Network architecture vision for 5G and beyond

Werner Mohr

Nokia, Munich, Germany

Moscow Wireless Week, October 1 to 3, 2018

Disclaimer: Presentation based on contributions from Networld2020 ETP, 5G PPP and Nokia

Outline

- Why to invest in networking research?
  - Economic considerations
  - Technology trends
- Networld2020 perspective on Smart Networks
- 5G PPP Architecture Working Group
- Industry example: Nokia perspective
- Challenges on ubiquitous coverage
- Networld2020 Research Agenda SRIA
- Conclusion

UN sustainable development goals 2030
Support by ICT

SUSTAINABLE DEVELOPMENT GOALS

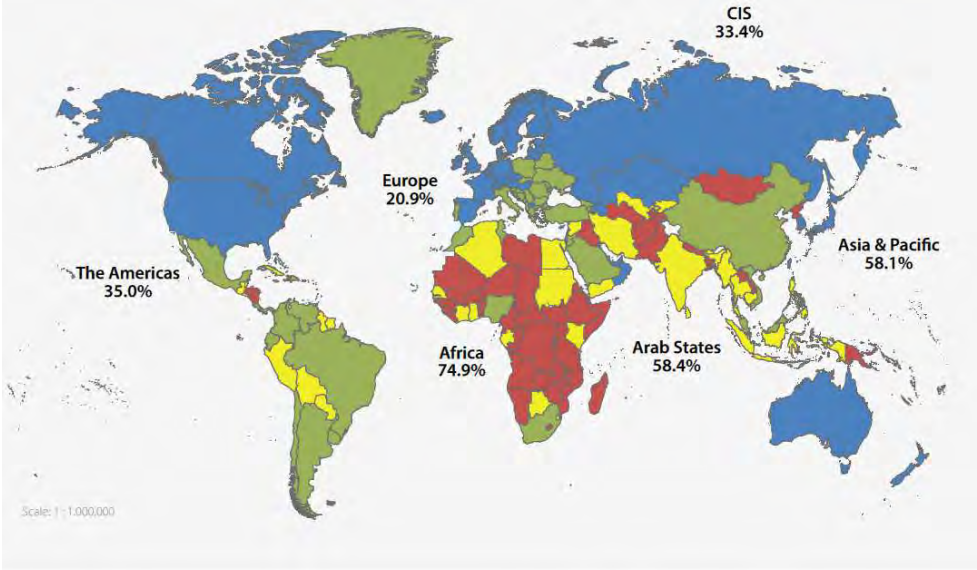
Source: United Nations: http://www.un.org/sustainabledevelopment/sustainable-development-goals/.

UN Broadband Commission for Sustainable Development 2025 Targets: "Connecting the Other Half"

1. By 2025, all countries should have a funded National Broadband Plan or strategy or include broadband in their Universal Access and Service (UAS) Definition.
2. By 2025, entry-level broadband services should be made affordable in developing countries at less than 2 % of monthly Gross National Income (GNI) per capita.
3. By 2025, Broadband-Internet user penetration should reach:
   a) 75 % worldwide
   b) 65 % in developing countries
   c) 35 % in Least Developed Countries
4. By 2025, 60 % of youth and adults should have achieved at least a minimum level of proficiency in sustainable digital skills.
5. By 2025, 40 % of the world's population should be using digital financial services.
6. By 2025, overcome unconnectedness of Micro-, Small- and Medium-sized Enterprises (MSMEs) by 50 %, by sector.
7. By 2025, gender equality should be achieved across all targets.

Source: United Nations – Broadband Commission for Sustainable Development 2025 Targets: "Connecting the Other Half". http://www.broadbandcommission.org/Documents/publications/wef2018.pdf.

Internet user penetration 2016



Percentage of individuals NOT using the Internet

- 0 - 25
- 26 - 50
- 51 - 75
- 76 - 100

By end 2016, 3.9 billion people - 53% of the world's population – is not using the Internet.

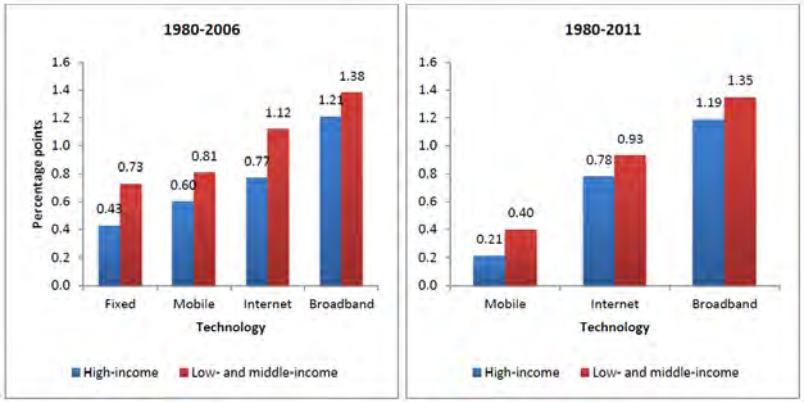
In the Americas and the CIS regions, about one third of the population is offline.

While almost 75% of people in Africa are non-users, only 21% of Europeans are offline.

In Asia and the Pacific and the Arab States, the percentage of the population that is not using the Internet is very similar: 58.1 and 58.4%, respectively.

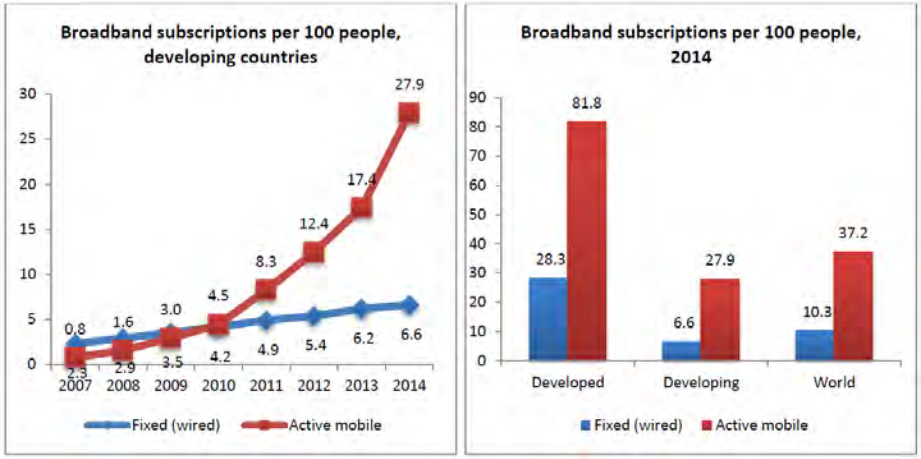
Source: ITU: ICT Facts and Figures 2016. https://www.itu.int/en/ITU-D/Statistics/Documents/facts/ICTFactsFigures2016.pdf, and ICT Facts and Figures 2017. https://www.itu.int/en/ITU-D/Statistics/Documents/facts/ICTFactsFigures2017.pdf.

Relation: Broadband access networks and economic growth



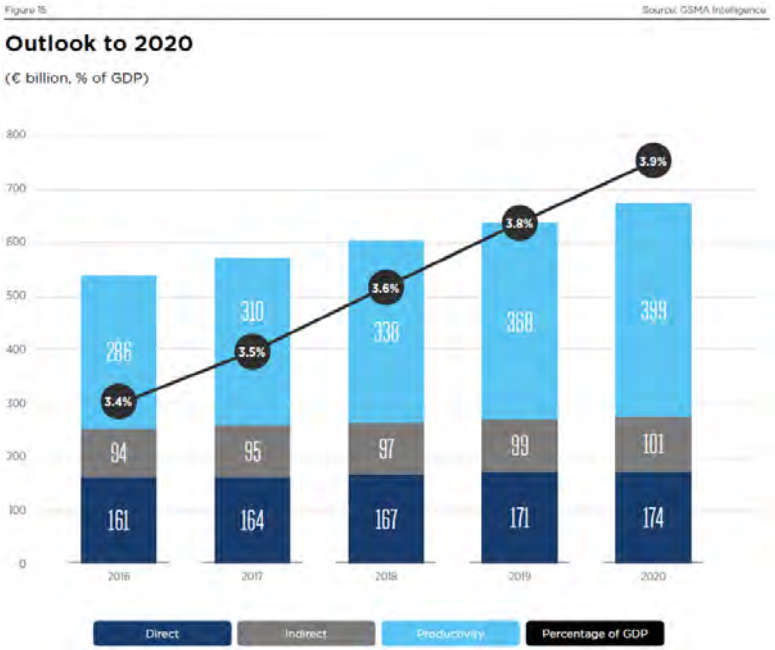
GDP growth impact from 10 percentage point increase in different ICTs, by country economic development category

Fixed and mobile broadband subscriptions

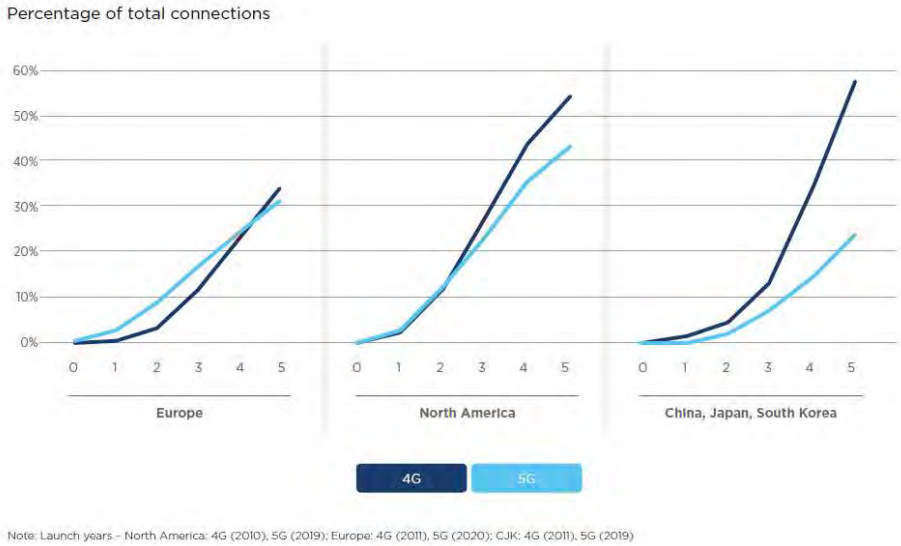


Source: World Bank: Exploring the Relationship Between Broadband and Economic Growth. Michael Minges, World Development Report, 2016. http://documents.worldbank.org/curated/en/178701467988875888/pdf/102955-WP-Box394845B-PUBLIC-WDR16-BP-Exploring-the-Relationship-between-Broadband-and-Economic-Growth-Minges.pdf.

ICT market size I



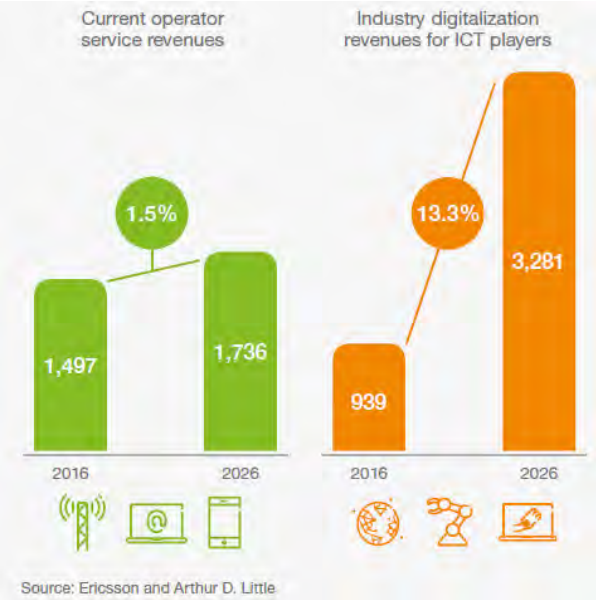
Total (direct, indirect and productivity) contribution to GDP (€ billion, % 2016 GDP)



4G and 5G adoption, years after first launch

Source: GSMA The Mobile economy report 2017, https://www.gsmaintelligence.com/research/?file=89a59299ac2f37508b252124726a1139&download.

ICT market size II

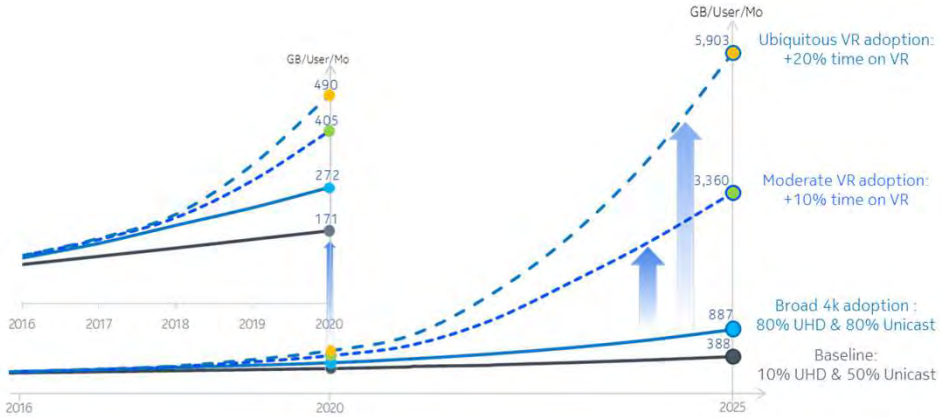


Revenue forecast (CAGR 2016 – 2026, US-$ billion)

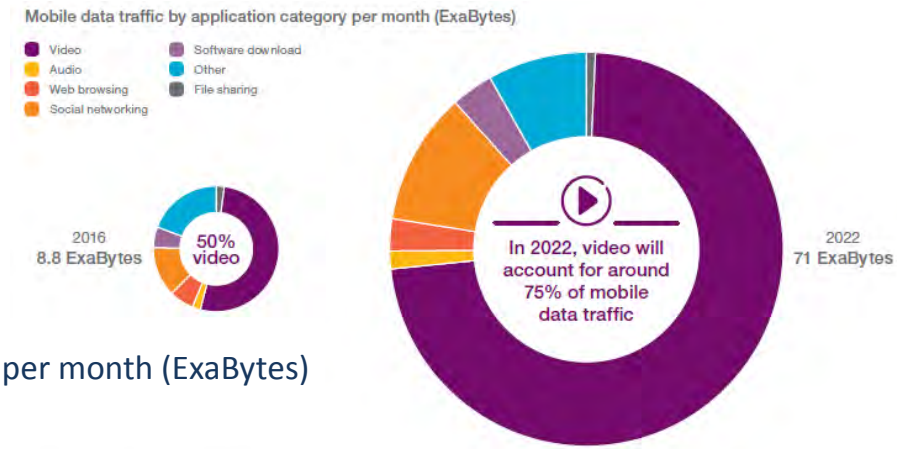
Where is the value potential of the Internet of Things

Source: Ericsson: The 5G Business Potential. 2017, https://www.ericsson.com/assets/local/news-and-events/events/2017/mwcs-2017/topic-3_ericsson_5g_business_potential.pdf.
McKinsey & Company: The Internet of Things: Mapping the value beyond the hype. McKinsey Global Institute, June 2015. https://www.mckinsey.de/files/unlocking_the_potential_of_the_internet_of_things_full_report.pdf.

Trends towards future systems I



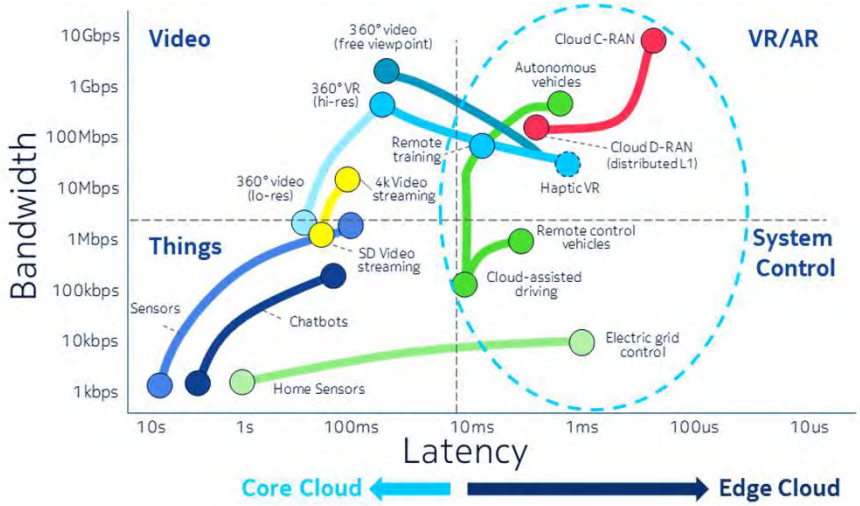
Seemingly infinite capacity - Exponential traffic growth drives massive capacity



Mobile data traffic by application category per month (ExaBytes)

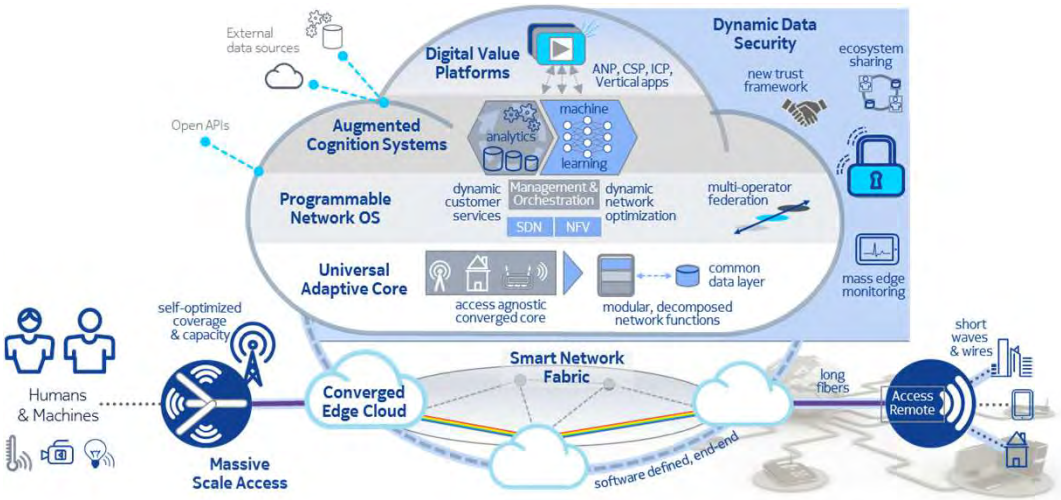
Source: Nokia Bell Labs Consulting: Demand Forecast for Per Capita Data Consumption (US). https://de.scribd.com/document/314849011/Nokia-Bell-Labs-Mobility-Traffic-Report
Ericsson: Ericsson mobility report https://www.ericsson.com/assets/local/mobility-report/documents/2017/ericsson-mobility-report-june-2017.pdf.

Trends towards future systems II



Requirements on throughput and latency depending on application

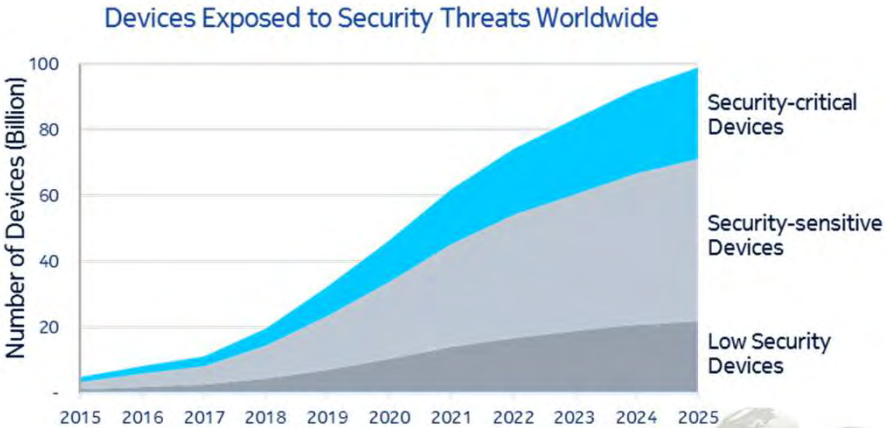
Potential high-level future network architecture



Source: Nokia.

Network security

The rise of Advanced Persistent Threats and Ransomware



Number of IoT devices

Source: Nokia Bell Labs Consulting: Demand Forecast for Per Capita Data Consumption (US). https://de.scribd.com/document/314849011/Nokia-Bell-Labs-Mobility-Traffic-Report

Technology vision
Societal perspective

- United Nations 2030 SDGs require Smart Networks in many different domains to support the digitalisation of society and economy in developing and developed countries
- ICT in general and ubiquitous and affordable communications networks (enabling mobile and fixed users) in particular is fundamental enabler of a modern society
- Smart Networks of the future will be
  - the nervous system of the Next Generation Internet (NGI) and other commercial networks and
  - the platform for driving the digital transformation
- Smart Networks are the foundation of the Human Centric Internet:
  - Energy-efficient and high-performance infrastructure on which NGI and other digital services can be developed and deployed
  - Application of intelligent software (Artificial Intelligence) for decentralised and automated network management, data analytics and shared contexts and knowledge
  - Virtualisation and strict policies will foster a free and fair flow of data which can be shared whilst at the same time protecting the integrity and privacy of data which is confidential or private: users should be able to control their environment in the Internet and not be controlled by the Internet

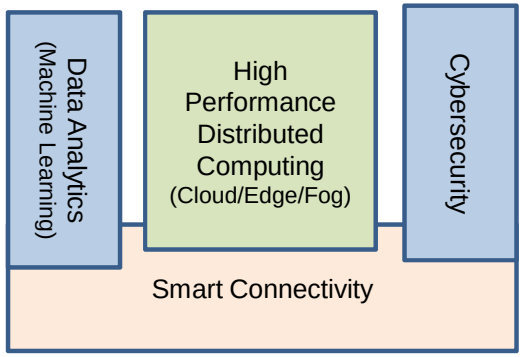
Source: Networld2020 European Technology Platform.

Technology vision
Interconnection of everything

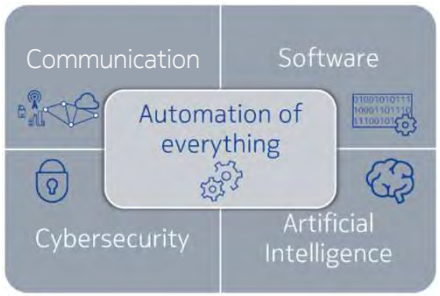
- From supercomputers and parallel computers, to data analytics, passing through cybersecurity, the Internet of Things (IoT), cooperative robots, or autonomous vehicles, it is universally agreed **that every system and application must be interconnected to its peers**, as well as to other related entities and systems
- Interconnection of everything provided by Smart Networks will be a distinguishable flavour of a competitive advanced society
- Smart Network architecture will be software defined and will provide features significantly going beyond connectivity
  - Multiservice and Mobile Edge Computing will allow to store and process data locally at the edges of the network to provide fast reactions and efficient use of network resources
  - Programmable aggregation and virtualisation functions as well as built-in security functions enabled (e.g. by the support of blockchains) will create a trusted environment for the Internet of smart things in which new applications and ideas can flourish
  - Future cost-effective communication systems and networks will increasingly be based on Artificial Intelligence (AI), Machine Learning (ML) and increased softwarisation in addition to requiring the continued development of classical communication technologies
  - It will intertwine distributed network, compute and storage resources to facilitate an agile composition of new services supporting a multitude of markets and industry sectors

Source: Networld2020 European Technology Platform.

Technology vision
Main characteristics and building blocks



Smart Networks in relation to other major areas



Key building block of Smart Networks

- Main characteristics of Smart Networks
  - Integrated Connectivity, Computing and Control (the 3Cs)
  - Converged heterogeneous networks, integrating the 3Cs, so as to enable the broadest range of ubiquitous and affordable mobile and fixed uses
  - Ubiquitous coverage and elimination of white spots
  - Support of hyper-converged overlays
  - Hundreds of trillions (10^{14}) of connected, active, devices and terminals
  - Massive numbers of tailored cost-effective services
  - Automated and greatly cost reduced network operation
  - High societal, vertical, autonomous and cross-sector penetration: Energy, transport, health, entertainment, security, industry, aerospace and many other sectors relying on this infrastructure
  - Multi-sensorial interfaces, multi-environment and wearables
  - Reality enhanced with virtual and augmented reality
  - Support of drone fleets and autonomous vehicles

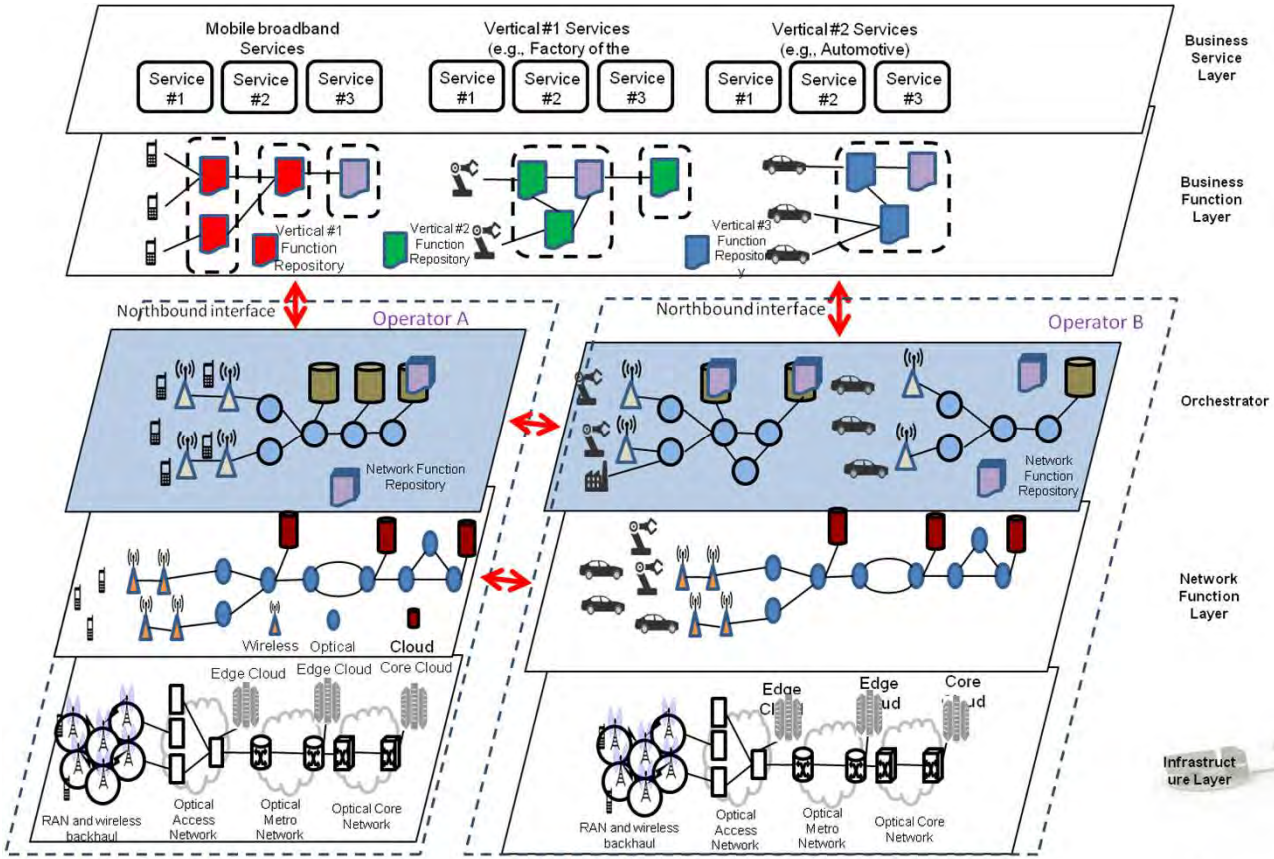
Source: Networld2020 European Technology Platform.

Technology vision
Key requirements

- Key requirements on Smart Networks
  - Seemingly infinite network capacity has to be provided in a flexible and cost-effective manner for the ever-increasing demand of applications and services
  - Ultra-low imperceptible latencies must be supported to enable a new class of highly responsible and interactive applications as well as a new level of industrial automation
  - Massive amounts of things and systems need to be connected in a scalable and cost-efficient way
  - Global reach and optimised local service delivery capabilities need to be combined in highly flexible ways and should be available on-demand for the value chains of web-based software and IoT platforms
  - Cognitive operations making use of Artificial Intelligence and Machine Learning mechanisms combined with cyber physical security are required to cope with the growing complexity of networks and systems
  - Personalised and perpetual protection has to be provided based on security, privacy and trust mechanisms that are able to cover the expanding threat surface due to the billions of IoT devices and are able to deal with the growing number of threats triggered by the increasing value of data

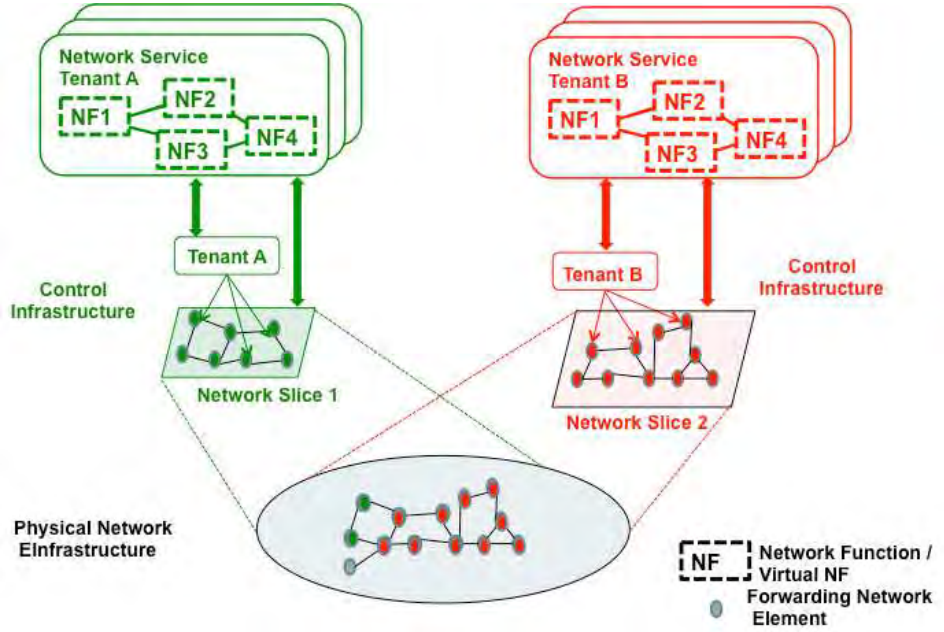
Source: Networld2020 European Technology Platform.

Integrated 5G architecture for mobile broadband and vertical services (5G PPP)

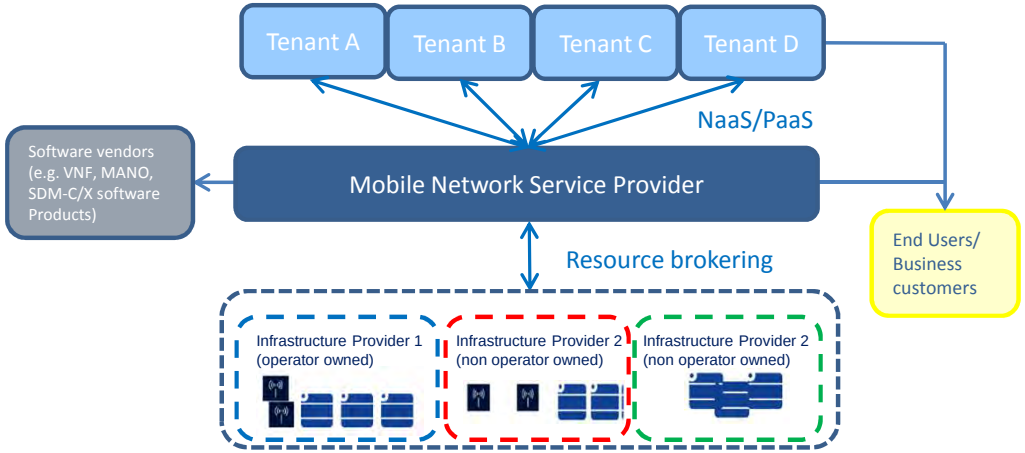


Source: 5G PPP Architecture Working Group: View on 5G Architecture. White Paper, Version 1.0, 2016. https://5g-ppp.eu/wp-content/uploads/2014/02/5G-PPP-5G-Architecture-WP-July-2016.pdf.

Network slicing, business realisation and stakeholders



Network Slicing Representation



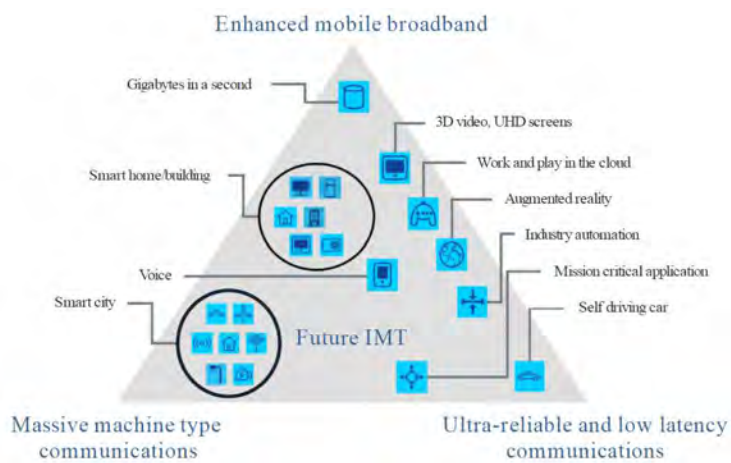
Relationship between stakeholders and Mobile Service Provider in the core place

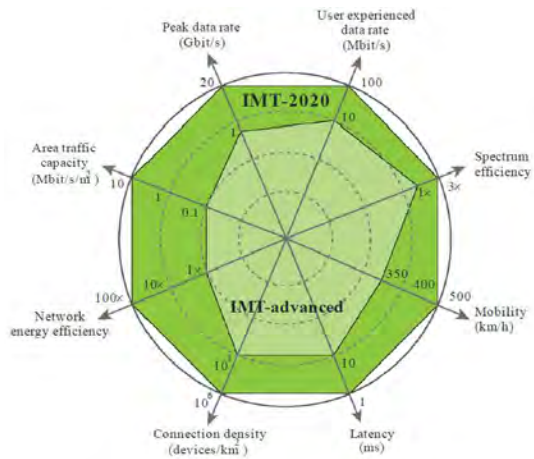
Source: 5G PPP Architecture Working Group: View on 5G Architecture. White Paper, Version 1.0, 2016. https://5g-ppp.eu/wp-content/uploads/2017/07/5G-PPP-5G-Architecture-White-Paper-2-Summer-2017_For-Public-Consultation.pdf.

On the way to the Gigabit society

Major requirements

- Europe pushing towards digitalization of society and economy
- Gigabit connectivity by means of 5G and optical networks is a key cornerstone
- 5G supports a wide range of application domains and technical parameters as basis of the digital transformation
- Users are human beings and machines especially in cooperation with vertical sectors





Sources: ITU-R: IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond. Recommendation ITU-R M.2083-0 (09/2015), https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.2083-0-201509-I!!PDF-E.pdf.

The change: the future is very different from the past

	Past	Future
Solutions	**Technology-driven**	**Human/Business need driven**
Driver	**Consumer** (BW)	**Industry & Consumer** (Latency & SLA)
Architecture	**Heavily Centralized**	**Massively Distributed**
Partnership	**Monoliths w/Limited APIs**	**Modular w/Co-design & Open specs**
Standards	**Definitive**	**Iterative**
Investment	**Singular** (Operator only)	**Multiple & Cooperative** (Many contributors/new players)
Flexibility	**Limited** (Provisioned)	**Large** (Software definable)
Sharing	**Static and Limited** (HW VPNs)	**Dynamic and Infinite** (SW Slices)
Innovation Speed	**Per annum/decade** (new services)	**Per hour/day** (new apps)

Fundamental digital needs for new human & business value creation

seemingly infinite capacity

1 **Need:**
100x capacity growth
in <10 years

imperceptible latency

2 **Need:**
Millisecond latency for networks
& new 'human' services

terascale things

3 **Need:**
Optimize TCO for
a trillion things

global-local alliance

4 **Need:**
Massive distribution of cloud
infra with global federation

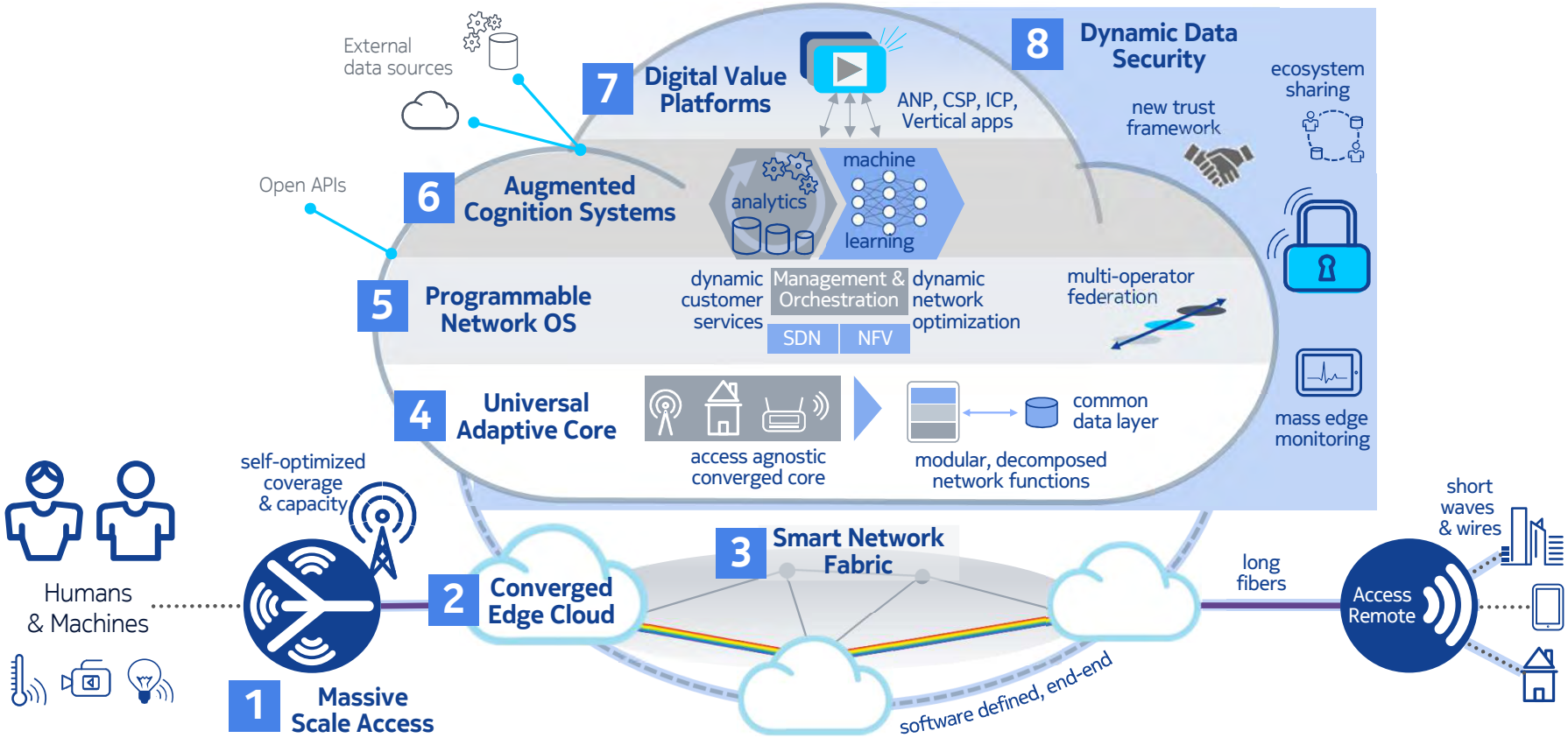
human cognitive operation

5 **Need:**
Human assistance & task
automation @ machine scale

personalized protection

6 **Need:**
Enable dynamic, contextual
security & trust @ terascale

High level architecture: The Future Network Architecture



Future network: cognitive + converged + cloud-optimized network (r)evolution

The 8 technology/architecture domains for a new digital reality

Massive Scale Access

1

The creation of ultra-small and ultra-close access nodes

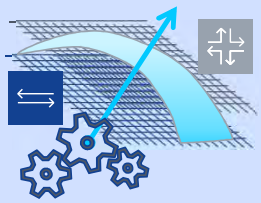
Converged Edge Cloud

The emergence of the edge cloud for low latency and high performance

2

Smart Network Fabric

3

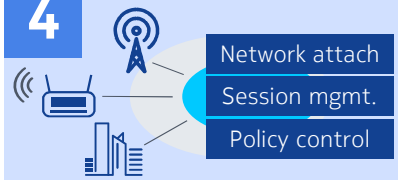


Creating dynamically reconfigurable IP + optical metro and core networks

Universal Adaptive Core

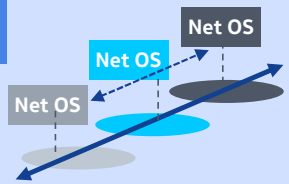
Access-agnostic core for seamless user experience

4



Programmable Network OS

5

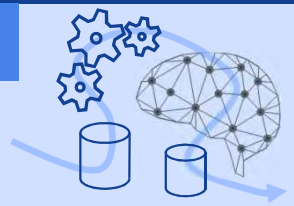


The emergence of the network OS to enable programmability and network federation

Augmented Cognition Systems

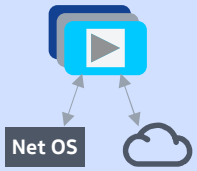
Pervasive cognitive capabilities for operating networks & systems

6



Digital Value Platforms

7



Digital value platforms augmented by advanced network capabilities

Dynamic Data Security

The emergence of new trust models & security architectures

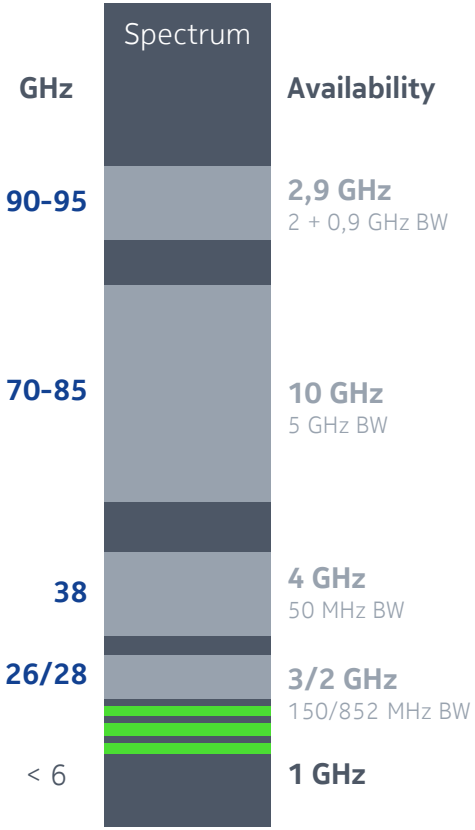
8

Digital Trust

Adaptable Security

Future success defined by leadership in multiple domains

1 Massive scale access – Enabled by spatial multiplexing and new spectrum



Frequency ↑
→ path loss ↑
Cells sizes ↓
→ mmWave ✓

Dynamic TDD

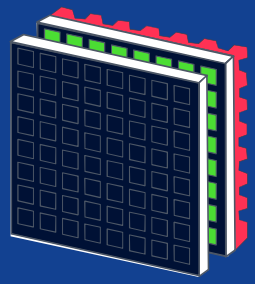
each slot usable for DL/UL/ backhaul

Latency

<1 ms

- Appropriate numerology
- Frame structure
- Variable scheduling intervals << 1 ms

Massive antenna arrays to overcome propagation challenges



≥ 16 element arrays at base station

Beamforming at RF

Polarization → 2 stream MIMO

Chip-scale array elements

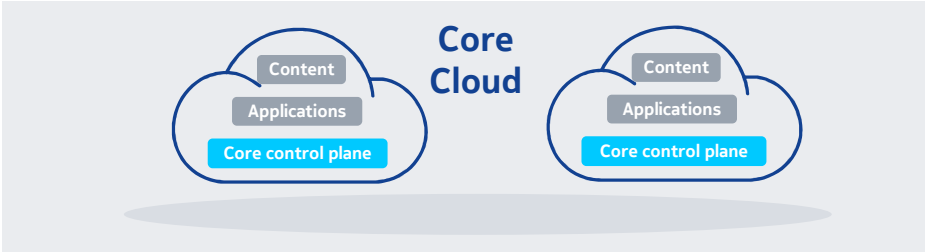
High digital data rates

1-2 GHz	**20 Gbps**	**> 100 Mbps**
bandwidth	2x2 MIMO	cell edge rates

cm/mm-wave & massive antenna arrays essential enablers of ultra-capacity RAN

2 Converged edge cloud – driven by low latency and high performance

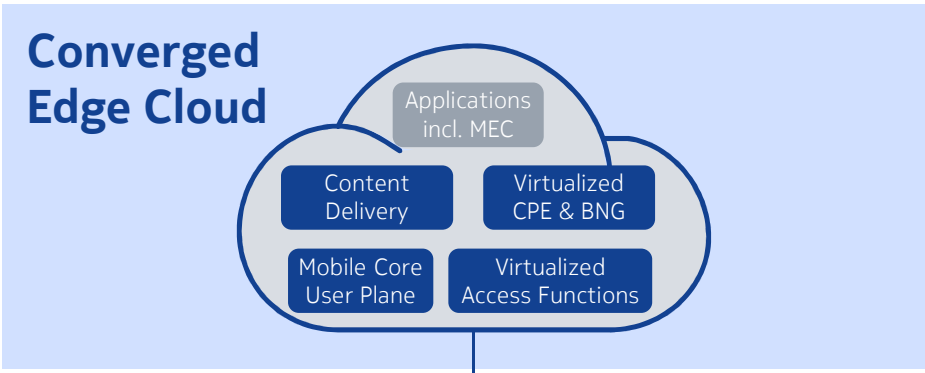
- Centralized data centers co-located with IP/optical PoPs
- 10 – 50ms latency



Unavoidable shifts in network architecture :

Distribution of key edge/core functions & applications to edge cloud to localize traffic and reduce latency

- Emerging metro data centers
- ~50k-250k subscribers (multiple/large metro)
- 1-5ms latency



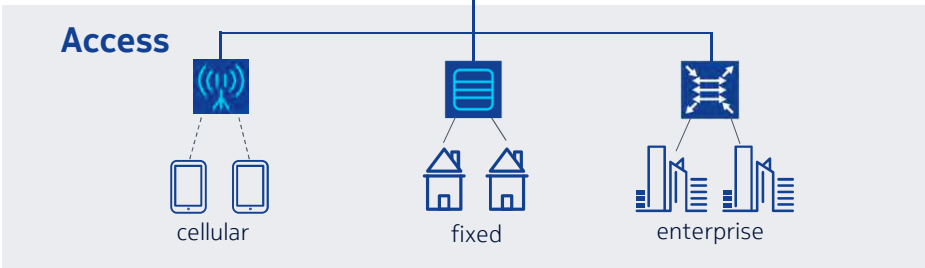
Low-latency applications

- applications and user plane functions close to the access

Massive network capacity

- scaling delivery for UHD video, VR/AR and personalized content consumption

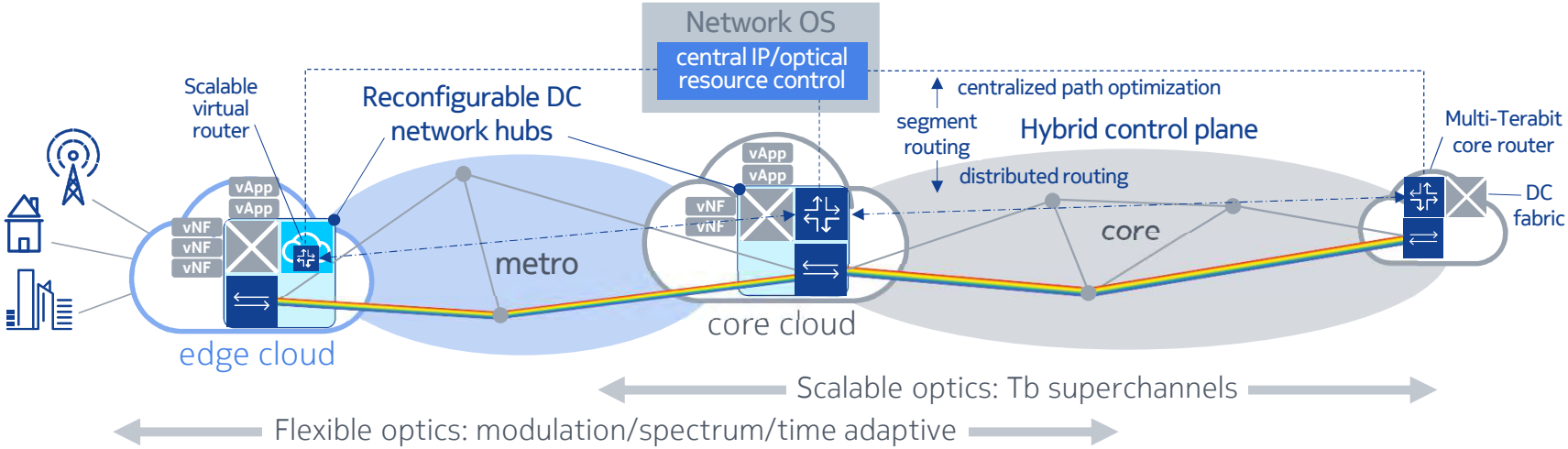
- Ultra-capacity long-reach fiber access
- Highly distributed remote nodes



Virtualization of SW-defined access functions in edge cloud for better agility and reduced TCO

Distribution of ultra-small remote units to achieve higher data rates

3 Smart network fabric - reconfigurable IP/optical fabric for dynamic digital delivery



Ultra-Scale Flexible Optics

- Spectral & spatial superchannels
- Spectrum-adaptive networking & fully flexible wavelength routing
- Dynamically adaptive optical-Ethernet switching

Cloud-Optimized IP Routing

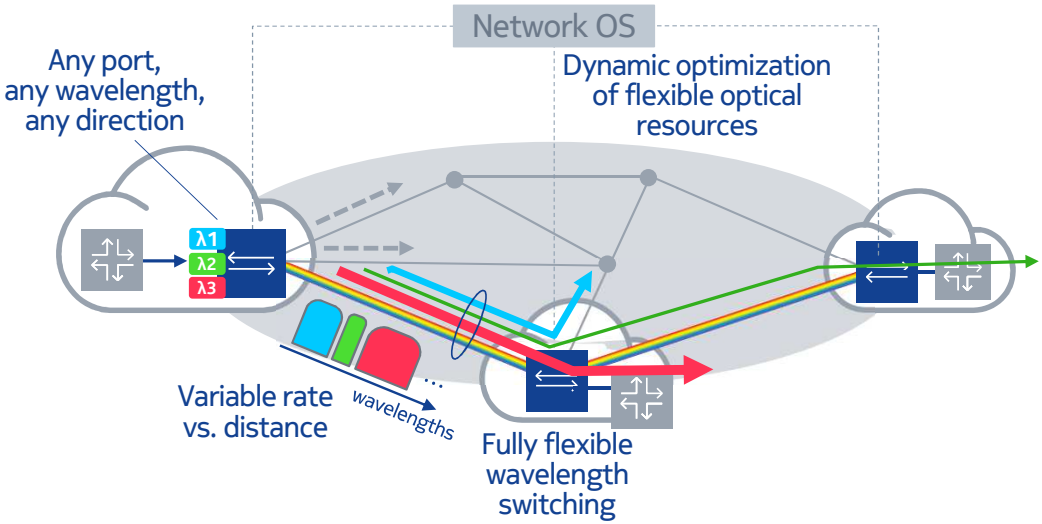
- From tiny virtual routing endpoints to massive multi-Tb core routers
- Scalable hybrid control plane
- Segment routed data plane with centralized traffic engineering

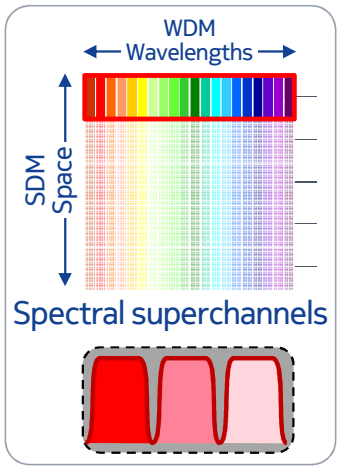
Cloud-Centric Network Fabric

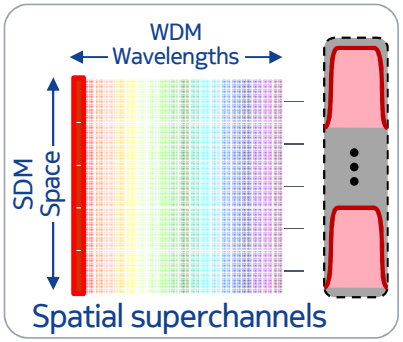
- Network built around new edge/ core data center hubs
- All network resources organized as programmable pools of capacity
- Network OS composition/control

Scale, flexibility, and programmability for new distributed cloud driven delivery

3 Smart network fabric – underpinned by flexible ultra-scale optical capacity







Superchannels aggregate spectrum for efficient very high rate interface rates

Flexible Optics Empower Programmability

- Assignable pools of optical interfaces and spectrum
- Adjust capacity vs. distance (via symbol rate, modulation order, or spectrum width), optimized at network level

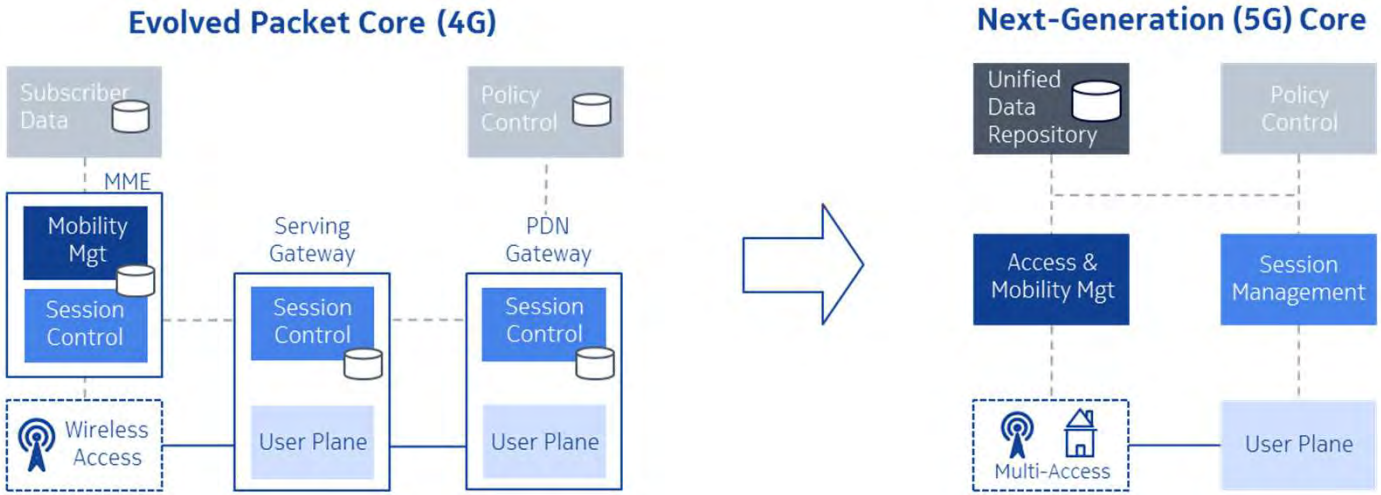
Superchannels Essential to Advancing Scale

- Spectral superchannels enable Tb+ interface rates
- Spatial superchannels and component integration required for future orders of magnitude scaling

Advanced optical networking technologies fundamental to efficiently scaling the network

4 Universal adaptive core

Extended packet core versus future network architecture



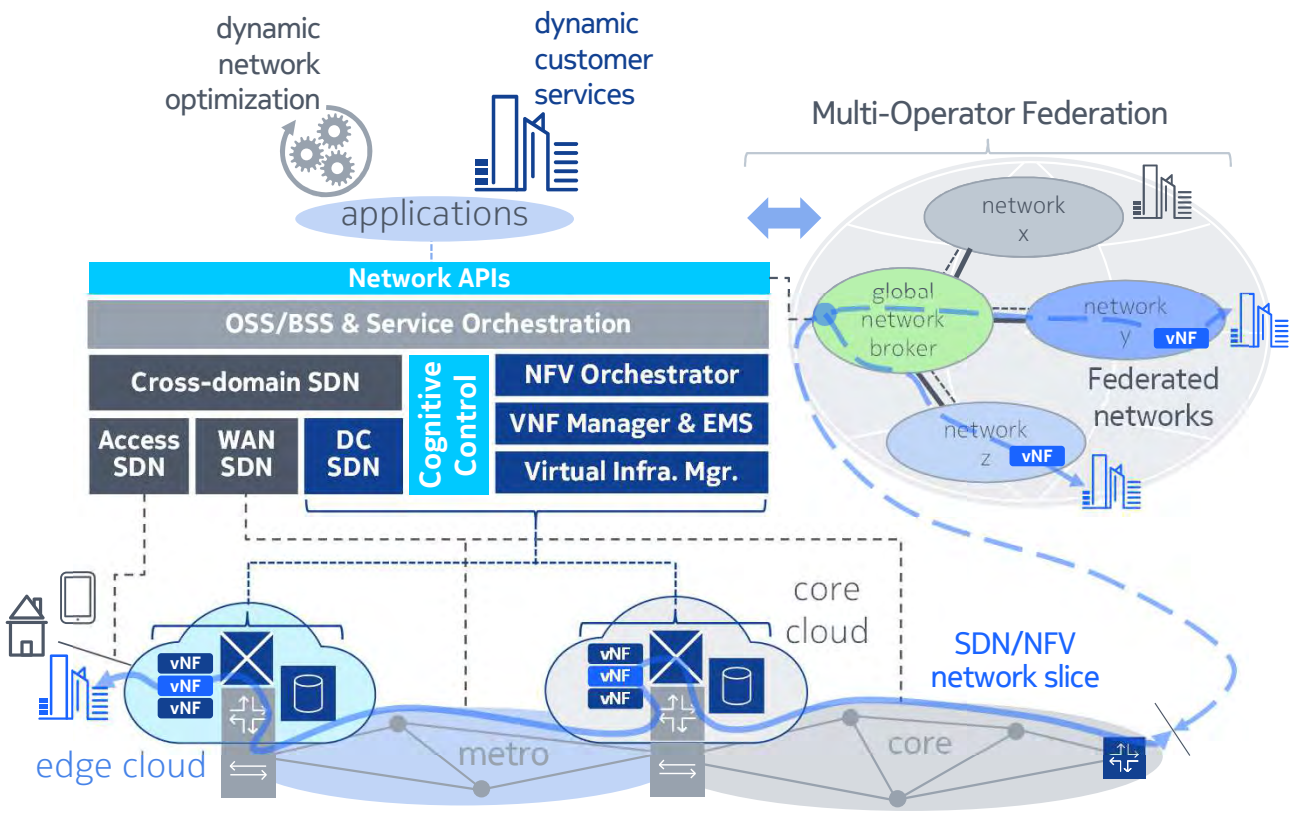
- *Radical simplification* by separating orthogonal functions — session management, access/mobility management and user plane are independent network functions to enable distributed user plane deployments for latency-critical applications hosted in edge clouds

- A *service-based architecture* allows for rapid creation of new services. Network functions will expose their capabilities as 'services' that can be consumed by any other network or application function, enabling flexible per-service software deployment.

5 Programmable Network OS – enabling multi-operator federation

Multi-Operator Federation

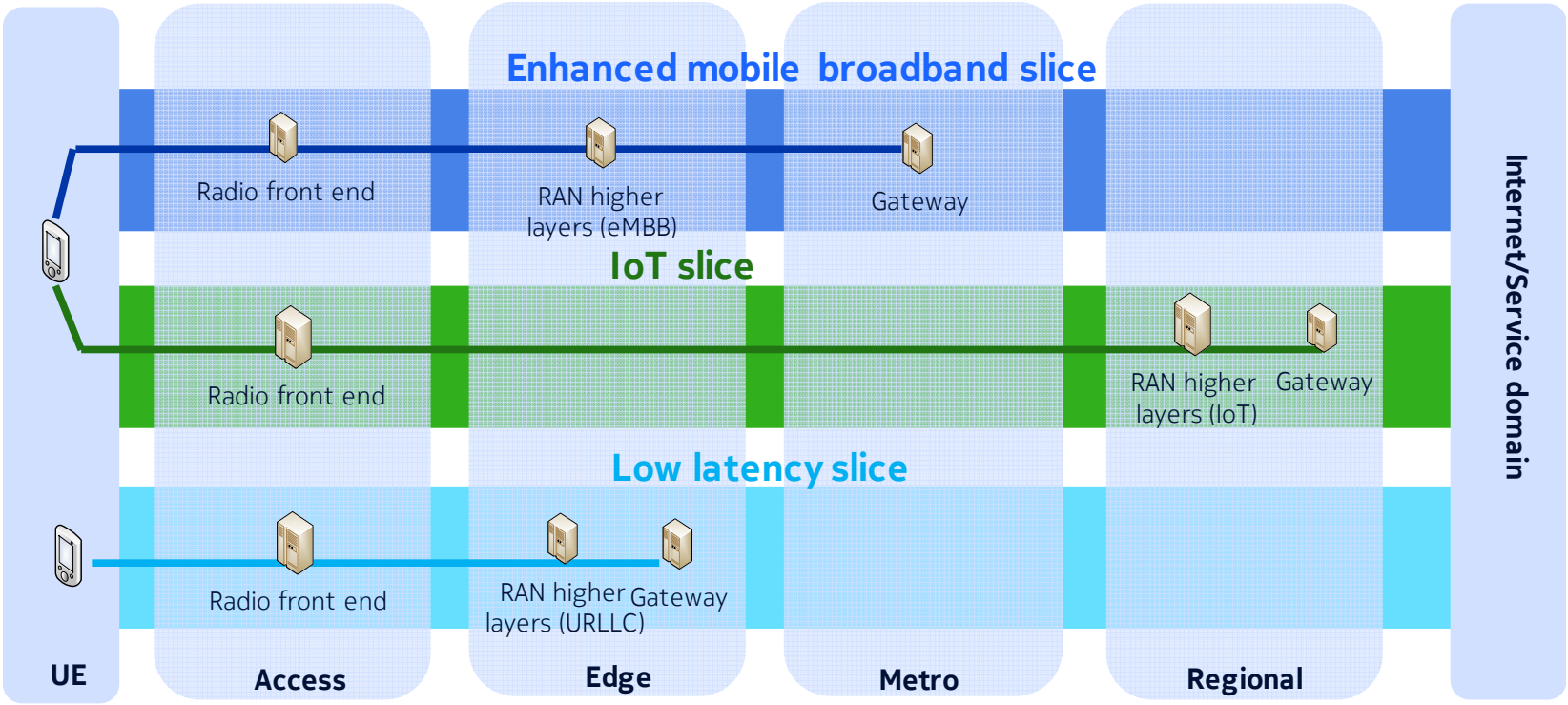
- Common service composition & APIs spanning multiple networks
- Unified network state & policy framework
- Enables global dynamic connectivity and network slicing services
- Via federated brokers and/or consortiums



Federation of network OS drives E2E network programmability in new global-local paradigm

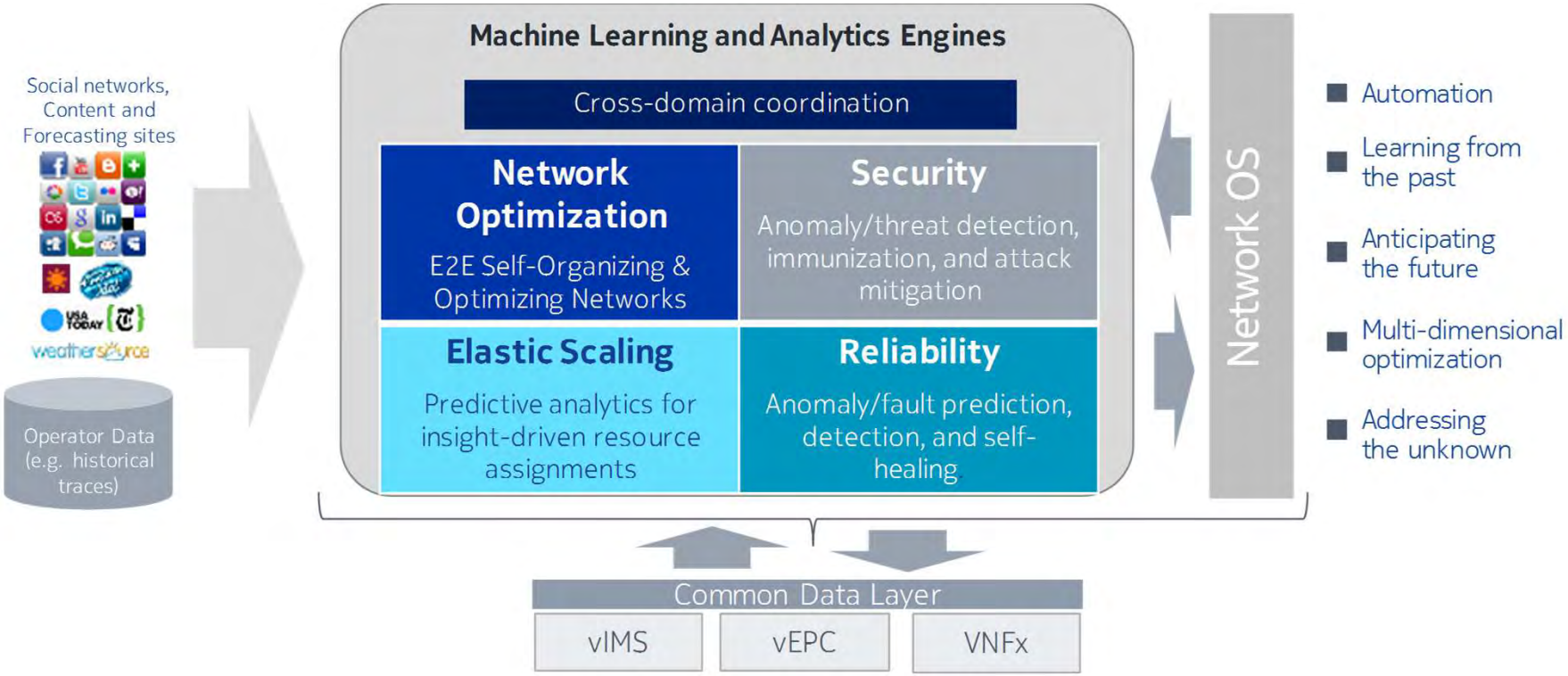
5 Network slicing

Example of network slices for different services



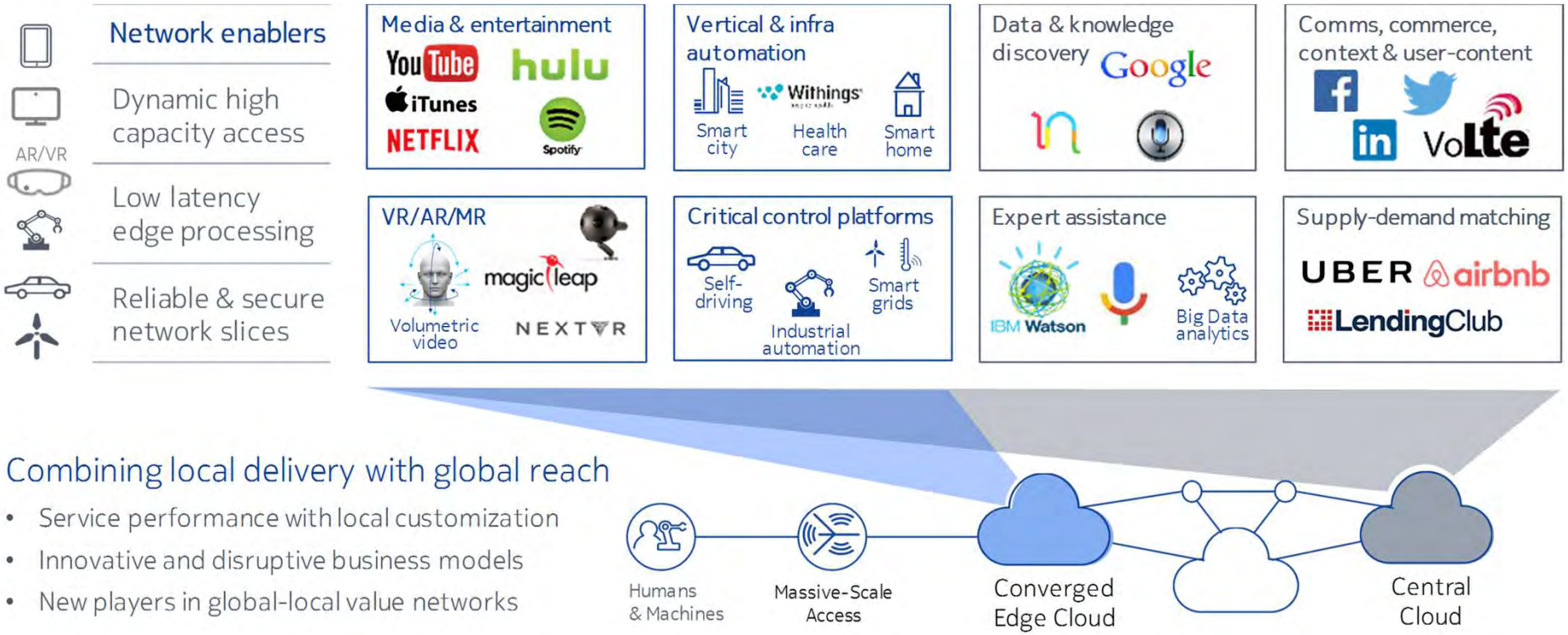
6 Augmented cognition systems

Cognitive cloud as analytics- and machine-learning-based autonomics engine



7 Digital value platforms

Types of existing and future digital value platforms

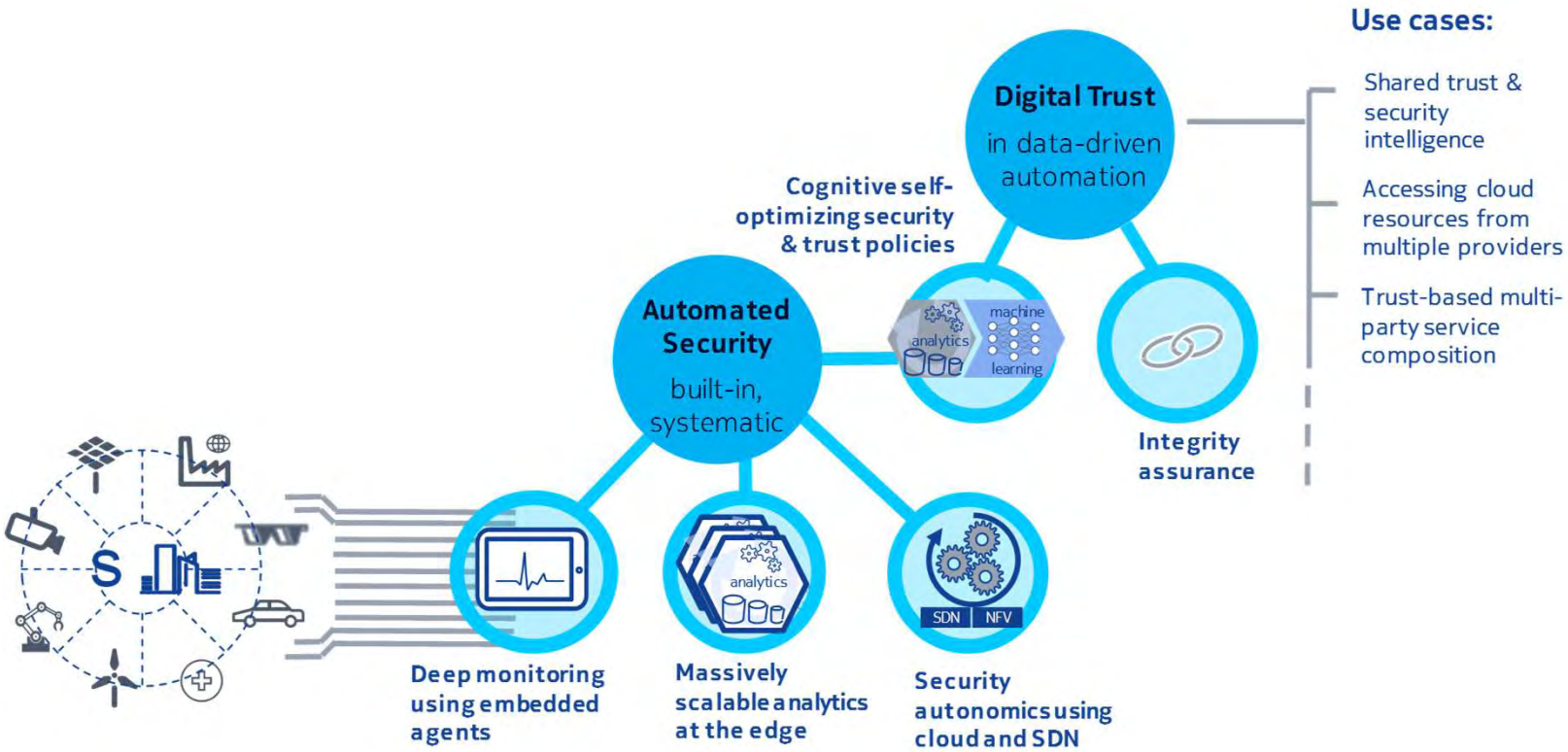


Combining local delivery with global reach

- Service performance with local customization
- Innovative and disruptive business models
- New players in global-local value networks

8 Dynamic data security

Dynamic data security based on digital trust and automated security

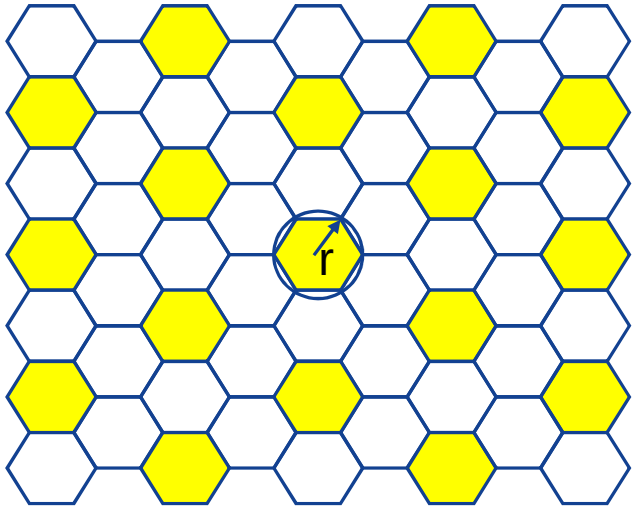


Challenges for a wide area and high throughout deployment

Basic deployment concepts

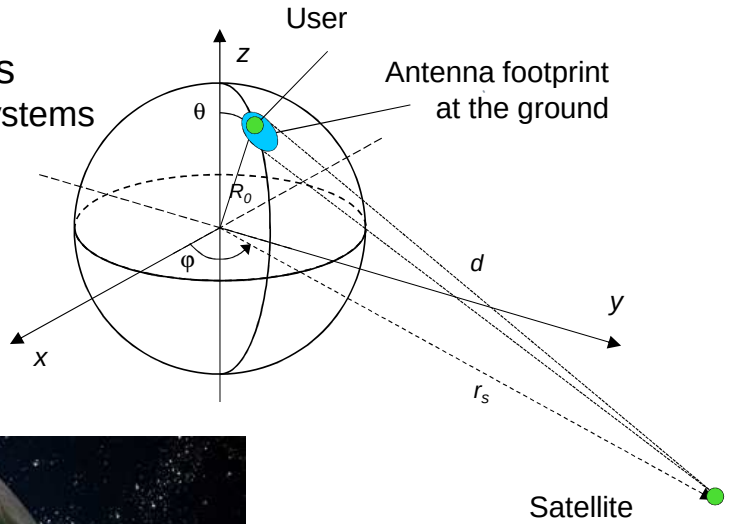
Cellular concept for frequency reuse

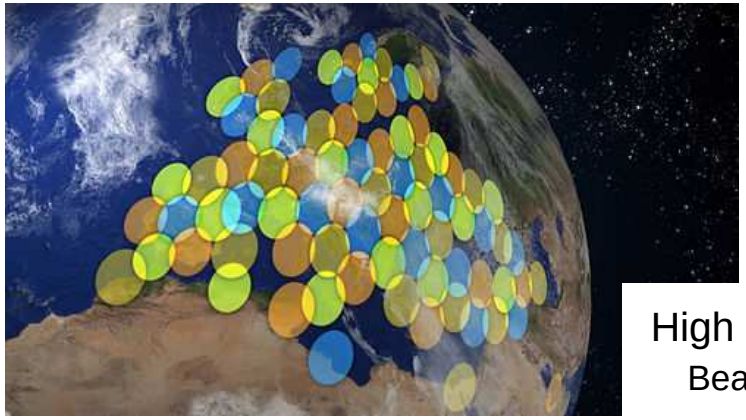
Basic approach in terrestrial mobile systems



Satellite systems

LEO, MEO and GEO systems





HTS: 1 Tbps aggregated throughput means 1000 simultaneously active users per cell with 1 Gbps/user

High Throughput Satellite systems

Beam-steering and frequency reuse

Source: High-throughput satellite, definition. Wikipedia, https://en.wikipedia.org/wiki/High-throughput_satellite.

Basic capacity, coverage and economic considerations

Terrestrial versus satellite systems

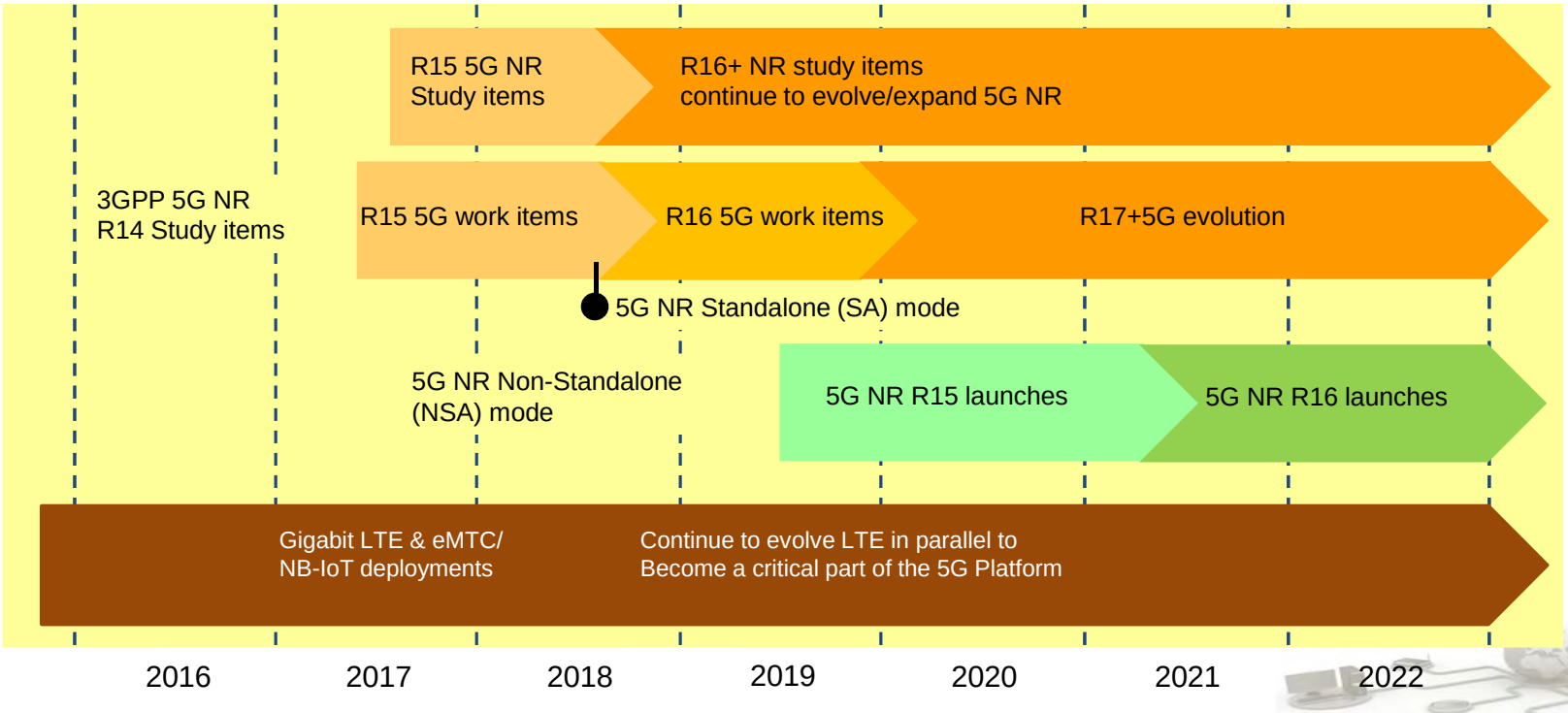
Terrestrial mobile communication system

- System capacity per area unit and user increased by
  - additional frequency spectrum
  - improvement of spectral efficiency of radio interface
  - mainly by decreasing cell size
- In high densely populated areas cell size flexibly adapted to traffic demand to very small cells
- In low densely populated areas maximum cell size determined by propagation conditions (maximum range), which may lead to uneconomic deployment in such areas
- Low latency by Converged Edge Cloud system architecture
- High mobility of users supported e.g. in trains

Satellite systems

- Coverage provision of huge areas economically
  - in low densely populated areas and
  - specific scenarios like ships and planes
- Different orbit concepts GEO, MEO and LEO offer opportunities for different size of coverage area at ground
- Cell size defined by orbit height, satellite antenna size and frequency range
- However, feasible minimum cell size much bigger than small cells in terrestrial mobile systems
- System capacity per area unit and user limited by minimum feasible cell size and throughput per satellite
- In LEO and MEO constellations lower latency possible but higher than in terrestrial systems due to longer propagation path and wide area diversity for feeder links
- LEO and MEO require circulating satellites, which result in very high Doppler shift and need for group handover between satellites

3GPP Release timeline for 5G versus LTE



Source: Miller, M.: Differentiate Between 4G LTE and Non-Standalone 5G NR Antennas Microwaves & RF, June 2018, pp. 60.

Research agenda (SRIA) from the Networld2020 perspective

1. **Network architecture and control**
   - Virtualised network control for increased flexibility; Integrated Fixed-Mobile Architecture; Slicing and orchestrators; Evolution of NFV/SDN and AI-based Network Control; Terminal aspects; Media Access Control; Network based localisation
2. **Radio technology and signal processing**
   - Spectrum re-farming and reutilisation; Millimeter Waves; Optical wireless communications; Terahertz communications including new materials (graphene); Ultra-massive MIMO; Non-orthogonal carriers, full duplex and transceiver design; Enhanced modulation and coding; Improved Positioning and Communication; Random access for massive connections; Wireless Edge Caching
3. **Optical networks**
   - Flexible capacity scaling; New switching paradigms; Deterministic networking; Optical wireless integration; Optical network automation; Security for mission critical services; Ultra-high energy efficiency; Optical integration 2.0
4. **Edge computing and meta-data**
   - Beyond mobile edge computing; Future directions for Fog Computing; Massive IoT services, Data analytics and data monetisation
5. **Network and service security**
   - Security transformation; Network-wide Security; Security and privacy in Internet of Things; Slice-Specific and Convergence on common Software Defined patterns; Distributed trust systems; Artificial Intelligence and machine learning applications
6. **Communication satellite technologies**
   - Enabled services; Ground segment; Space segment; Communication architectures; Convergence with heterogeneous networks
7. **Human centric and vertical services**
   - Digital service transformation; From software-centric to human-centric services; Services everywhere, infrastructure no limits; Network-unaware vertical services; Extreme automation and real-time zero-touch service orchestration; Service injection loop
8. **Future and emerging technologies**
   - The physical stratum: communication and computing resources including nano and bio-nano things and quantum networks; Algorithms and data; Applications.

Source: Networld2020 ETP, and "Visions for Future Communications Summit" - Futurecomms Summit, Lisbon, October 23 And 24, 2017.

Research agenda (SRIA) from the Networld2020 perspective

- UN 2030 Sustainable Development goals good starting point to identify needs on future systems, where and how communication technology can support such goals by the digitalisation of society and economy in developing and developed countries
- Availability of broadband access increases economic growth. However challenges with availability
- Huge global ICT market in different domains (communication and IoT) with challenging technical requirements
- Network security is a general concern for future systems
- Architecture visions of Networld2020, 5G PPP and industry are converging
- Networld2020 developed a revised Strategic Research and Innovation Agenda as basis for future research in Horizon Europe

Thank you for your attention!

www.networld2020.eu