The ITU Radiocommunication Assembly,

International Mobile Telecommunications

considering

a) that ITU has contributed to standardization and harmonized use of IMT, which has provided telecommunication services on a global scale;

b) that technological advancement and the corresponding user needs will promote innovation and accelerate the delivery of advanced communication applications to consumers;

c) that Question ITU-R 229/5 addresses further development of the terrestrial component of IMT and the relevant studies under this Question are in progress within ITU-R;

3G 4G

d) that Recommendation ITU-R M.1645 defines the framework and overall objectives of the future development of IMT-2000 and systems beyond IMT-2000;

e) that for global operation and economies of scale, which are key requirements for the success of mobile telecommunication systems, it is desirable to establish a harmonized timeframe for future development of IMT considering technical, operational and spectrum related aspects;

f) that wireless communication applications are expected to expand into new market segments to facilitate the digital economy, e.g. smart grid, e-health, intelligent transport systems and traffic control, which would bring requirements beyond what can be addressed in today's IMT application areas;

g) that rapid uptake of smartphones, tablets and innovative mobile applications created by users has resulted in a tremendous increase in the volume of mobile data traffic;

h) that the number of devices accessing the network are expected to increase due to the emerging applications of Internet of Things (IoT);

i) that technologies such as beamforming, massive-Multiple Input Multiple Output (MIMO) are easier to implement in higher frequencies due to short wavelength;

mmWave

j) that wide contiguous bandwidth would enhance data delivery efficiency and ease the complexity of hardware implementation;

k) that the cell size is being reduced (e.g. the order of some tens of metres) to provide larger area traffic capacity in dense areas;

l) that IMT interworks with other radio systems,

recognizing

a) that some administrations had deployed IMT-Advanced systems before global deployment due to the rapid increase of data traffic;

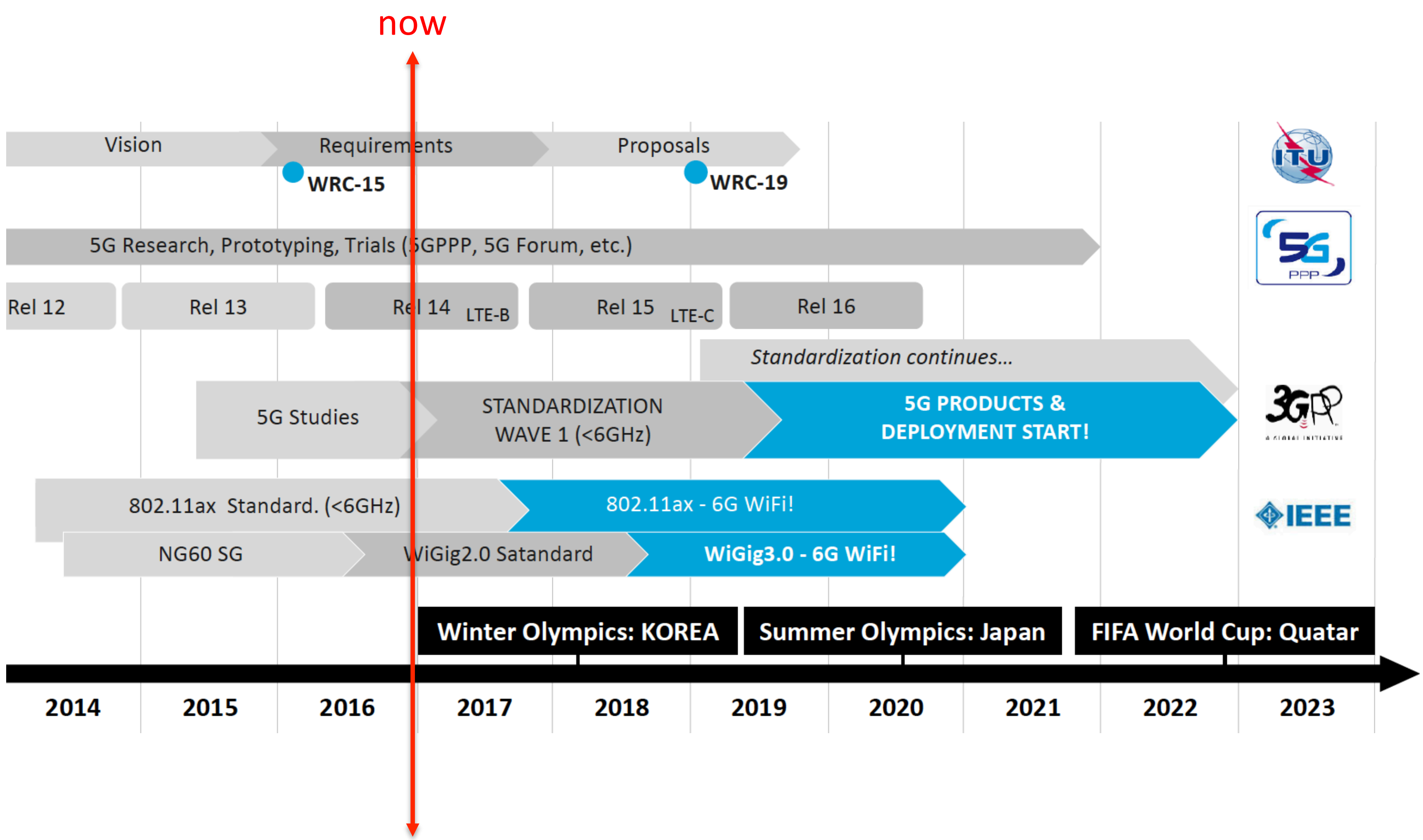
b) that development of new radio interfaces that support the new capabilities of IMT-2020 is expected along with the enhancement of IMT-2000 and IMT-Advanced systems,

noting

that pursuant to Article 44 of the ITU Constitution, Member States shall endeavour to apply the latest technical advances as soon as possible,

recommends

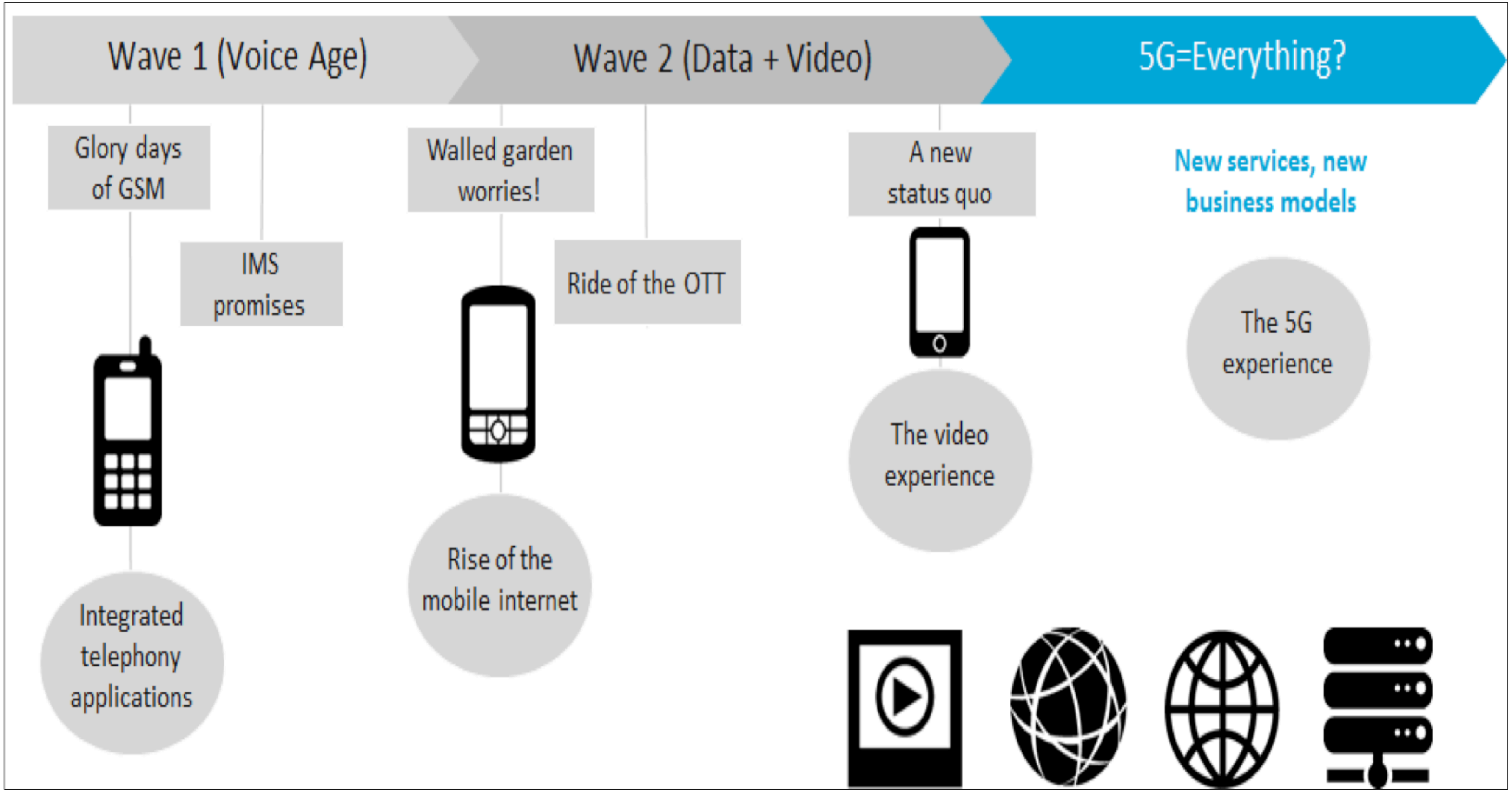
that the Annex should be used as the framework and the overall objectives for the future development of IMT for 2020 and beyond.

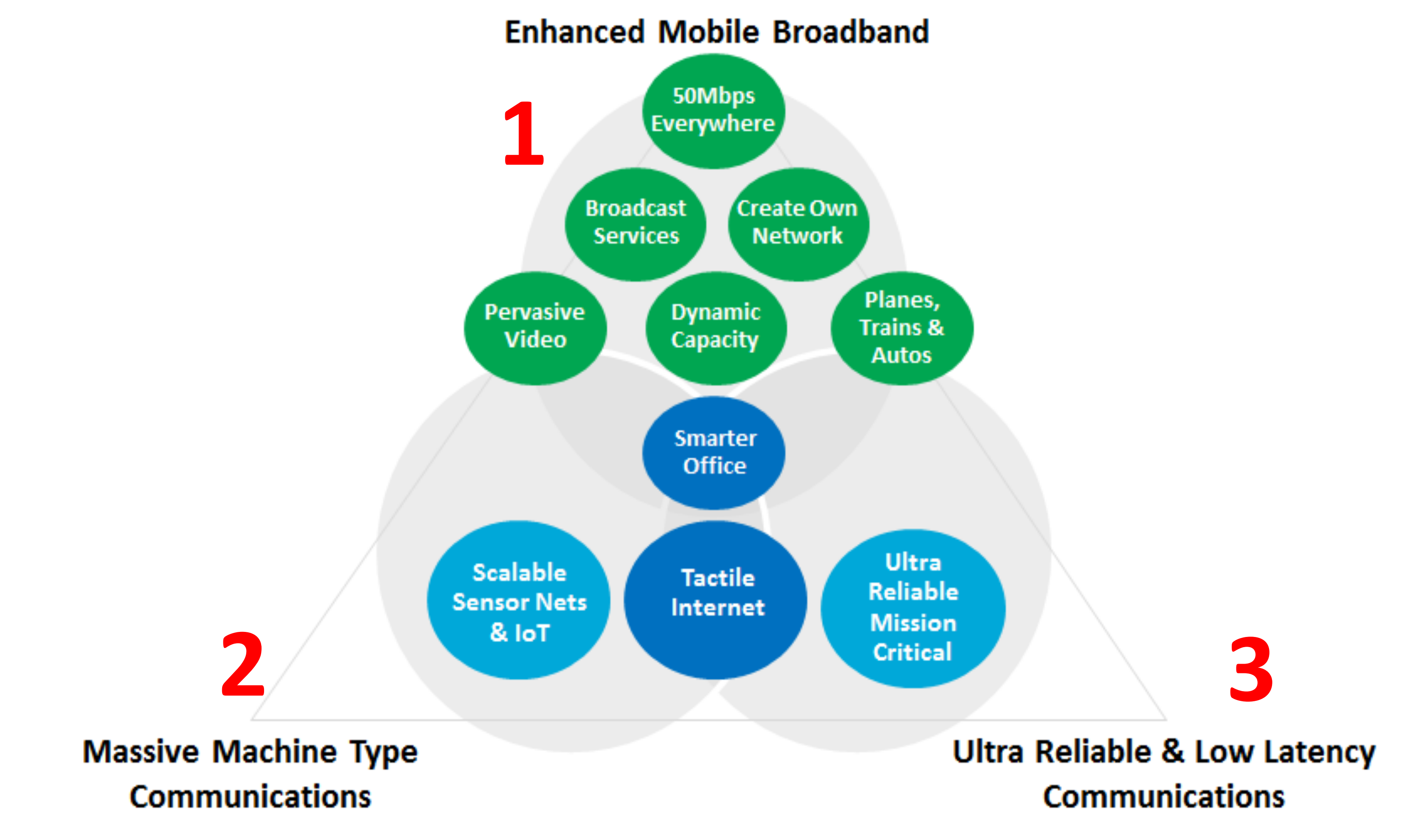

now
Vision
Requirements
Proposals
WRC-15
WRC-19
5G Research, Prototyping, Trials (5GPPP, 5G Forum, etc.)
Rel 12
Rel 13
Rel 14 LTE-B
Rel 15 LTE-C
Rel 16
Standardization continues...
5G Studies
STANDARDIZATION WAVE 1 (<6GHz)
5G PRODUCTS & DEPLOYMENT START!
802.11ax Standard. (<6GHz)
802.11ax - 6G WiFi!
NG60 SG
WiGig2.0 Satandard
WiGig3.0 - 6G WiFi!
Winter Olympics: KOREA
Summer Olympics: Japan
FIFA World Cup: Quatar
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
ITU
5G PPP
3GPP
IEEE

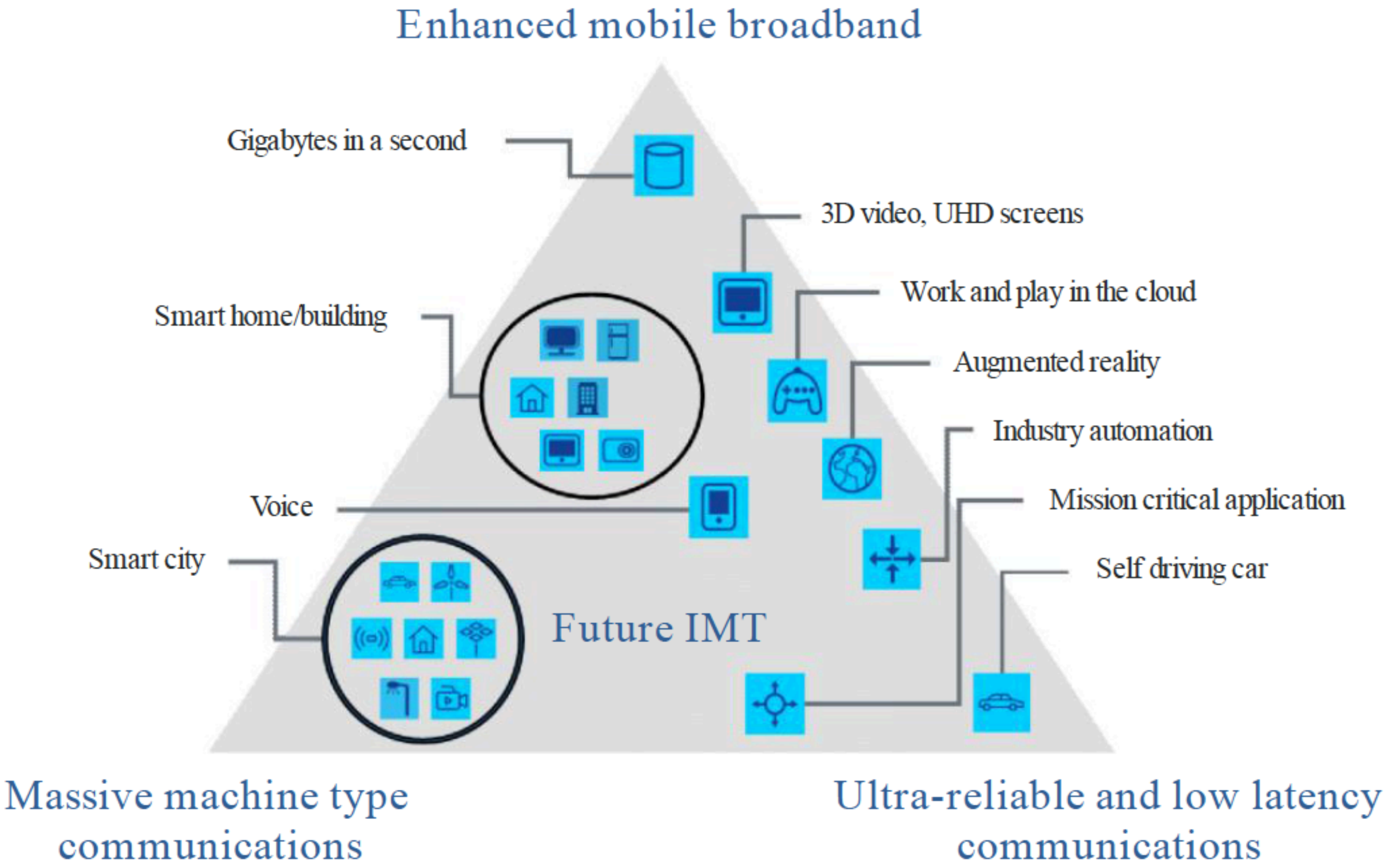
5G

- What are its objectives?
- What does it aim to be capable of doing?
- What uses does it aim to support?
- What technical advances does it rely on?
- What are the big challenges for it?

OBJECTIVES


Wave 1 (Voice Age)
Wave 2 (Data + Video)
5G=Everything?
Glory days of GSM
IMS promises
Walled garden worries!
Ride of the OTT
A new status quo
New services, new business models
Integrated telephony applications
Rise of the mobile internet
The video experience
The 5G experience


Enhanced Mobile Broadband
1
50Mbps Everywhere
Broadcast Services
Create Own Network
Pervasive Video
Dynamic Capacity
Planes, Trains & Autos
Smarter Office
Scalable Sensor Nets & IoT
Tactile Internet
Ultra Reliable Mission Critical
2
3
Massive Machine Type Communications
Ultra Reliable & Low Latency Communications


Enhanced mobile broadband
Gigabytes in a second
3D video, UHD screens
Work and play in the cloud
Smart home/building
Augmented reality
Industry automation
Voice
Mission critical application
Smart city
Self driving car
Future IMT
Massive machine type communications
Ultra-reliable and low latency communications

5G - Capabilities

- 5G aims to enable a truly pervasive video experience;
- 5G will enable a revolution in the smart office;
- 5G goal is to deliver 50Mbps everywhere;
- 5G will allow you to create your own network if you that is what you want to do;
- 5G will support dynamic increase of capacity on the fly;
- 5G will enable a working solution on planes, trains and cars;
- 5G will deliver a single scalable solution for sensor networks and the IoT;
- 5G will enable an ultra-reliable network for mission critical applications;
- 5G will make the realization of the tactile internet possible;
- 5G will deliver a meaningful and efficient broadcast service.

5G: technical targets (in numbers)

- **1,000 X** in mobile data volume per geographical area reaching a target of 0.75 Tb/s for a stadium.
- **1,000 X** in number of connected devices reaching a density ≥ 1M terminals/km2.
- **100 X** in user data rate reaching a peak terminal data rate ≥1 Gb/s for cloud applications inside offices.
- **1/10 X** in energy consumption compared to 2010 while traffic is increasing dramatically at the same time.
- **1/5 X** in end-to-end latency reaching delays ≤ 5 ms.
- **1/5 X** in network management Operational Expenditure (OPEX).
- **1/1,000 X** in service deployment time reaching a complete deployment in **≤ 90 minutes**.
- Guaranteed user data rate **≥ 50 Mb/s**.
- Capable of IoT terminals **≥ 1 trillion**.
- Service reliability **≥ 99.999%** for specific mission critical services.
- Mobility support at speed **≥ 500 km/h** for ground transportation.
- Accuracy of outdoor terminal location **≤ 1 m**.

The relative targets are to be measured against a 2010 baseline

5G: technical objectives

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KEY STEP CHANGES IN FUNCTIONALITY

Massive System Capacity

- Traffic demands for mobile-communication systems are predicted to increase dramatically. **<u>See the very first lecture's slides</u>**.
- To support this traffic in an ***affordable*** way, 5G networks must deliver data with much ***lower cost per bit*** compared with the networks of today. Furthermore, the increase in data consumption will result in an increased energy footprint from networks. 5G must therefore consume significantly lower energy per delivered bit than current cellular networks.
- The exponential increase in connected devices, such as the deployment of billions of wirelessly connected sensors, actuators and similar devices for massive machine connectivity, will place demands on the network to support new paradigms in device and connectivity management that do not compromise security.
- Each device will generate or consume very small amounts of data, to the extent that they will individually, or even jointly, have limited impact on the overall traffic volume. However, the sheer number of connected devices seriously challenges the ability of the network to provision signaling and manage connections. **What does the MAC look like that handles tens of thousands of devices per basestation?**

Very High Data Rates ***Everywhere***

- Every generation of mobile communication has been associated with higher data rates compared with the previous generation. In the past, much of the focus has been on the peak data rate that can be supported by a wireless-access technology under ideal conditions. However, a more important capability is the data rate that can actually be provided under ***real-life conditions*** in different scenarios.
- 5G should support data rates exceeding **10Gbps** in specific scenarios such as indoor and dense outdoor environments.
- Data rates of several **100Mbps** should generally be achievable in urban and suburban environments.
- Data rates of at least **10Mbps** (*some say minimum **50Mbps***) should be accessible almost ***everywhere***, including sparsely-populated rural areas in both developed and developing countries. Need for low-ARPU solutions.
- **What's an ARPU???**

Very Low Latency

- Very low latency will be driven by the need to support new applications.
- Some envisioned 5G use cases, such as traffic safety and control of critical infrastructure and industry processes, may require much lower latency compared with what is possible with the mobile-communication systems of today.
- A move from <u>communication networks</u> to <u>control networks</u>.
- To support such latency-critical applications, 5G should allow for an application end-to-end latency of 1ms or less, although application-level framing requirements and codec limitations for media may lead to higher latencies in practice.
- Many services will distribute computational capacity and storage close to the air interface. This will create new capabilities for real-time communication and will allow ultra-high service reliability in a variety of scenarios, ranging from entertainment to industrial process control.

Ultra-High Reliability

- In addition to very low latency, 5G should also enable connectivity with ultra-high reliability and ultra-high availability.
- For critical services, such as control of critical infrastructure and traffic safety, connectivity with certain characteristics, such as a specific maximum latency, should not merely be ‘typically available.’
- Rather, loss of connectivity and deviation from quality of service requirements must be extremely rare. For example, some industrial applications might need to guarantee successful packet delivery within 1 ms with a probability higher than **99.9999** percent.

Very Low Device Cost and Energy Consumption

- Low-cost, low-energy mobile devices have been a key market requirement since the early days of mobile communication.
- However, to enable the vision of billions of wirelessly connected sensors, actuators and similar devices, a further step has to be taken in terms of device cost and energy consumption.
- It should be possible for 5G devices to be available at very low cost and with a battery life of **several years** without recharging.

Energy-Efficient Networks

- While device energy consumption has always been prioritized, energy efficiency on the network side has recently emerged as an additional objective, for three main reasons:
  - Energy efficiency is an important component in reducing operational cost, as well as a driver for better dimensioned nodes, leading to lower total cost of ownership.
  - Energy efficiency enables off-grid network deployments that rely on medium-sized solar panels as power supplies, thereby enabling wireless connectivity to reach even the most remote areas.
  - Energy efficiency is essential to realizing operators' ambition of providing wireless access in a sustainable and more resource-efficient way.
- The importance of these factors will increase further in the 5G era, and energy efficiency will therefore be an important requirement in the design of 5G.

5G

- How does it compare to 4G?

4G purposed mainly for VIDEO… *IMT-2020* **5G** video ++ ● IoE ● TACTILE internet ● mission critical

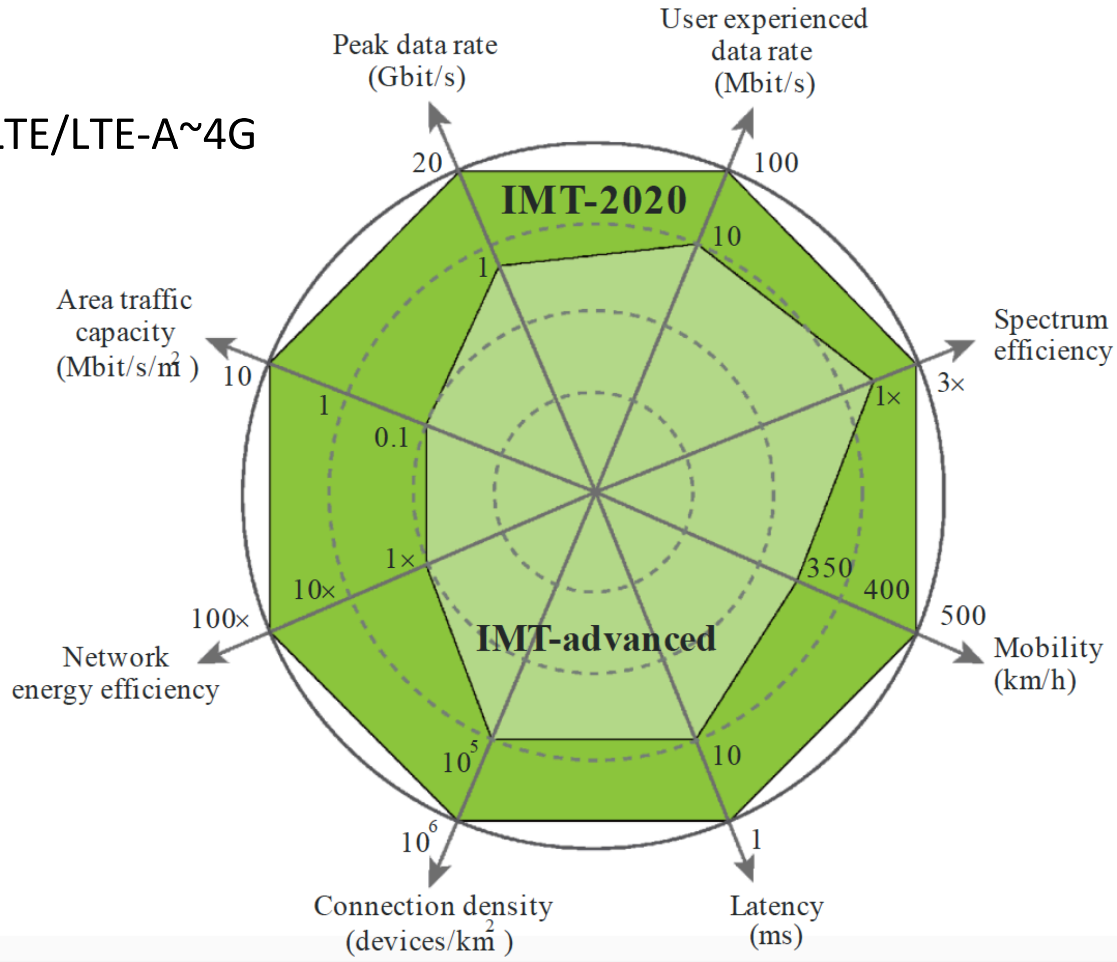
	LTE	LTE-A
Peak Data Rate:	50Mbps 150Mbps	500Mbps 1Gbps
Spectral Efficiency:	16.32	30
Carrier Bandwidth:	upto20MHz	upto100MHz
Latency (RTT):	~10ms	~5ms

<1millisecond latency (when needed)	**10-50Gbps peak data rates**	**90% Energy reduction per service**
100-500MHz Carrier Bandwidth	Higher Density: Millions of connections per km^2	Higher Traffic Volume: 1-10 Tbps per km^2
Rapid Service Creation (from days to minutes)	Sustainable Total Cost of Owner for all players	User Definable Security & Privacy

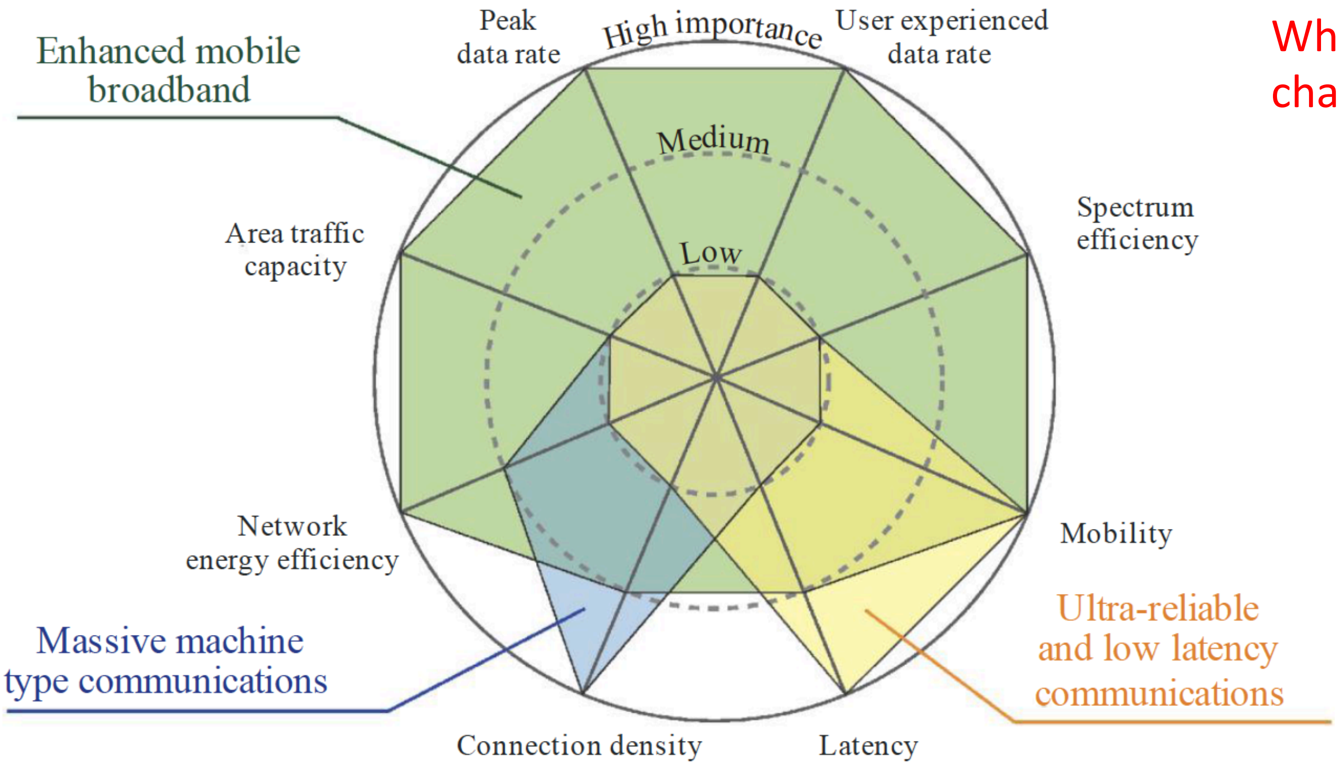
*Key requirements harmonized & agreed in ITU-R WP5D

IMT-Advanced ~ LTE/LTE-A~4G

IMT-2020 ~ 5G



How the ITU sees 5G v 4G



What's the challenge here?

5G

- How does it compare to 4G?

- 5G is about more than the technical differences.
- It’s a new way of thinking about networking.
- Its success will take more than just better radios.

5G FOR THE DIGITAL ECONOMY

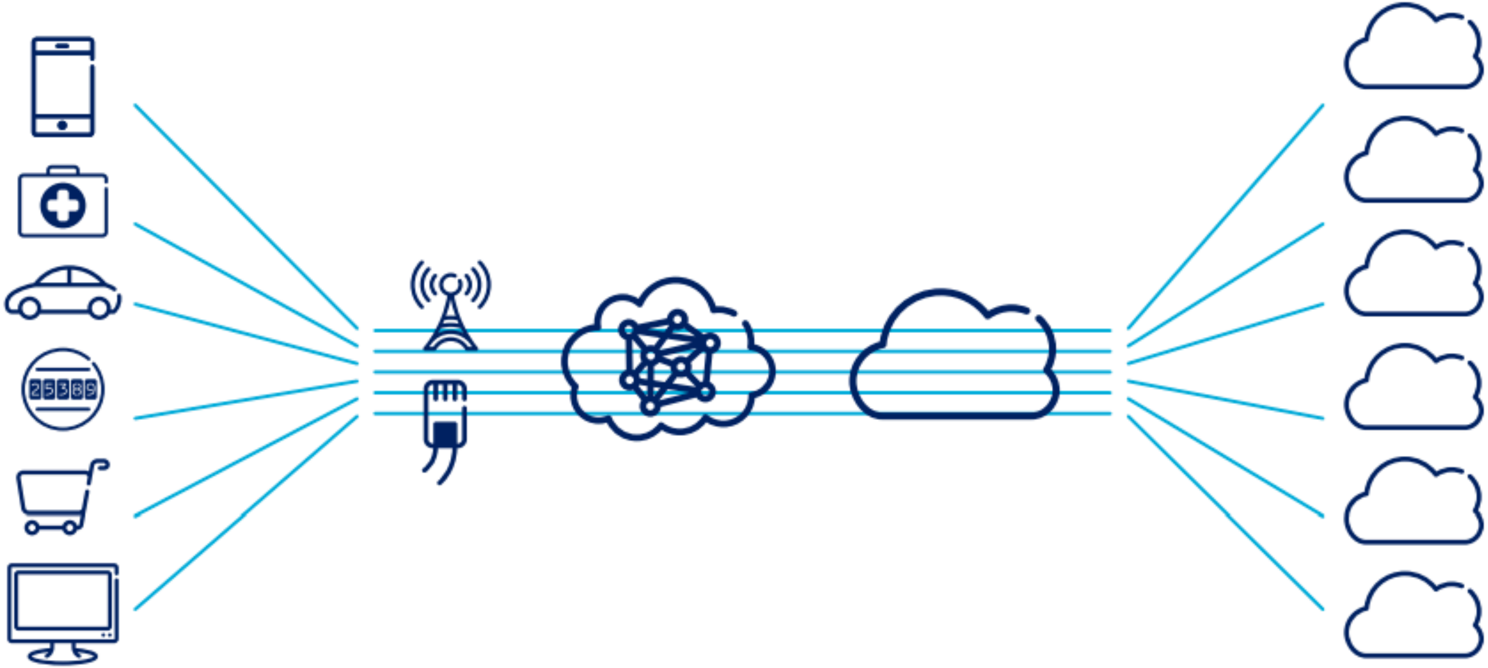
DIVERSE and
UNPREDICTABLE

5G FOR THE DIGITAL ECONOMY

OTT v 5G

- Previously (or to date) most innovation has occurred over-the-top of the network.
- Apple, Android platforms enable developers to create apps that use the network as a dumb/passive bit pipe.
- No network customisation for apps or services.

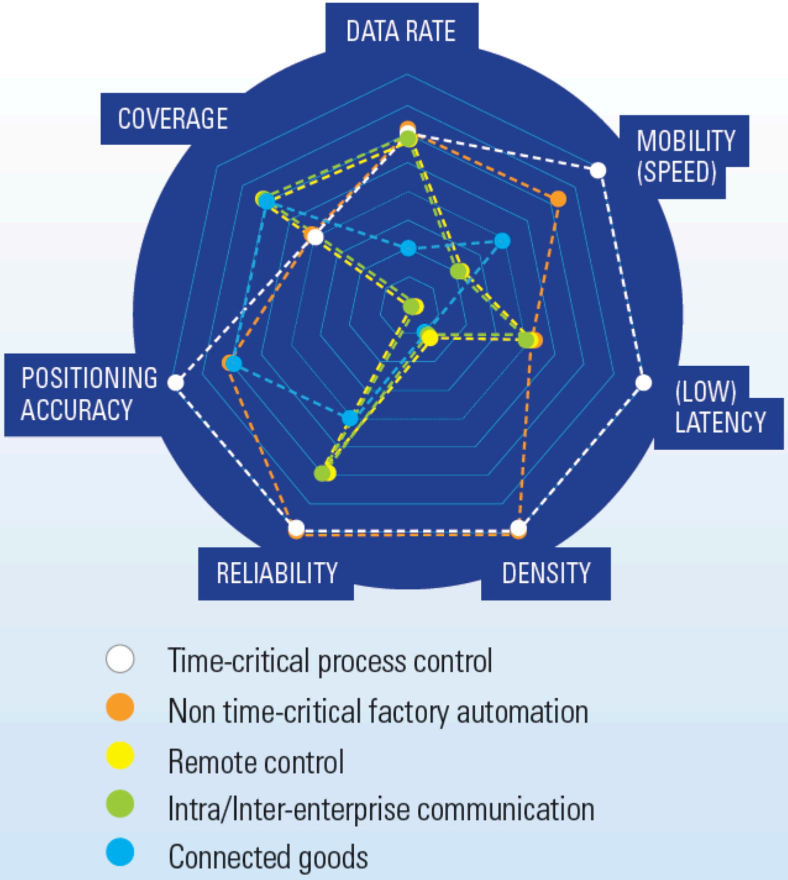
5G. VG. V for Verticals



- Moving from one-size-fits-all dumb bit pipe to tailored network services.

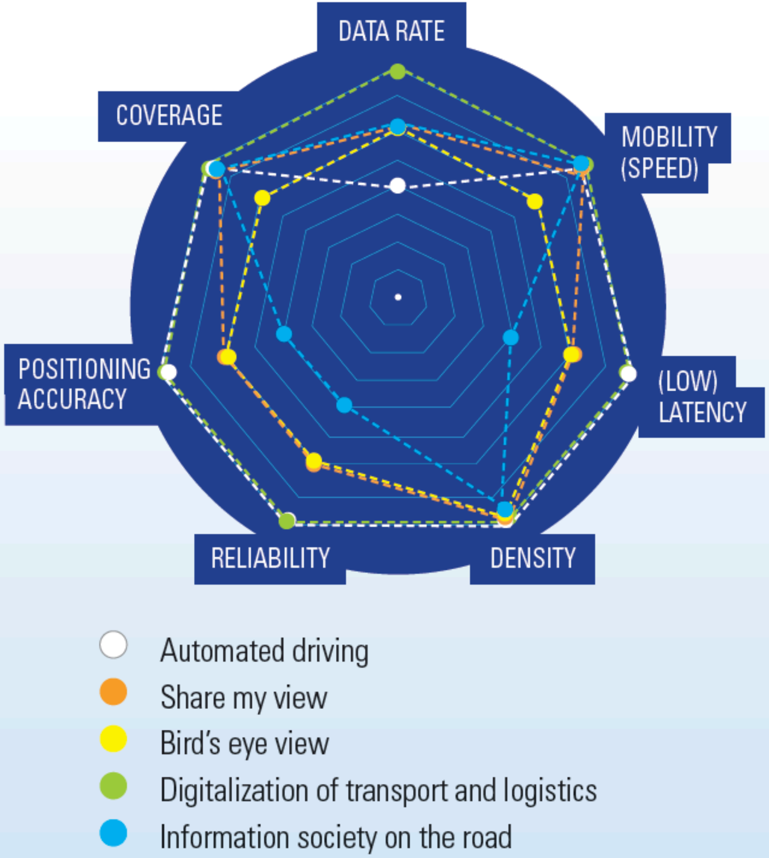
Paper	Vertical details
4G Americas	Automotive, health, public safety
Ericsson 5G	Automotive, health, government, utilities, manufacturing and transport
GSMA	Automotive, augmented reality, tactile internet, virtual reality
Intel	Specific verticals not mentioned
ITU	Specific verticals not mentioned
Metis	Activities: virtual reality office, smart grid, emergency communications, IoT, traffic efficiency and latency
NGMN	Automotive, health, energy and home
Samsung	Connected car, fitness and healthcare
Qualcomm	Autonomous vehicles, healthcare and emergency response

FACTORIES



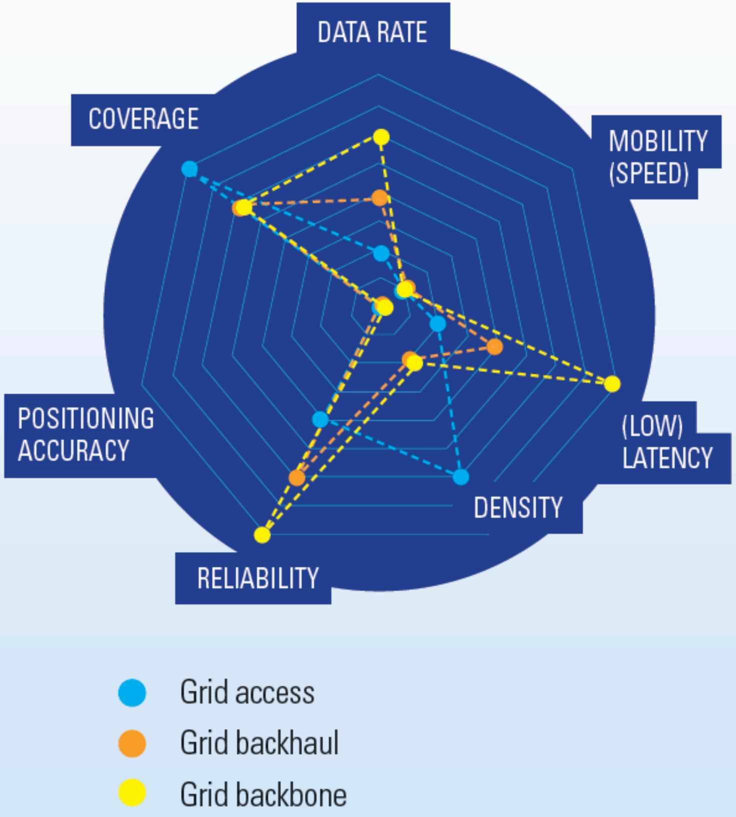
DATA RATE
MOBILITY (SPEED)
(LOW) LATENCY
DENSITY
RELIABILITY
POSITIONING ACCURACY
COVERAGE
Time-critical process control
Non time-critical factory automation
Remote control
Intra/Inter-enterprise communication
Connected goods

AUTOMOTIVE



DATA RATE
MOBILITY (SPEED)
(LOW) LATENCY
DENSITY
RELIABILITY
POSITIONING ACCURACY
COVERAGE
Automated driving
Share my view
Bird's eye view
Digitalization of transport and logistics
Information society on the road

ENERGY


DATA RATE
MOBILITY (SPEED)
(LOW) LATENCY
DENSITY
RELIABILITY
POSITIONING ACCURACY
COVERAGE
Grid access
Grid backhaul
Grid backbone

One-size-doesn't fit all

- Traditional, one-size-fits-all network architectures with purpose-built systems for support and IT worked well for **single-service subscriber networks** with **predictable** traffic and growth.
- However, the resulting vertical architecture has made it difficult to scale telecom networks, adapt to changing subscriber demands and meet the requirements of emerging use cases.
- Cloud technologies together with software-defined networking (SDN) and Network Functions Virtualization (NFV) provide the tools that enable architects to build systems with a greater degree of abstraction – which enhances network flexibility.
- Cloud, SDN and NFV technologies allow vertical systems to be broken apart into building blocks, resulting in a horizontal network architecture that can be chained together – both programmatically and virtually – to suit the services being offered and scaled.

5G NETWORK SLICING

Network slicing

- Take a network and build it so flexibly that it can be:
  - Shared by multiple different user-types
  - Architecture is tailored to use-type needs
  - Resources allocated in a granular fashion
  - Billed in a granular fashion
- **5G-as-a-Service** ← XaaS - very influenced by cloud thinking

Network Slices

- A **network slice** is a connectivity service defined by a number of customizable software-defined functions that govern geographical coverage area, duration, capacity, speed, latency, robustness, security and availability.
- The concept of network slices is not a new one; a VPN, for example, is a basic version of a network slice. But the wide range of use cases and tougher requirements that future networks will need to support suggests that network slices in the context of 5G will be defined on a whole new level, more like networks on-demand.

SDN – Software Defined Networks

- The benefit of SDN lies in its ability to provide an abstraction of the physical network infrastructure. Through network-wide programmability – the capability to change the behavior of the network as a whole – SDN greatly simplifies the management of networks.
- The level of network programmability provided by SDN allows several network slices, customized and optimized for different service deployments, to be configured using the same physical and logical network infrastructure. One physical network can therefore support a wide range of services and deliver these services in an optimal way.

NFV– Network Function Virtualisation

- By separating hardware from software, NFV allows a network function to be implemented programmatically instead of by a physical piece of hardware. This capability enables instant scalability, which supports the delivery of services like capacity or coverage on demand.
- The most significant benefit brought about by NFV is the flexibility to execute network functions independently of location. By virtualizing a network function, it is no longer bound to a specific location or node. The same network function can be executed in different places for different network slices. Depending on the use case, a network function could either be placed in a centralized data center (DC) or close to a base station. By placing network functions accordingly, the same physical infrastructure can provide connectivity with different latencies.

Softwarization of
networks is a key trend.

Network slicing

The benefit of slicing networks is not just the capability to deliver a wide range of connectivity services to any industry, but also to ensure that usage can be billed accordingly. Slicing networks provides greater insight into network resource utilization, as each slice is customized to match the level of delivery complexity required by the service or services using the slice.

SLAs will be a big feature of 5G

SMART METER SERVICE

- A utilities company, for example, requires connectivity for its smart meters.
  - This need could be translated into a network slice that connects a number of machine-to-machine (M2M) devices with a latency and data rate that enables upload of periodic status updates within a given time. The security level of the service is medium, and it is a data-only service that requires high availability and high reliability.
  - Additional network functions associated with higher levels of security, longer durations or increased reliability could be configured to suit the needs of the application.

SENSOR UTILITY SERVICE

- The same utilities company may require connectivity for its fault sensors. The network slice for this type of service needs to be able to receive round-the-clock status indicators or alarms from all the M2M devices in the system. This use case requires data-only coverage with high availability and robustness, and medium security and latency.
- Again, depending on the use case, a network slice delivering this connectivity service can be configured with different network functions to enable higher levels of security, **or near-zero** latency, for example.

Network slicing

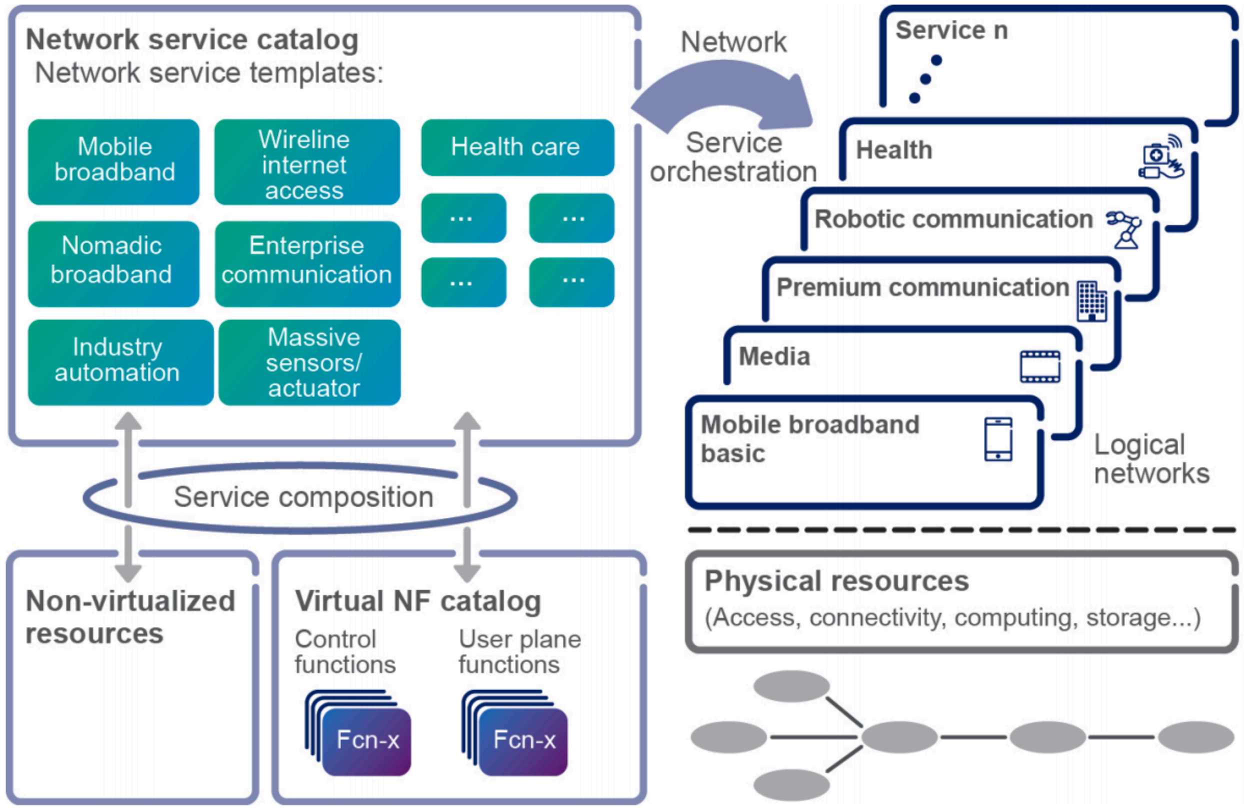
MEDIA SERVICE

- An operator wants to provide all of its subscribers in a given country with very high throughput for its video-streaming service. High data speeds and low latency are the key requirements for this network slice. ← Netflix slice.

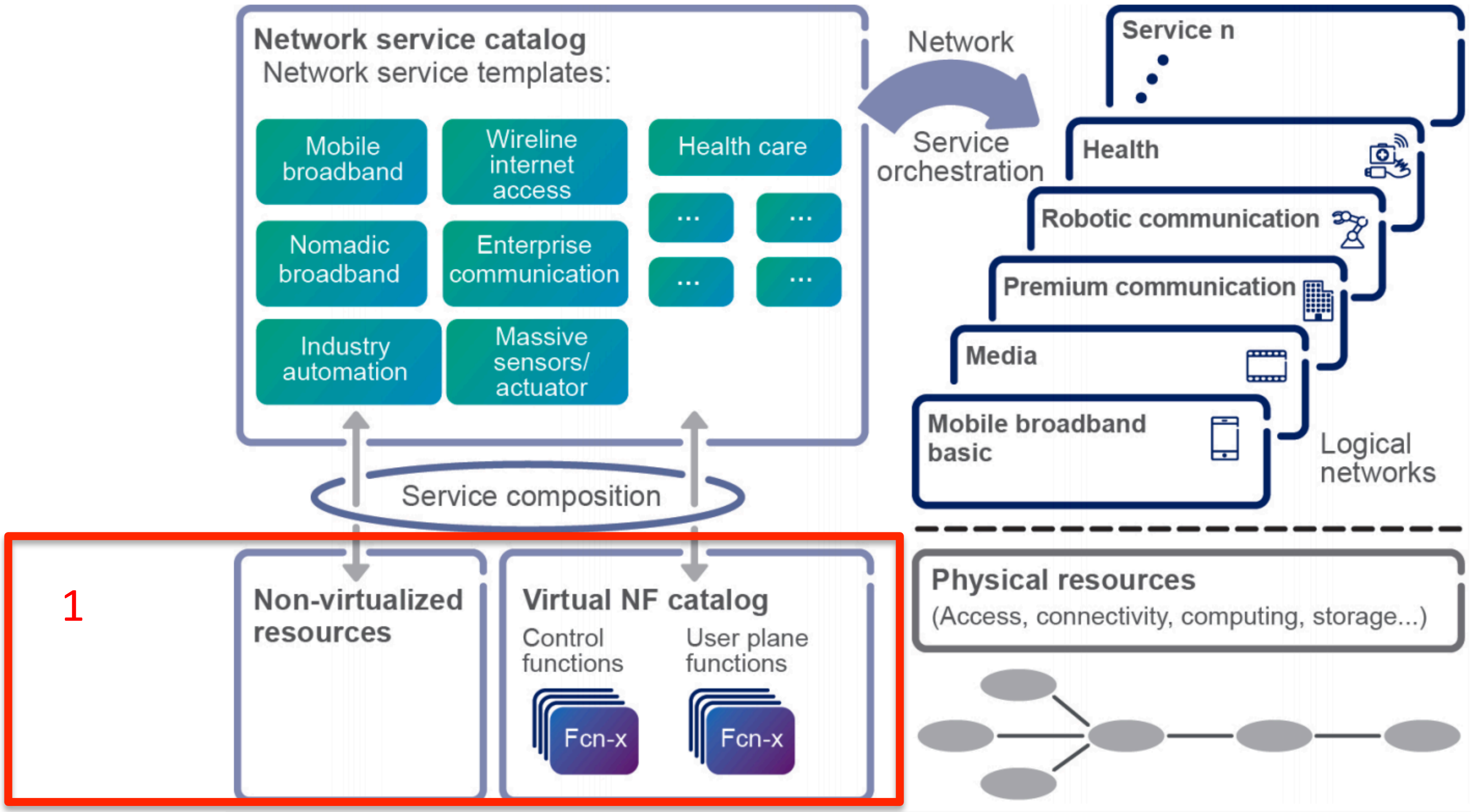
CAPACITY/COVERAGE ON DEMAND

- Certain mission-critical services may need instant access to network capacity or coverage in the event of an emergency. ← HSE ambulance slice
- Such use cases can be prearranged through agreements and provided by the operator on demand. The critical aspect for this use case is the business agreement.

5G is (or will be??) a programmable, dynamic network



5G is (or will be??) a programmable, dynamic network



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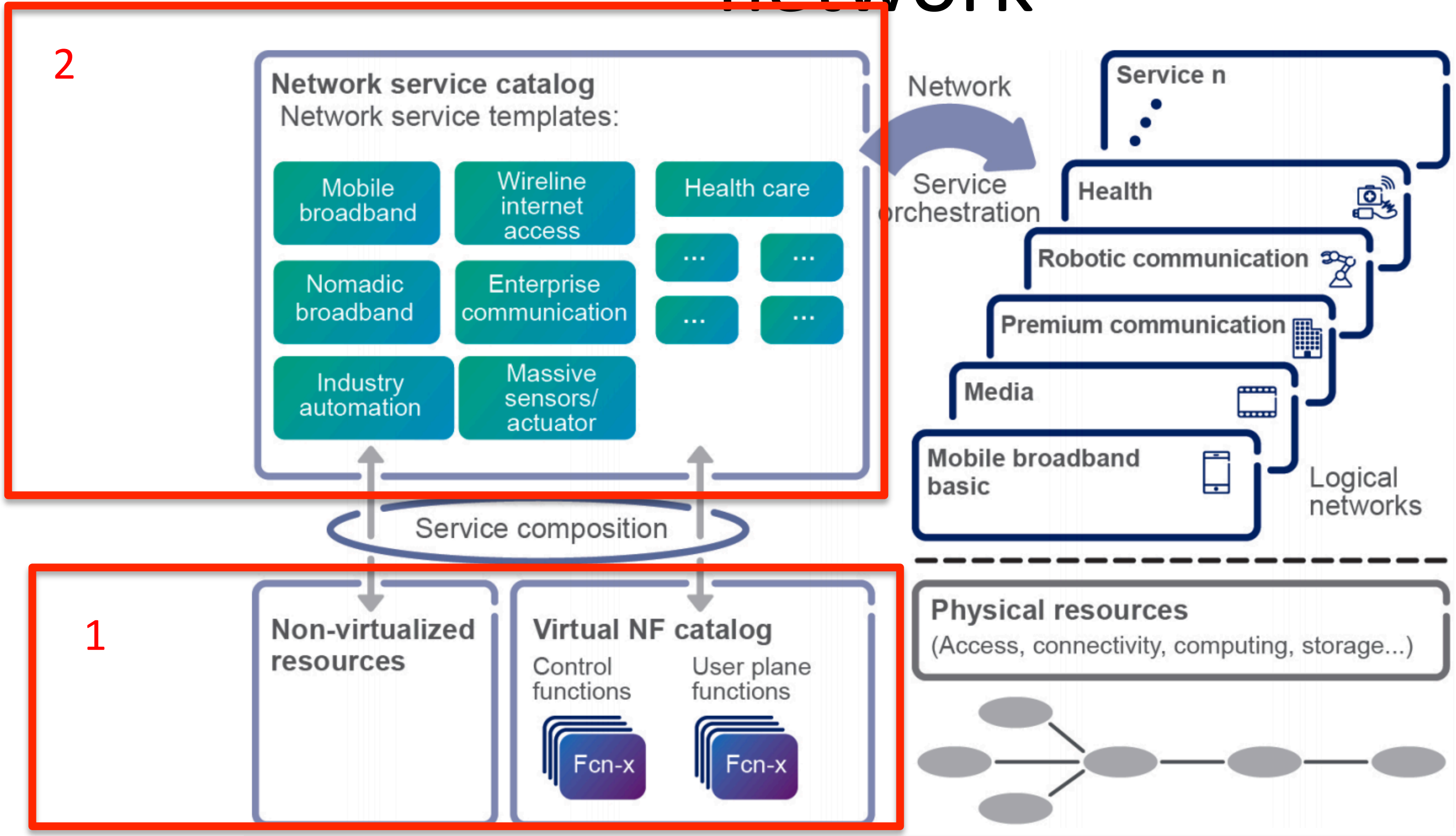

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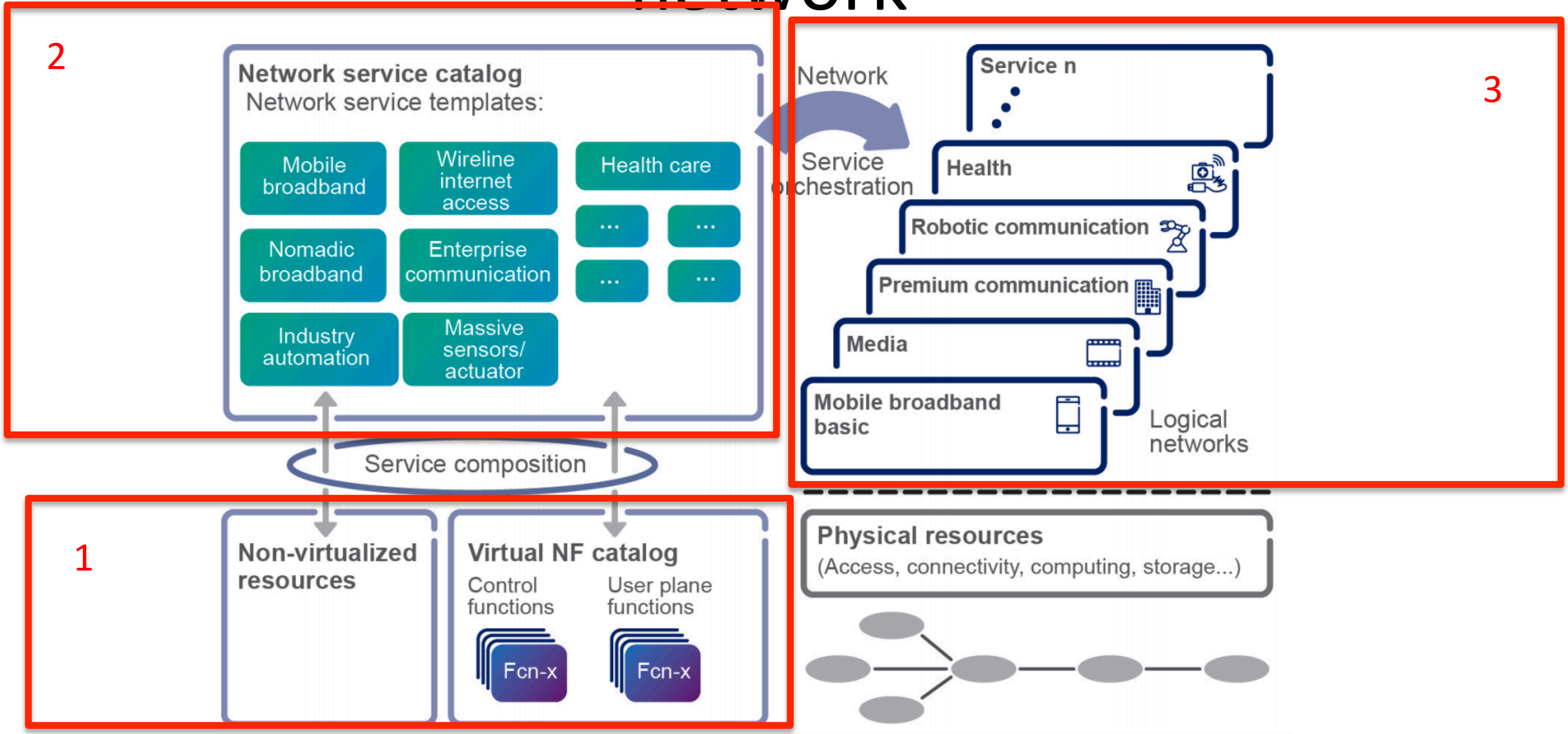
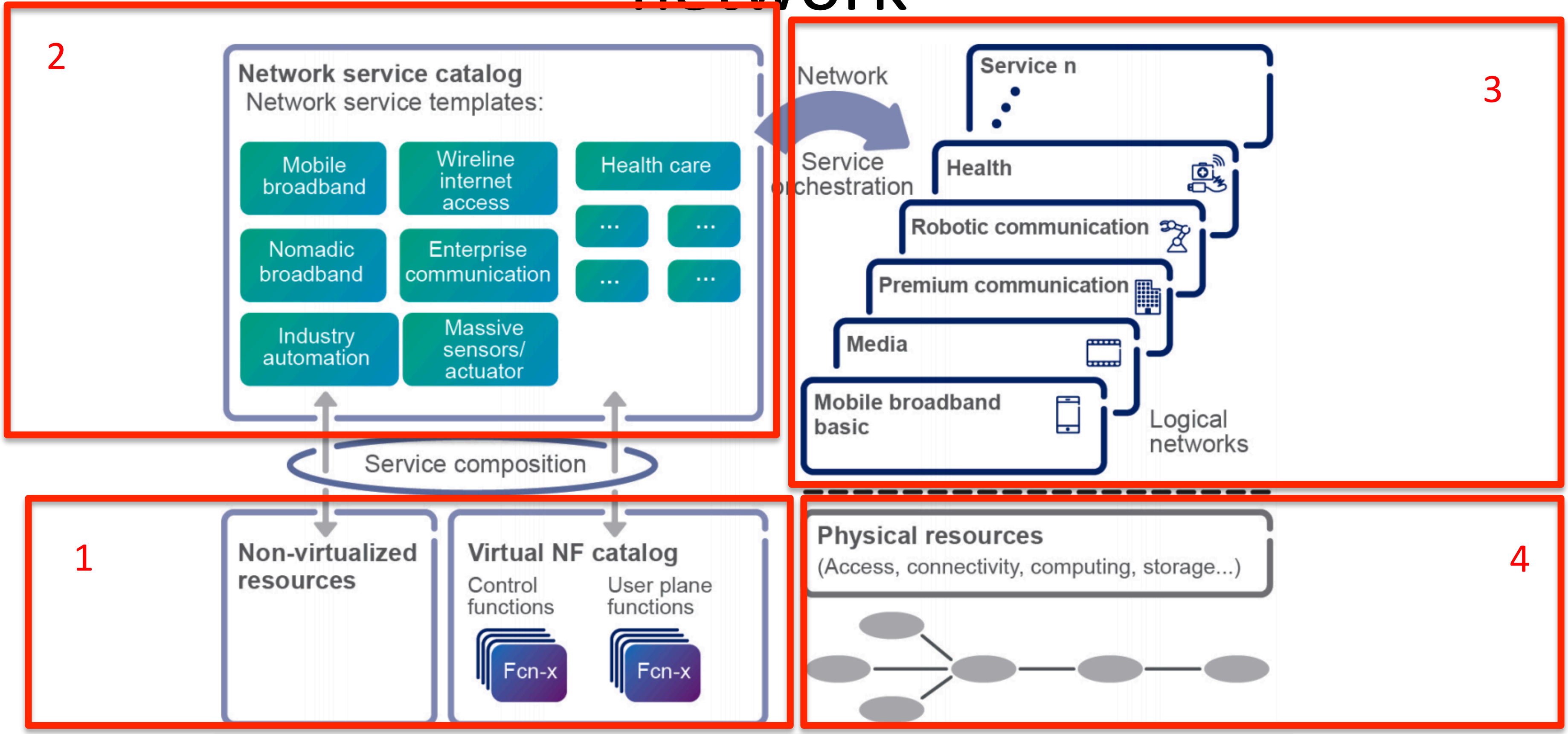
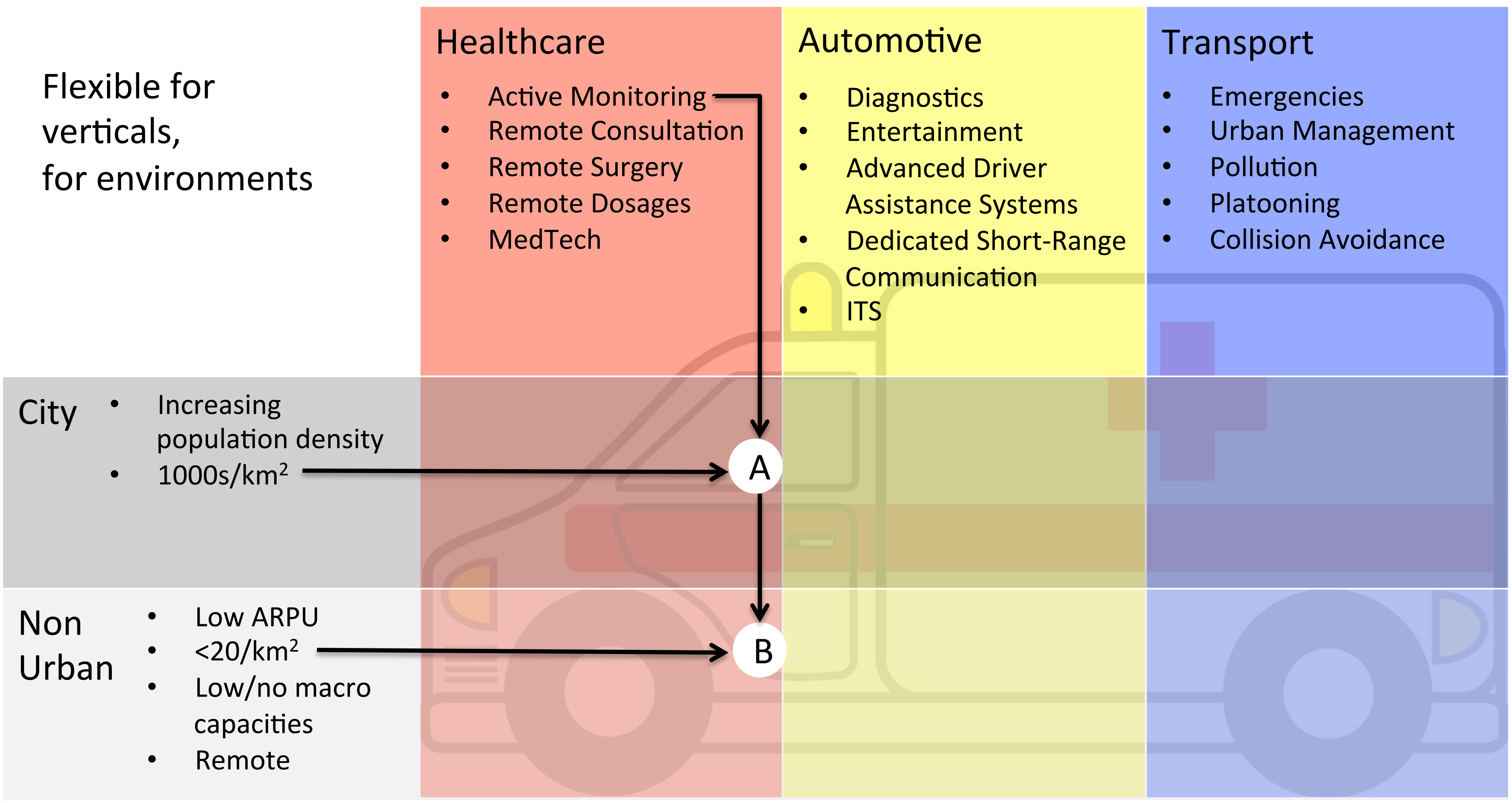


5G is (or will be??) a programmable, dynamic network



Flexible for verticals, for environments	Healthcare	Automotive	Transport
	• Active Monitoring • Remote Consultation • Remote Surgery • Remote Dosages • MedTech	• Diagnostics • Entertainment • Advanced Driver Assistance Systems • Dedicated Short-Range Communication • ITS	• Emergencies • Urban Management • Pollution • Platooning • Collision Avoidance
City • Increasing population density • 1000s/km^2			
Non Urban • Low ARPU • <20/km^2 • Low/no macro capacities • Remote			



Flexible for verticals, for environments
Healthcare
Active Monitoring
Remote Consultation
Remote Surgery
Remote Dosages
MedTech
Automotive
Diagnostics
Entertainment
Advanced Driver Assistance Systems
Dedicated Short-Range Communication
ITS
Transport
Emergencies
Urban Management
Pollution
Platooning
Collision Avoidance
City
Increasing population density
1000s/km²
Non Urban
Low ARPU
<20/km²
Low/no macro capacities
Remote
A
B

Flexible for
verticals,
for horizontals

Slicing from A-Z

Healthcare

- Active Monitoring
- Remote Consultation
- Remote Surgery
- Remote Dosages
- MedTech

Automotive

- Diagnostics
- Entertainment
- Advanced Driver Assistance Systems
- Dedicated Short-Range Communication
- ITS

Transport

- Emergencies
- Urban Management
- Pollution
- Platooning
- Collision Avoidance

City

- Increasing population density
- 1000s/km^2

Non Urban

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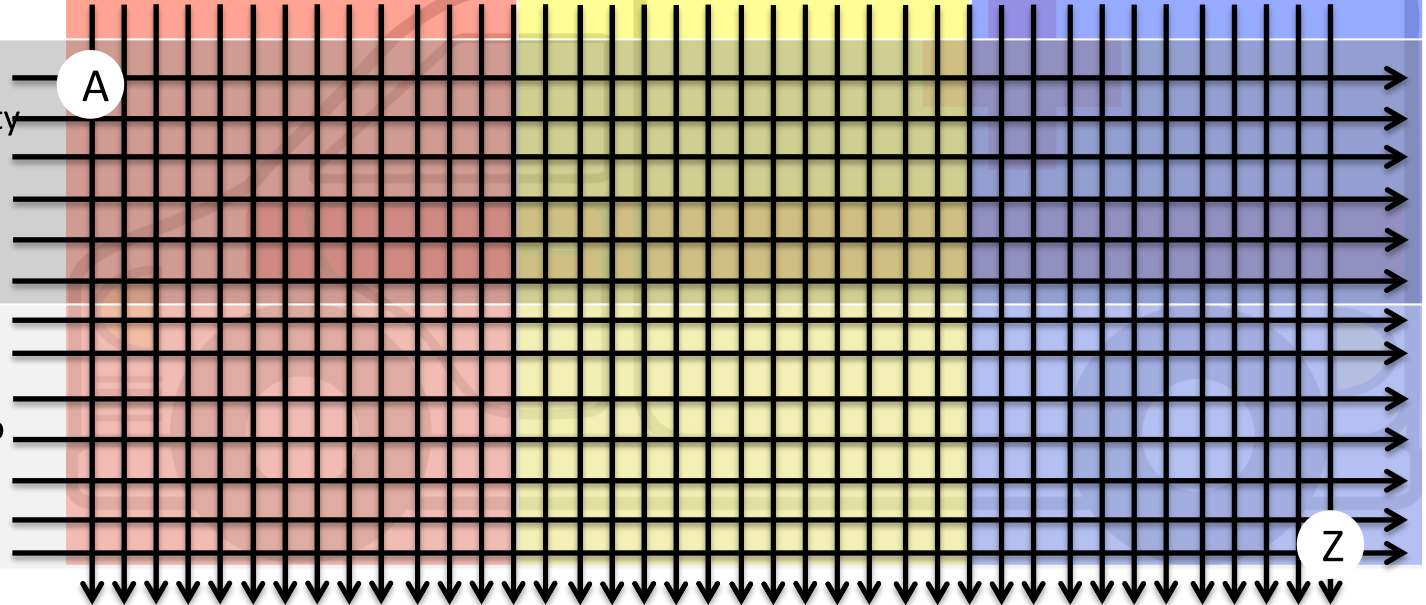

5G Use cases

When thinking of 5G think of non-consumer or non-entertainment uses.

MEDIA

- Predictions for 15 billion video-enabled devices by 2020. To a large extent, these will **be industrial video devices** for machine monitoring, remote medicine, security, surveillance and image recognition, and large amounts of media data will be carried on both the uplink and the downlink.
- 5G will need to support near-zero latency interactions for use cases like remote medicine, as well as more cost- and radio-resource efficient operations with relaxed latency requirements.
- In particular, uplink video will become more significant than it is today, as professional and user-generated content will be uploaded from cellular systems. Devices like cameras and wearables will be equipped with 5G radios, enabling continuous streaming of content in the uplink to the cloud.
- Video will be an important tool for emergency services like the police, fire brigade, and ambulance to provide civil protection and perform emergency management. Efficient media delivery with ultra-low latency for group call services, or relaxed latency for distribution of warning messages, will provide all teams involved in, for example, a rescue operation with access to the same media information, such as video streams from helmet-mounted or helicopter-mounted cameras. This use case requires **both uplink and downlink network capacity** with very high availability and high speed mobility requirements. However, such features will be provided in a more cost- and resource-efficient manner, so that resource intensive operation modes are only used when needed.

Use cases

When thinking of 5G think of communication for ***control*** rather than just file transfer.

REMOTE MACHINERY

- 5G will need to support remote control of heavy machinery – like excavators in mines and wood processors in forests. The benefit of this type of use case is to remove the need for people to work in hazardous environments or maybe to increase efficiency – through the ability to manage several machines simultaneously – or time can be saved when drivers are no longer required on location.
  - Control of exoskeletons etc
- Crucial to this use case is the ability to transport high quality video, audio and other sensory information from the remote machine's environment to the controller.
- To control machinery in real time, the latency of the communication link between the machine and the controller needs to be extremely low. This necessity not only puts requirements on radio access, but also on the transport and core networks.
- In such scenarios, **long transport links should be avoided**, and processing may need to be moved closer to the machinery or to the remote controller. In addition, as the machinery or driver are likely to be on the move, the supporting network will need to be able to adapt to mobility.

TECHNOLOGY ADVANCES

5G Ultra dense & D2D

D2D is for vehicles is a area receiving lots of attention – ***<u>V2V</u>***

DIRECT DEVICE-TO-DEVICE COMMUNICATION

- The possibility of limited direct device-to-device (D2D) communication has recently been introduced as an extension to the LTE specifications.
- In the 5G era, support for D2D as part of the overall wireless-access solution should be considered from the start. This includes peer-to-peer user-data communication directly between devices, but also, for example, the use of mobile devices as relays to extend network coverage.
- D2D communication in the context of 5G should be an integral part of the overall wireless-access solution, rather than a stand-alone solution. Direct D2D communication can be used to offload traffic, extend capabilities and enhance the overall efficiency of the wireless-access network. Furthermore, in order to avoid uncontrolled interference to other links, direct D2D communication should be under network control. This is especially important for the case of D2D communication in licensed spectrum.

5G Ultra lean design

- Ultra-lean radio-access design is important to achieve high efficiency in 5G networks. The basic principle of ultra-lean design can be expressed as: minimize any transmissions not directly related to the delivery of user data. Such transmissions include signals for synchronization, network acquisition and channel estimation, as well as the broadcast of different types of system and control information.
- Ultra-lean design is especially important for dense deployments with a large number of network nodes and highly variable traffic conditions. However, lean transmission is beneficial for all kinds of deployments, including macro deployments.
- By enabling network nodes to enter low-energy states rapidly when there is no user-data transmission, ultra-lean design is an important component in delivering high network energy performance. Ultra-lean design will also enable higher achievable data rates by reducing interference from non-user-data-related transmissions.

5G Radios

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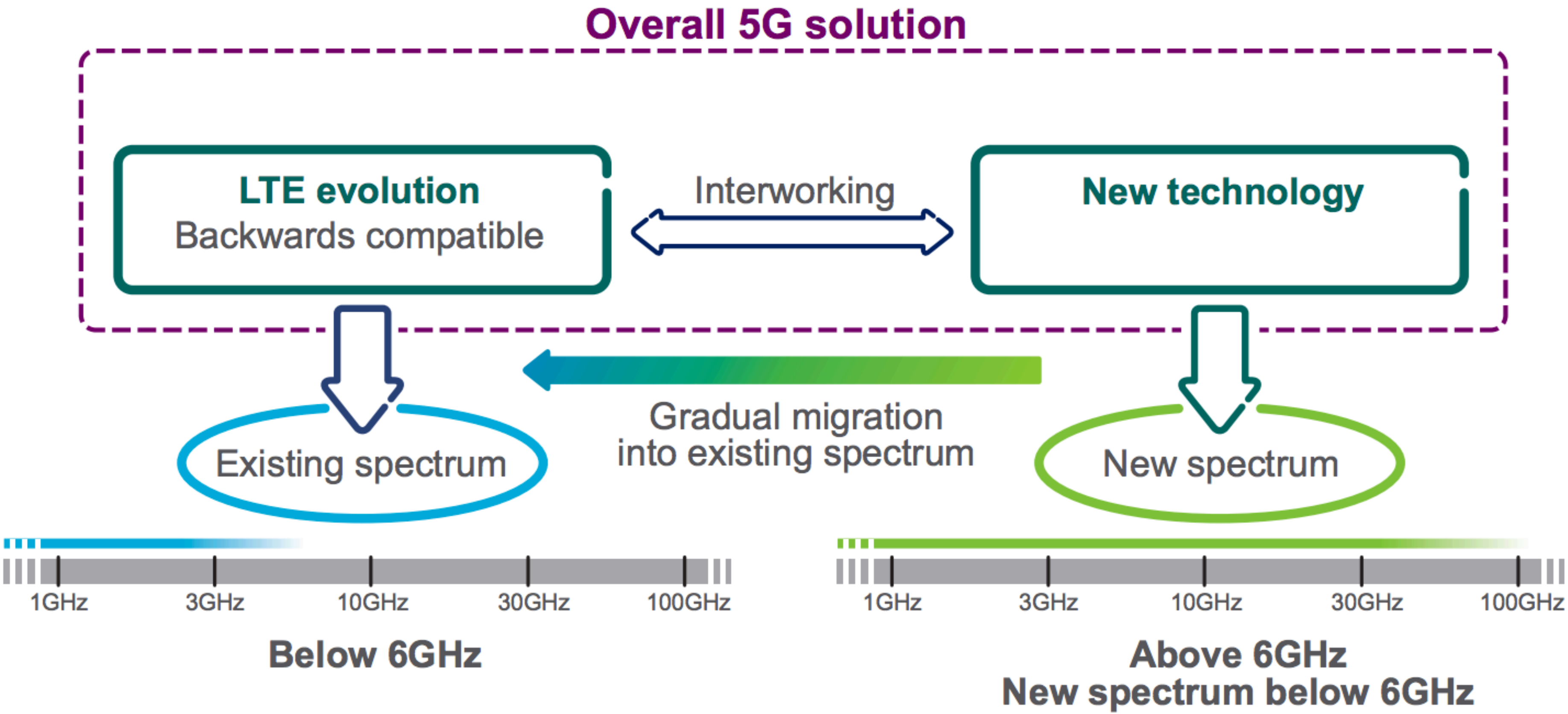
- The specification of 5G will include the development of a new flexible air interface, NX, i.e. new waveforms to replace OFDM/A, which will be directed to extreme mobile broadband deployments. NX will also target high-bandwidth and high-traffic-usage scenarios, as well as new scenarios that involve mission-critical and real-time communications with extreme requirements in terms of latency and reliability.
- In parallel, the development of Narrow-Band IoT (NB-IoT) in 3GPP is expected to support massive machine connectivity in wide area applications. NB-IoT will most likely be deployed in bands below 2GHz and will provide high capacity and deep coverage for enormous numbers of connected devices.

5G Radios and Spectrum



5G Radios and Spectrum