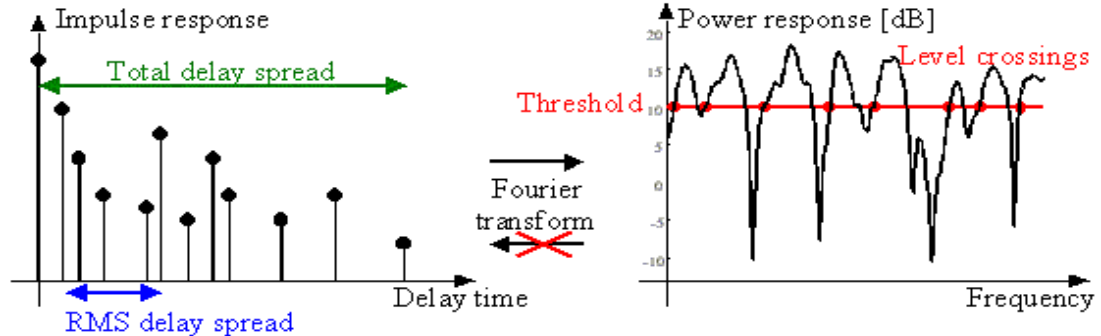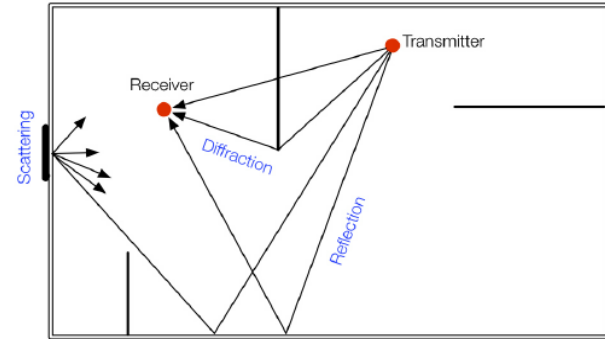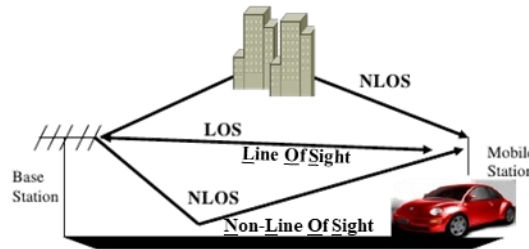
Ref: http://www.wirelesscommunication.nl/reference/chaptr03/ind_chan/rds_est.htm
https://www.slideshare.net/deepakecrbs/ofdma-basics

Radio – Space Diversity

Multiple Antenna Systems

- ”Smart antenna” gain – **Beamforming**
  - This increases the average signal-to-noise (SNR) ratio through focussing energy into desired directions

- “Spatial diversity” gain – **Receive Diversity**
  - Receiving on multiple antenna elements reduces fading problems. The diversity order is defined by the number of decorrelated spatial branches

- “Spatial multiplexing” gain – **Multi-Input Mukti-Output**
  - A matrix channel is created, opening up the possibility of transmitting over several spatial modes of the matrix channel increasing the link throughput at no additional frequency, timer or power expenditure

Radio – Space Diversity

MIMO
Multiple-**I**nput **M**ultiple-**O**utput
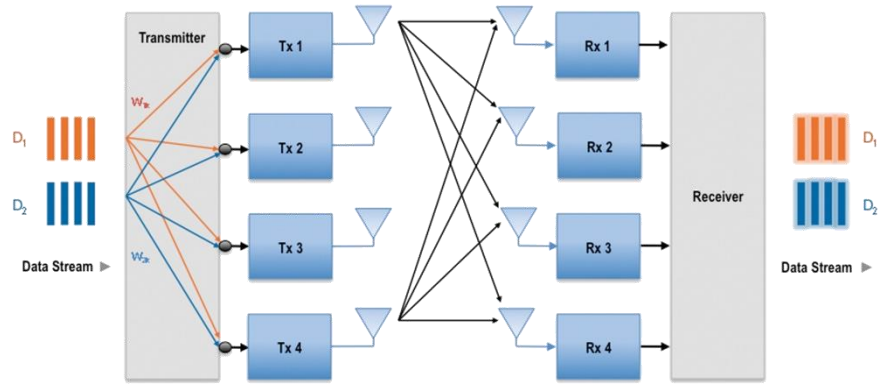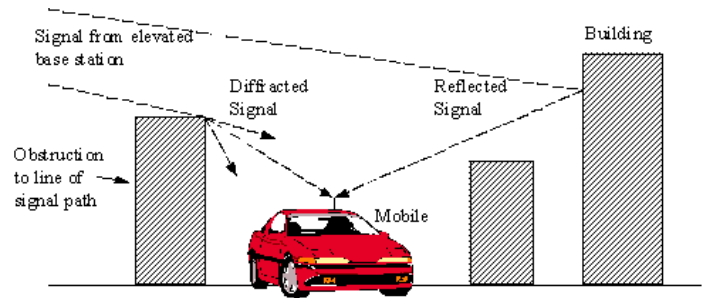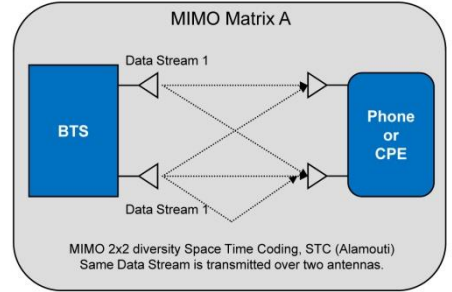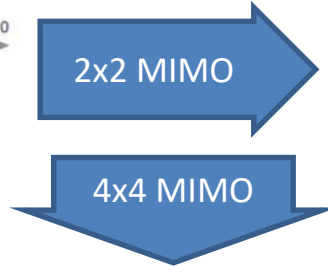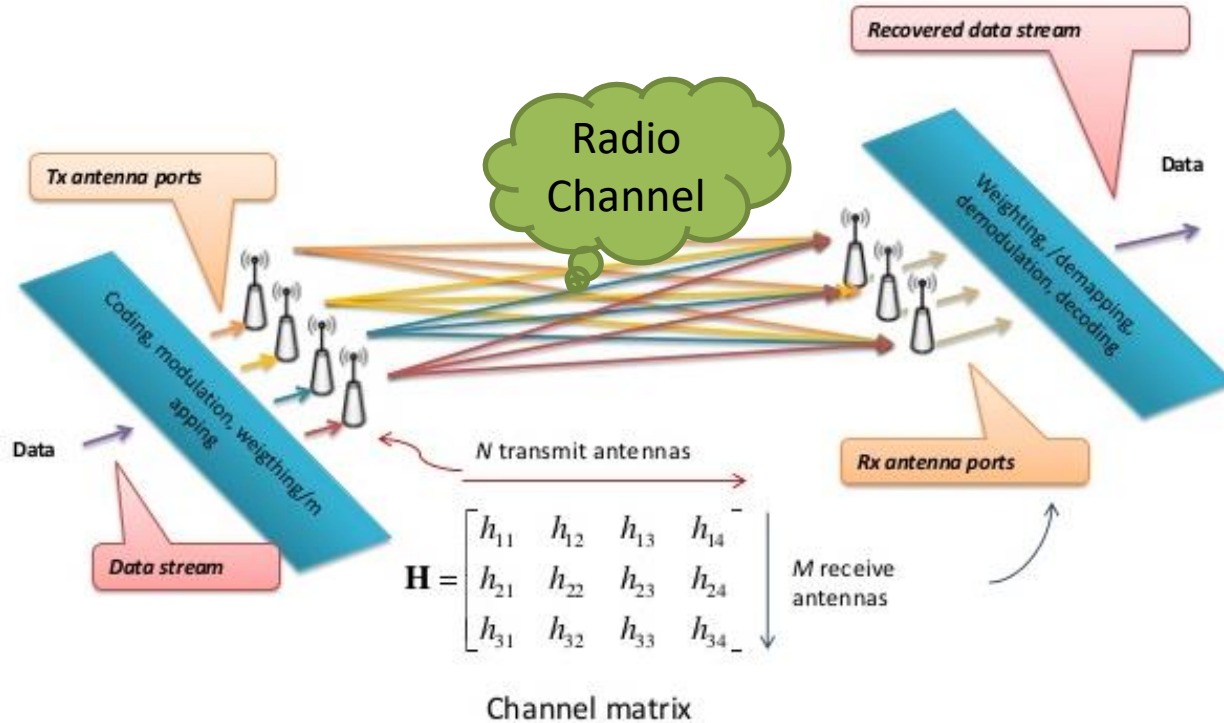
2x2 MIMO

4x4 MIMO

MIMO Matrix A

MIMO 2x2 diversity Space Time Coding, STC (Alamouti)
Same Data Stream is transmitted over two antennas.

Radio – Space Diversity

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Radio – Space Diversity

Ref: https://www.slideshare.net/hamdani2/day-one-ofdma-and-mimo

Radio – Space Diversity

Transmitting independent data over different antennas

Receiver must un-mix the channel

Radio – Space Diversity

$$\mathbf{H} = \begin{bmatrix} h_{11} & h_{12} & h_{13} & h_{14} \\ h_{21} & h_{22} & h_{23} & h_{24} \\ h_{31} & h_{32} & h_{33} & h_{34} \end{bmatrix}$$

rank(**H**) determines how many streams are possible to transmit

Ref: https://www.slideshare.net/hamdani2/day-one-ofdma-and-mimo

Radio – Space Diversity

Ref: https://www.slideshare.net/hamdani2/day-one-ofdma-and-mimo
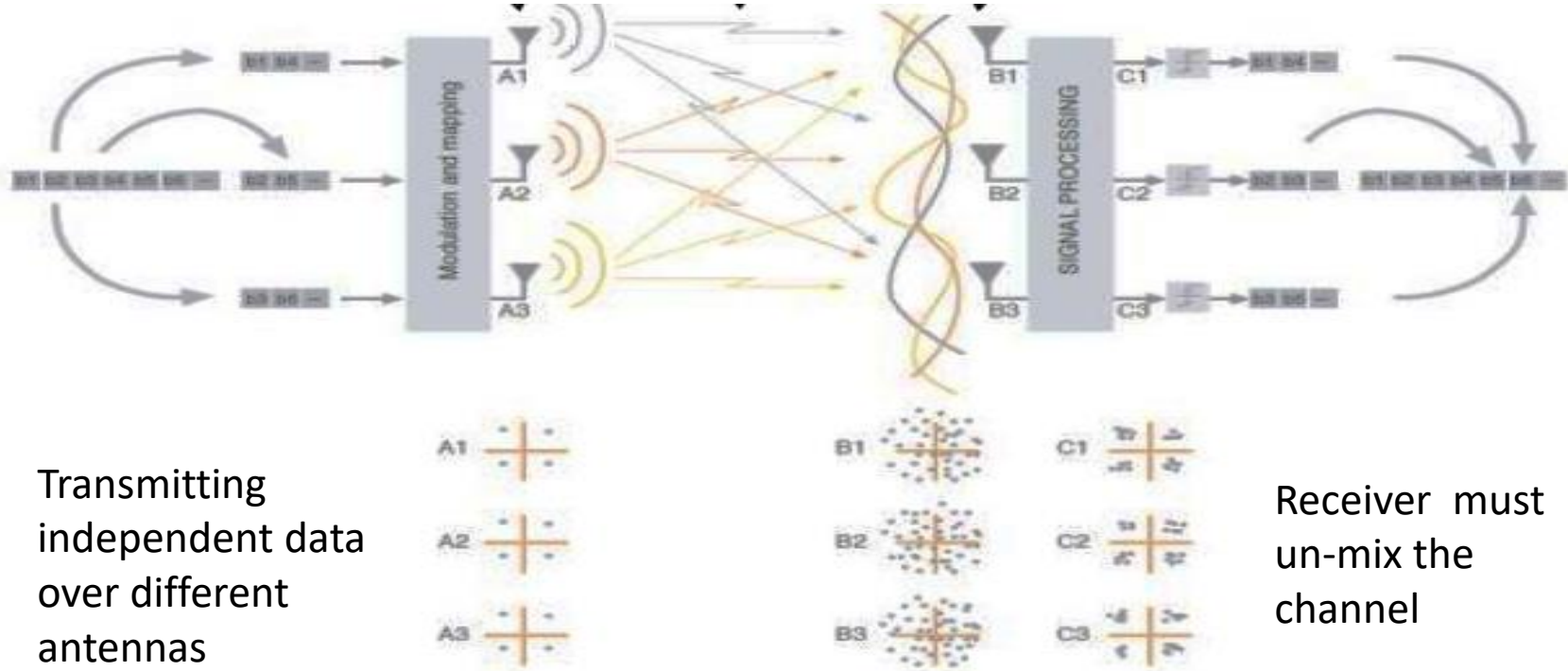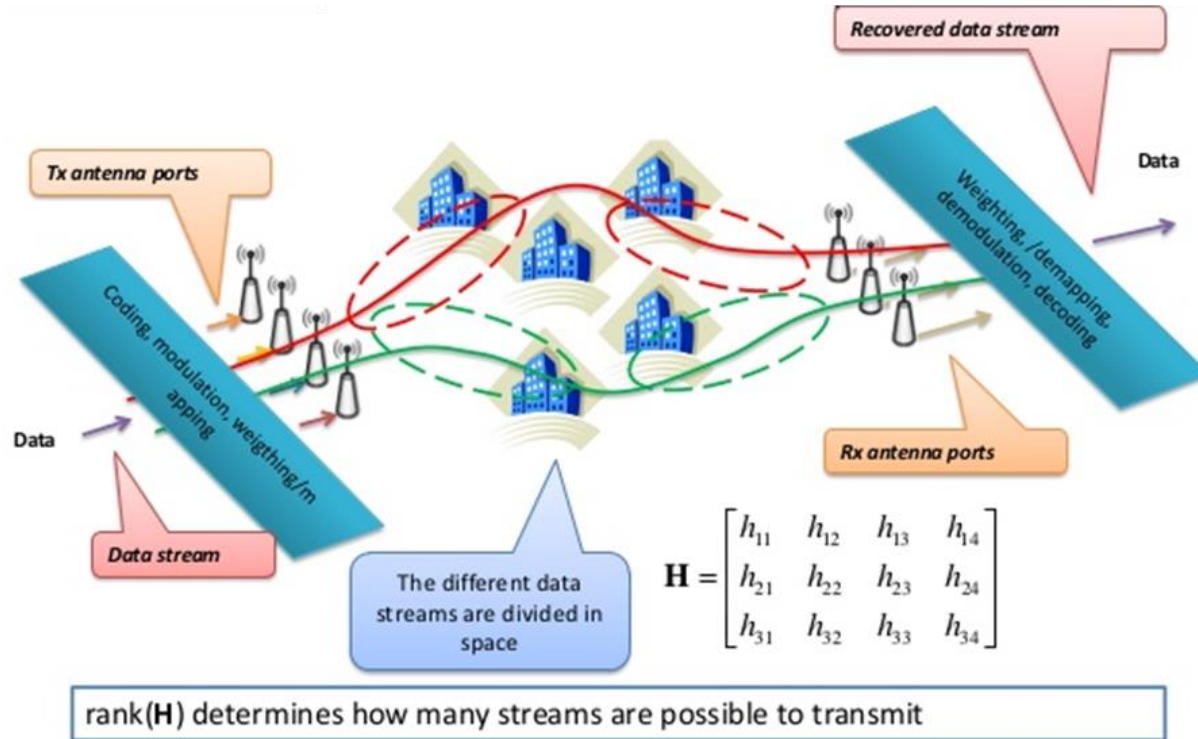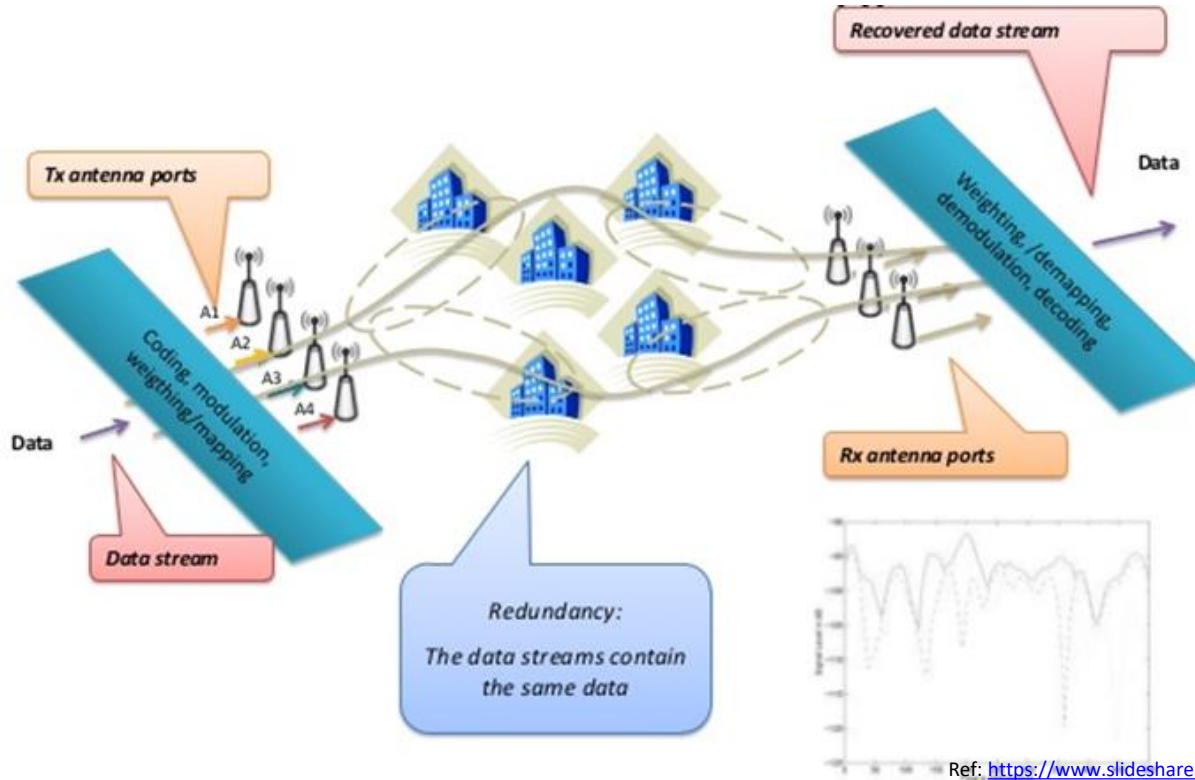
Radio – Space Diversity
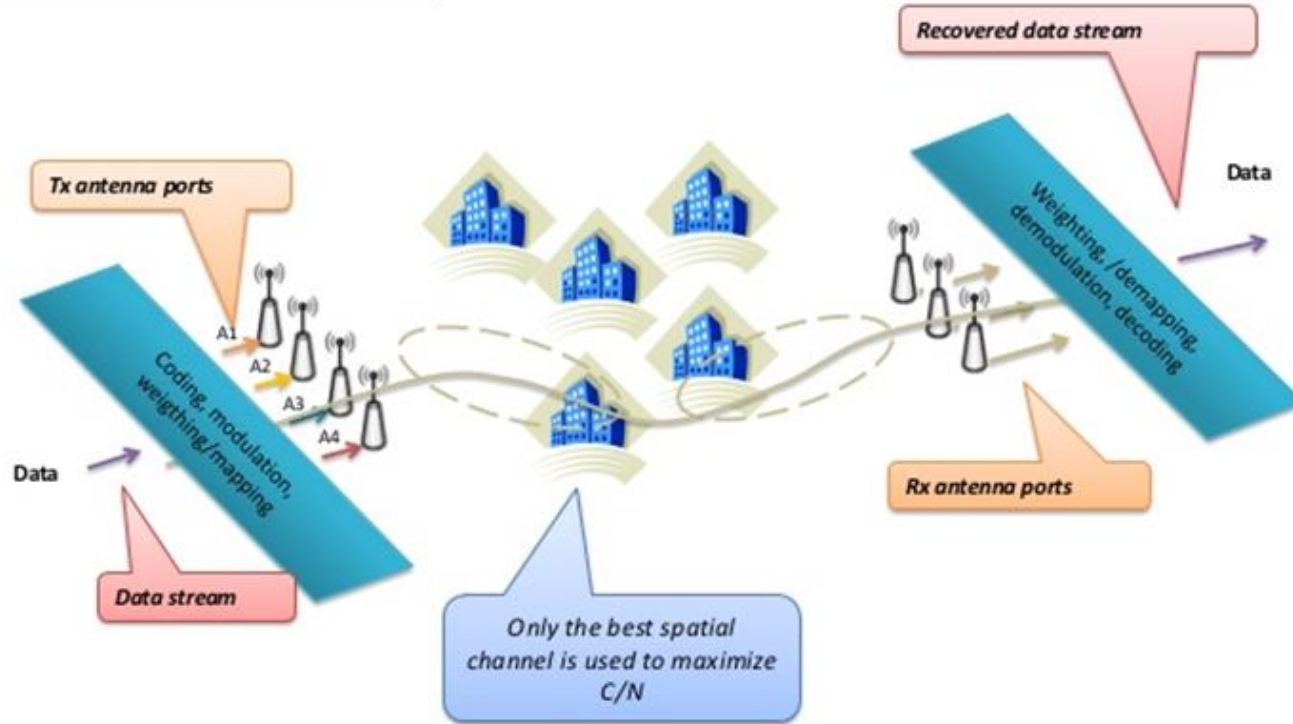
Radio – 5G New Radio Features

Technologies

- Ultra Low Latency

- Massive MIMO

- Full Duplex MIMO

- & …

4G / 5G face off

Ref: https://www.youtube.com/watch?v=LhECDSuXRDs

Radio 5G New Radio

Full Duplex
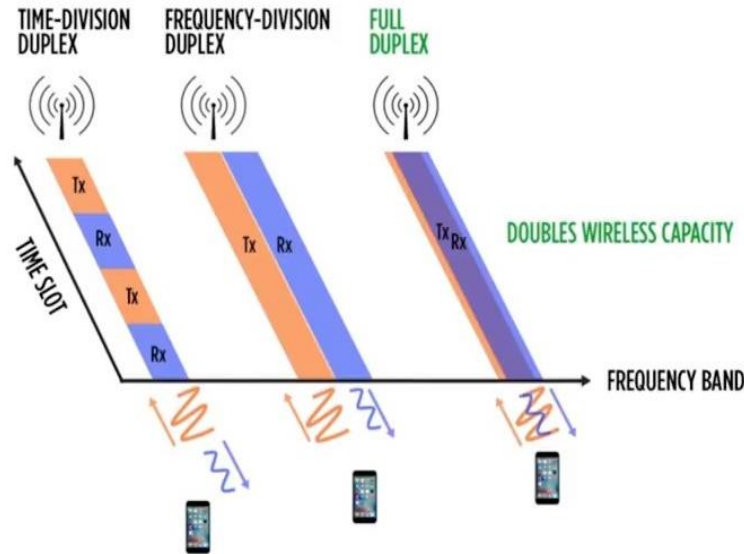
Massive MIMO

#2. Massive MIMO

Radio – 5G Spectrum

Spectrum – OFCOM

- Low bandwidth spectrum at 700 MHz band, for coverage

- 3.4 – 3.8 GHz as a "primary" band, which will provide capacity

- 24.25 – 27.5 GHz as the "pioneer" millimetre wave band to give ultra-high capacity with limited range.
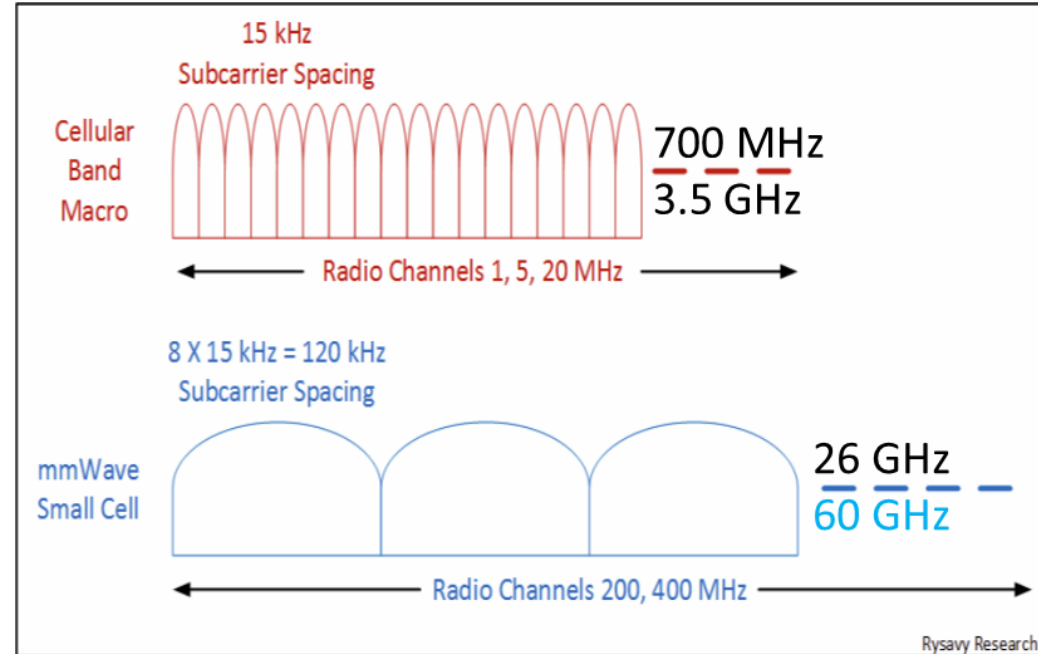
Ref: http://www.rysavy.com/Articles/2017-08-5G-Americas-Rysavy-LTE-5G-Innovation.pdf

3GPP – Evolution to 5G NR

1G ➔ Analogue Radio

2G / GPRS ➔ Circuit Switched (CS) ➔ SMS ➔ Data

3G / UMTS ➔ From CS+Data to High Seed Packet Access (HSPA)

4G / LTE ➔ **3GPP – Rel-10/11/12**

- All IP, No Circuit Switch
- Mobile Broadband
- Voice over LTE (IMS/VoLTE)

4G/LTE Advanced Pro➔ **3GPP – Rel-13 & Beyond**

- Cellular Internet of Things
- Mission Critical Push To Talk
- Dedicated Core Networks, Traffic Steering, …

5G ➔ **3GPP- Rel-15 & Beyond**

- Massive MIMO
- mm-Wave
- 5G-Core & 5G-NR (new Radio)
- Ultra-Low Latency
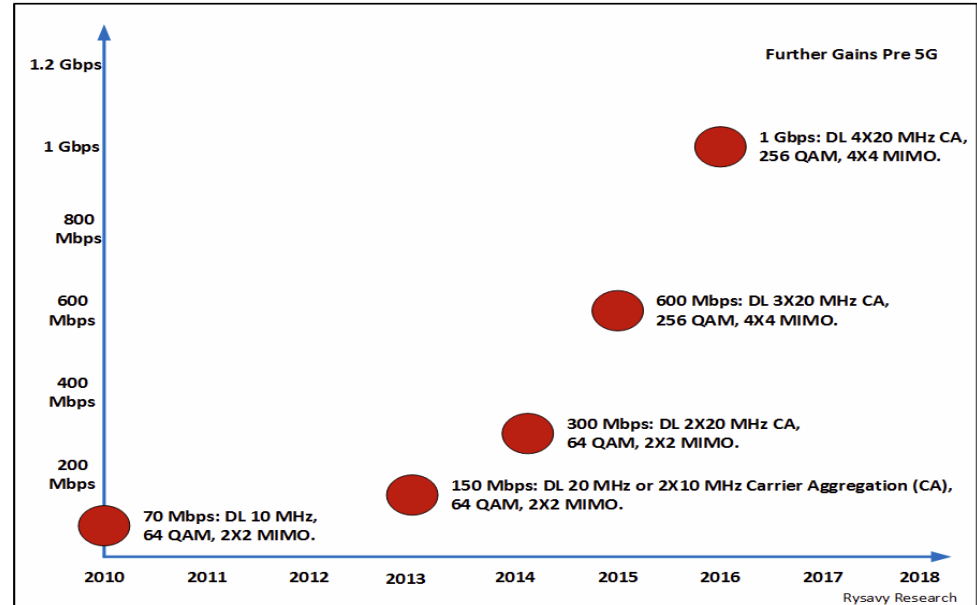
Ref: http://www.rysavy.com/Articles/2017-08-5G-Americas-Rysavy-LTE-5G-Innovation.pdf

Radio – Disruptive Technologies

- IEEE 802.11.xx >>> WiGig
- 2.16GHz Bandwidth, SC or OFDM
- WiGig –802.11ad – 60Ghz

SC-OFDM

BPSK
QPSK
16-QAM

4.62
Gbps
Max.

OFDM

QPSK
16-QAM
64-QAM

6.75
Gbps
Max.
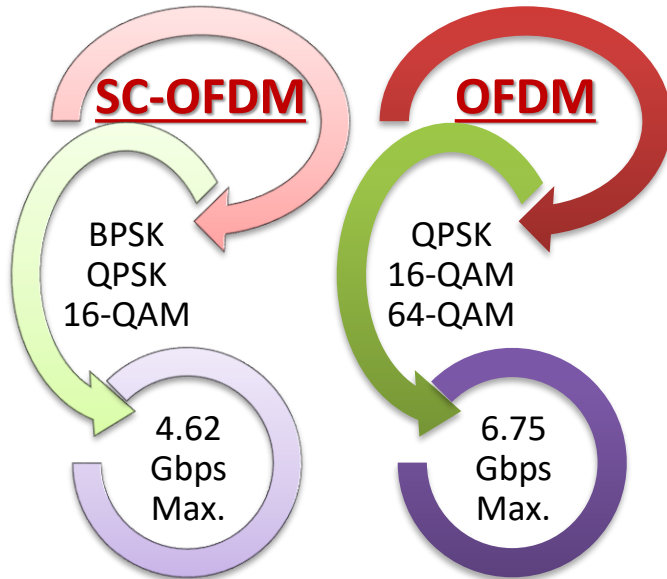
2G Core Network

3G Core Network
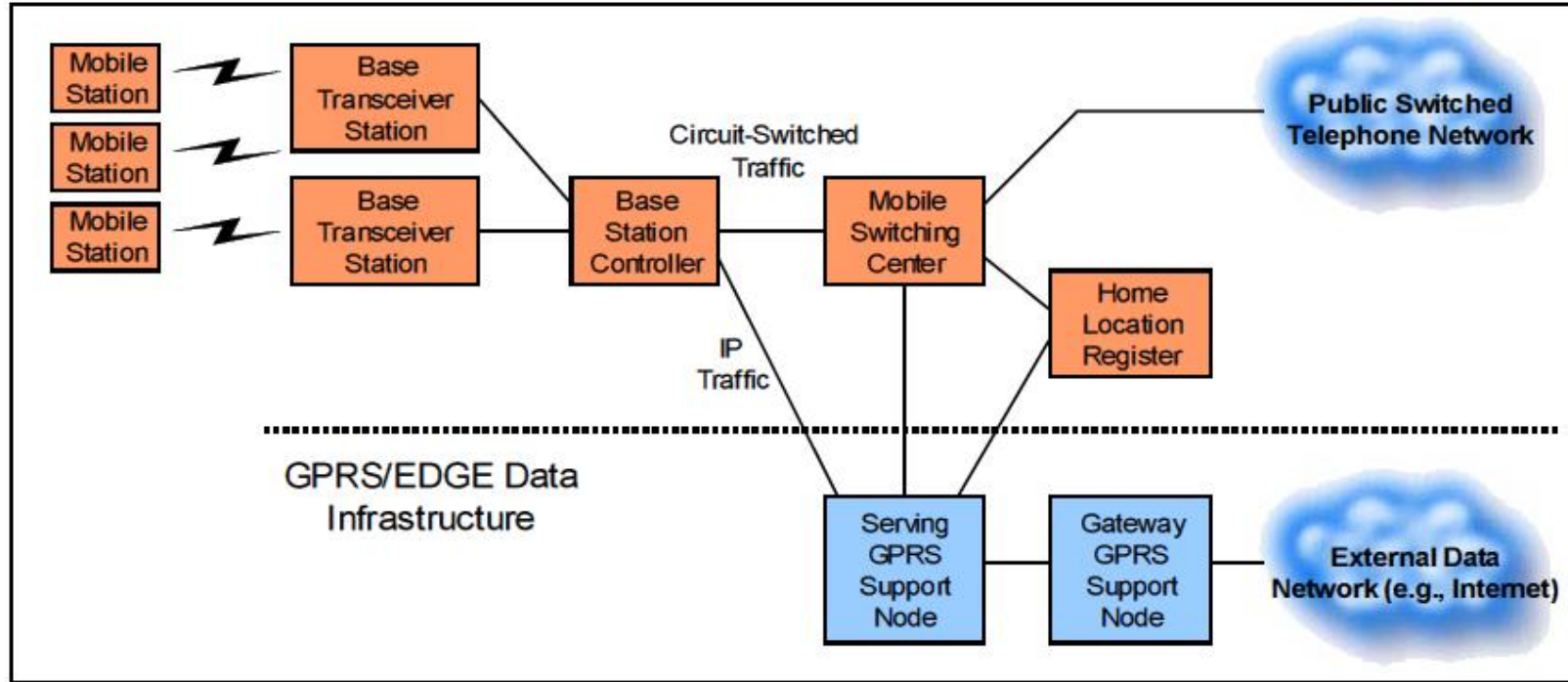
UMTS Rel. 99 Core Network

4G Core Network

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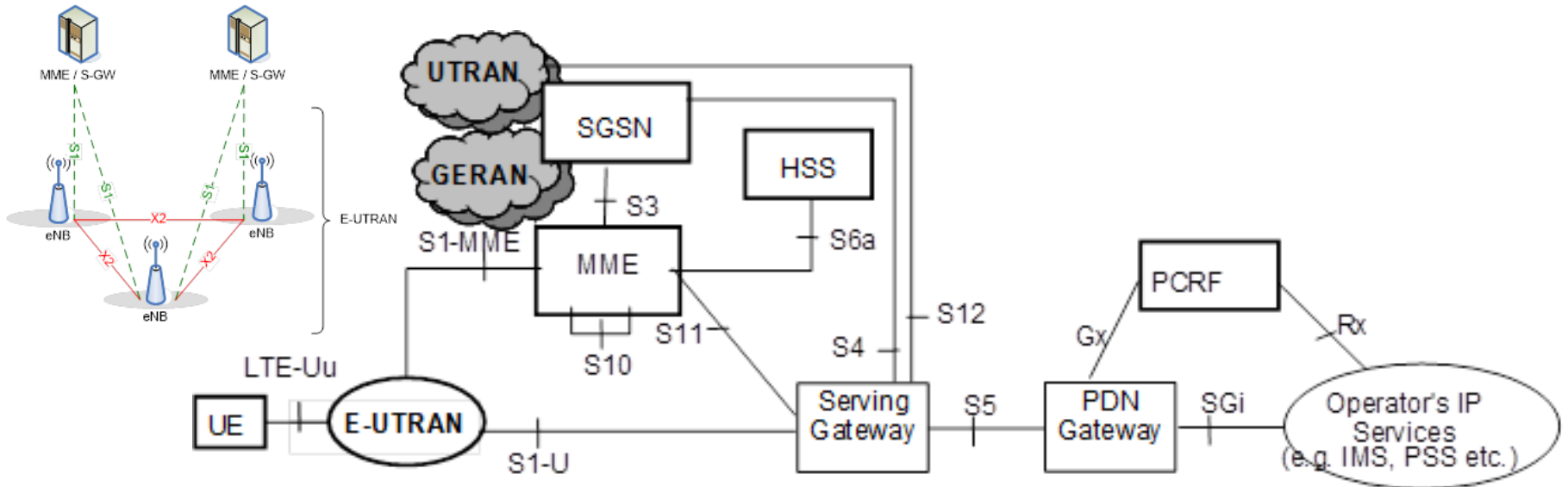
5G Core Network

(AUSF)   Authentication Server Function
(AMF)   Core Access and Mobility Management Function
(DN)   Data network, e.g. operator services or Internet access
(UDSF)   Unstructured Data Storage network function
(NEF)   Network Exposure Function
(NRF)   NF Repository Function
(NSSF)   Network Slice Selection Function
(PCF)   Policy Control function
(SMF)   Session Management Function
(UDM)   Unified Data Management
(UDR)   Unified Data Repository
(UPF)   User plane Function
(AF)   Application Function
 (UE)   User Equipment
((R)AN)   (Radio) Access Network
(5G-EIR) 5G-Equipment Identity Register
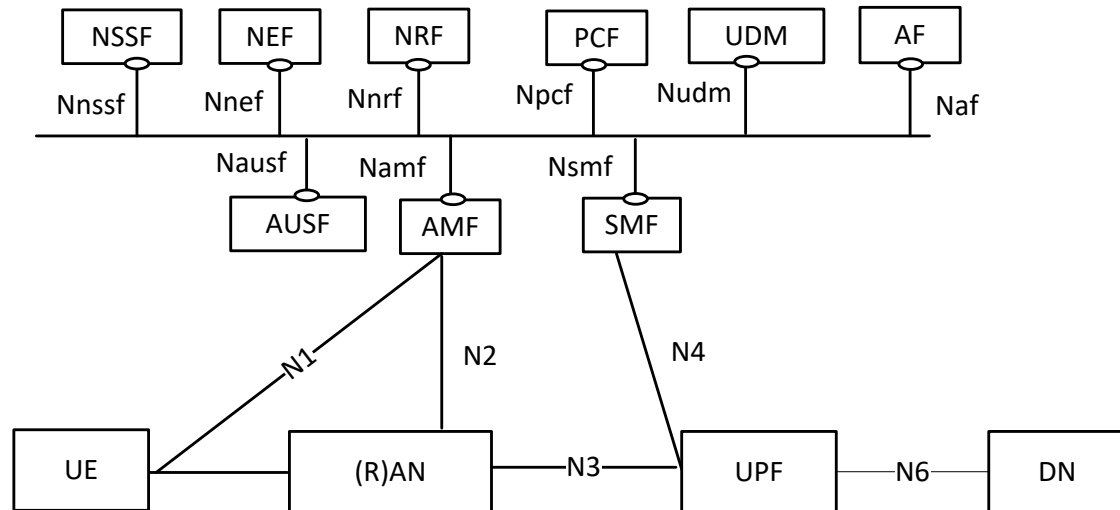
5G Core Network
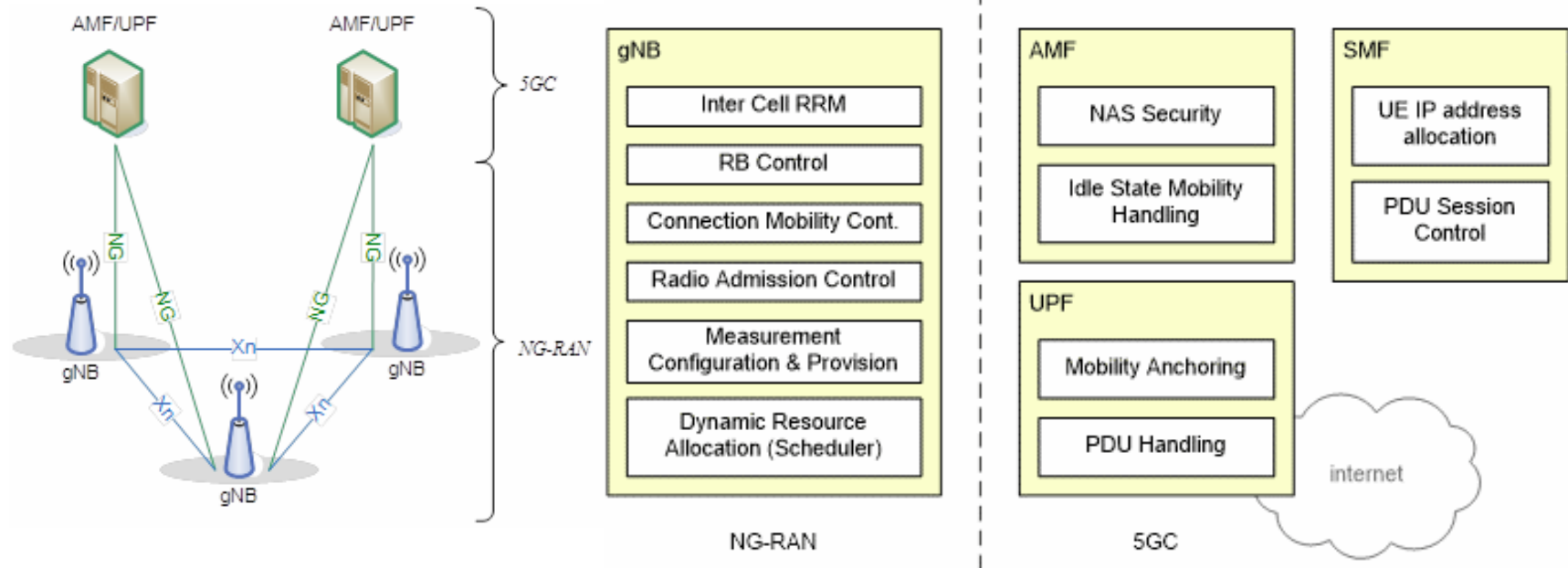
5G Core Network – Access Agnostic

5G Core Network – Access Agnostic

Rysavy Research
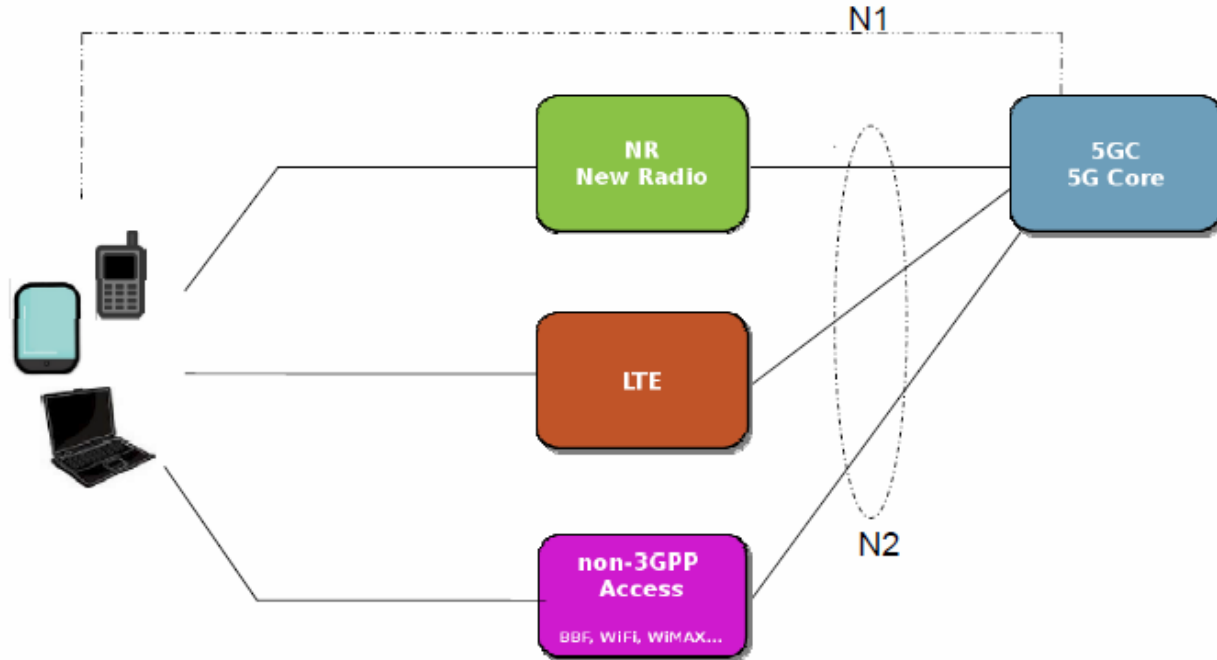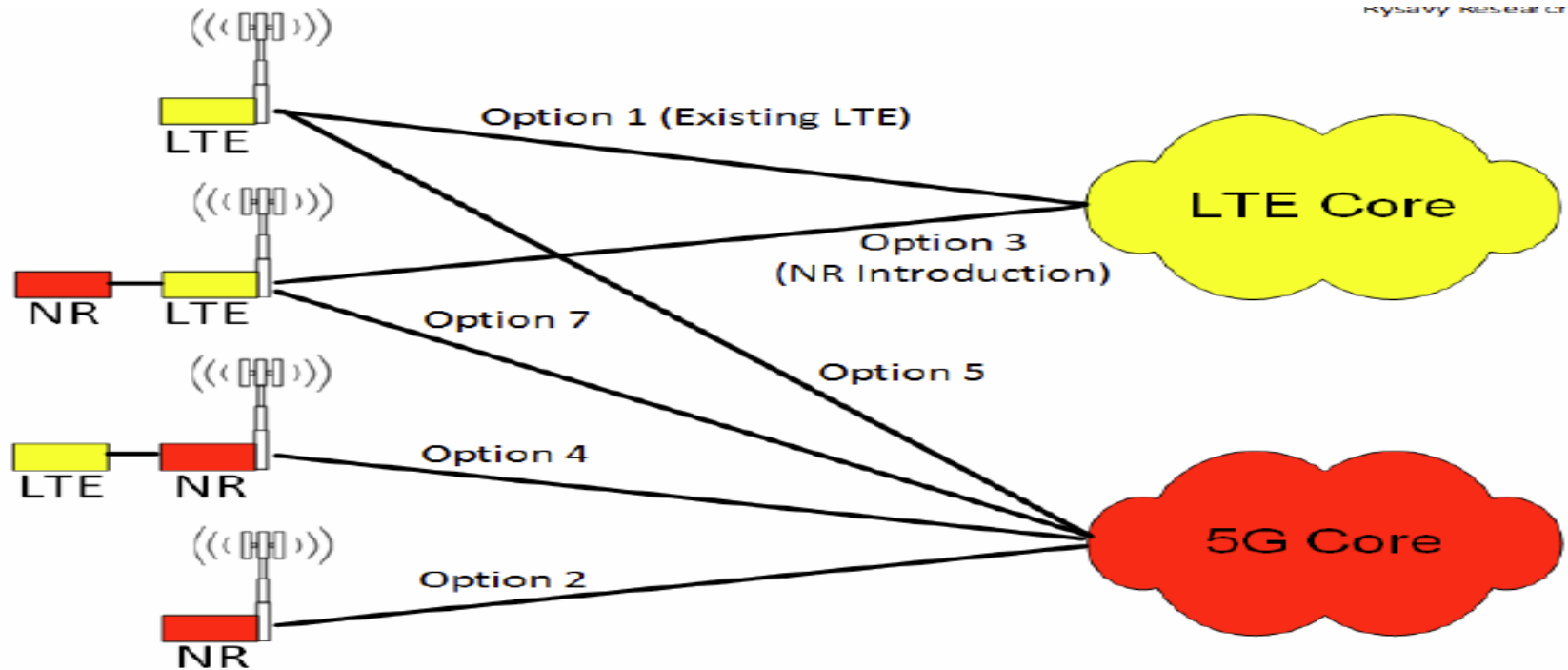
5G Network layers

Three-planes based 5G network architecture
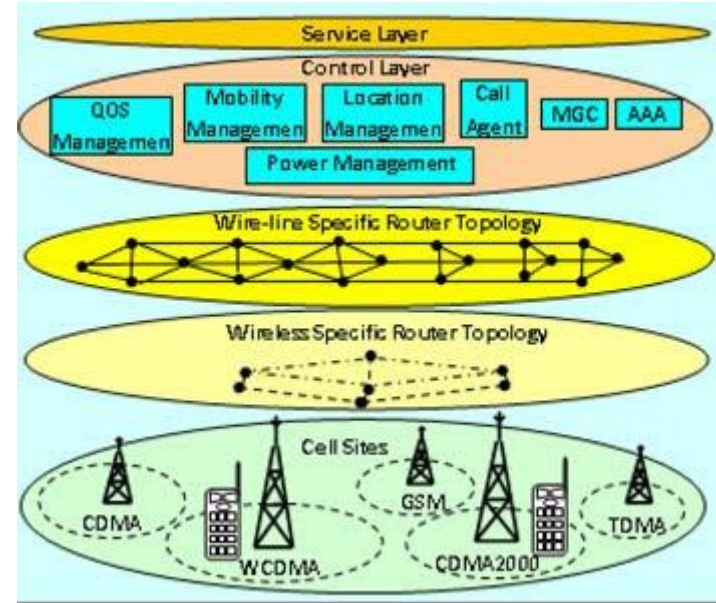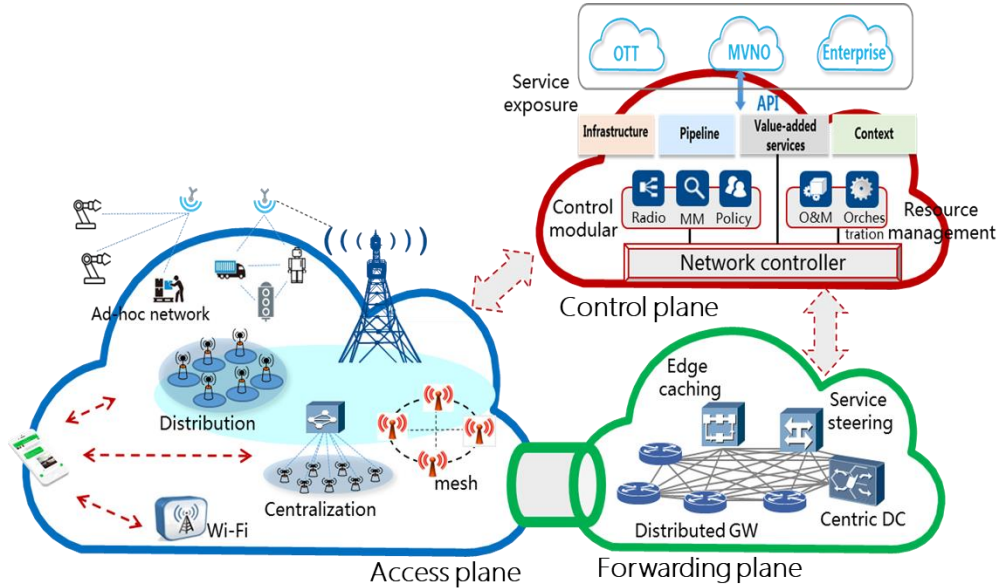
Vendors

Operators

& Now… Gov. Cities, Industries

The stakeholders

Stakeholders

GENERAL DIAGRAM - THE 5G PPP TARGET STAKEHOLDERS

End Users

Network Operators

Technology Vendors

Changing Landscape
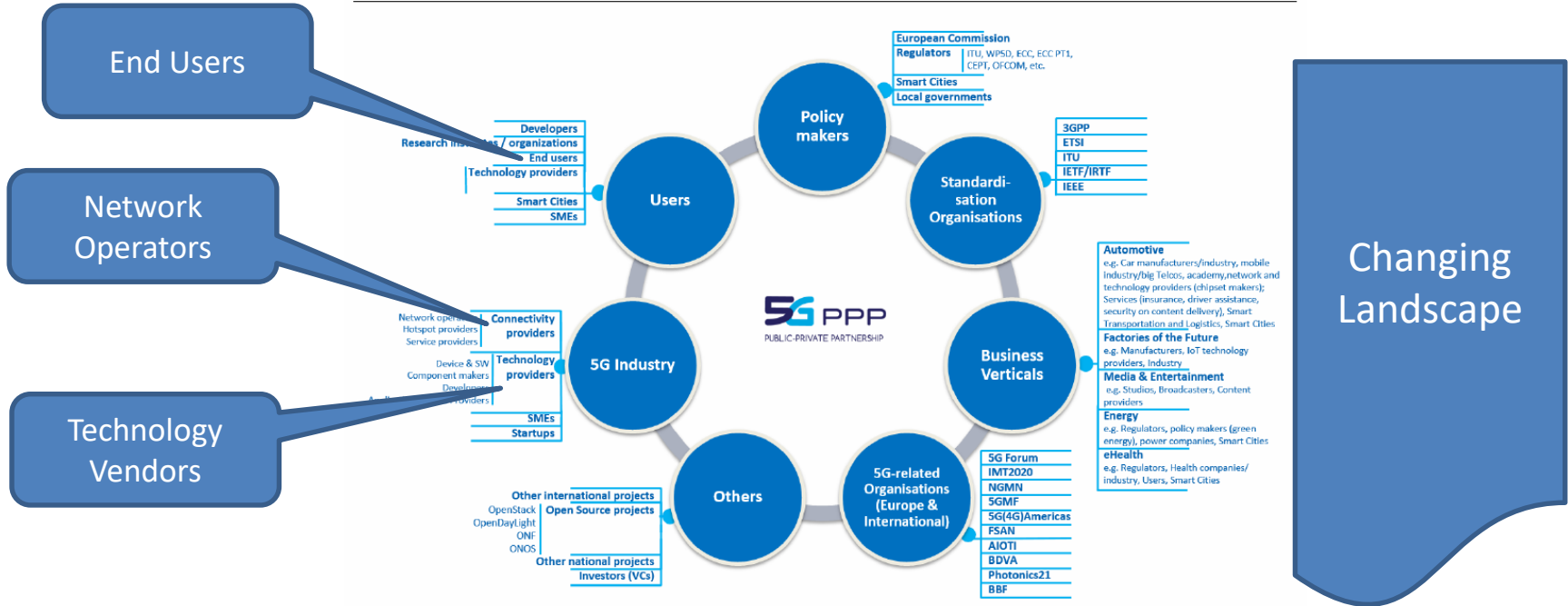
The 5G PPP Target stakeholders

Ref: https://5g-ppp.eu/wp-content/uploads/2016/06/StakeholdersGlossary_v13.pdf

UK's 5G testbed – …gov.uk

Department for Digital, Culture, Media & Sport

Minister for Digital Matt Hancock said:

- We want to be at the head of the field in 5G. This funding will support the pioneering research needed to ensure we can harness the potential of this technology to spark innovation, create new jobs and boost the economy.

- We know 5G has the potential to bring more reliable, ultrafast mobile connectivity, with quicker reaction times and larger data capabilities, and I'm thrilled to announce King's College London and the universities of Surrey and Bristol have agreed to collaborate on this project.

Three universities to develop £16m 5G test network

Ref: https://www.gov.uk/government/news/three-universities-to-develop-16m-5g-test-network

UK's Top Universities

The 5G Hub will be the foundation to create and support projects in multiple areas, such as connected cars and autonomous driving, Industry 4.0, Health and many others, addressing major socio-economic and productivity challenges.

The 5G Hub will use collaborative partnership of working between the three Universities to develop the described 5G capabilities, but ready for expansion to include other organisations from next year onwards.

Ref: https://www.surrey.ac.uk/mediacentre/press/2017/%C2%A316m-investment-will-create-new-5g-hub-partnership-linking-three-universities

5G – University of Surrey

- The University of Surrey's 5G Innovation Centre (5GIC) will lead the project and develop 5G radio technologies and a fully virtualised mobile core network at 3.5GHz and 700 MHz frequency bands for enhanced Mobile Broadband (eMBB) and Ultra Reliable Low Latency Communications (URLLC).
    - virtualised mobile core network
    - 5G radio technologies
    - 3.5GHz and 700 MHz bands
    - enhanced Mobile Broadband (eMBB)
    - Ultra Reliable Low Latency Communications (URLLC).

Ref: https://www.surrey.ac.uk/mediacentre/press/2017/%C2%A316m-investment-will-create-new-5g-hub-partnership-linking-three-universities

5G – University of Bristol

- Bristol University will deploy 5G capability in the extensive Smart City and Smart Campus test beds in the city, targeting full 5G and fibre infrastructure convergence.

- Bristol will also contribute to the key Software Defined Network technologies for end-to-end 5G service delivery.

- Public demonstrators will be the focus of delivery, targeting media, gaming and transport applications.
    - 5G Smart City and Smart Campus test beds
    - full 5G and fibre infrastructure convergence
    - Software Defined Network technologies
    - Public demonstrators

Ref: http://www.bristol.ac.uk/news/2017/july/5g-test-network.html

5G – Kings College London University

- King's College London is driving the vision for ultra-low latency 5G tactile internet developments with Internet of Skills applications.

- Through the King's College London 5G Tactile Internet Lab, the university is also pioneering several important 5G co-design approaches with various industries, including smart cities, smart transport, performing arts and health.
  - ultra-low latency 5G tactile internet
  - smart cities & smart transport
  - performing arts
  - eHealth.

University of Bristol's 5G Testbed

The use cases for future 5G networks demand diverse range of requirements that can or may be overcome with automation and dynamic allocation of core network and infrastructure resources.

Ref: http://www.bristol.ac.uk/smart
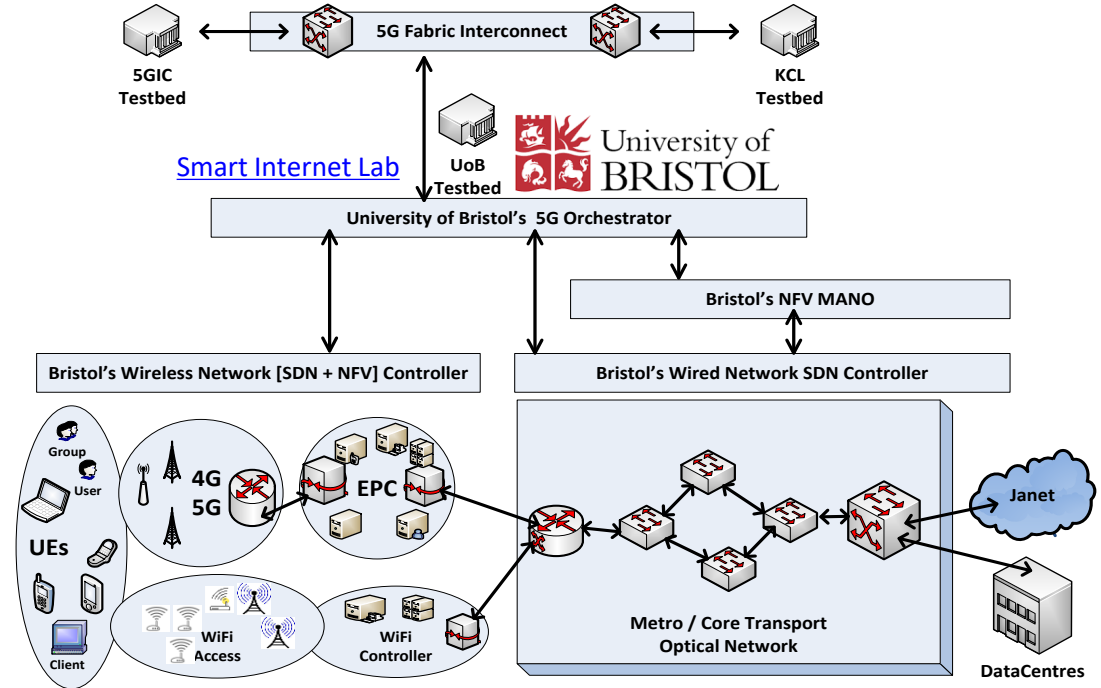
ETSI Technology Clusters

ETSI defines the standards for variety of technology sectors based on ITU recommendations –

- The basic performance criteria for 5G systems have been set by the ITU in their IMT-2020 Recommendation.

- ITU-R M.2083 describes three overall usage scenarios for 5G systems:

Ref: http://www.etsi.org/technologies-clusters

ETSI

1. **Enhanced Mobile Broadband** to deal with hugely increased data volumes, overall data capacity and user density

2. **Massive Machine-type Communications** for the IoT, requiring low power consumption and low data rates for very large numbers of connected devices

3. **Ultra-reliable and Low Latency Communications** to cater for safety-critical and mission critical applications

Ref: http://www.etsi.org/technologies-clusters
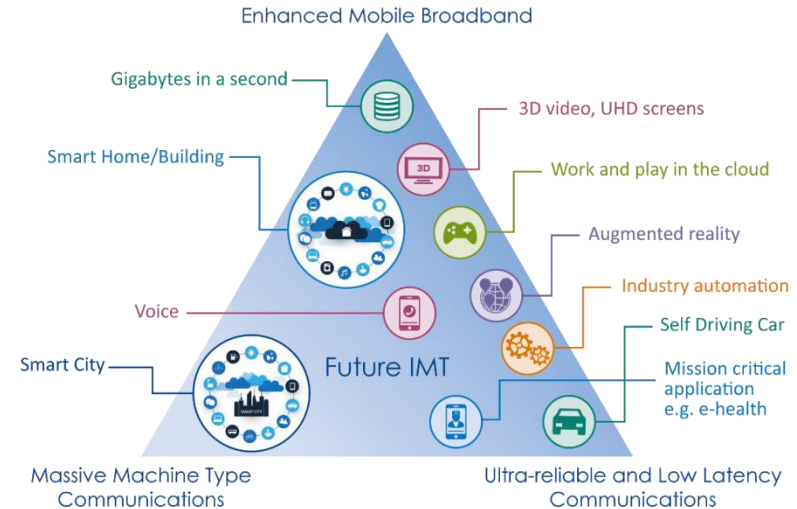
ETSI

Stakeholder activity reported by ETSI

Public Safety (blue light):	Broadcasting/media delivery:	
- Very active in ETSI/3GPP - Influential in LTE standards	- Active in ETSI/3GPP - New activity in ISG MBC	Very active

Rail industry:	Automotive industry:	Education:	
- Active in ETSI - Recent contributor to 3GPP	- Active in ETSI - Recent contributor to 3GPP	- Contributions made to 3GPP via individual members	Active

Aeronautical (drones):	Health/wellbeing:	Utilities:	
- Peripheral to 3GPP	- Present in ETSI but low level of activity/influence	- Institutional relationship - Low standards influence	Present

Factory automation (Industry 4.0):	Agriculture:	Exploration, mining:	
- Institutional relationship - Low standards influence			Low activity

Ref: http://www.etsi.org/technologies-clusters

Radio 3GPP Releases

Towards 5G - Chip maker's view

Accelerating 5G NR, the global standard for 5G

QUALCOMM

3GPP 5G NR R14 Study Item

R15 5G NR Study Items

R16+ 5G NR study items continue to evolve/expand 5G NR

R15 5G work items | R16 5G work items | R17+5G evolution

We Are Here

5G NR Standalone (SA) mode

Intermediate milestone for 5G NR Non-Standalone (NSA) mode

5G NR R15 launches' | 5G NR R16 launches

Enabling deployments as early as 2019

Gigabit LTE and LTE IoT deployments

Continue to evolve LTE in parallel to become a critical part of the 5G Platform

2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022

1. Forward compatibility with R16 and beyond

15

Ref: https://www.youtube.com/watch?v=LhECDSuXRDs

Towards 5G - Vendor's view

Ref: https://www.youtube.com/watch?v=LhECDSuXRDs

5G-PPP

NGMN

3GPP

Standardisation

3GPP – Defined Use Cases
massive Internet of Things

focuses on use cases with massive number of devices (e.g., sensors and wearables). This group of use cases is particularly relevant to the new vertical services, such as

- smart home and city
- smart utilities
- e-Health
- smart wearables
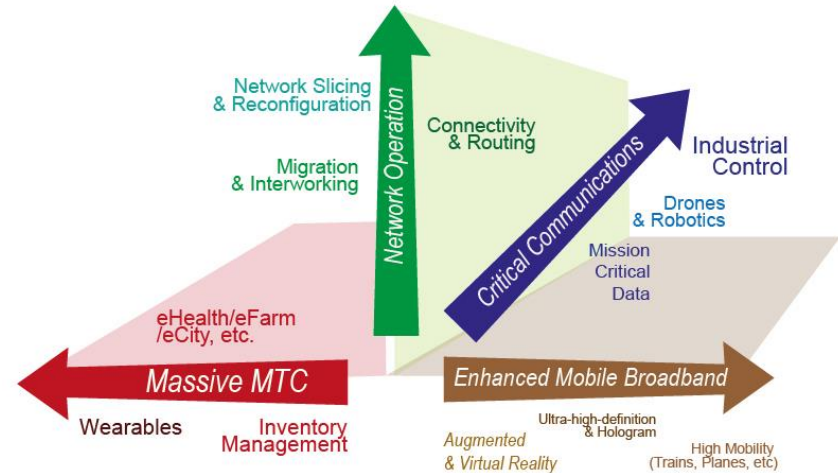
TR 22.861:

3GPP – Defined Use Cases
Critical Communications

The main areas where improvements are needed for are

- latency
- reliability
- availability

This is to enable, for example, **industrial control** applications and **tactile Internet**.
These requirements can be met with

- an improved radio interface
- optimized architecture
- dedicated core and radio resources.
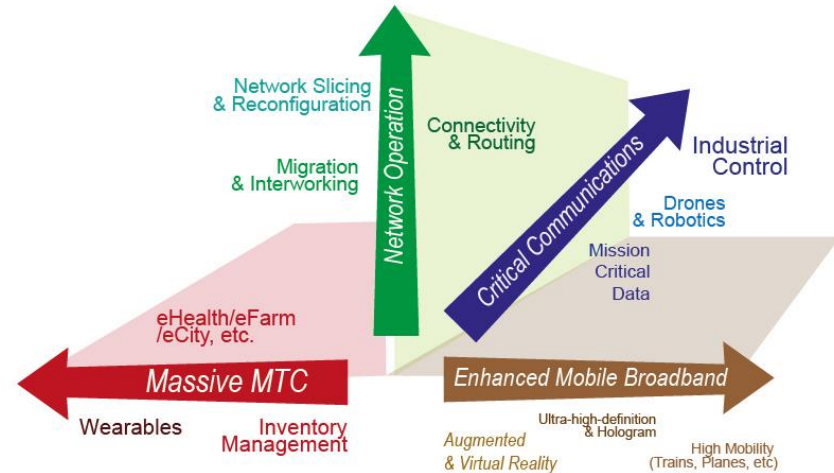
TR 22.862

3GPP – Defined Use Cases
enhanced Mobile Broadband

includes a number of different use case families related to

- higher data rates

- higher density

- deployment and coverage

- higher user mobility

- devices with highly variable user data rates

- fixed mobile convergence

- small-cell deployments.
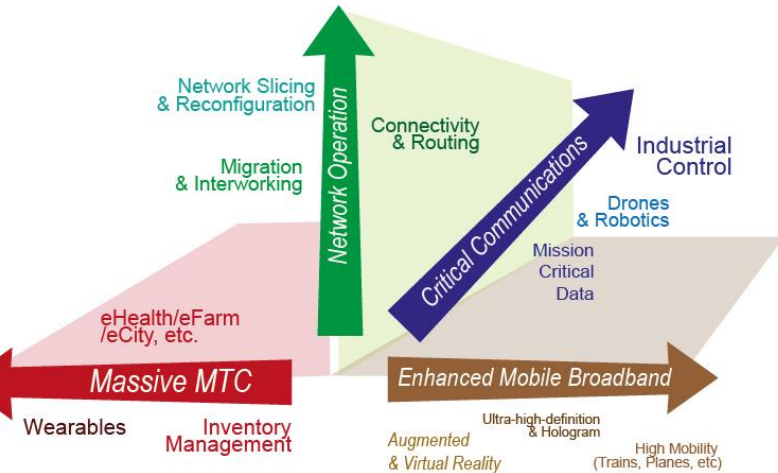
TR 22.863

3GPP – Defined Use Cases
Network Operation

The use case group addresses the functional system requirements, including aspects such as:

- flexible functions and capabilities

- new value creation

- migration and interworking

- optimizations and enhancements

- security
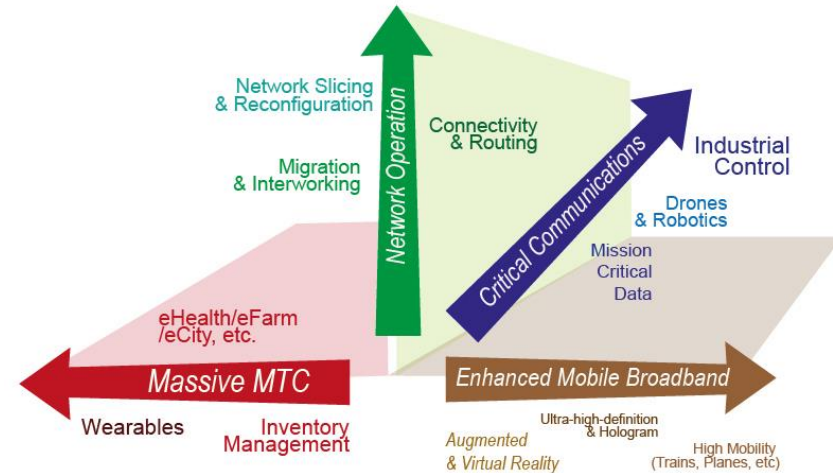
TR 22.864

3GPP – 5G Requirements

Basic 5G System

- Mobility Management & Roaming

- Session Management & Session Continuity

- QoS & Policy Frameworks

- Access Agnostic

- Interworking & Migration – "Option 3"

- IMS / VoLTE support

3GPP - Release for 5G

3GPP Release 14
5G Study Items

Pre-Standard Deployments

3GPP Release 15
5G Non Standalone

18 months

Release 15 5G
NSA Deployments

Release 15
Standalone

18 months

Release 15 Standalone
Deployments

Standardization

3GPP Release 16
5G Phase 2

18 months

Release 16
Deployments

3GPP Release 17
5G Enhancements

2016   2017   2018   2019   2020   2021

http://www.rysavy.com/Articles/2017-08-5G-Americas-Rysavy-LTE-5G-Innovation.pdf

3GPP – 5G Challenges

- Software & Service centric transformation
  - Telecoms -> Multiple Stakeholders
  - Bit Pipe -> Enabler Platform
  - Phones -> Things
  - Procedures -> Services
  - Protocols -> APIs
  - Dedicated Hardware -> Orchestrated Resources
    - Network Function -> Virtualization
    - Network -> Slice

Radio 1G to 5G

1G
ETACS / AMP
- Analogue

2G
GSM
- Single Carrier
- GMSK / TDMA
- Circuit Switched (CS)
- SMS

3G
UMTS
- Single Carrier
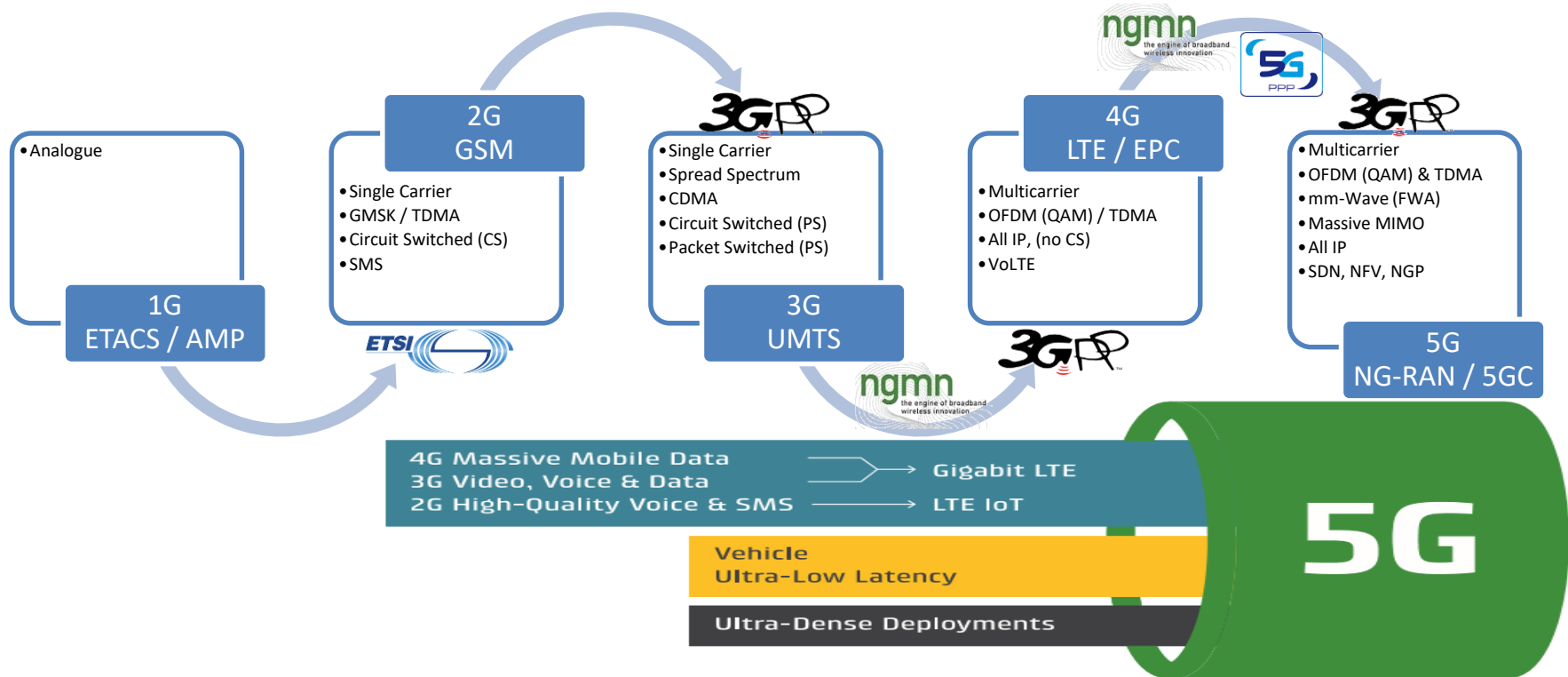- Spread Spectrum
- CDMA
- Circuit Switched (PS)
- Packet Switched (PS)

4G
LTE / EPC
- Multicarrier
- OFDM (QAM) / TDMA
- All IP, (no CS)
- VoLTE

5G
NG-RAN / 5GC
- Multicarrier
- OFDM (QAM) & TDMA
- mm-Wave (FWA)
- Massive MIMO
- All IP
- SDN, NFV, NGP

4G Massive Mobile Data
3G Video, Voice & Data ⟶ Gigabit LTE
2G High-Quality Voice & SMS ⟶ LTE IoT

Vehicle
Ultra-Low Latency

Ultra-Dense Deployments

5G

Technology Enablers for 5G

Users of 5G networks

The opportunities

Subscribers & Technology

Wireless Subscribers by Technology, 2005-2019

Ref: https://www.youtube.com/watch?v=LhECDSuXRDs

Devices Trend


Ref: https://www.youtube.com/watch?v=LhECDSuXRDs
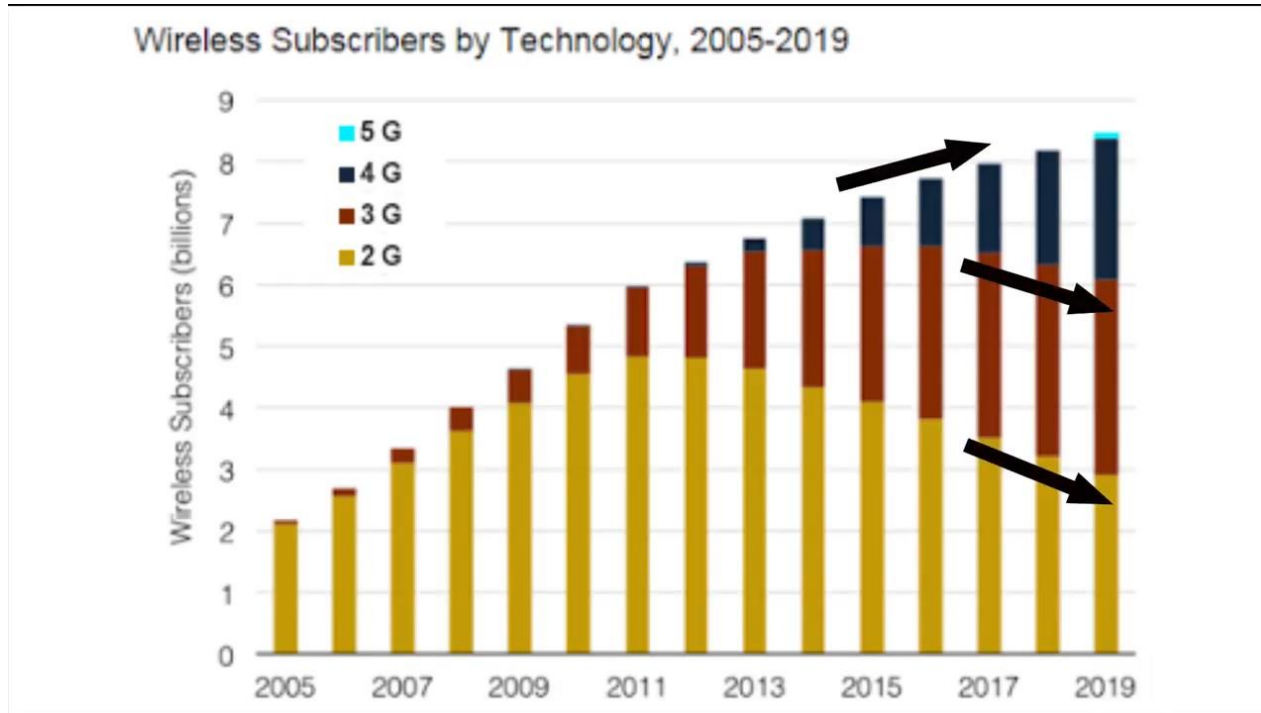
Technology Enablers

- mm-Wave Radios
- Massive MIMO Radio Solutions
- Spectrum (UK)
  - 3.4 to 3.8 GHz (400 MHz)
  - 24.25 to 27.5 GHz (3.25 MHz)
- 5G New Radio Physical Layer
  - 3GPP Rel-13 vs Rel-15

- Software Defined Networks (SDN)
- Virtualising Network Functions (NFV / VNF)
- Separation of User and control plane
- Network slicing to enable service creation with network functions and resources
- Low latency services
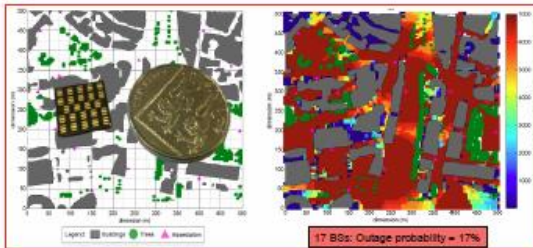- Massive

Technology Enablers - Research

Smart Internet Lab
www.bristol.ac.uk/smart
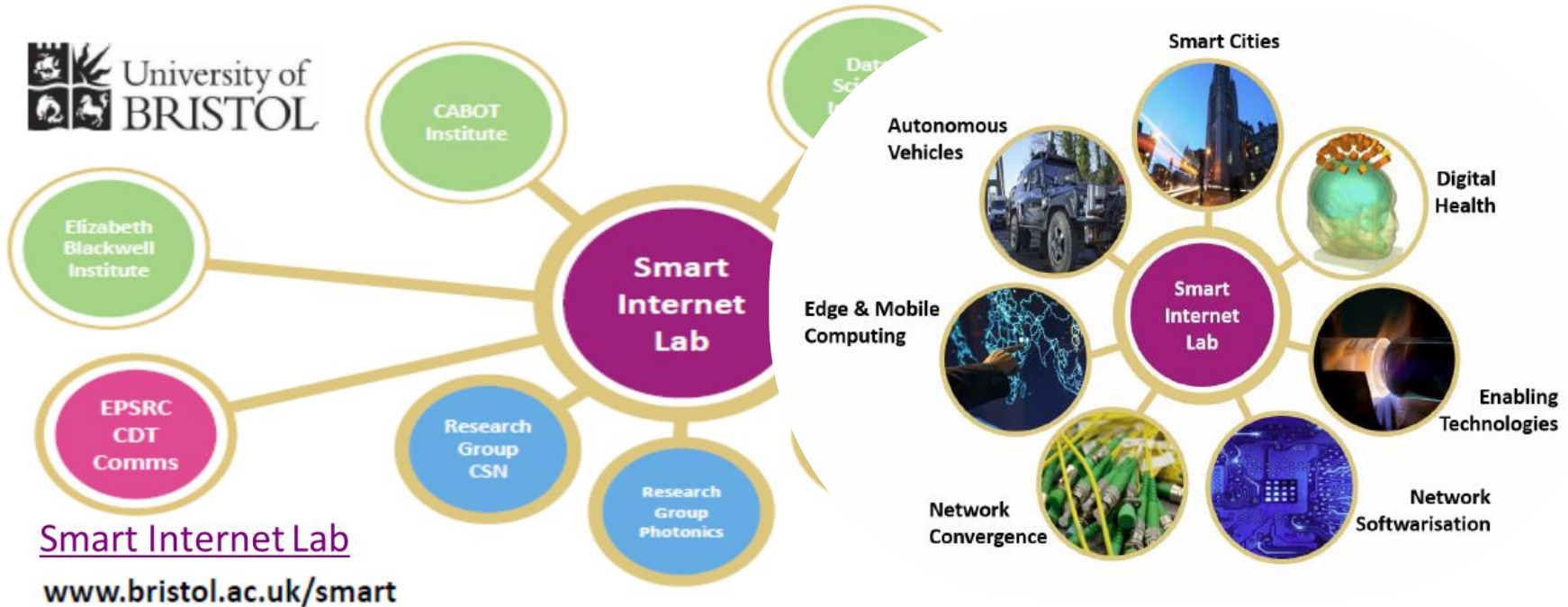
Technology Enablers - Radio
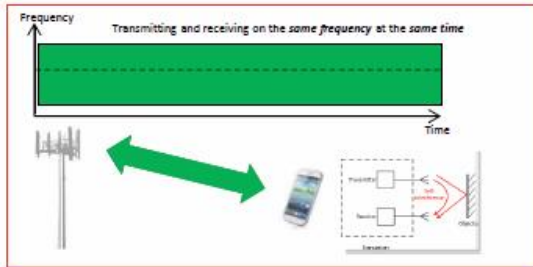
Full Duplex

Massive MIMO

Millimetre Wave

Linear & Efficient RF

Smart Internet Lab
Ref: http://www.bristol.ac.uk/smart
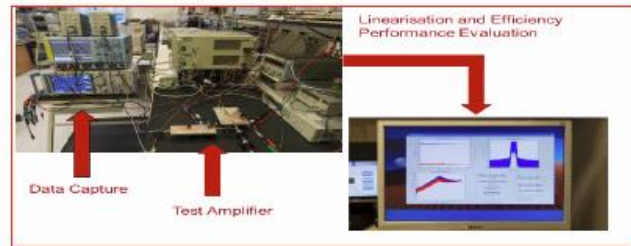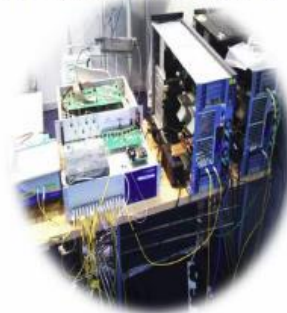
Technology Enablers – Core Networks

Programmable Ultra High Speed Optical Networks

Optical Data Center   Network Convergence   Software Defined Networking

Smart Internet Lab
Ref: http://www.bristol.ac.uk/smart

NGMN – Business Models

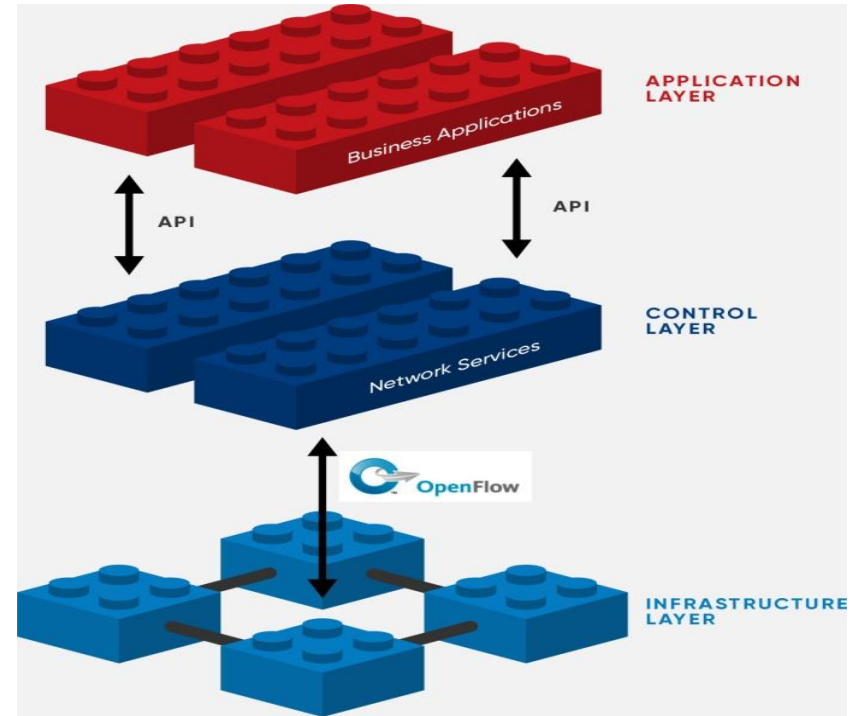| Role	Business Models	
Asset Provider	**XaaS: IaaS, NaaS, PaaS** Ability to offer to and operate for a 3rd party provider different network infrastructure capabilities (Infrastructure, Platform, Network) as a Service.	**Network Sharing** Ability to share Network infrastructure between two or more Operators based on static or dynamic policies (e.g. congestion/excess capacity policies)
Connectivity Provider	**Basic Connectivity** Best effort IP connectivity in retail (consumer/business) & wholesale/MVNO	**Enhanced Connectivity** IP connectivity with differentiated feature set (QoS, zero rating, latency, etc..) and enhanced configurability of the different connectivity characteristics.
Partner Service Provider	**Operator Offer Enriched by Partner** Operator offering to its end customers, based on operator capabilities (connectivity, context, identity etc.) enriched by partner capabilities (content, application, etc..)	**Partner Offer Enriched by Operator** Partner offer to its end customers enriched by operator network and other value creation capabilities (connectivity, context, identity etc.)

NGMN – Value Creation
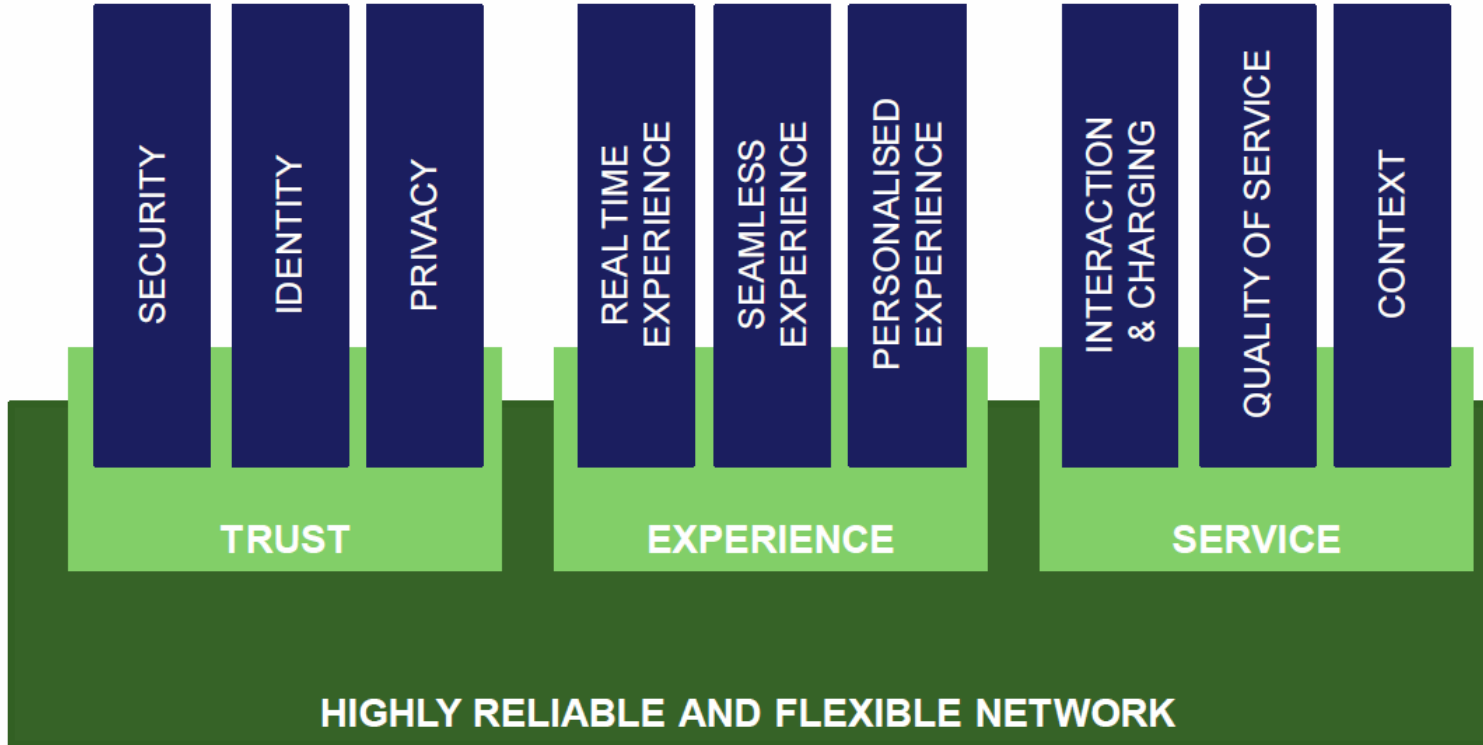
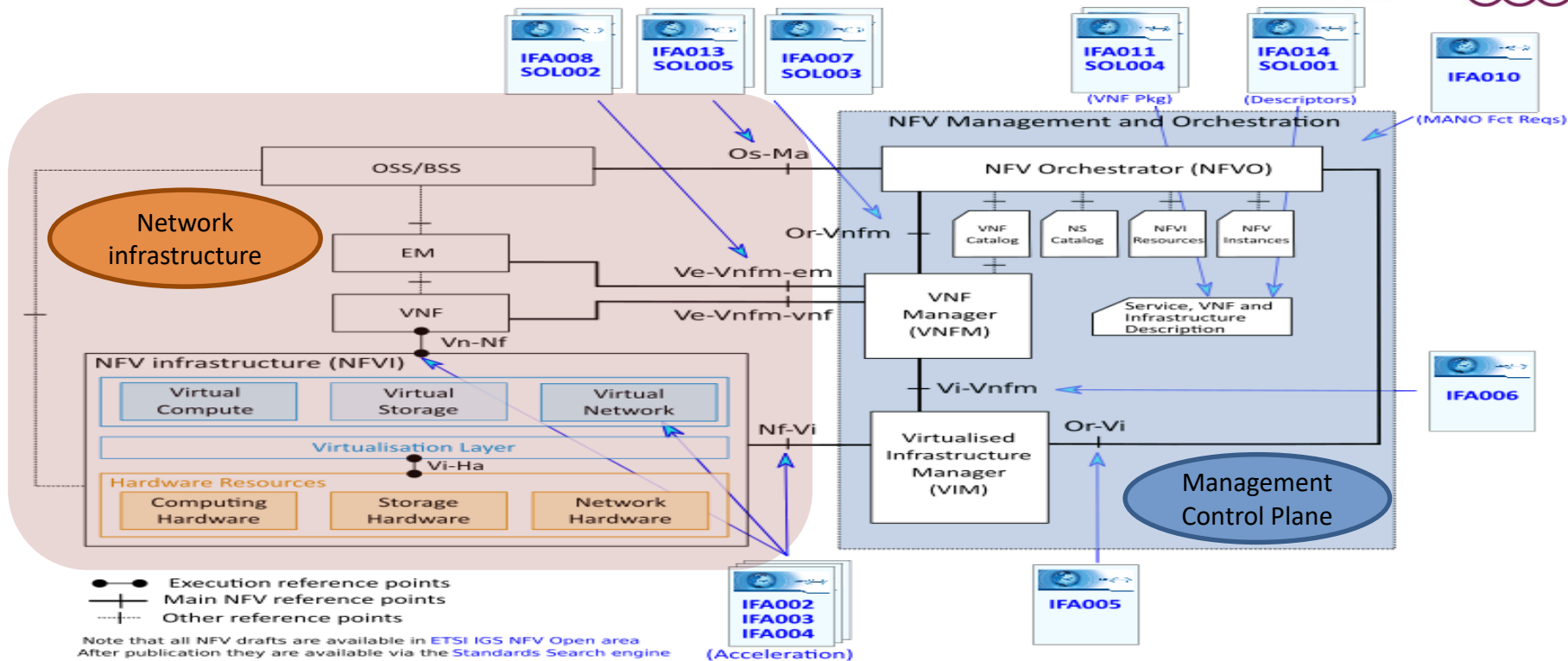# Software-Defined Networking (SDN)

What is SDN?

The physical separation of the network control plane from the forwarding plane; where it controls several devices. Key notes-

- – Centralising Network Control Logic
  - • Reactive to network events
- – Enhanced network programmability
  - • Finer granularity of traffic control
- – Avoid vendor locking through open standard API
  - • E.g. Openflow protocol

ETSI – NFV-MANO Functional Blocks
Working towards standardisation of NFV and MANO

Ref: ETSI GS NFV-IFA 009 V1.1.1 (2016-07)
https://docbox.etsi.org/isg/NFV/Open/Drafts
http://www.etsi.org/technologies-clusters/technologies/nfv

5G – Cloud networking through SDN & NFV

Figure 3: Future architecture of the carrier network enabled by SDN and NFV
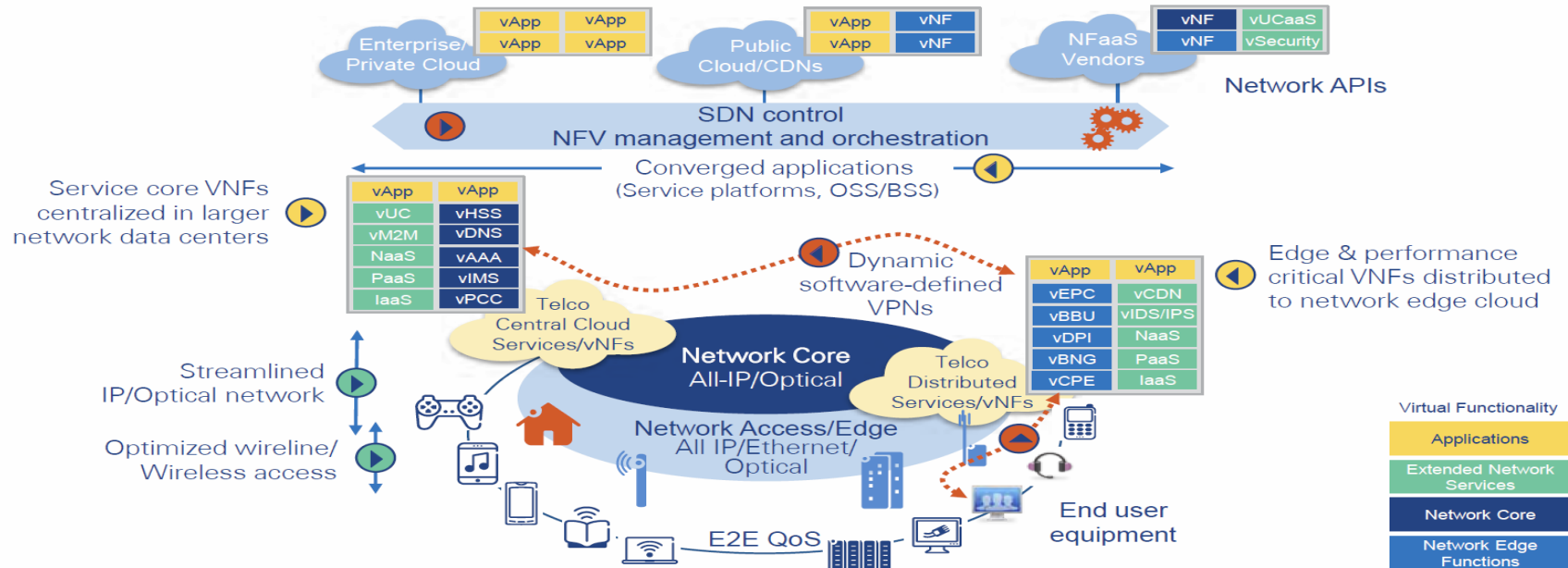
Source: Arthur D. Little; Bell Labs

What is Network Slicing?

Network slicing can be seen as –

Method and approach for allocating isolated infrastructure resources to different tenants of the shared infrastructure …

Technologies used include –

- NFV, SDN, MANO

All for the sake sharing the infrastructure…
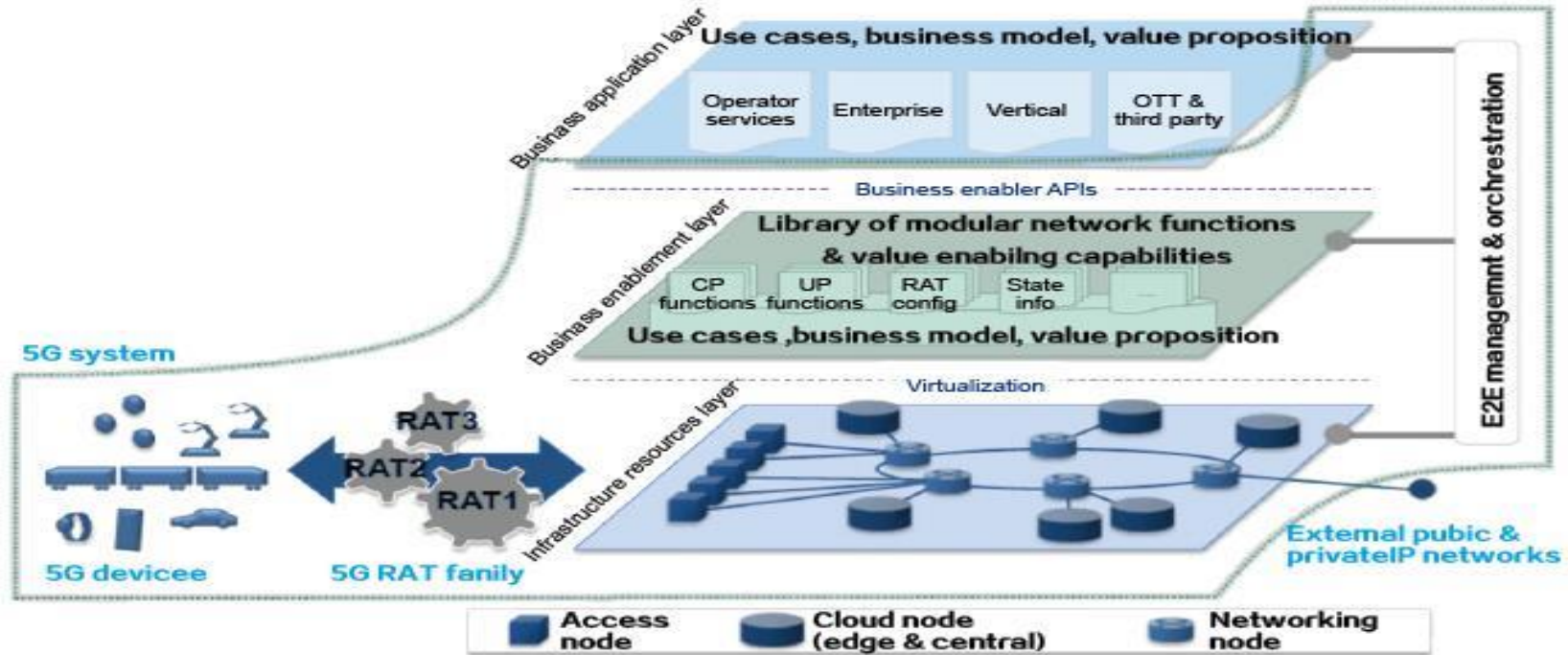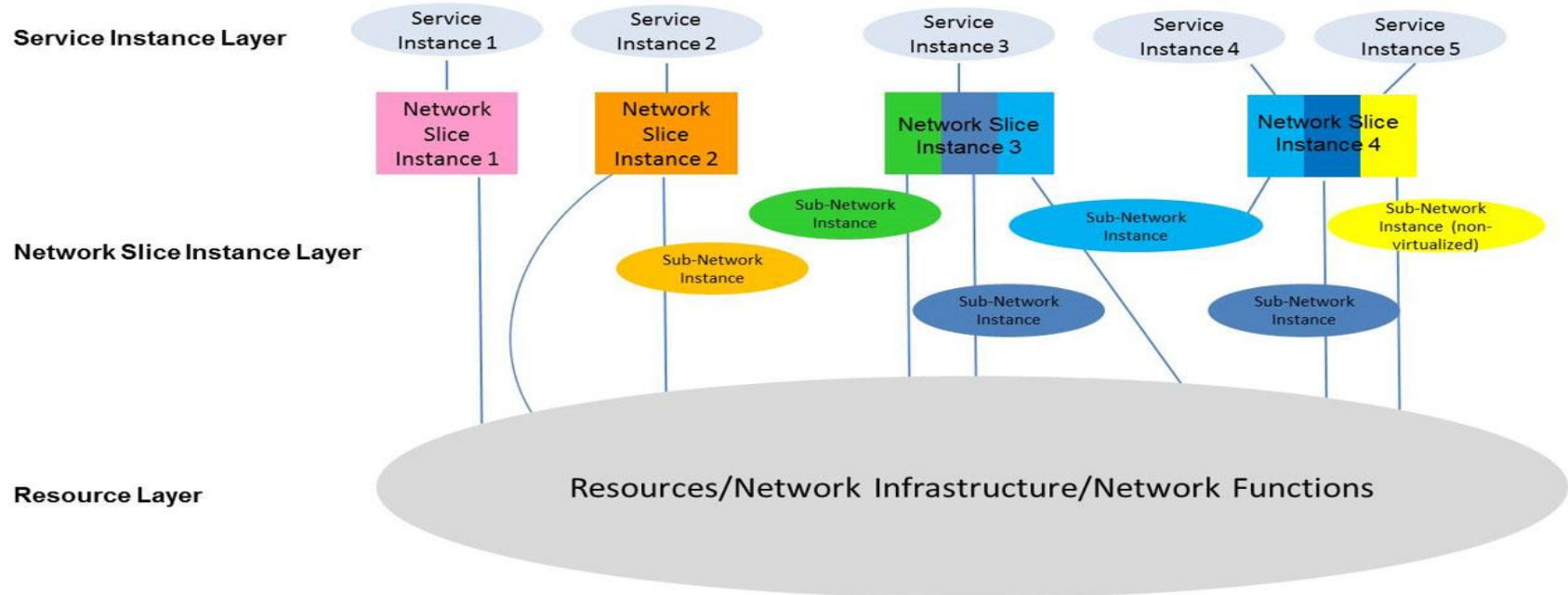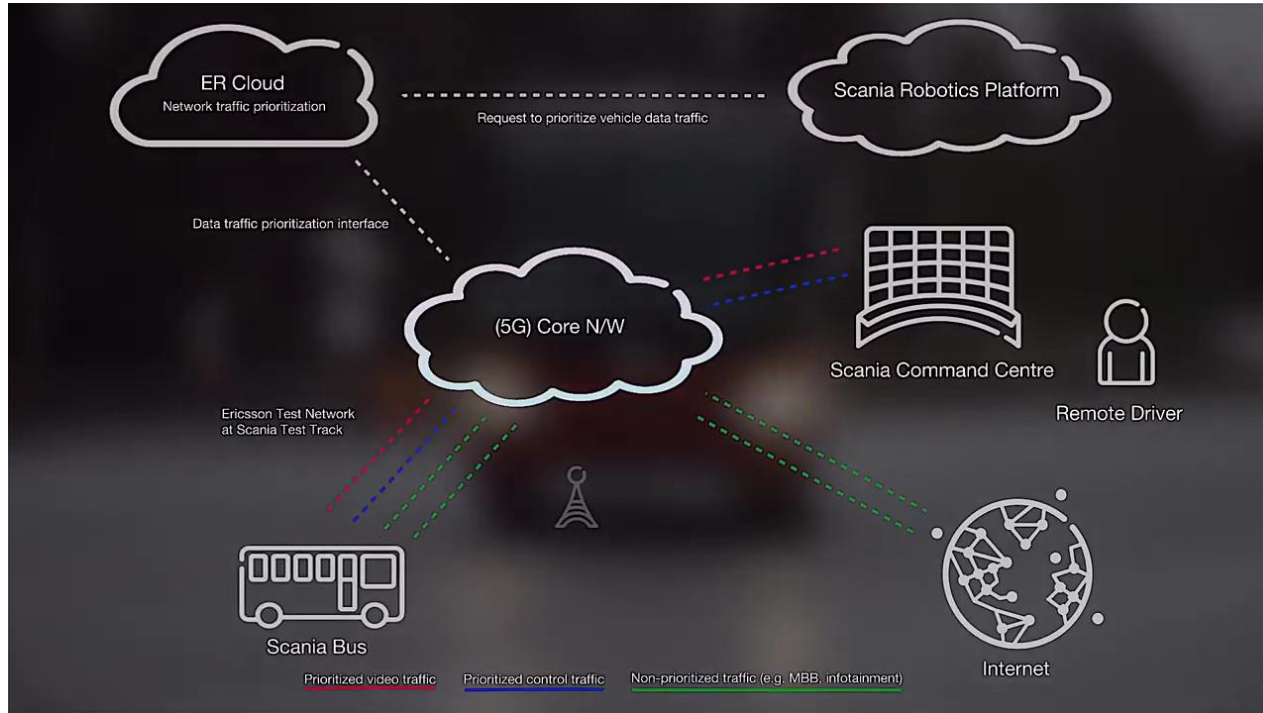
Network Slicing

Figure 1. Three-layer network architecture proposed by NGMN.

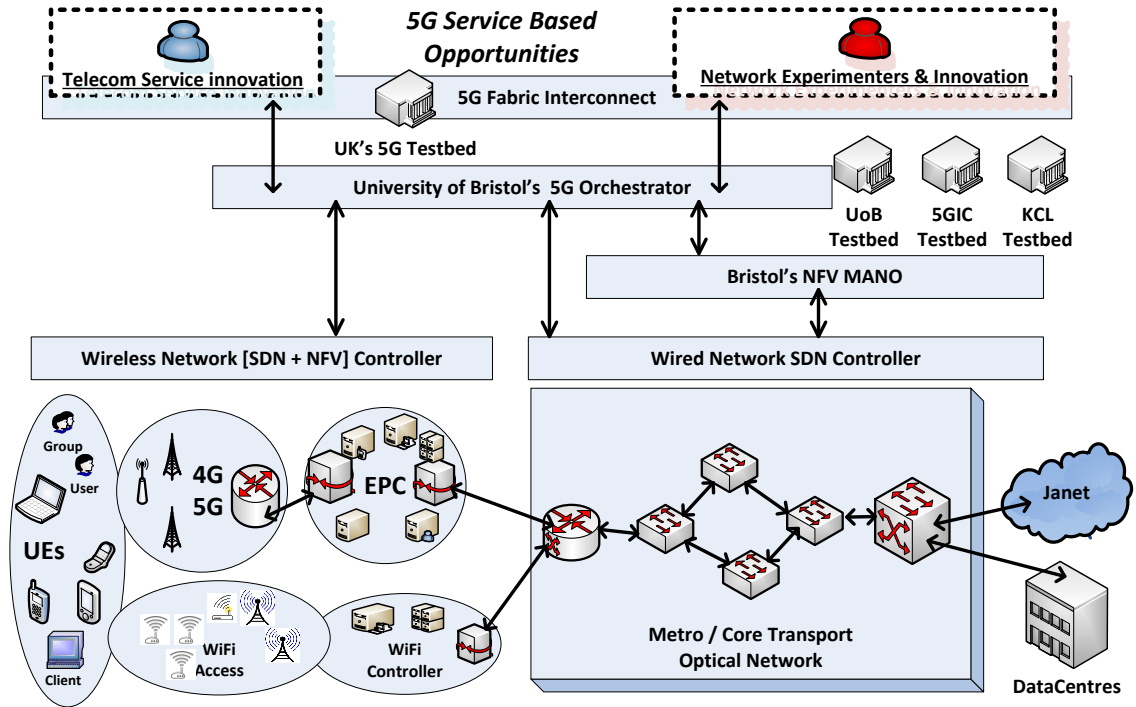# Network Slicing

Source: NGMN Alliance

Network Slicing

5G - Opportunities

- Traditional Telecom Services
- Services in the context of the vertical industries
  - V2x
  - eHealth
  - Social Care
  - …
- Network Slicing as a Service
  - Professional services
  - Service creation & innovation
  - …

What do we mean by 5G…

Capabilities:	Markets:
1. Capacity	1. Smartphones
2. Latency	2. Tablets/MBB
3. Reliability	3. Professional
4. Resilience	4. Emergency
5. Availability	5. Safety
6. Speed	6. Vehicles
7. Security	7. Machine
8. Energy usage	8. Sensor / Things

In 5G we are defining technologies for when untethered connectivity is essential for everything that we do, always providing a sufficient data rate, giving the users the perception of an infinite capacity environment, stretching the bounds of mobile and communication far beyond where it is today.

The connectivity and performance will be there, let's develop the services to use it…

Andy Sutton
2015
Visiting Professor at
the University of Salford

What do we mean by 5G...

5G Research - technologies for connecting everything!

SON | Separation of control and user plane | Ultra low-latency | Application aware | Ultra reliable

Ultra high capacity | On demand services | Energy efficient | Device to device | Seamless mobility

5G Network (with 4G and evolved WiFi)

In-building coverage | New waveforms | Wide area coverage | New spectrum | Stadiums and hot-spots

NFV SDN | Always sufficient rate (speed) | Sharing | Internet of Things

Massive MIMO | Ultra dense networks | Ultra-high definition video | Full duplex

Security...

Dr. Hamid Falaki
Principal Consultant
Samian Consultancy Limited
hfalaki@samianconsultancy.co.uk

Thank You