Satellite Communications in the 5G Ecosystem

Lecturers: Dr. Shree Krishna Sharma, SnT, UL

Dr. Konstantinos Liolis, SES

Lecturer Introduction

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Dr. Shree Krishna Sharma is currently Research Scientist at the SigCom, SnT. Prior to this, he worked in different academic positions as a Senior Research Fellow at the Ryerson University, Canada, as a Postdoctoral Fellow at the University of Western Ontario, Canada and as a Research Associate at the SnT after receiving his PhD degree in Wireless Communications from the University of Luxembourg in 2014. He has published about 100 technical papers in scholarly journals, international conferences and scientific books, and has over 1900 google scholar citations with an h-index of 22. He is the recipient of several prestigious awards including "2018 EURASIP Best Journal Paper Award", "Best Paper Award" in CROWNCOM 2015 conference and "FNR Award for Outstanding PhD Thesis 2015". He is a Senior Member of IEEE, an associate editor for IEEE Access and is a lead editor of the IET book on "Satellite Communications in the 5G Era".

Dr. Konstantinos Liolis is Senior Systems Engineer at SES S.A., Luxembourg, managing technology innovation projects. He has 15 years of international working experience, both technical and managerial, in more than 40 contracted technology innovation projects in ICT with major focus on satellite communications. He received the Dipl.-Eng. degree in Electrical and Computer Engineering from the National Technical University of Athens (NTUA), Greece, in 2004; the MSc degree in Electrical Engineering from the University of California at San Diego (UCSD), USA, in 2006; and the PhD degree in Electrical Engineering from NTUA in 2011. He is PMI PMP® certified project manager. He has published more than 70 scientific papers and also numerous contributions to international standardization bodies (ETSI, 3GPP, DVB, ITU-R). He serves the Editorial Board of the Wiley's International Journal of Satellite Communications and Networking.

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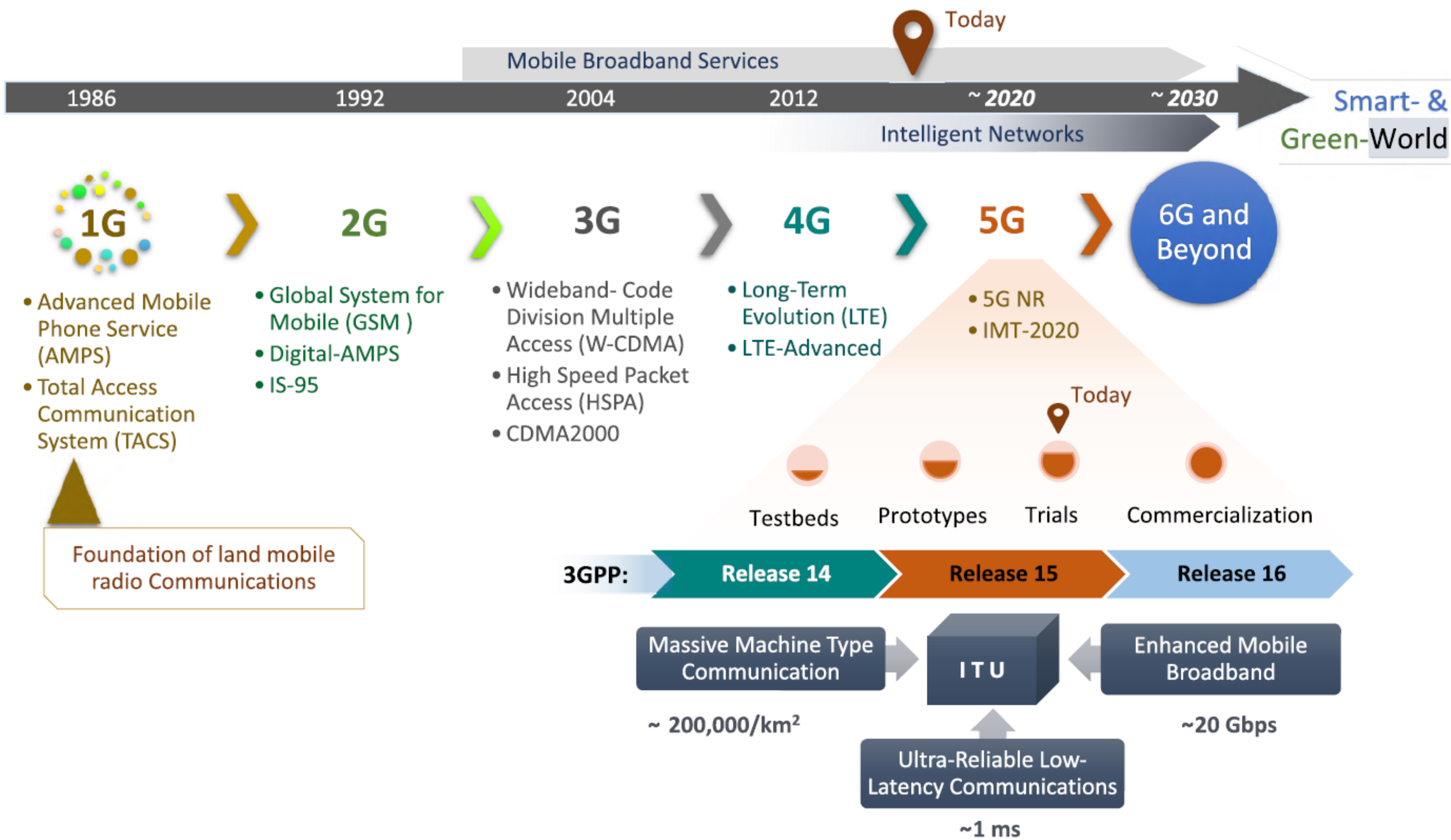
Lecture Outline

Topic	Presenter	Duration
Lecture Introduction	Dr. Shree Krishna Sharma	5 min
Introduction to 5G	Dr. Shree Krishna Sharma	15 min
Key 5G Technologies	Dr. Shree Krishna Sharma	25 min
Q&A	All	5 min
Break	**-**	**20 min**
Satellite Role in 5G Ecosystem	Dr. Shree Krishna Sharma	10 min
Enablers for 5G SatCom	Dr. Shree Krishna Sharma	10 min
Satellite Use Case Categories in 5G	Dr. Konstantinos Liolis	10 min
Q&A	All	5 min
Break	**-**	**20 min**
Relevant Technology Innovation Projects	Dr. Konstantinos Liolis	40 min
Over-the-Air Satellite 5G Demos	Dr. Konstantinos Liolis	10 min
Q&A	All	5 min

Introduction to 5G

Cellular Evolution

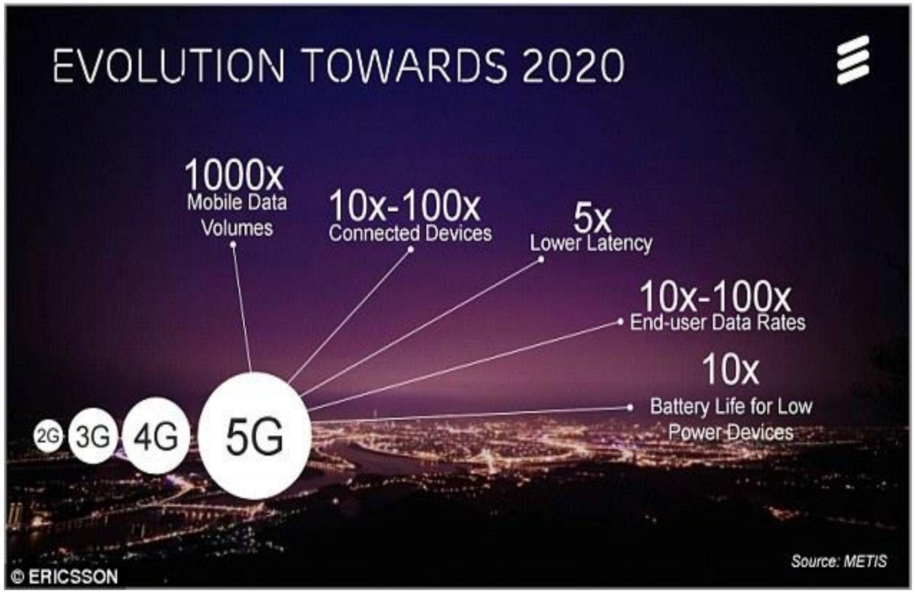


S. J. Nawaz, Shree K. Sharma, S. Wyne, M. Patwary and MD Asaduzzaman, "Quantum Machine Learning for 6G Communication Networks: State-of-the Art and Vision for the Future", *IEEE Access,* vol. 7, pp. 46317-46350, Mar. 2019.

5G Objectives

❑ Key Objectives of 5G networks

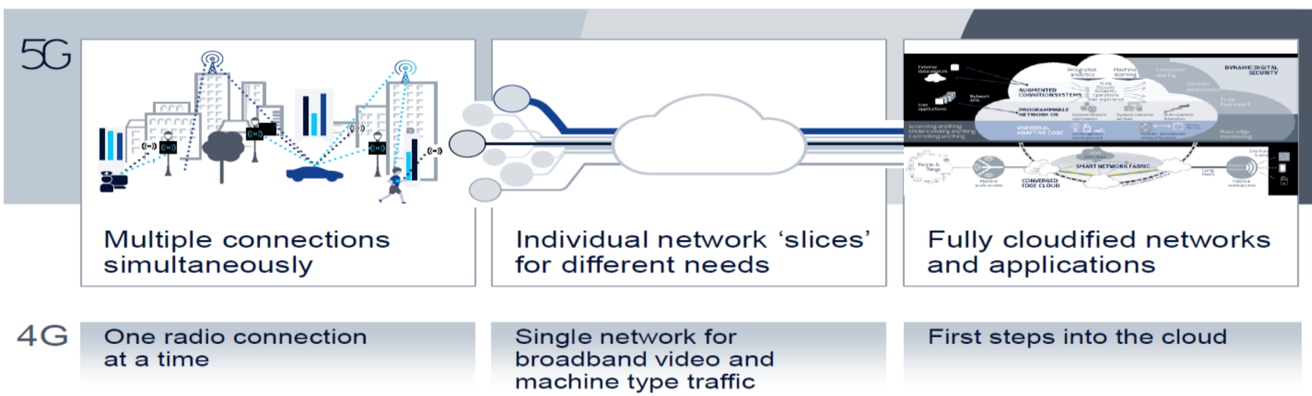
- To support the expected mobile growth
- To support various emerging services (mMTC, URLLC, IoT) and to enable their coexistence
- To enhance various network performance metrics
  - ➢ Massive connectivity
  - ➢ Ultra-high reliability
  - ➢ Low-latency
  - ➢ High resource efficiency
  - ➢ Reduced energy consumption/High energy efficiency
  - ➢ Enhanced security
- To bring agility in network characteristics (Virtualization, SDN, slicing)



4G versus 5G

- **4G versus 5G**

	4G	5G
Metadata	important	crucial
Packet size	Long (MBB)	Short (URLLC)- Long (eMBB)
Design	Throughput-centric, Average delay good enough	Latency and reliability centric / tails MATTER
Reliability	95% or less	$1 - 10^{-x}$ $x = [3, 4, 5, 6, 8, 9]$
Rate	Shannonian (long packets)	Rate loss due to short packets
Delay violation	Exponential decay using effective bandwidth	Faster decay than exponential
Latency	15 ms RTT based on 1 ms subframe	1 ms and less, shorter TTI, HARQ RTT
Queue size	unbounded	bounded
Frequency bands	sub-6GHz	Above- and sub-6GHz (URLLC at sub-6GHz)
Scale	A few users/devices	billion devices

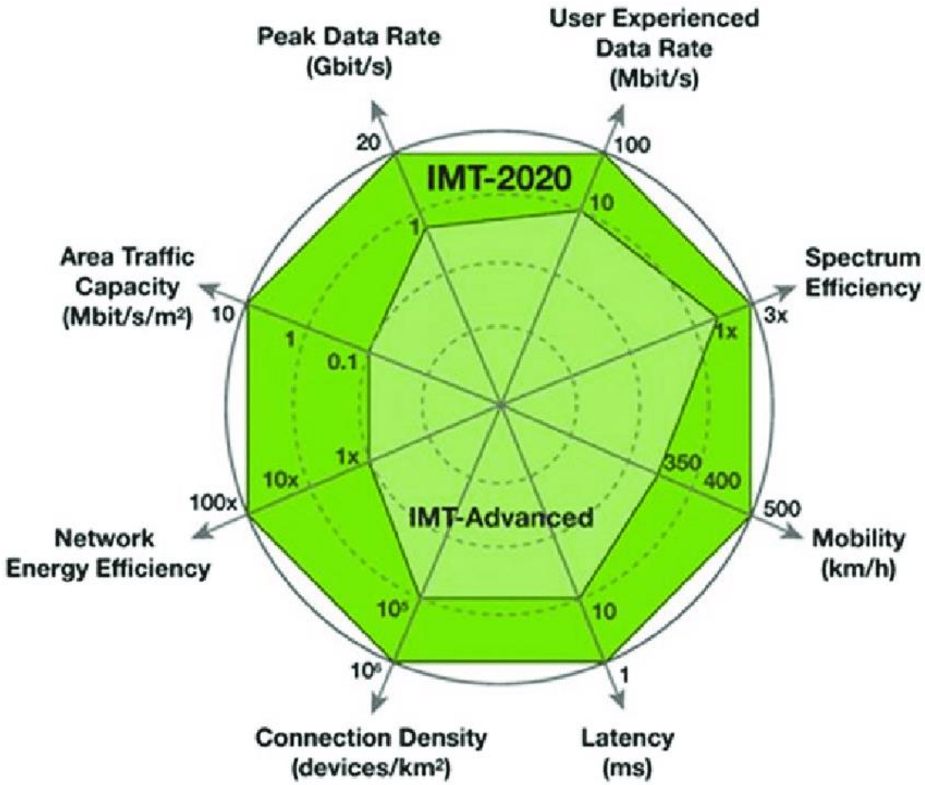


- Source: Nokia

- M. Bennis, M. Debbah and H. V. Poor, "Ultrareliable and Low-Latency Wireless Communication: Tail, Risk, and Scale," in *Proc. IEEE*, pp. 1834-1853, Oct. 2018.

5G Requirements

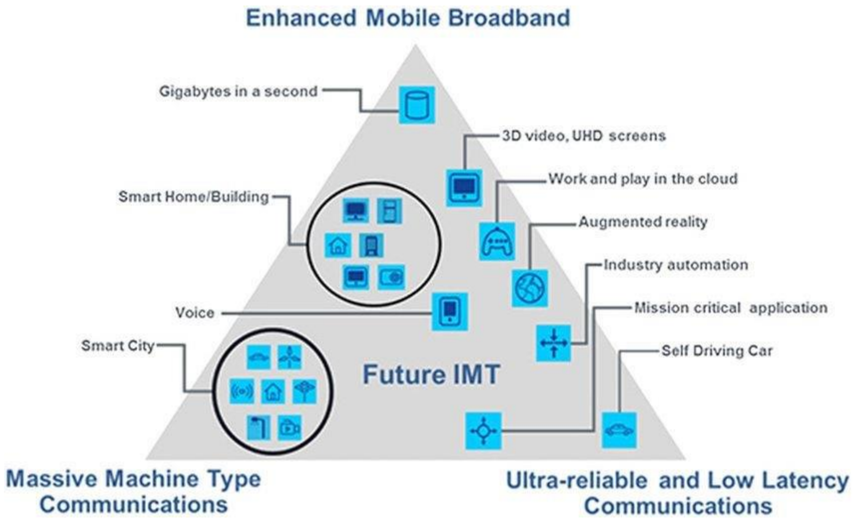
- ❑ ITU-R (IMT 2020) 5G Requirements

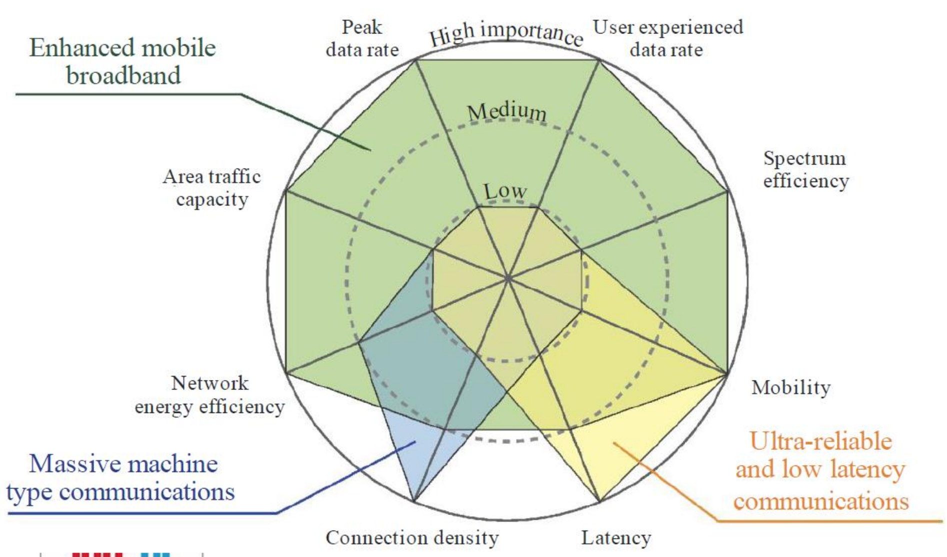


- ITU-R M.2083-0

- ❑ **Definition of Metrics**
- **Peak data rate**: maximum rate per user under ideal conditions.
  - 10 Gbps for mobiles, 20 Gbps for static cases under ideal conditions.
- **User experienced data rate**: Rate across the coverage area per user.
  - 100 Mbps in urban/suburban areas
  - 1 Gbps in hotspots
- **Latency**: Contribution of radio link to the end-to-end latency between sender and receiver
- **Area traffic capacity**: Throughput per m^2
- **Spectrum efficiency**: Throughput per Hz per cell
- **Connection density**: Devices per km^2
- **Energy efficiency**: Transmitted bits/Joule
- **Mobility**: Maximum speed at which seamless handover and QoS is guaranteed

Major Emerging Services

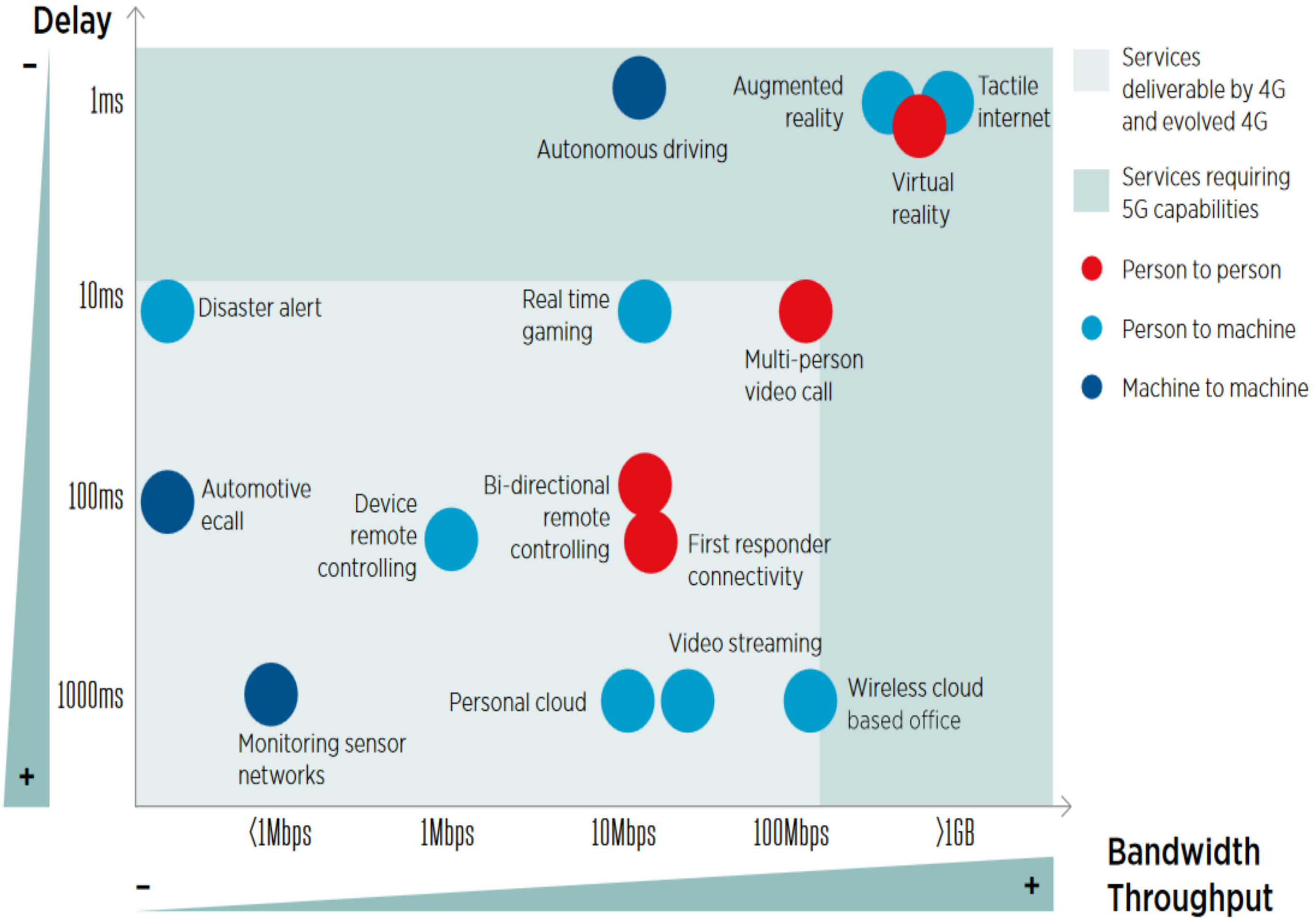




- ❑ Source: ITU-R M.2083

- ❑ **eMBB**
  - High data-rate applications
  - Maximize rate, moderate reliability (e.g., $10E^{-3}$)
- ❑ **mMTC**
  - Massive number of devices but unknown active subset
  - maximize arrival rate, low reliability (e.g., $10E^{-1}$)
- ❑ **URLLC**
  - High reliability (e.g., $10E^{-5}$) while localized in time
  - eHealth, factory automation, disaster and rescue

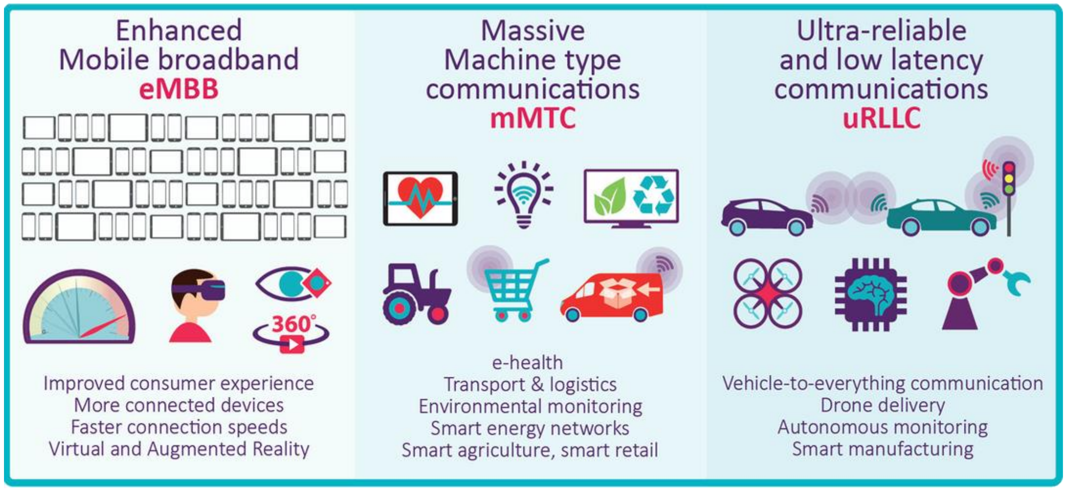
5G Scenarios



Source: GSMA Intelligence, “Understanding 5G” (Dec. 2014)

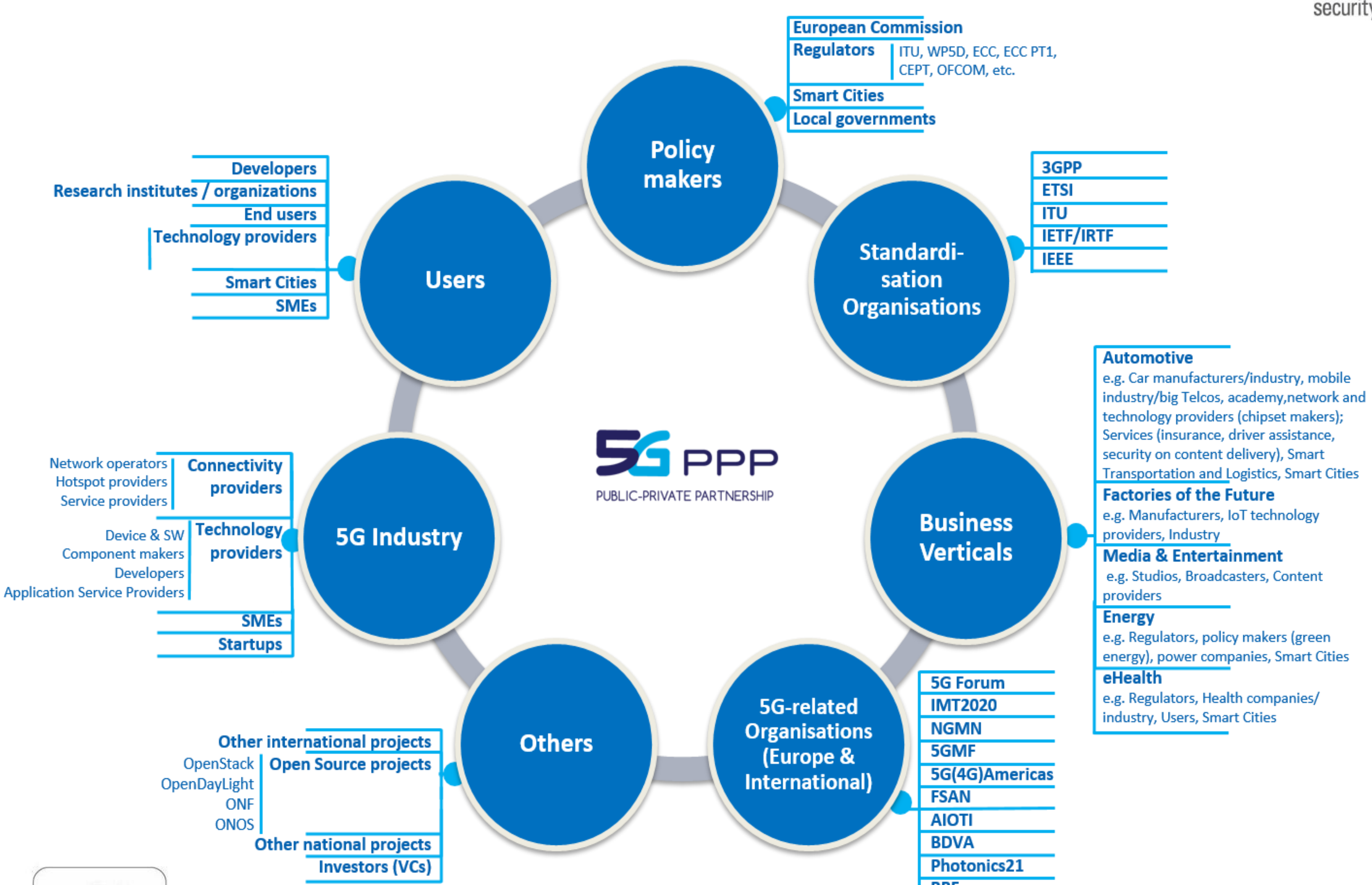
5G Verticals

- Internet of Things (IoT) Verticals
  - Smart Home
  - eHealthCare
  - Smart Grid
  - Smart City
  - Industrial Automation
  - Internet of Vehicles
- D2D Communications
- M2M Communications
- V2V/V2I Communication
- Tactile Internet



- Source: Cambridge Wireless

5G Ecosystem



Key 5G Technologies

Key Dimensions

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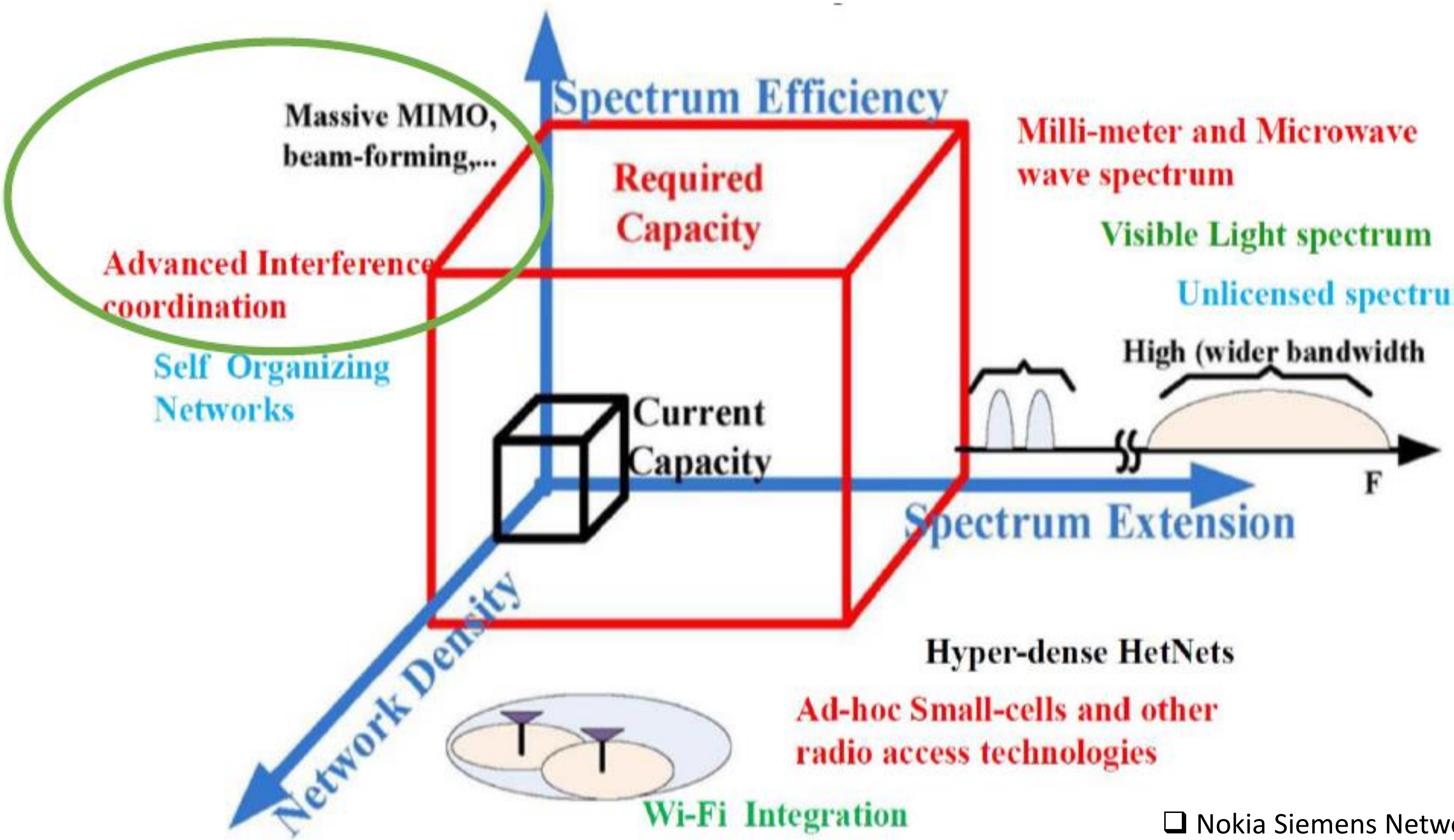

- Nokia Siemens Networks

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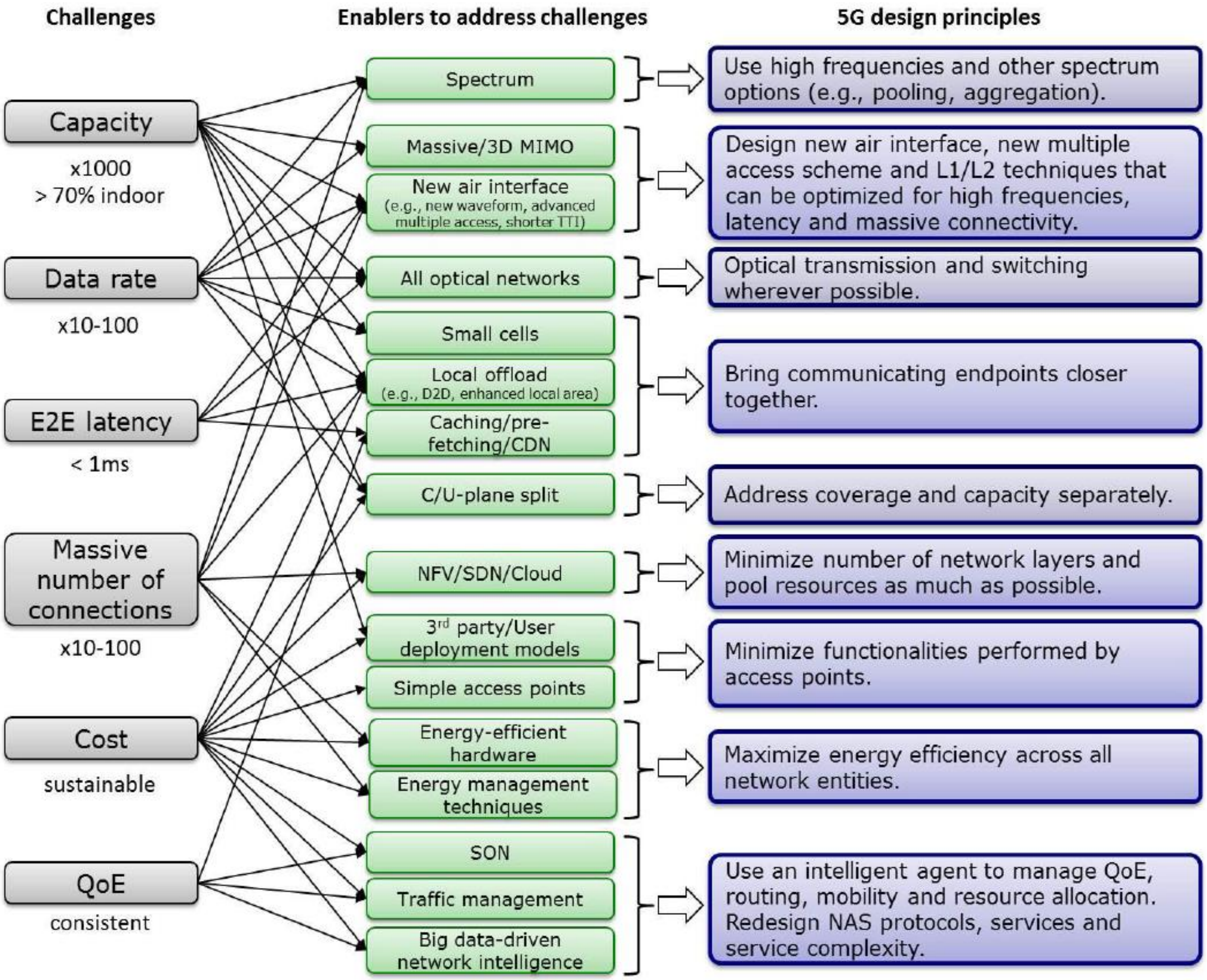
5G Enablers



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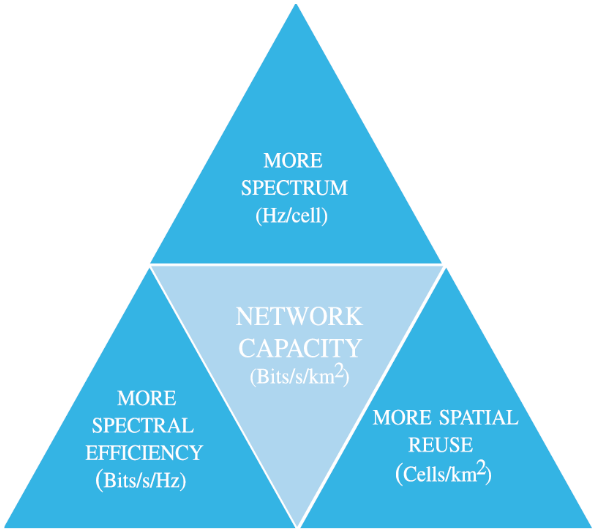
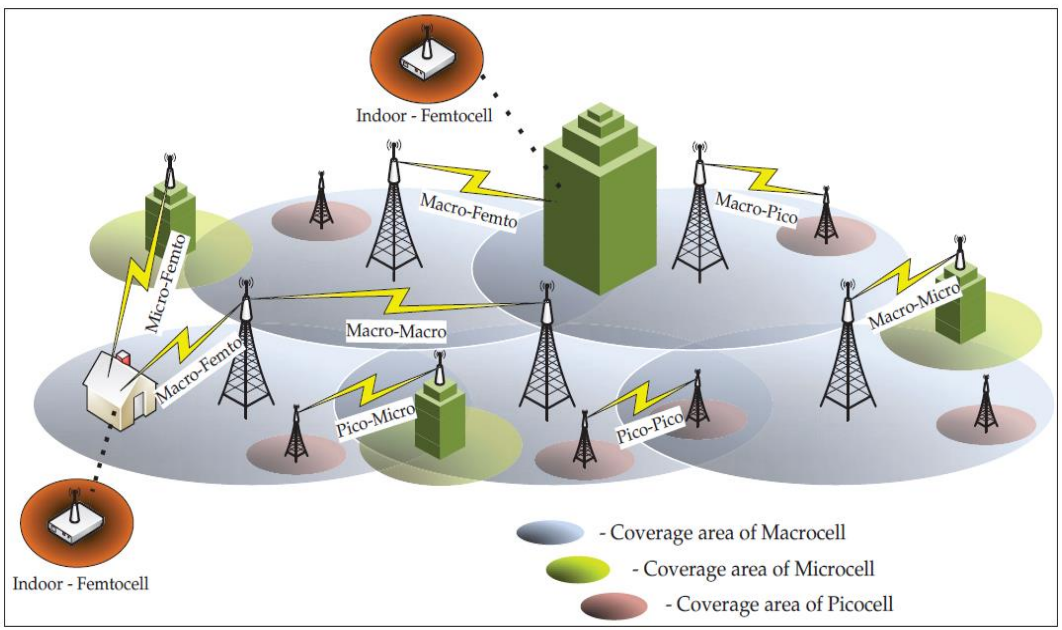
- P. K. Agyapong, *et al.*, "Design considerations for a 5G network architecture," in *IEEE Communications Magazine*, vol. 52, no. 11, pp. 65-75, Nov. 2014.

Network Densification

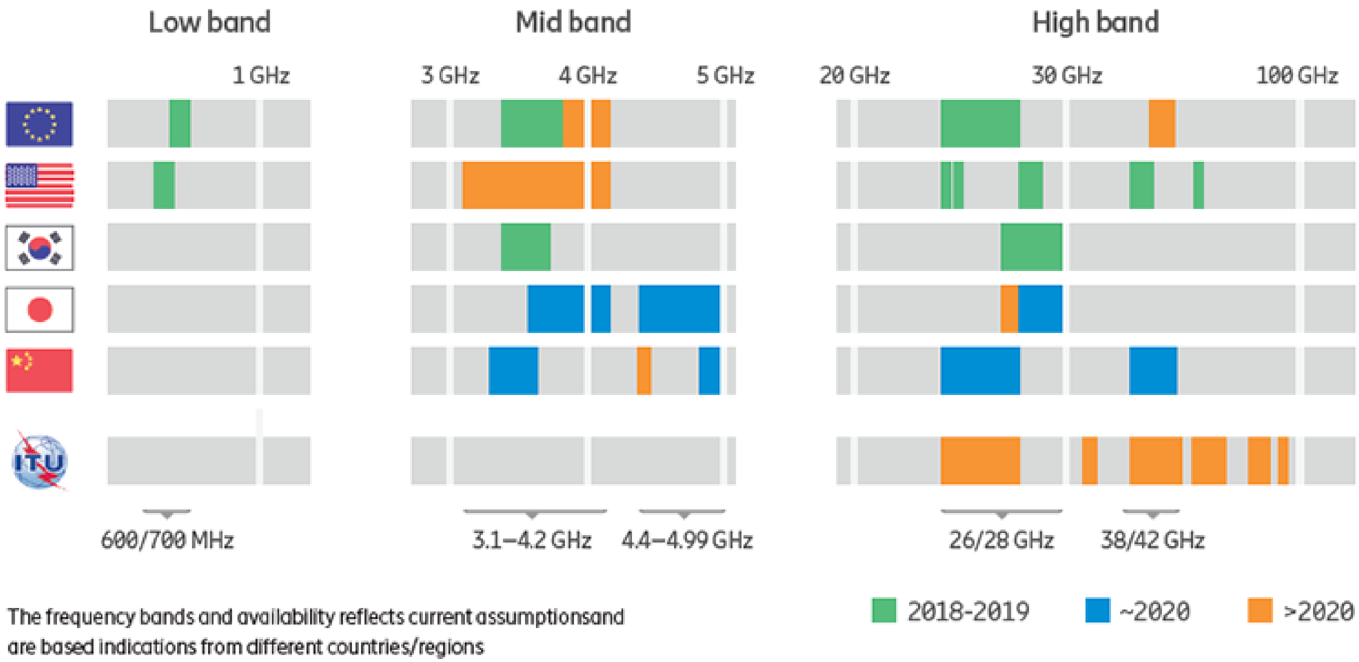




- Cellular Densification
  - Aim: increase the number of available channels per unit coverage area
  - Frequency reuse, Co-channel interference
    - Cell splitting
    - Cell sectoring
    - Microcell zone
    - Coordinated multipoint
- Macro cells
  - Up to 35 Km
  - Power 20-40W
- Small cells
  - Low power (20mW-20W) wireless access points
  - Enhanced capacity and coverage
  - Types
    - Micro cell (Up to 2 Km)
    - Pico cells (Up to 200 m)
    - Femto cells (Up to 10 m)

- Hasan, *et al*, Green cellular

5G Spectrum



- Source: Ericsson

- **Higher bands**
  - Larger bandwidth
  - Higher system capacity
  - More number of served users
- **Low and Mid bands**
  - Better propagation characteristics
  - Building penetration
  - Higher Coverage area
  - Few number of base stations

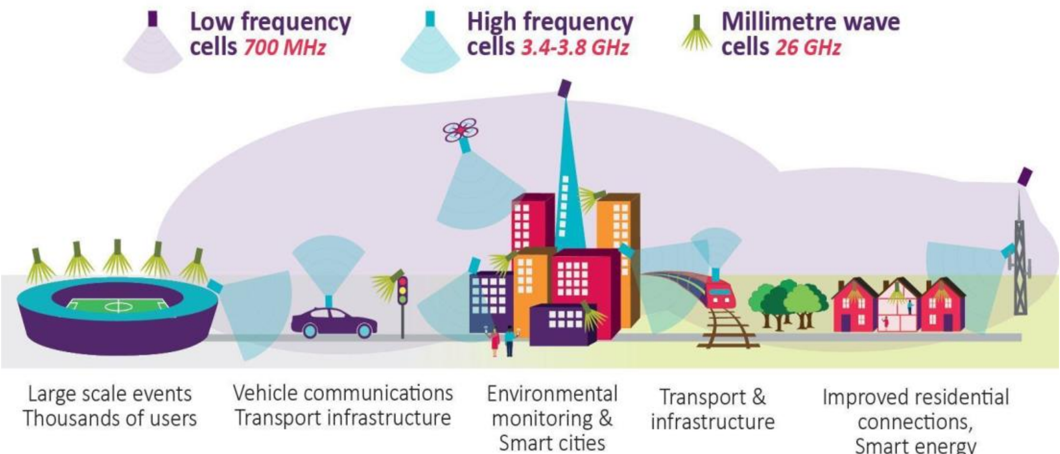
mmWave Communications

❑ mmWave Characteristics

- Pros
  - Huge usable bandwidth available (>150 GHz), higher data rate
  - Thousands of antennas can be packed into small space due to smaller wavelengths
  - Very high directivity with extremely narrow beams
- Cons
  - Limited coverage due to severe path loss: need of many sites
  - High penetration loss
  - Connection establishment challenging due to high directionality
  - Highly susceptible to rain fading

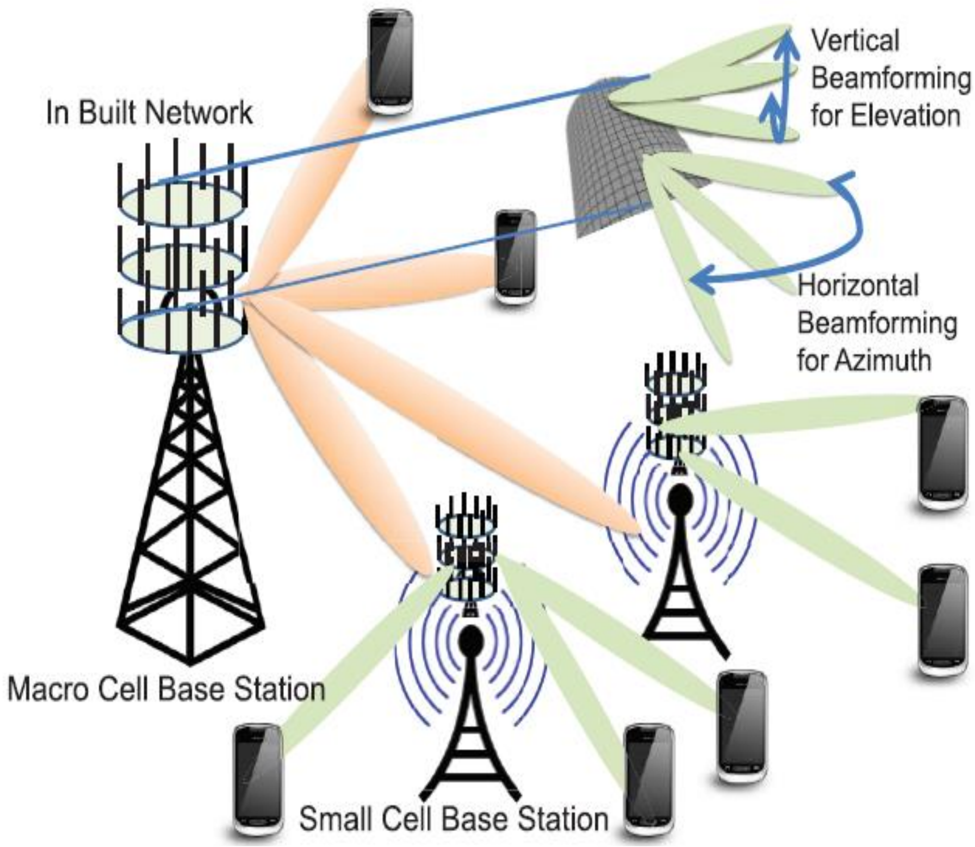
❑ mmWave Applications

- Cellular Networks: 5G Picocells, Wireless backhaul
- Wireless LANs: Multiple gigabit wireless systems (IEEE 802.11ad), IEEE 802.15.3c, ECMA-387, Wireless-HD



❑ OFCOM.

Massive MIMO and Smart Beamforming



- **Massive MIMO**
  - Large number of service antennas over active terminals

Pros

- Higher spectral efficiency
- Higher energy efficiency
- Precise tracking of users with narrow beams
- Simplification of MAC layer
- Robustness against interference and jamming
- Channel hardening

Cons

- Pilot contamination
- FDD mode of operation
- Practical channel models instead of i.i.d. ones
- Hardware impairments

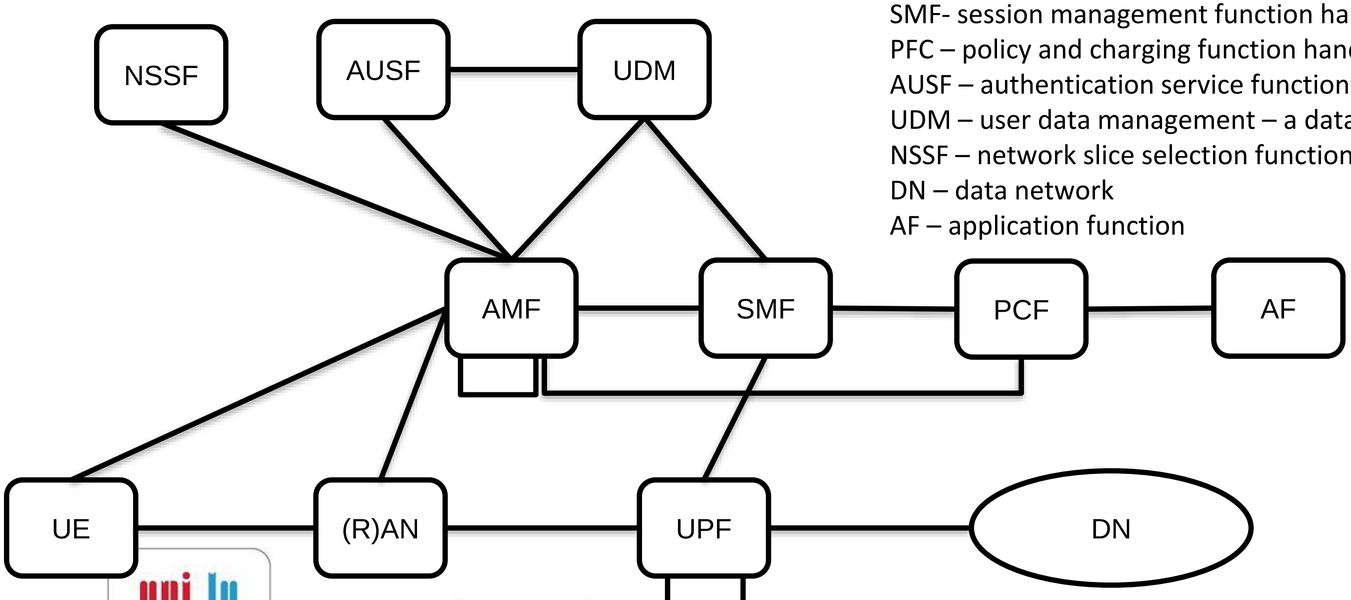
- **3D beamforming**
  - Controls the beam pattern in both elevation and azimuth planes

- M. Agiwal, A. Roy and N. Saxena, "Next Generation 5G Wireless Networks: A Comprehensive Survey," in *IEEE Communications Surveys & Tutorials*, vol. 18, no. 3, pp. 1617-1655, thirdquarter 2016.
- S. K. Sharma, S. Chatzinotas, J. Grotz and B. Ottersten, "3D Beamforming for Spectral Coexistence of Satellite and Terrestrial Networks," *2015 IEEE 82nd Vehicular Technology Conference (VTC2015-Fall)*, Boston, MA, 2015, pp. 1-5.

3GPP Core Network

- 3GPP standardized a new core network architecture, including the following main features:
  - Separation of **control and data plane**
  - Separation of **access and mobility** from the session management function
  - Integration of the **network slice selection** functionality
  - …

UE – user equipment (smartphone)
(R)AN – radio access network
UPF – user plane functions which may be chained
AMF – the main control entity handling the access and mobility functionality
SMF- session management function handling the data path establishment & control
PFC – policy and charging function handling specific subscriber policies
AUSF – authentication service function
UDM – user data management – a database with subscriber information
NSSF – network slice selection function
DN – data network
AF – application function



Software Defined Networking (SDN)

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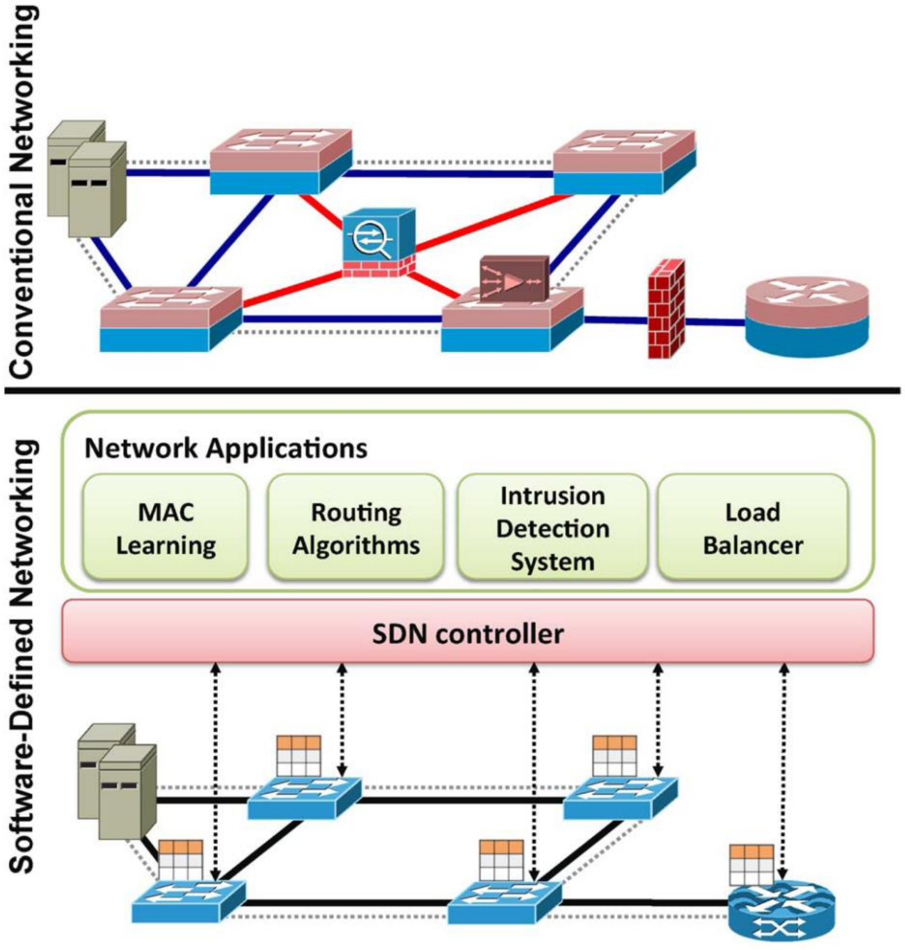
- **Limitations of current 4G networks**
  - **Vendor specific** interfaces and software associated with hardware
  - **Complex and expensive** network operation
  - Cannot dynamically adapt according to network conditions
  - **Tight coupling of data and control planes** in the same devices and highly decentralized structure

- **Main Features of SDN**
  - **Decoupled** control plane and data planes
  - Control logic is moved to the SDN controller
  - Control plane software on general purpose hardware and simple forwarding elements
  - High flexibility due to **flow programming and reconfigurable signal processing**
  - **Network-wide global knowledge** of the network state and automatic monitoring



- D. Kreutz, and et al, "Software-Defined Networking: A Comprehensive Survey", *Proc. of IEEE*, vol. 103, no. 1, Jan. 2015.
- T. Chen, and et al, "Software defined mobile networks: concept, survey, and research directions", in *IEEE Communications Magazine*, vol. 53, no. 11, pp. 126-133, November 2015.

Network Function Virtualization (NFV)

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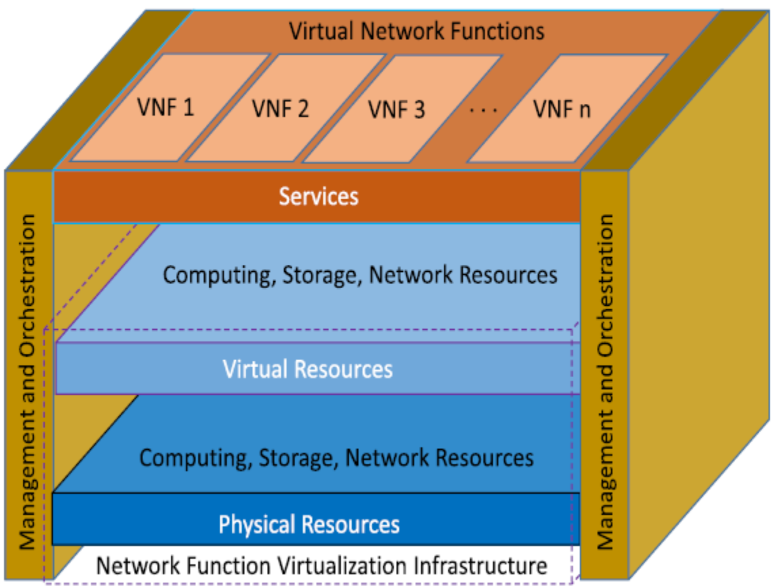
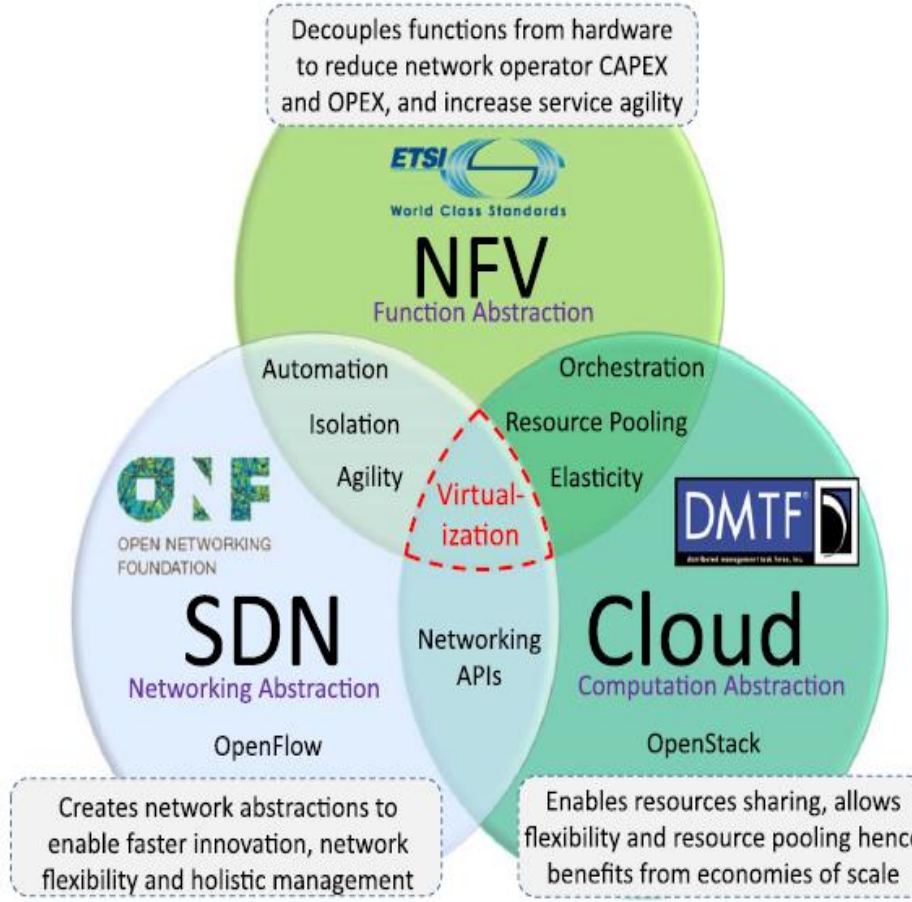
Key concepts and benefits

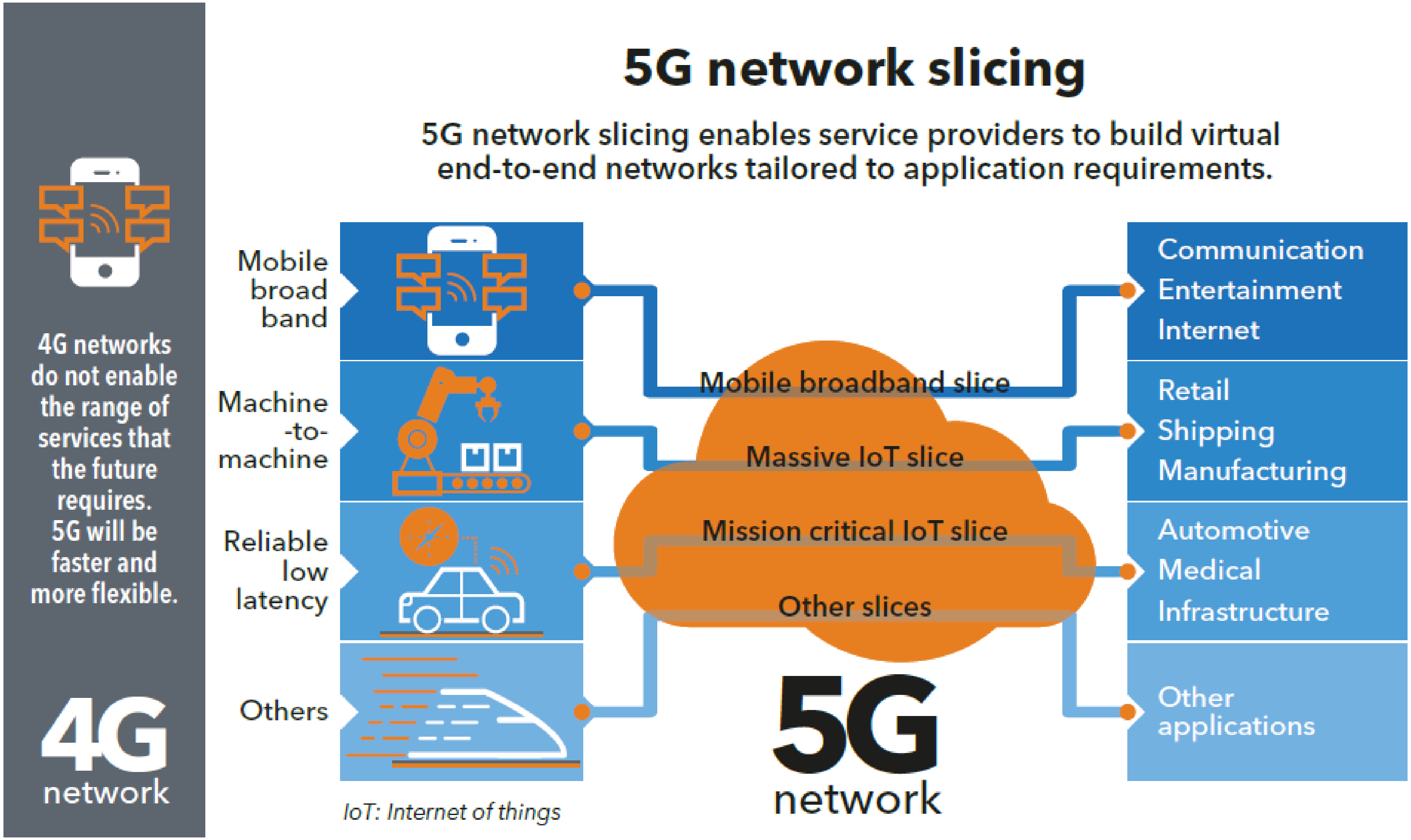
- **Decoupling of hardware from software**
  - multiple isolated software programs sharing the u hardware
- Separate timelines for development and mainter software and hardware
- **Infrastructure sharing**/reallocation
- **Dynamic adaptation** with the network conditions (traffic demands)





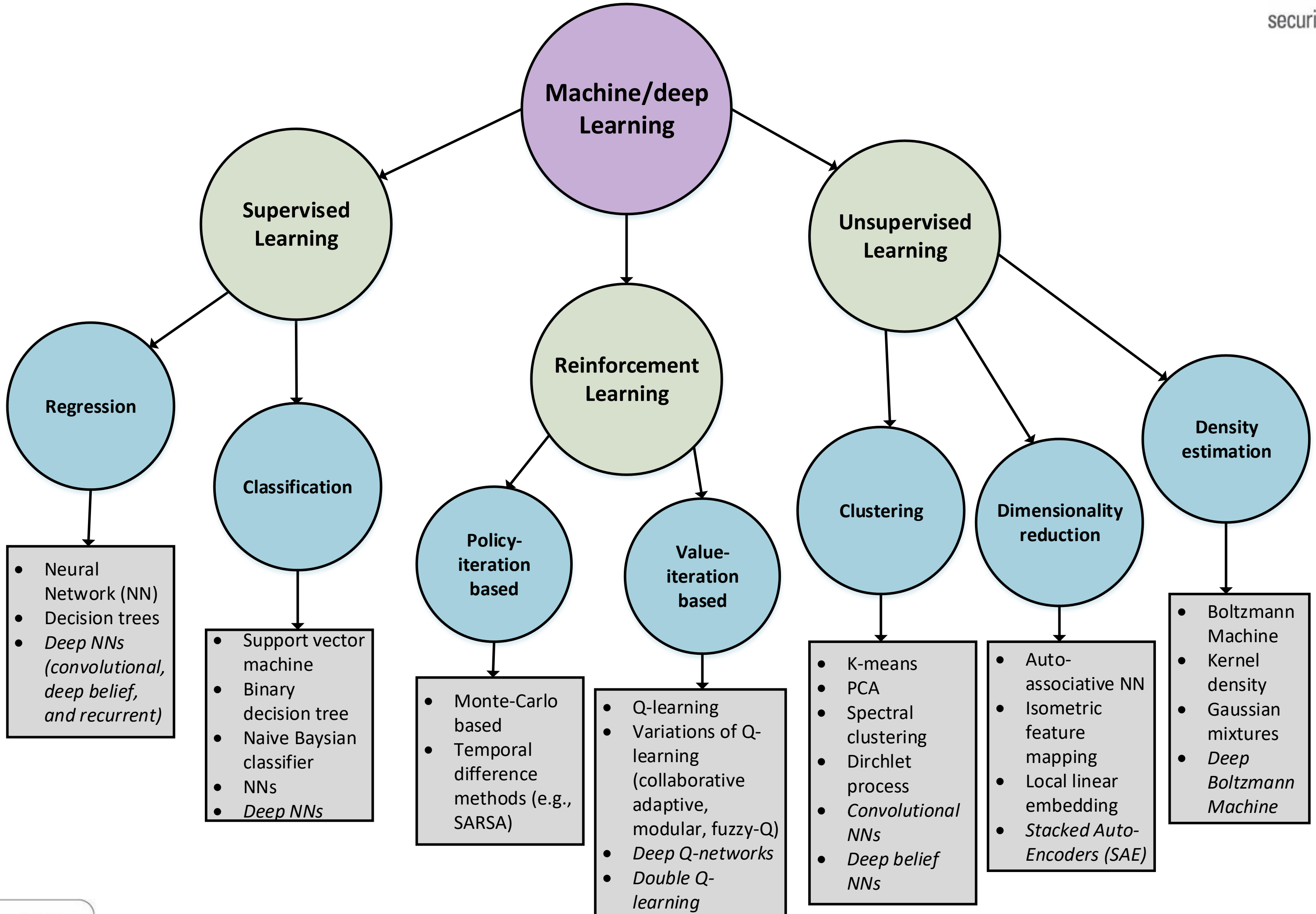
- R. Mijumbi, *et al.*, "Network Function Virtualization: State-of-the-Art and Research Challenges," in *IEEE Communications Surveys & Tutorials*, vol. 18, no. 1, pp. 236-262, Firstquarter 2016.

Network Slicing



❑ Source: SDX Central

Machine/Deep Learning



❑ Shree K. Sharma and X. Wang, “Towards Massive Machine Type Communications in Ultra-Dense Cellular Networks: Current Challenges and Machine Learning-Assisted Solutions”, in *IEEE Commun. Surveys and Tutorials*, May 2019.

Collaborative Edge-Cloud Processing

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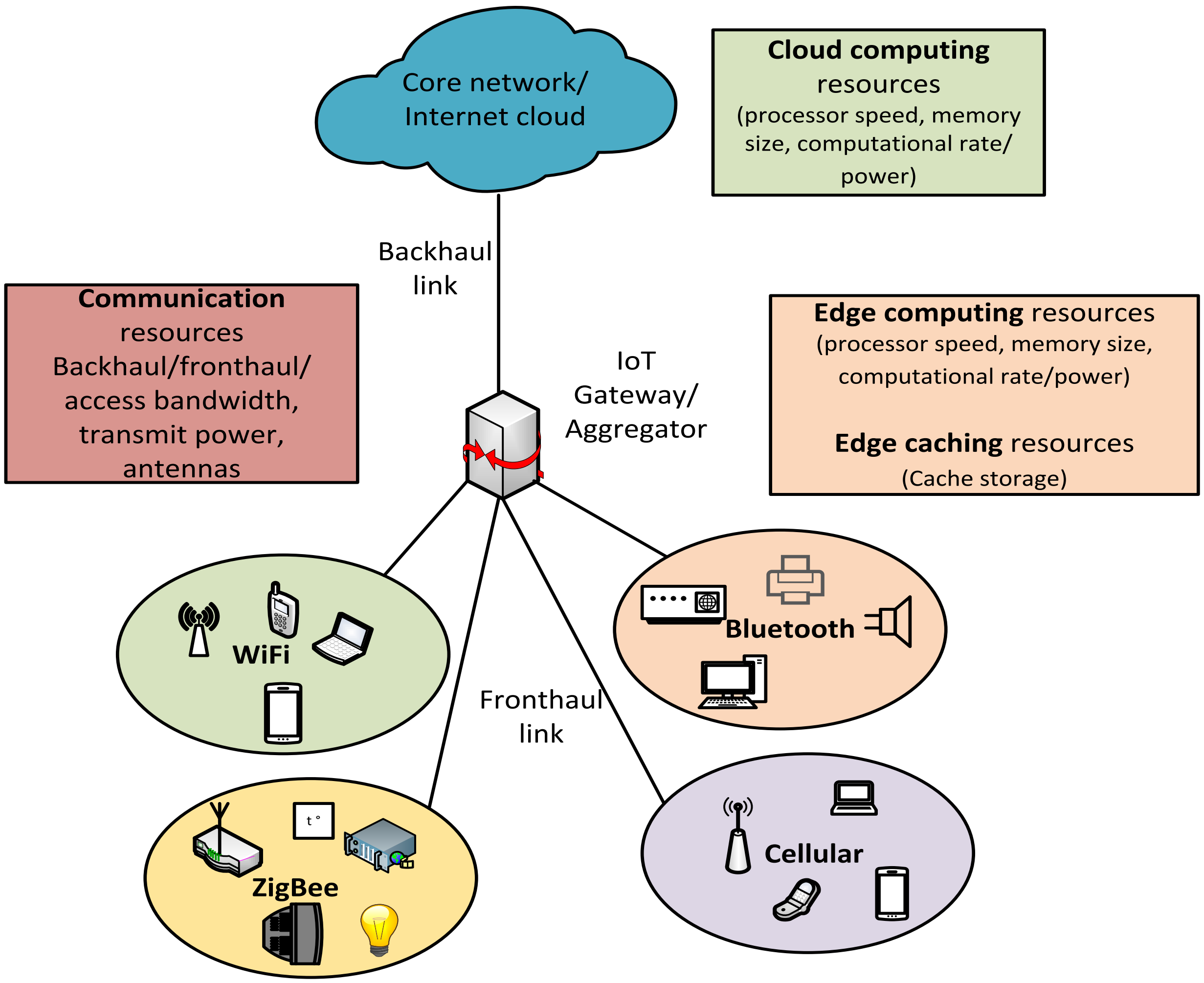
- ❑ **Cloud computing**
  - ➢ **Massive computing** power and storage capacity
  - ➢ **Global view** and **historical data**
- ❑ **Edge/fog computing**
  - ➢ Can support **low latency, location-awareness, high mobility and geo-distributed** services



❑ Shree K. Sharma and X. Wang, "Live Data Analytics with Collaborative Edge and Cloud Processing in Wireless IoT Networks", *IEEE Access*, vol. 5, pp. 4621-4635, March 2017.

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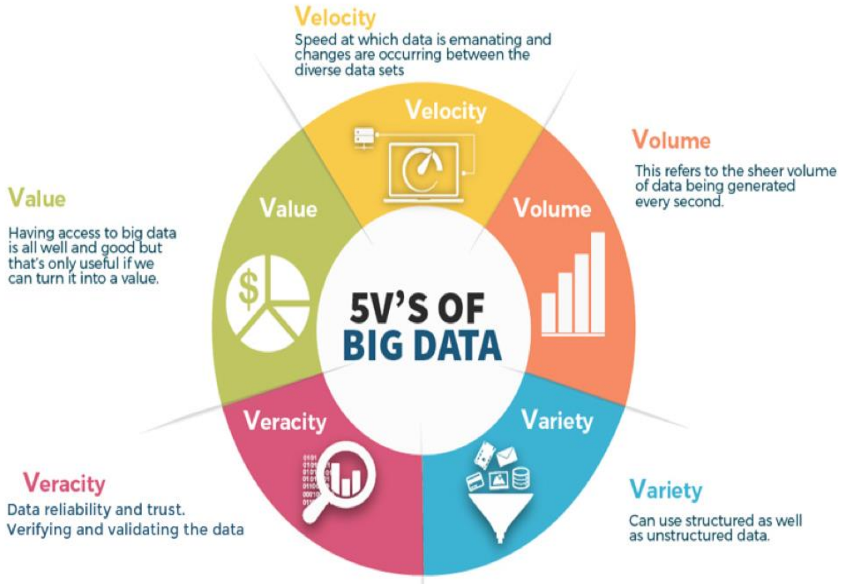
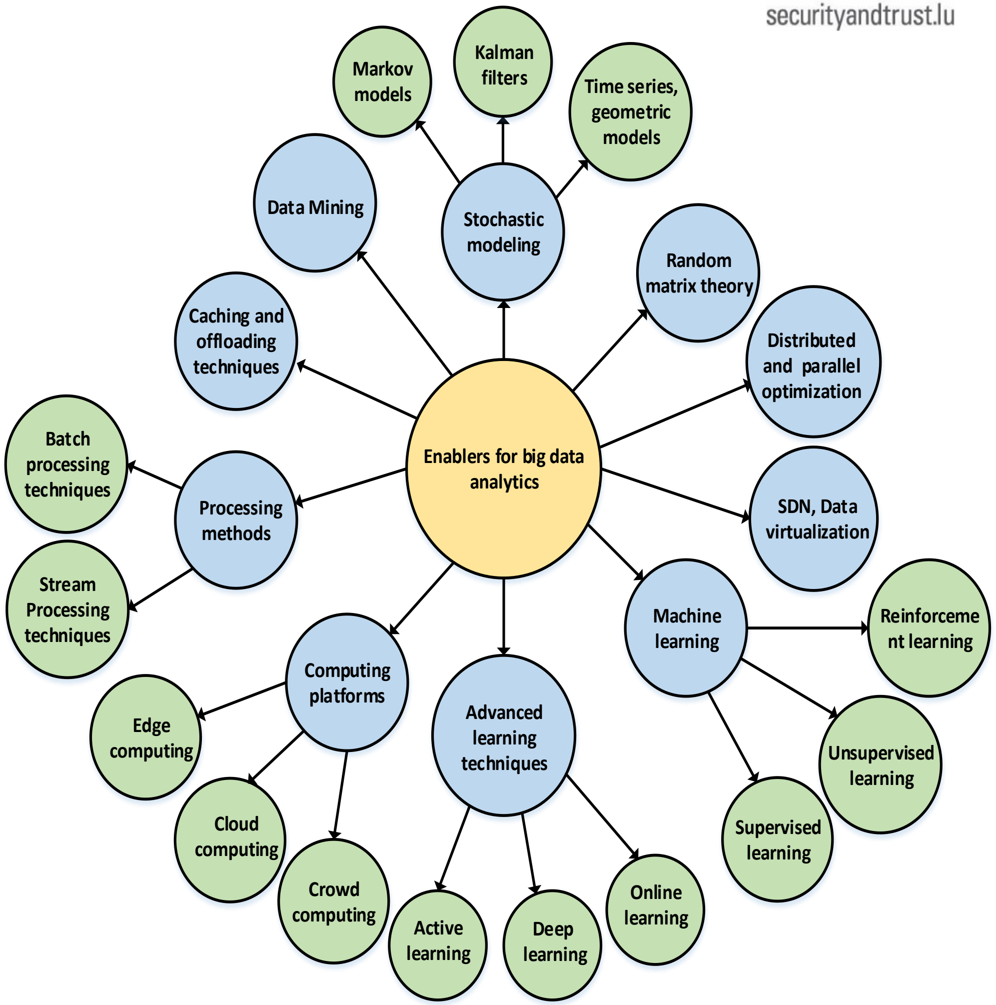
Big Data Analytics



❑ Source: Tech Entice

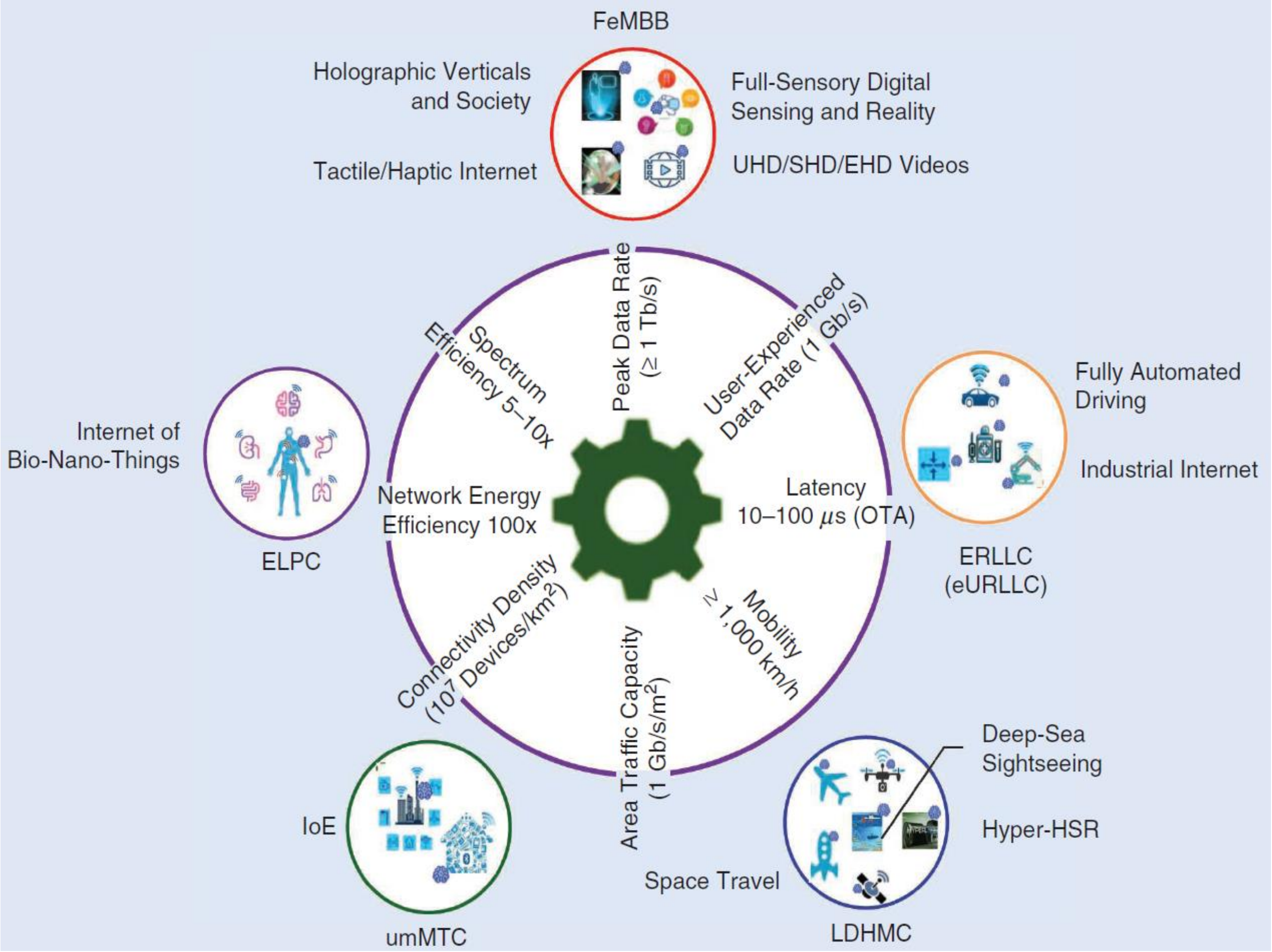


- Issues
  - Distributed and heterogeneous data structure
  - Real-time requirements
  - Weak data semantics
  - Data inaccuracy

❑ Shree K. Sharma and X. Wang, "Live Data Analytics with Collaborative Edge and Cloud Processing in Wireless IoT Networks", *IEEE Access*, vol. 5, pp. 4621-4635, March 2017.

Beyond 5G

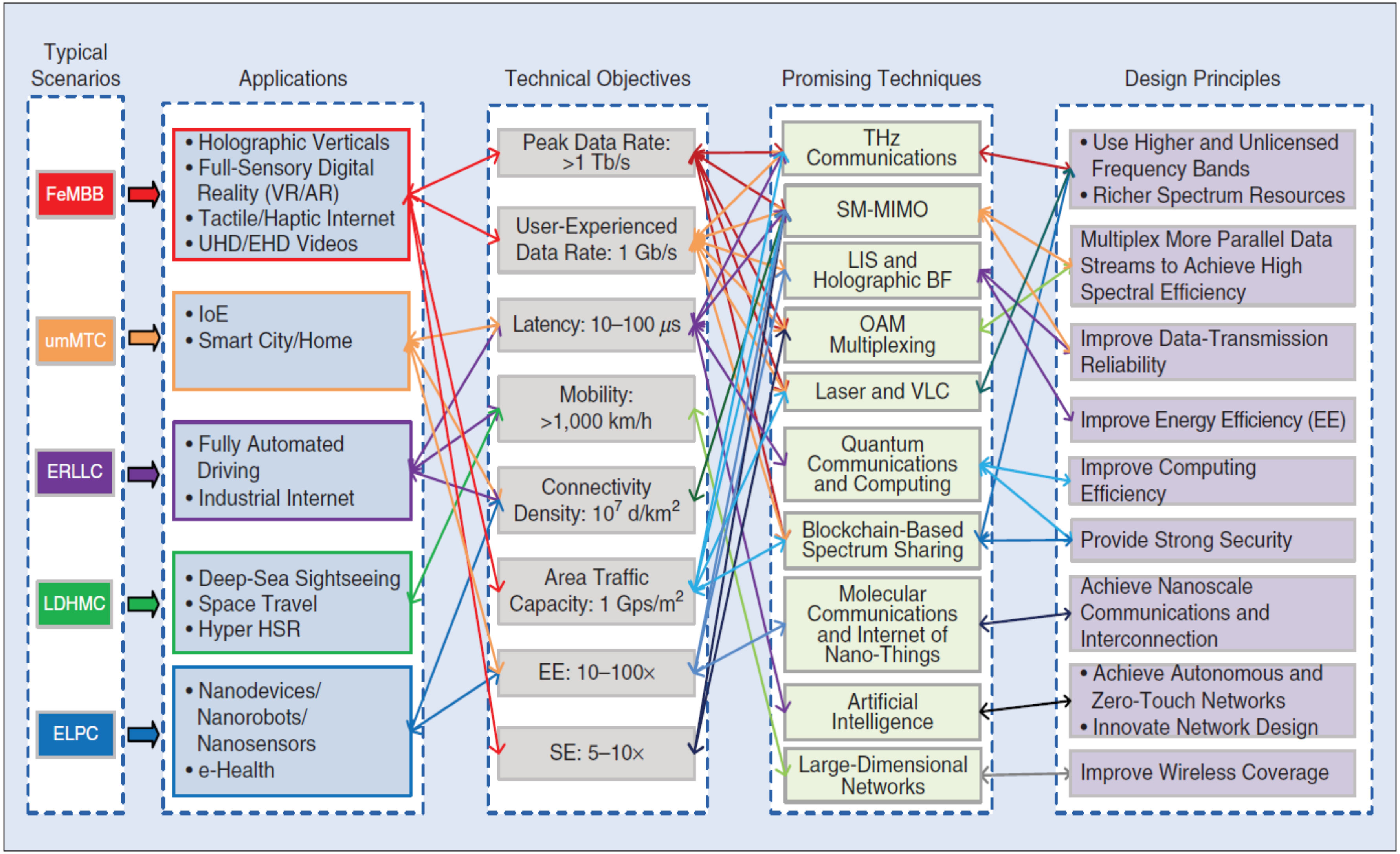
Scenarios for B5G Netwoks



- FeMBB:Further enhanced MBB
- ELPC: extremely low-power communications
- LDHMC: long-distance and high-mobility comm.
- umMTC: ultra-massive MTC
- HSR: Hyper high-speed railway

❑ Z. Zhang *et al.*, “6G Wireless Networks: Vision, Requirements, Architecture, and Key Technologies,” in *IEEE Vehicular Technology Magazine*, doi: 10.1109/MVT.2019.2921208.

Beyond 5G



❑ Z. Zhang *et al.*, “6G Wireless Networks: Vision, Requirements, Architecture, and Key Technologies,” in *IEEE Vehicular Technology Magazine*, doi: 10.1109/MVT.2019.2921208.

Role of Satellite in 5G

Key Satellite Features that Enhance the Networked Society

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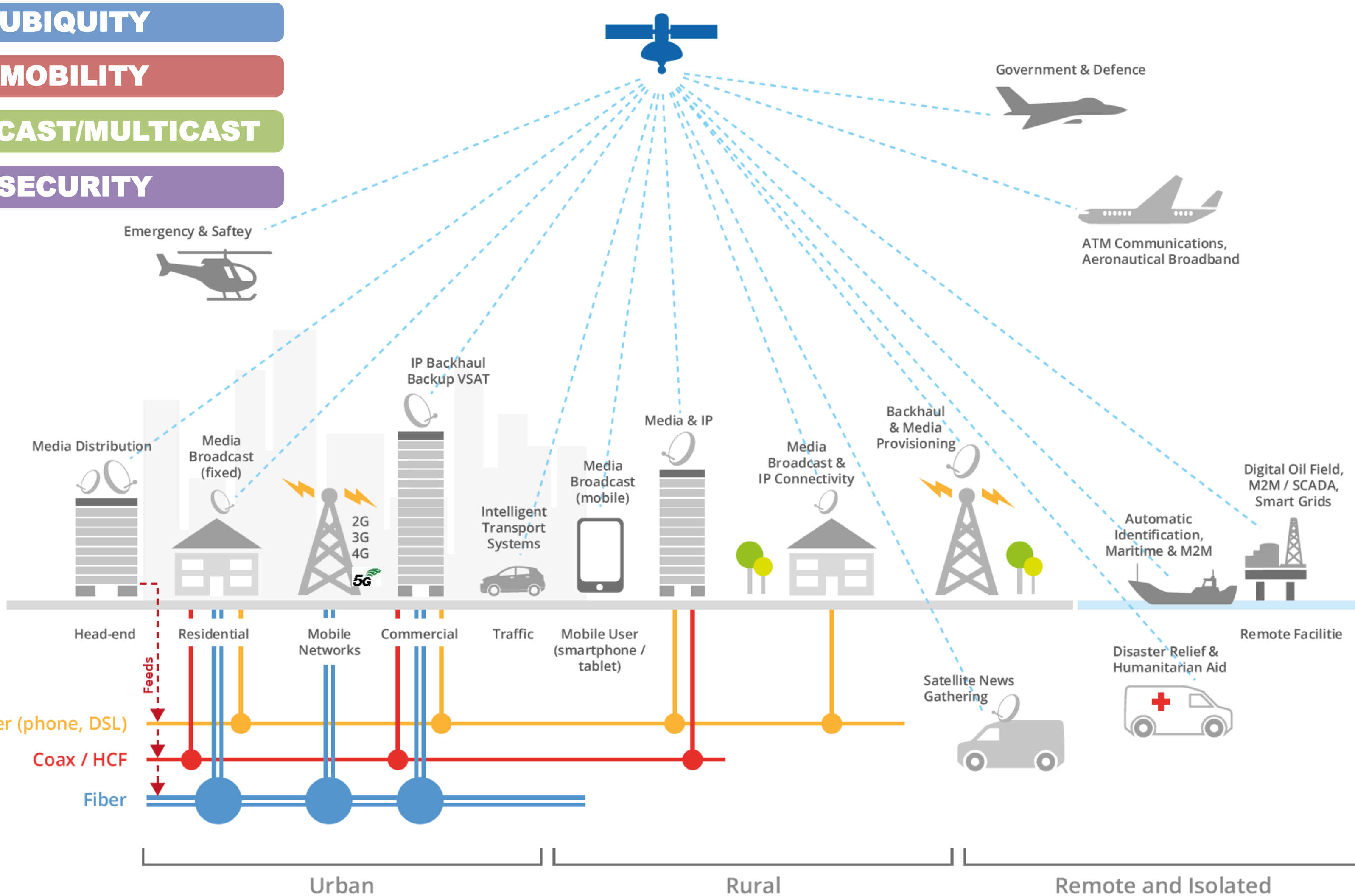
UBIQUITY

MOBILITY

BROADCAST/MULTICAST

SECURITY



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- Source: ESOA White Paper

5G SatCom

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SatCom advantages over terrestrial 5G

- Global coverage
- Multicasting/broadcasting
  - Enable 5G networks to achieve **sub-ms latency** by multi-casting contents to caches located at the individual cells, even in the places without fiber connections
- Isolated/remote areas
- Mobility
- Security
- Connectivity to aeronautical, maritime, disaster relief, and emergency scenarios

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Role of Satellite in 5G

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Service Category	Deployment Scenario/Services	3GPP SA Use Case (TR 22.891-200)
Multimedia delivery	Mobile Broadcast	5.53 Vehicular Internet & Infotainment 5.56 Broadcasting Support 5.64 User Multi-Connectivity across operators
	Content Caching	5.36 In-network and device caching
	Broadcast to home	5.56 Broadcasting Support
Broadband	Mobile Broadband to users and Vehicles	5.28 Multiple RAT connectivity and RAT selection 5.29 Higher User Mobility 5.53 Vehicular Internet & Infotainment
	Fixed Broadband to homes and enterprises	5.41 Domestic Home Monitoring
	Ubiquitous coverage- Remote areas services	5.30 Connectivity Everywhere 5.10 Mobile broadband services with seamless wide-area coverage
	Backhaul Connectivity	5.30 Connectivity Everywhere 5.10 Mobile broadband services with seamless wide-area coverage
	Broadband to moving platforms- flights, ships etc.	5.30 Connectivity Everywhere 5.12 Connectivity for drones 5.29 Higher User Mobility
Machine Type Communication	Fleet Tracking	5.43 Materials and inventory management and location tracking
	Asset Management	5.43 Materials and inventory management and location tracking
	Wide area sensor management	5.42 Low mobility devices 5.73 Delivery Assurance for High Latency Tolerant Services
Critical Communication	Disaster Management	5.3 Lifeline communications / natural disaster 5.31 Temporary Service for Users of Other Operators in Emergency Case
	Air Traffic Management	
	Reliable Communication	5.73 Delivery Assurance for High Latency Tolerant Services
Vehicular Communication	Traffic Updates and Software Upgrades	5.33 Connected Vehicles
	eCalls and Emergency Notifications	5.3 Lifeline communications / natural disaster 5.31 Temporary Service for Users of Other Operators in Emergency Case

- Sources: 3GPP, INMARSAT

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Role of Satellite in 5G

Key areas where satellite can play role in 5G

- Coverage expansion
- Backhauling services to fixed or moving base stations
- Complementing connectivity for mobile devices (ships, vehicles, trains, planes)
- Multi-gigabit per second data rates for enhanced mobile broadband
- Offloading a temporarily congested network
- Internet of Things (IoT)/M2M
- Spectrum sharing
- Resilience, Security and Availability
- Providing emergency response/disaster recovery communications

- B. G. Evans, "The role of satellites in 5G", *2014 7th Advanced Satellite Multimedia Systems Conference and the 13th Signal Processing for Space Communications Workshop (ASMS/SPSC)*, Livorno, 2014, pp. 197-202.
- ESOA White Paper

5G SatCom

Main 5G SatCom challenges

- Latency minimization
- Spectrum scarcity
- Energy consumption reduction
- Localization issue
- Integration Issues
- Resilience integrated 5G-satellite
- QoE guarantee
- Supporting multiple heterogeneous services
  - IoT/M2M
  - High rate video services

- B. G. Evans, “The role of satellites in 5G”, *2014 7th Advanced Satellite Multimedia Systems Conference and the 13th Signal Processing for Space Communications Workshop (ASMS/SPSC)*, Livorno, 2014, pp. 197-202.

SatCom Trends

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Cellular		Research ideas	Operational/Proposed systems
1G	1970s 1980s	Mobile satellite expts ATS-6 Non-GEO mobile cellular architecture proposed	Inmarsat formed Inmarsat operates – maritime
2G GSM	1990s	Motorola announce Iridium system LEO Orcom system proposed Teledesic announce non-GEO fixed systems Globalstar/ICO proposed Super GEO's announced Agrani/Apmt/Aces/Thuraya	Inmarsat operates – land/aero Regionals: Omnitracs, Euteltracs, Amsc, Optus Inmarsat Sats-spots Iridium operational Orbcom operational Globalstar operational World space radio
3G IMT-2000	2000s	Integrates S/T/UMTS for content proposed Satin EU project DVB-S2 standard	Iridium/Globstar/Orbcoms Thuraya operational Inmarsat IV's –100's spots and DSP processor Xm, SIRIUS, DARS MBSAT
4G	2010s	High throughput satellite	Inmarsat Global express constellation – 100's fixed spots and additional steerable spot beams Iridium-NEXT operational- features data transmission O3b satellite constellation
5G	2020s	High throughput satellite Several hundred spot beams Higher frequency bands – Q/V/W Optical for gateway connections Up to 30 m deployable antennas at L/S bands Adaptive beam hopping and forming Mobility management integration Progressive pitch technology	OneWeb satellite constellation SpaceX satellite constellation Samsung satellite constellation LeoSat constellation

- O. Onireti and M. A. Imran, "The role of satellite communications in 5G Ecosystem", *Chapter 1 in satellite communications in the 5G Era*, IET, 2018.

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5G SatCom Enablers

5G SatCom Enablers

- **SDN**
- **NFV**
- **Onboard processing**
- **Mega-LEO**
- **GaN**
- **Cognitive SatCom**
- **Caching and Multicasting**
- Integrated 5G satellite network management and orchestration
- Multilink and heterogeneous transport
- Common 5G-SatCom control plane/user plane functions

SDN and NFV

- Enablers for more **flexible and enhanced integration** of satellite and terrestrial components.

- **Benefits to 5G satCom**
  - **Efficient and dynamic sharing** of a satellite core network infrastructure among satellite network operators and other players
  - **On-demand QoS and on-demand bandwidth** management
  - Enables a **multi-service network** with each service requiring a specific performance guarantee
  - **Simplified network management and resource provisioning**
  - **Offloading** of Complex network functionalities to the cloud
  - **Optimal sharing** of the satellite network resources and infrastructure

Onboard Processing

- **Satellite payload types**
  - **Bent-pipe**
    - Filter and forward architecture
    - Network and connectivity functions have to be addressed by complex gateways
  - **Digital transparent**
    - Includes a processor in the signal path to filter and switch/route the signals to the required beams
    - Flexibility in terms of signal processing including filtering and routing
  - **Regenerative**
    - Provides additional signal processing functionalities than the digital transparent as signals can be regenerated.
    - Additional gain in the link budget due to onboard demodulation and decoding

- **Advantages of OBP to 5G SatCom**
  - **Higher user and system throughput** via onboard predistortion and interference mitigation
  - Flexibility in terms of **resource management, information routing and mesh connectivity**
  - Increased flexibility in terms of **bandwidth and frequency configuration** at the payload level
  - Enhanced **payload reconfigurability** to support cross-band inter-transponder operations
  - **Adaptation** to application changes (e.g., frequency, bandwidth, modulation, coding)

- R. Wansch, *et al.*, "On-board processing for satellite-terrestrial integration", *Chapter 1 in satellite communications in the 5G Era*, IET, 2018.

Maga-LEO

- **GEO systems**
  - Global large capacity coverage
  - High propagation delay and limited onboard processing capabilities
- **Mega LEO**
  - LEO systems with hundreds of satellites
  - Aims to provide ubiquitous broadband connectivity
  - Low propagation delay and innovative in terms of onboard technologies

Planned LEO-HTS mega-constellations

Constellation	LeoSat	SpaceX	OneWeb
No. of satellites	78–108	4,000	640+
Altitude (km)	1,400	1,100	1,200
Latency (ms)	50	20–30	20–30
User speed	1.6 Gbps	1 Gbps	50 Mbps
Cost ($)	3.5B	10B	2.3B
Announced market	Enterprise, mobility, backhaul	Broadband, backhaul	Broadband, mobility

- O. Onireti and M. A. Imran, "The role of satellite communications in 5G Ecosystem", *Chapter 1 in satellite communications in the 5G Era*, IET, 2018.

GaN Technology

- Current Satellite systems rely on Gallium Arsenide (GaAs) and travelling wave tubes (TWT) technologies for most of its RF front-end hardware

- Maturation of **GaN technology and commercial adoption** increasing
  - Eliminates the kW power supplies for TWTAs and cooling hardware for GaAs solid state power amplifies
    - Reduction in size and weight, saving **fuel and area on the payload**

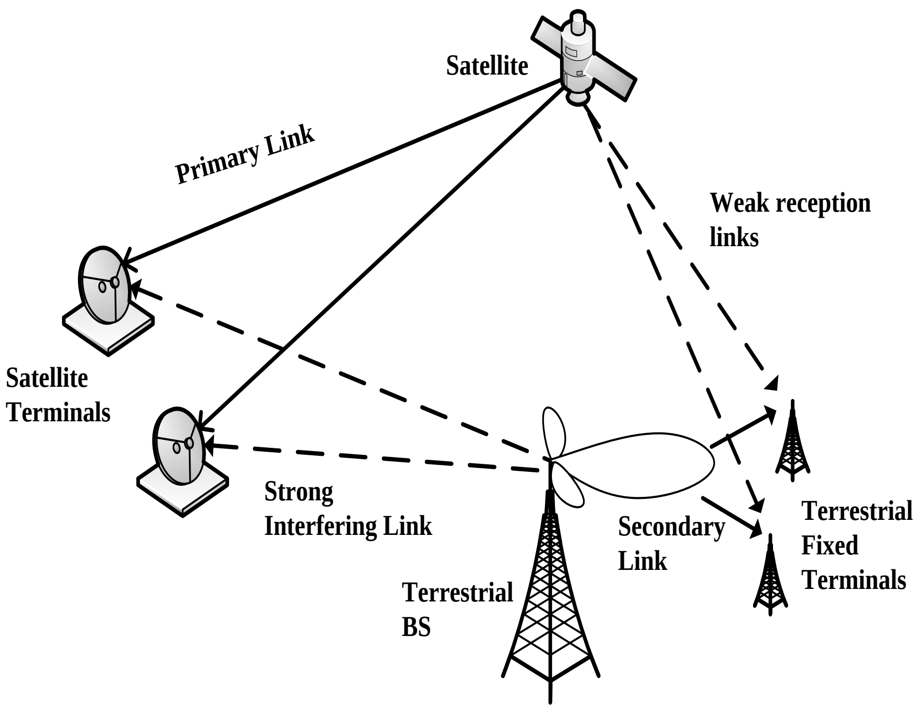
- Suitability of **GaN technology** for 5G satCom
  - High power efficiency and high operational frequency
  - Reliability, radiation hardness and high-temperature operation
  - Enables small form-factor nano- and micro-satellites (restrictions in physical size, mass, power consumption and cost)

- Yuk K, Branner GR, Cui C, “Future directions for GaN in 5G and satellite communications”, In: IEEE 60th International Midwest Symposium on Circuits and Systems (MWSCAS); 2017. p. 803–806.

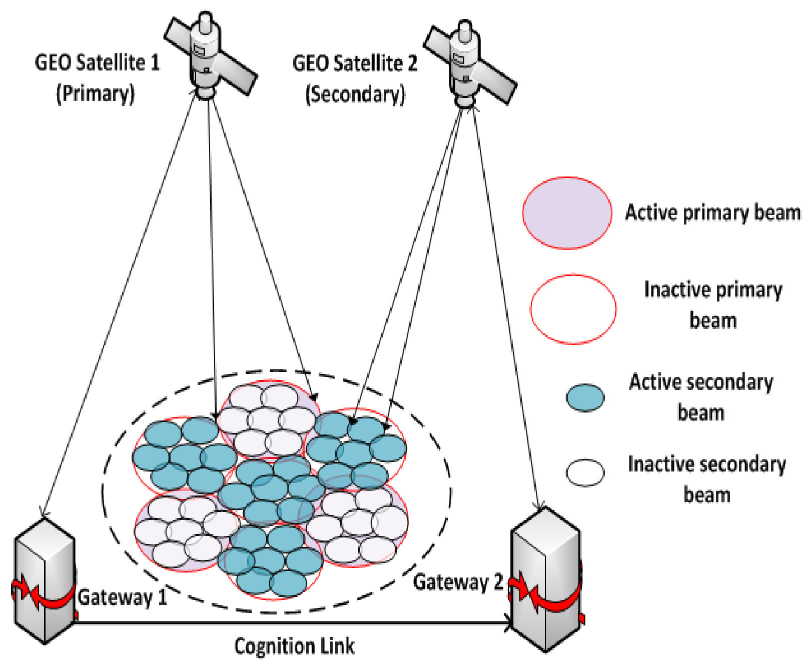
Cognitive SatComs

- Coexistence of **a satellite system with a terrestrial system** or with **another satellite system** over a common set of radio frequencies.

Hybrid Satellite-terrestrial Scenario



Dual Satellite Coexistence Scenario



- Shree K. Sharma, S. Chatzinotas, and B. Ottersten, "Transmit Beamforming for Spectral Coexistence of Satellite and Terrestrial Networks", in *Proc. 8th Int. Conf. CROWNCOM*, July 2013, pp. 275-281
- Shree K. Sharma, S. Chatzinotas, and B. Ottersten, "Cognitive Beamhopping for Spectral Coexistence of Multibeam Satellites", *Int. Journal of Satellite Commun. and Networking*, Mar. 2014.

Caching and Multicasting

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❑ **Edge Caching**

- Bringing contents closer to the end-user: Low content access latency
- Improved network performance in terms of delay and throughput

❑ **Satellite-assisted caching**

- **Terrestrial backhaul**: a multihop unicast network
  - Cached contents have to go via multiple links and has to be transmitted individually towards each BS
- **Satellite backhaul: wide-area coverage** for **broadcasting** contents to all terrestrial BSs or **multicasting** contents to multiple groups of BSs
- **Offloading** contents from terrestrial networks
- **OBP technology** enables caching on-satellite to further enhance network performance for content delivery

❑ A. Kalantari, M. Fittipaldi, S. Chatzinotas, T. X. Vu and B. Ottersten, "Cache-Assisted Hybrid Satellite-Terrestrial Backhauling for 5G Cellular Networks," *GLOBECOM 2017 - 2017 IEEE Global Communications Conference*, Singapore, 2017, pp. 1-6.
❑ Wu H, Li J, Lu H, *et al.*Atwo-layer caching model for content delivery services in satellite-terrestrial networks. In: IEEE Global Communications Conference (GLOBECOM); 2016. p. 1–6.

Satellite Use Case Categories in 5G

Satellite Use Case Categories in 5G

(Satellite "Sweet Spots" in the 5G Ecosystem)

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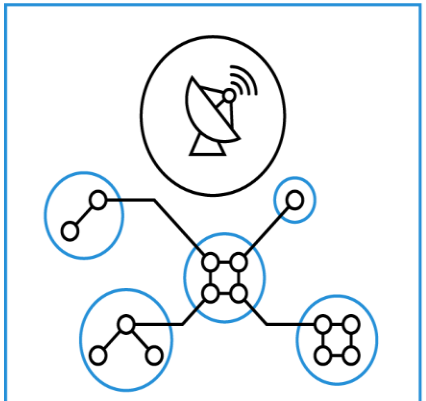
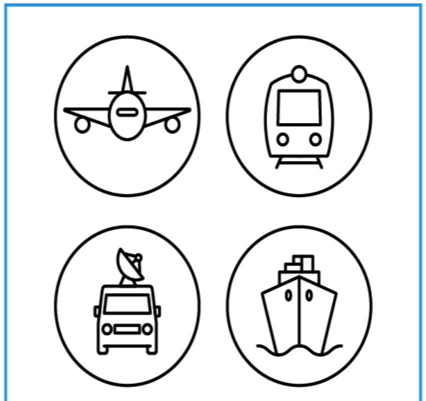


TRUNKING & HEAD-END FEED

Satellites provide a very high speed direct connectivity option to remote / hard-to-reach locations

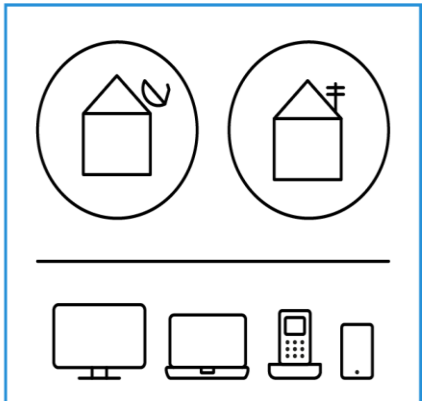
BACKHAULING & TOWER FEED

Satellites provide a high speed connectivity (incl. multicast content) to wireless towers, access points and the cloud



COMMS ON THE MOVE

Satellites provide a direct and/or complementary connection for users on the move (e.g. on planes, trains, automobiles and ships)



HYBRID MULTIPLAY

Satellites deliver content complementing terrestrial broadband (as well as direct broadband connectivity in some cases)

Satellite's ubiquitous availability helps accelerate global 5G deployment on the ground, at sea and in the air

Trunking and Head-end Feed

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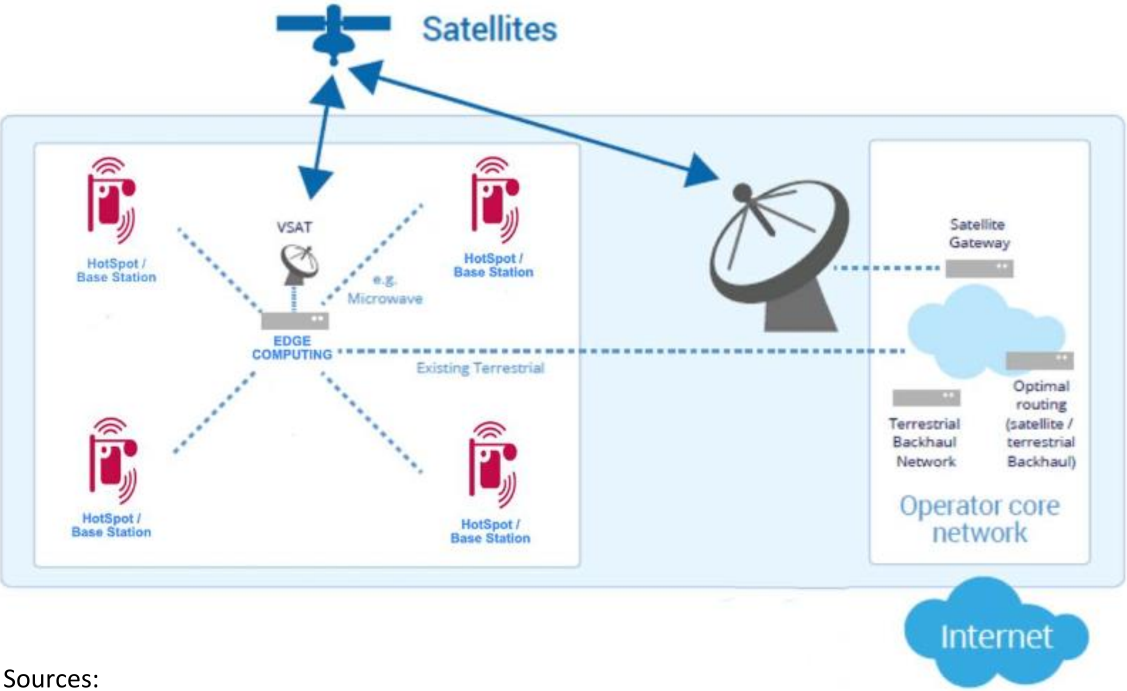


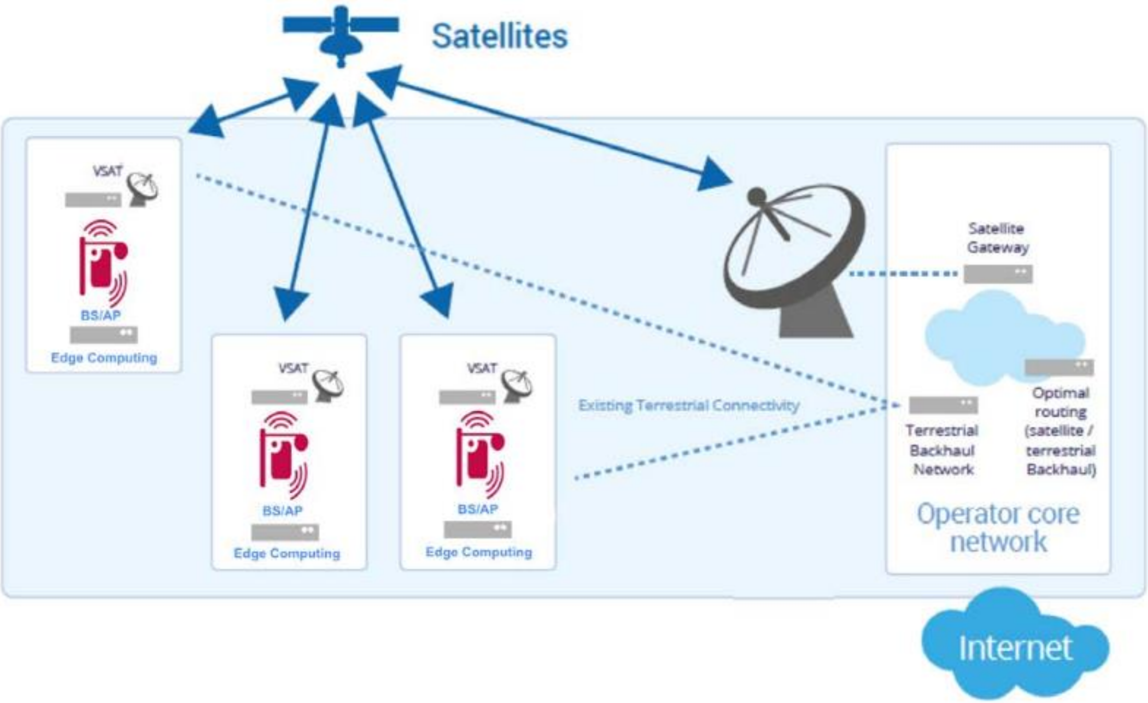
Sources:
(1) ESOA White Paper "Satellite Communication Services: An integral part of the 5G Ecosystem"
(2) ECC Report 280 "Satellite Solutions for 5G"

- Very high speed satellite link (up to Gbps speed) from GEO and/or non-GEO satellites provides connectivity to remote / hard-to-reach areas where there is limited or no existing terrestrial connectivity available
- Satellite user links are bidirectional since only broadband (unicast) communications are supported (i.e., no broadcast/multicast)
- No use of multicasting to populate edge caches

Example Relevant Satellite Use Cases in 5G:

- Broadband connectivity to remote areas. E.g., coverage on lakes, islands, mountains, rural areas, isolated areas or other areas that can be efficiently served by satellites;
- Community 5G Wi-Fi where satellite-based 5G Wi-Fi services are provided to remote communities with limited or no broadband internet service.
- Disaster relief: During natural disasters or other unforeseen events where satellites are the only option;
- Emergency response: in wide-scale natural disasters, and other specific emergency situations.
- Secondary/backup connection (limited in capability) in the event of the primary connection failure. This example covers the resiliency use case in low ARPU regions to ensure service reliability;
- Remote cell connectivity: E.g., stand-alone cells, Periodically occurring events, rarely repeated events (concerts/festivals, one-off sport events).
- Broadband connectivity to tactical cells for mission critical communications;
- Broadband connectivity for network head-ends;

Backhauling and Tower Feed



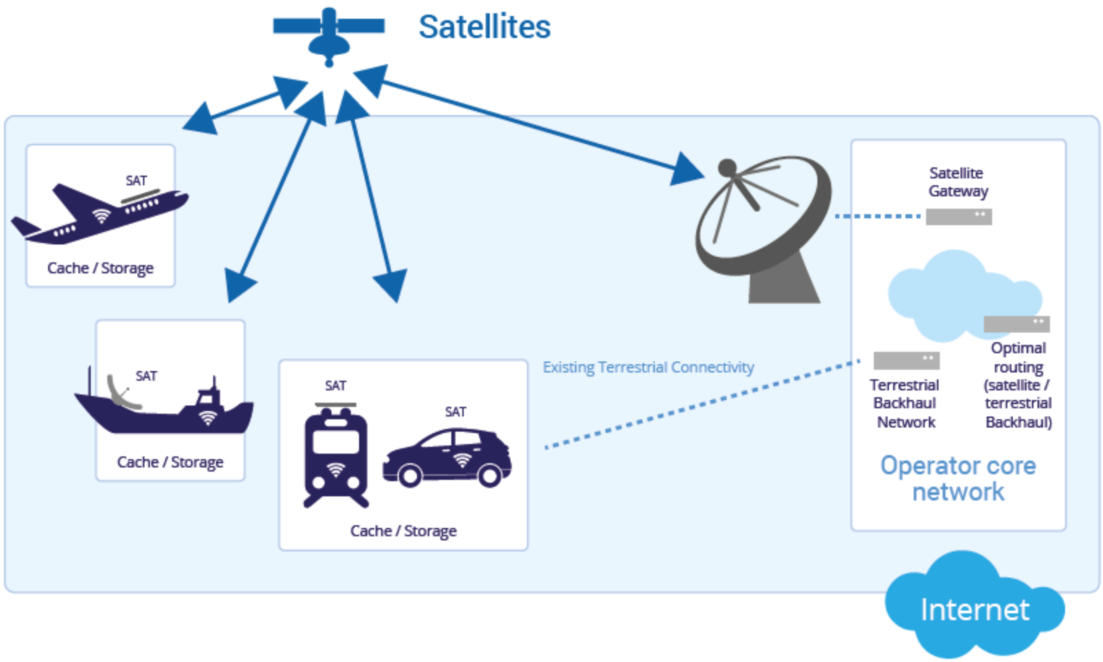
Example Relevant Satellite Use Cases in 5G:

- Efficient broadcast service to end users, etc. (e.g., video, software download), support of low bit-rate broadcast service e.g. for emergency messages and synchronisation of remote sensors and actuators;
- Providing efficient multicast/broadcast delivery to network edges for content such as live broadcasts, ad-hoc broadcast/multicast streams, group communications, MEC VNF update distribution.

Sources:
(1) ESOA White Paper “Satellite Communication Services: An integral part of the 5G Ecosystem”
(2) ECC Report 280 “Satellite Solutions for 5G”

- Very high speed satellite link (up to Gbps speed), direct to the cell towers, from GEO and/or non-GEO satellites complements existing terrestrial connectivity
- Satellite user links are either bidirectional (broadband, unicast) and/or unidirectional (broadcast/multicast)
- Use of multicasting to populate edge caches

Communications on the Move



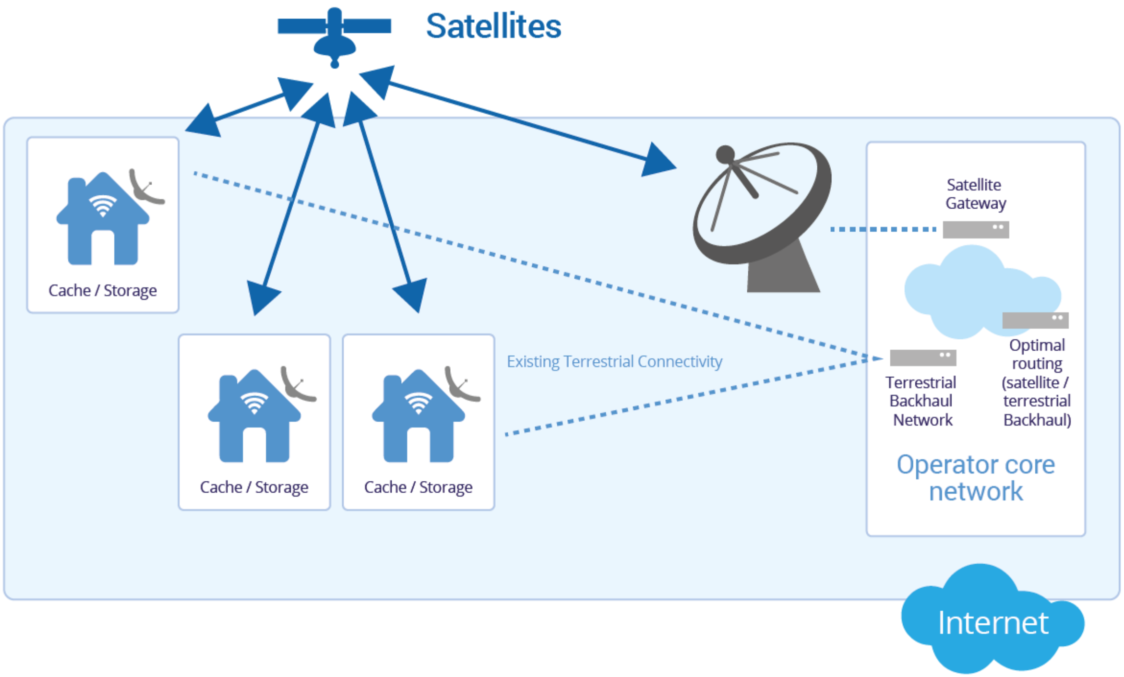
Sources:
(1) ESOA White Paper “Satellite Communication Services: An integral part of the 5G Ecosystem”
(2) ECC Report 280 “Satellite Solutions for 5G”

- Very high speed, multicast-enabled, satellite link (up to Gbps speed), direct to the plane, vehicles, train or vessel, from GEO and/or non-GEO satellites complements existing terrestrial connectivity, where available
- Satellite user links are either bidirectional (broadband, unicast) and/or unidirectional (broadcast/multicast)
- Use of multicasting to populate edge caches

Example Relevant Satellite Use Cases in 5G:

- Broadband connectivity to moving platforms, such as cars, airplanes or vessels
- Connectivity complementing terrestrial networks: broadband and content multicast connectivity to platforms on the move, in conjunction with a terrestrial-based connectivity link to base stations or relay-on-board moving platforms such as high speed trains/buses and other road vehicles, to ensure service reliability for major events in ad-hoc built-up facilities;
- Connectivity for remotely deployed battery activated (M2M/IoT) sensors, or handset devices with messaging/voice capabilities via satellite (e.g. fleet management, asset tracking, livestock management, farms, substations, gas pipelines, digital signage, remote road alerts, emergency calls, mission critical/public safety communications, etc.);
- IoT devices on containers (e.g. for tracking and tracing) connected via a Relay UE on a transport vehicle such as a ship, train or truck;
- For connected cars, enabling Over the Air Firmware and Software (FOTA/SOTA) services, information updates such as map information including points of interest (POI), real-time traffic and parking availability (Telematics) as well as infotainment, increased coverage and reliability for e-Call services, vehicle tracking and remote diagnostics

Hybrid Multiplay



Example Relevant Satellite Use Cases in 5G:

- Connectivity complementing terrestrial networks, such as broadband connectivity to home/office small cell in underserved areas in combination with terrestrial wireless or wireline.
- High speed connectivity to individual homes and offices, with the ability to multicast the same content (video, HD/UHD TV, as well as other non-video data) across a large coverage (e.g. for local storage and consumption) or unicast to individual users or devices
- Same capability also allows for an efficient broadband connectivity for aggregated IoT data
- In-home distribution via Wi-Fi, WiGig or very small cell 3G/4G/5G

Sources:

(1) ESOA White Paper “Satellite Communication Services: An integral part of the 5G Ecosystem”

(2) ECC Report 280 “Satellite Solutions for 5G”

- ▲ Very high speed, multicast-enabled, satellite link (up to Gbps speed), direct to the home or office, from GEO and/or non-GEO satellites complements existing terrestrial connectivity
- ▲ Satellite user links are either bidirectional (broadband, unicast) and/or unidirectional (broadcast/multicast)
- ▲ Use of multicasting to populate edge caches
- ▲ DTH satellite TV, integrated within the home or office IP network
- ▲ Local cell towers correspond to home/office small cells (femtocells)

Relevant Technology Innovation Projects

Outline

– Project “SaT5G” (Satellite and Terrestrial Network for 5G)
– Project “SATis5” (Demonstrator for Satellite-Terrestrial Integration in 5G Context)
– Project “EdgeSAT” (Edge Network Computing Capabilities For Satellite Remote Terminals)
– Project “5G-VINNI” (5G Verticals Innovation Infrastructure)

Technology Development Approach for Satellite Integration into 5G

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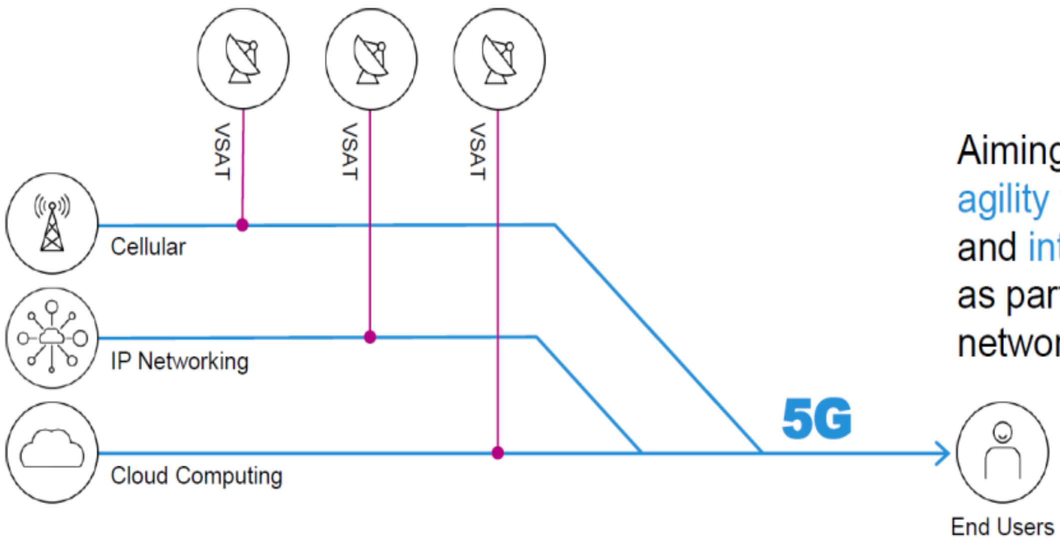
- **Short/Mid-term:** Fully-fledged implementation for operational integration of satellite backhauling into 5G heterogeneous "network of networks" via plug & play approach with focus on higher layer enablers *(SDN, NFV, Network Slicing*, *MEC,* etc) under common network management and orchestration



Aiming to add agility to VSAT and interface as part of 5G networks

Satellite into 5G is mainly about the higher layers, not about 5G waveforms, ultra-low latency, or cell towers in space

- **Long-term:** Possibility to use a 3GPP standardised version of 5G NR for the satellite waveform

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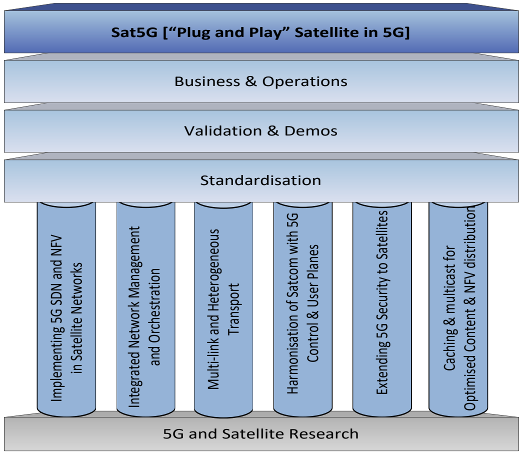
SaT5G Project at a Glance

SaT5G: Satellite and Terrestrial Network for 5G

Further info: http://sat5g-project.eu/

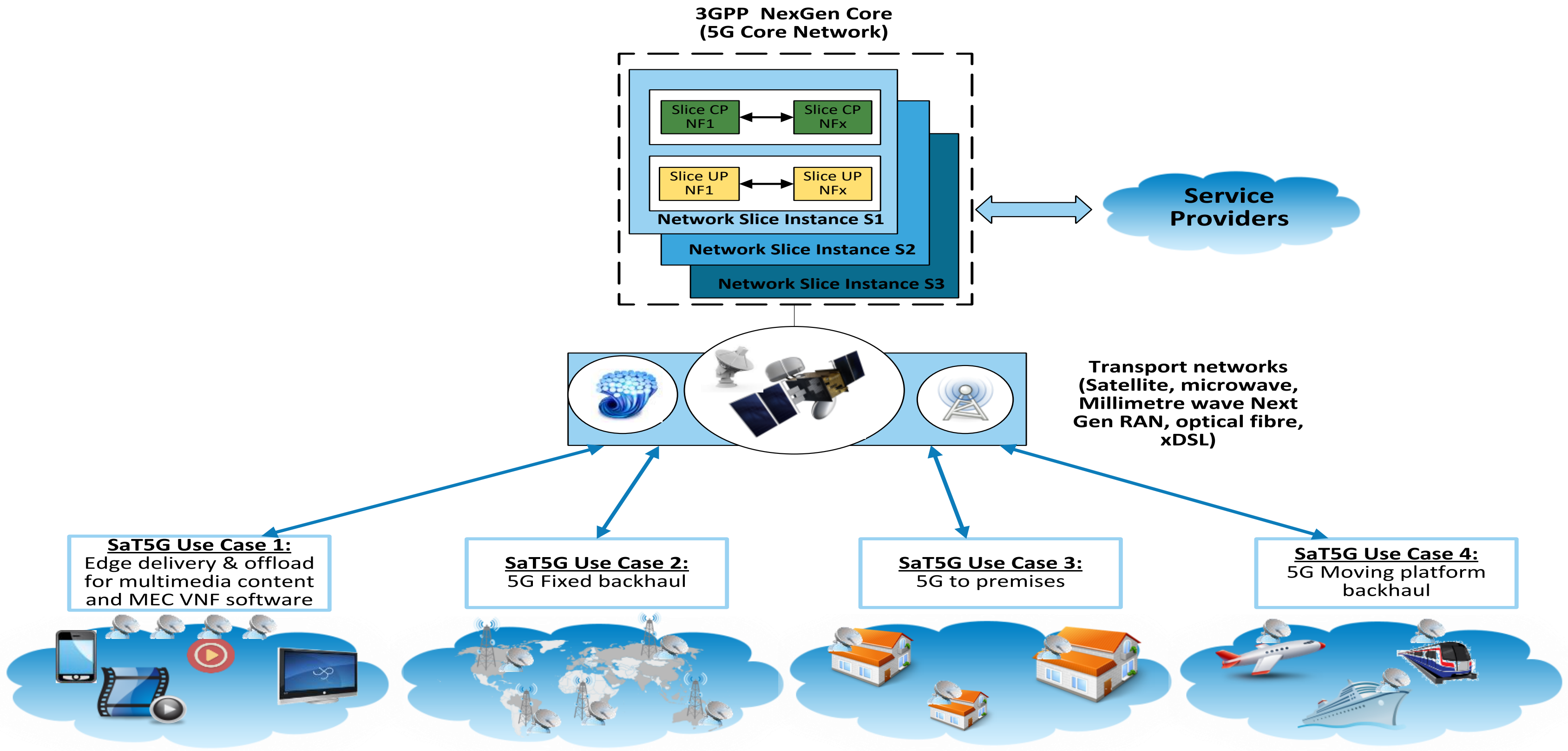
- Customer: European Commission (EC)
- Funding Programme: EC H2020 5G PPP Phase 2
- Total Budget: 8.3 MEUR (100% funded)
- Duration: June 2017 – November 2019 (30 months)
- Main Objective:
  - To research, develop, validate and demonstrate key technology enablers for “plug-and-play” integration of SatCom into 5G networks, with focus on 5G use cases for enhanced mobile broadband (eMBB)
- Consortium:
  - EU consortium comprising 16 partners from SatCom and non-SatCom industries
  - **SES**: Consortium Partner, Steering Committee Member, WP Leader



Satellite and Terrestrial Network for 5G

SaT5G Use Cases

Focus on eMBB Usage Scenario



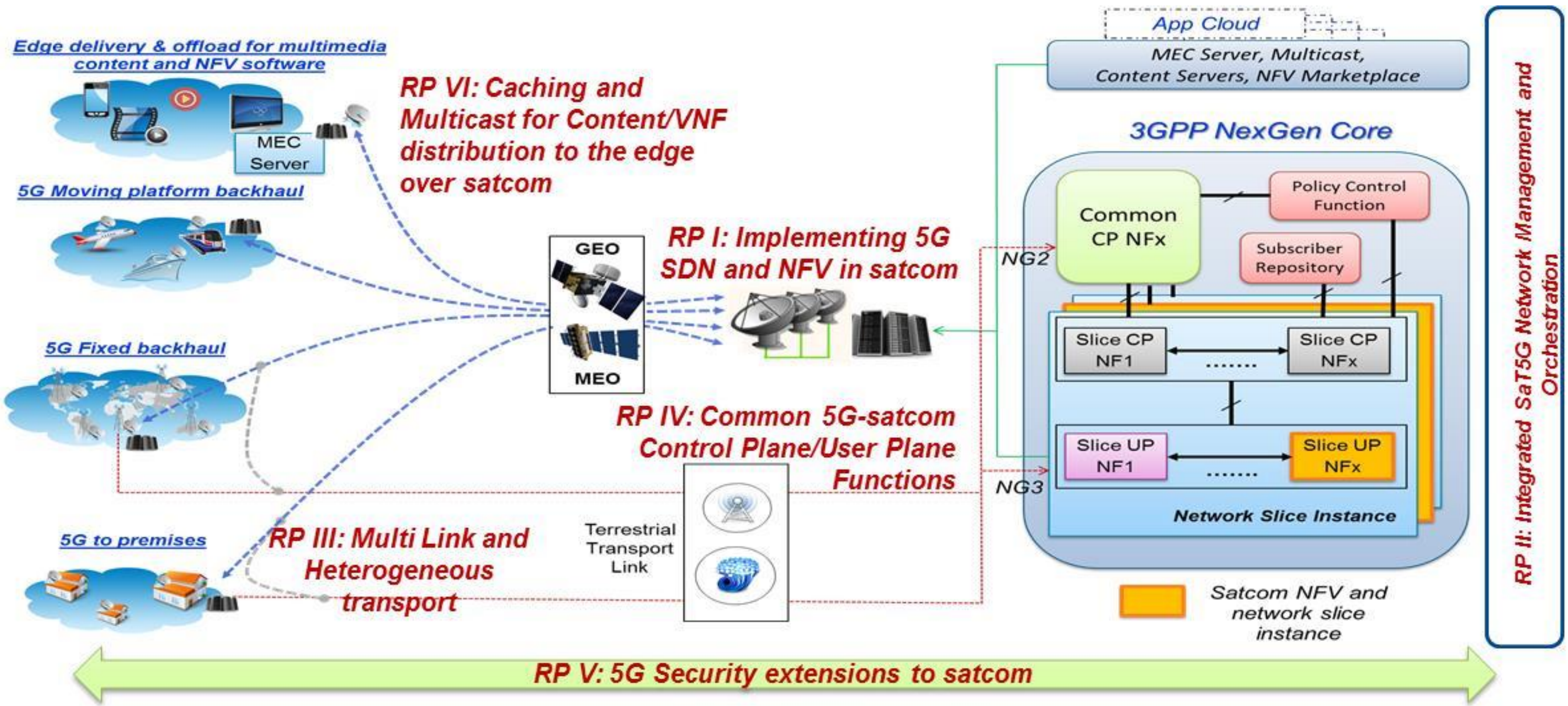
Relevant References:

[1] K. Liolis, A. Geurtz, R. Sperber, D. Schulz, S. Watts, G. Poziopoulou, B. Evans, N. Wang, O. Vidal, B. Tiomela Jou, M. Fitch, S. Sendra Diaz, P. Sayyad Khodashenas, N. Chuberre, "Use Cases and Scenarios of 5G Integrated Satellite-Terrestrial Networks for Enhanced Mobile Broadband: The SaT5G Approach", ***Wiley's International Journal of Satellite Communications and Networking*** *– Special Issue "Integrated Satellite-Terrestrial Networks in Future Wireless Systems*, 2018;1–22. https://doi.org/10.1002/sat.1245

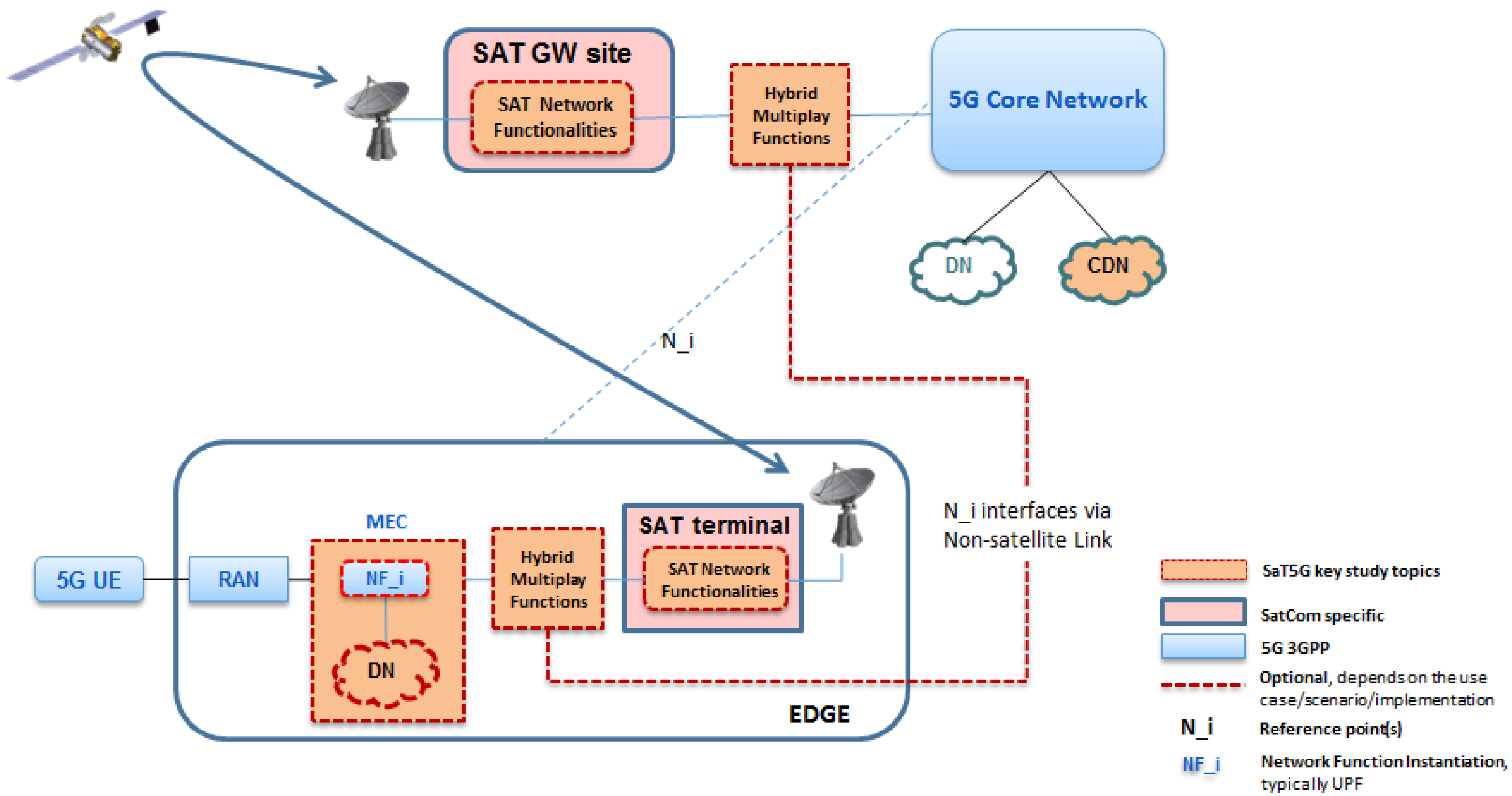
[2] K. Liolis, A. Geurtz, R. Sperber, D. Schulz, S. Watts, G. Poziopoulou, B. Evans, N. Wang, O. Vidal, B. Tiomela Jou, M. Fitch, S. Sendra Diaz, P. Sayyad Khodashenas, N. Chuberre, "Satellite Use Cases and Scenarios for 5G eMBB", Book: ***"Satellite Communications in the 5G Era"***, Editors: S. K. Sharma, S. Chatzinotas, P.-D.M. Arapoglou, IET, 2018, ISBN: 978-1-78561-427-9.

Satellite and Terrestrial Network for 5G

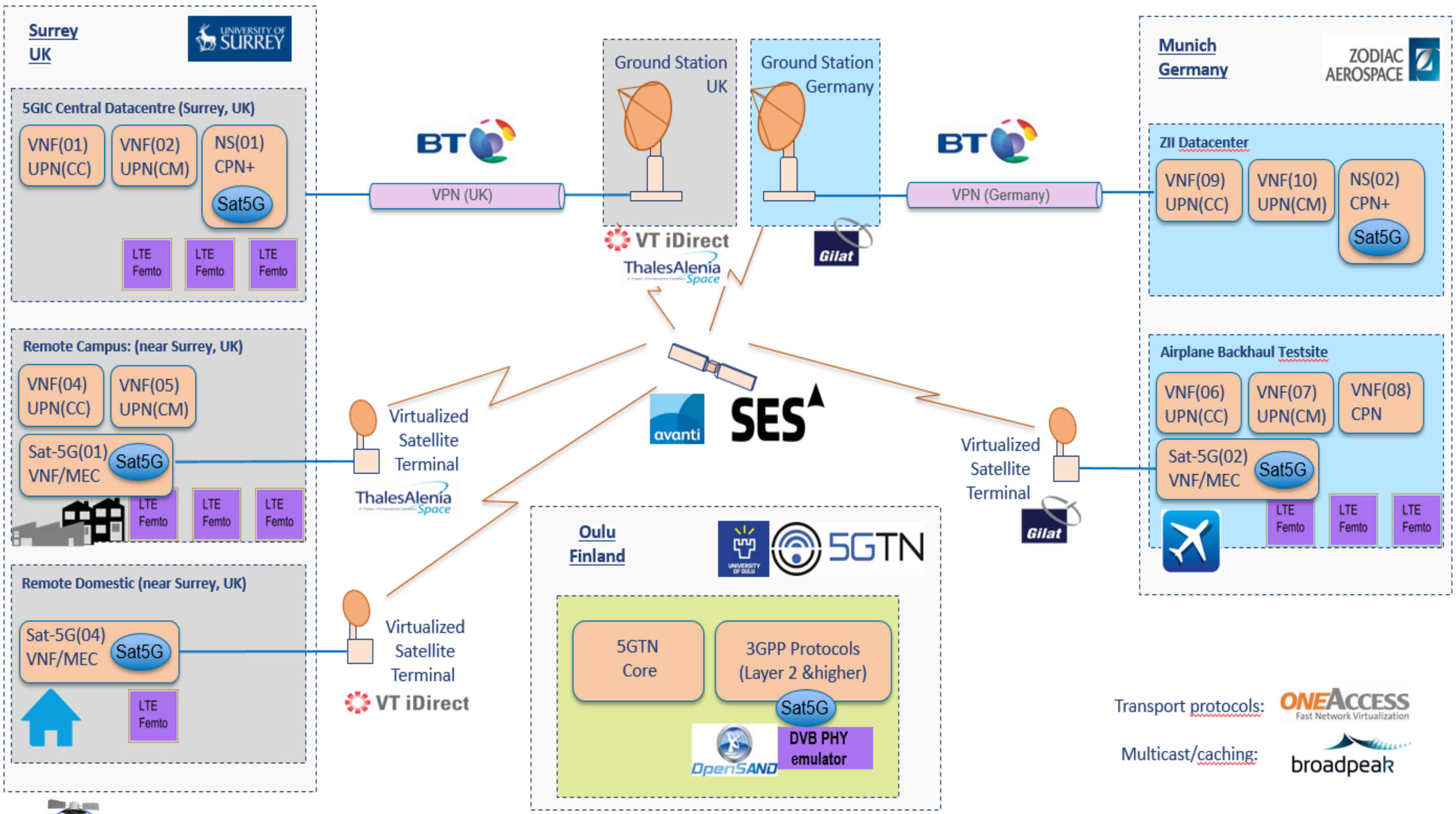
SaT5G Use Cases & Research Pillars



SaT5G Reference Backhaul Architecture



SaT5G Demo Testbeds



SaT5G Satellite and Terrestrial Network for 5G

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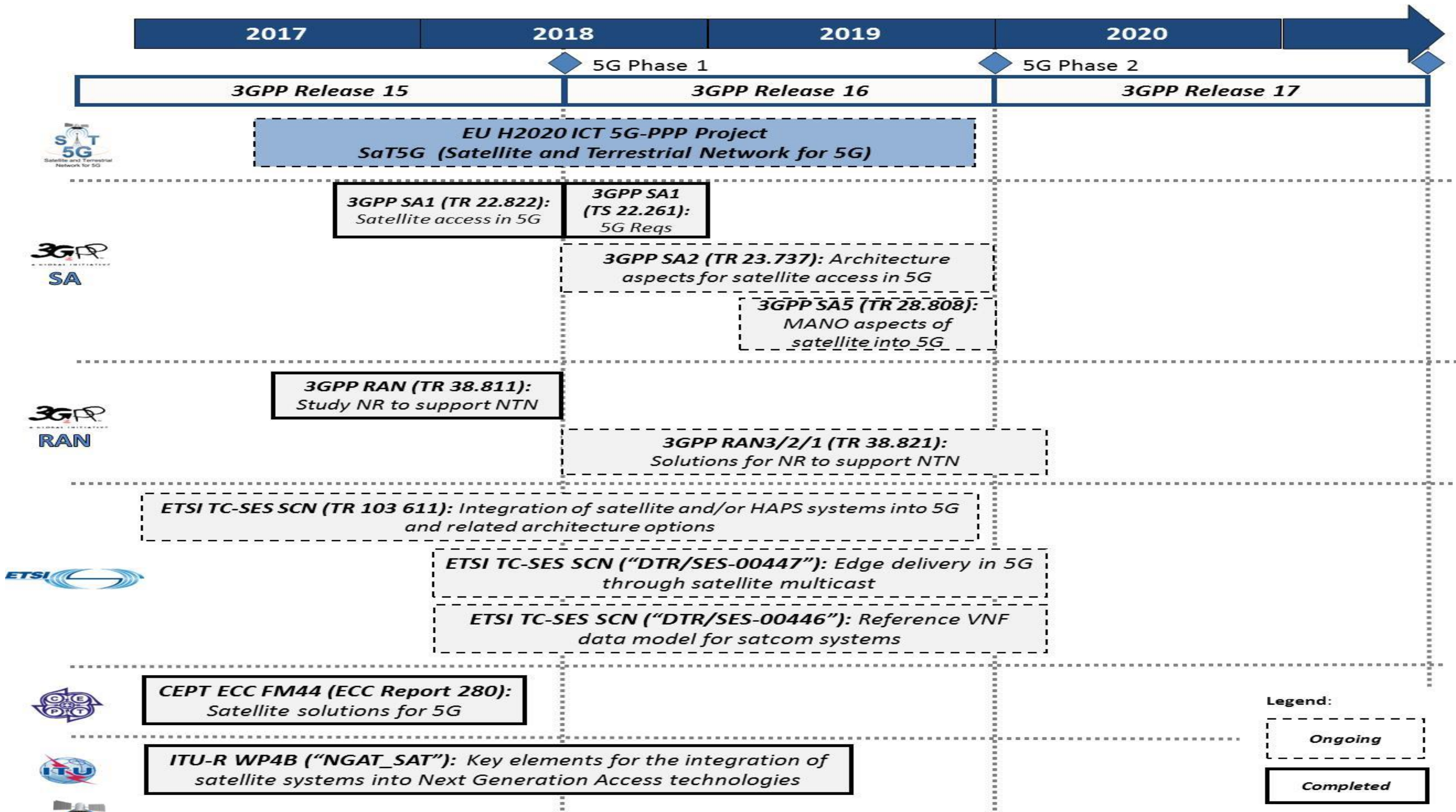
SaT5G Standardization Activities



SATis5 Project at a Glance

SATis5: Demonstrator for Satellite-Terrestrial Integration in 5G Context

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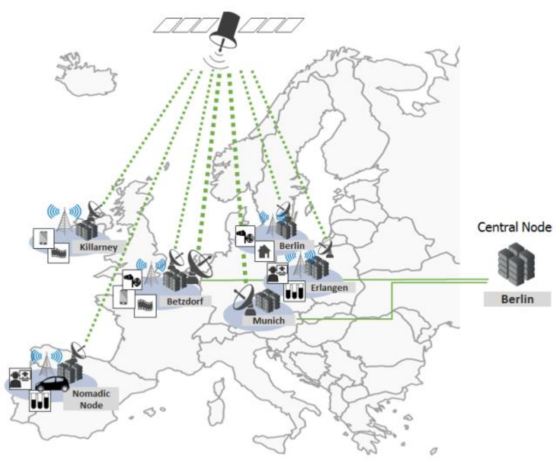
- Customer: European Space Agency (ESA)
- Funding Programme: ESA ARTES Advanced Technology
- Total Budget: 1.4 MEUR (100% funded)
- Duration: October 2017 – September 2019 (24 months)
- Main Objective:
  - To build a large-scale real-time live end-to-end 5G integrated network PoC testbed that enables the satellite terrestrial convergence into 5G context. Focus on both eMBB and mMTC use cases.
- Consortium:
  - EU consortium comprising 8 partners based in DE, IRL, LU
  - **SES**: Consortium Partner, WP Leader

Further info: https://artes.esa.int/projects/satis5-0



5G-Satellite Convergent Architecture
Key Elements

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- Edge-Central Network Split
  - Adding functionality to the satellite remote site to make the end-to-end communication more efficient
- Hybrid Terrestrial-Satellite Systems
  - Main goal of convergence is (as seamless as possible) interoperability with terrestrial
- Multi-slicing Environment
  - Providing the means to customize the end-to-end network
  - Enable different edge-central network split models per use case

Relevent References:

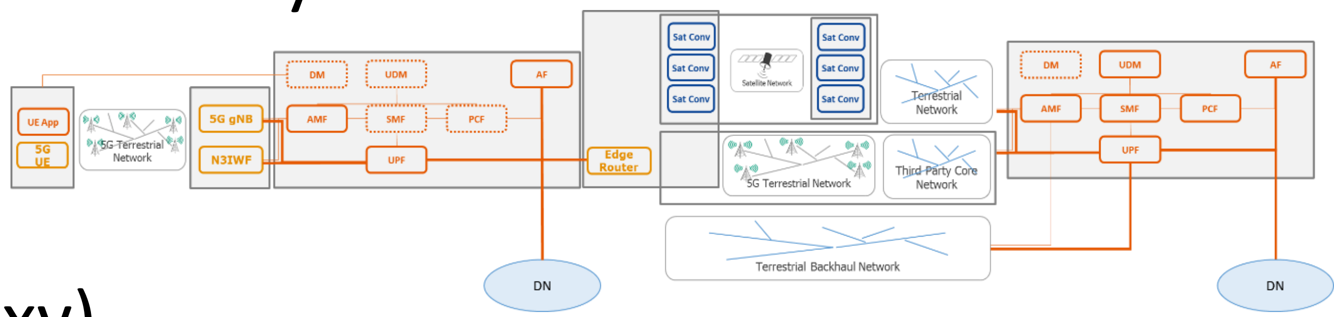
[1] M. Corici, K. Liolis, *et al.*, “SATis5: A 5G Testbed Integrating Satellite and Terrestrial Infrastructures”, in Proc. ***9th Advanced Satellite Multimedia Systems Conference & 15th Signal Processing for Space Communications Workshop (ASMS/SPSC 2018)***, Berlin, Germany, September 2018.

[2] M. Corici, K. Liolis, *et al.*, “SATis5 Solution: A Comprehensive Practical Validation of the Satellite Use Cases in 5G”, in Proc. ***24th Ka and Broadband Communications Conference and 36th International Communications Satellite Systems Conference (ICSSC)***, Niagara Falls, Canada, October 2018.

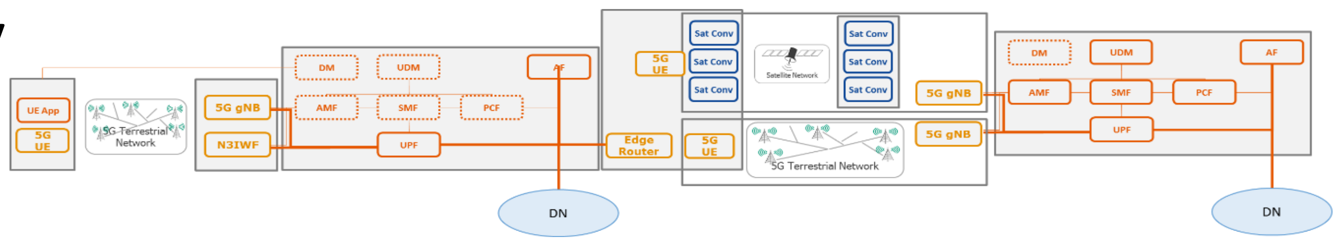
SATis5

5G-Satellite Convergent Architecture Connectivity Models

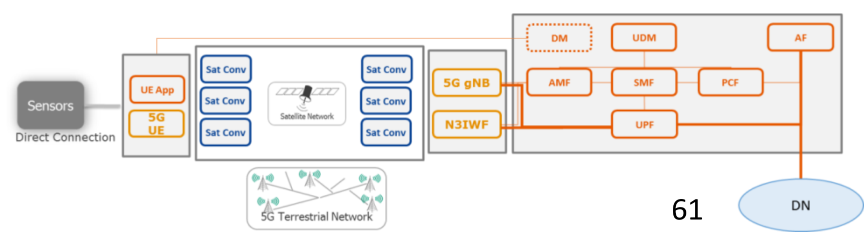
- Backhaul Connectivity



- Indirect (Proxy) Connectivity



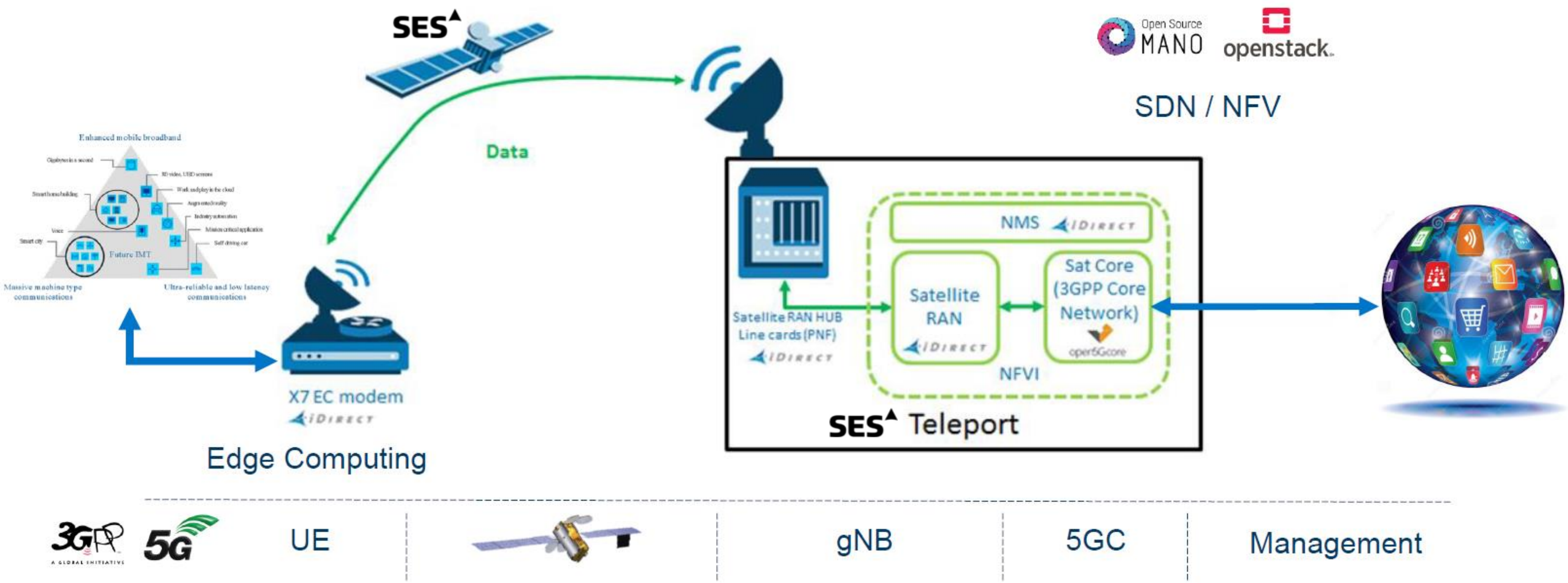
- Direct Connectivity



SATis5

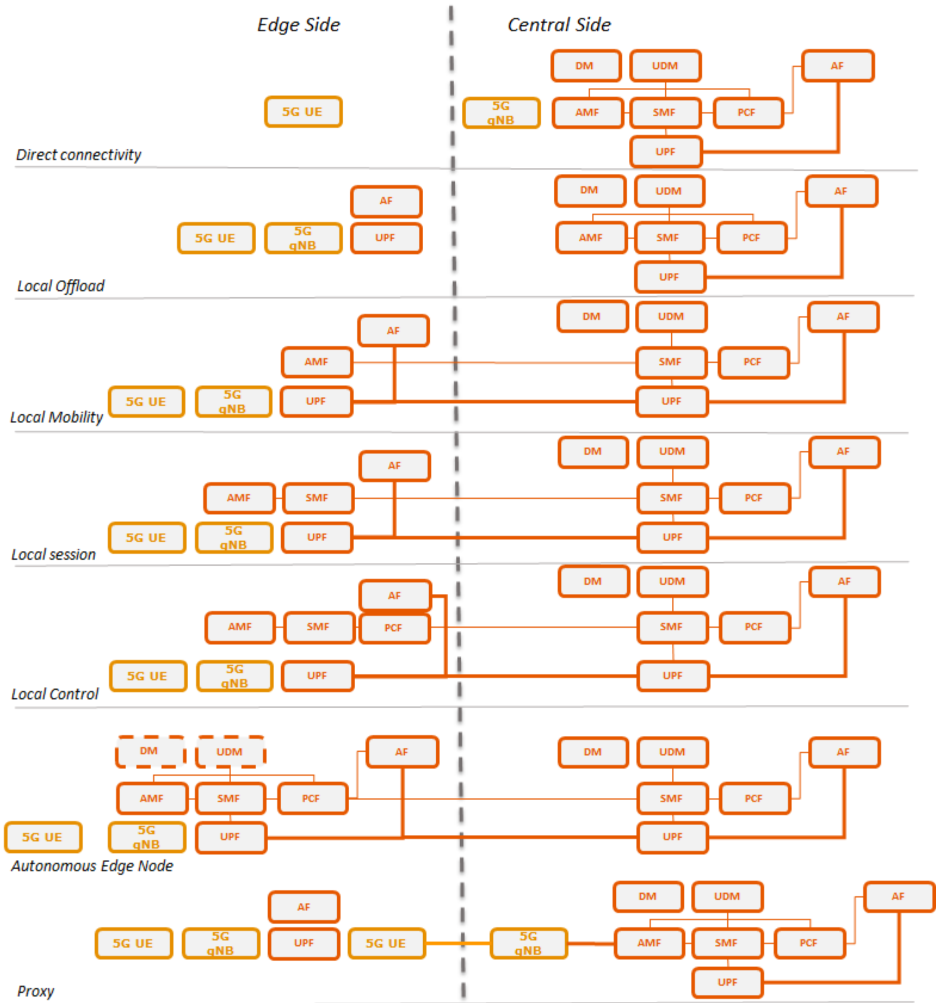
Satellite Integration into 3GPP Network Architecture

Allows management & operation of satellite network by MNO in seamless way as if it was standard 3GPP 5G cellular access network



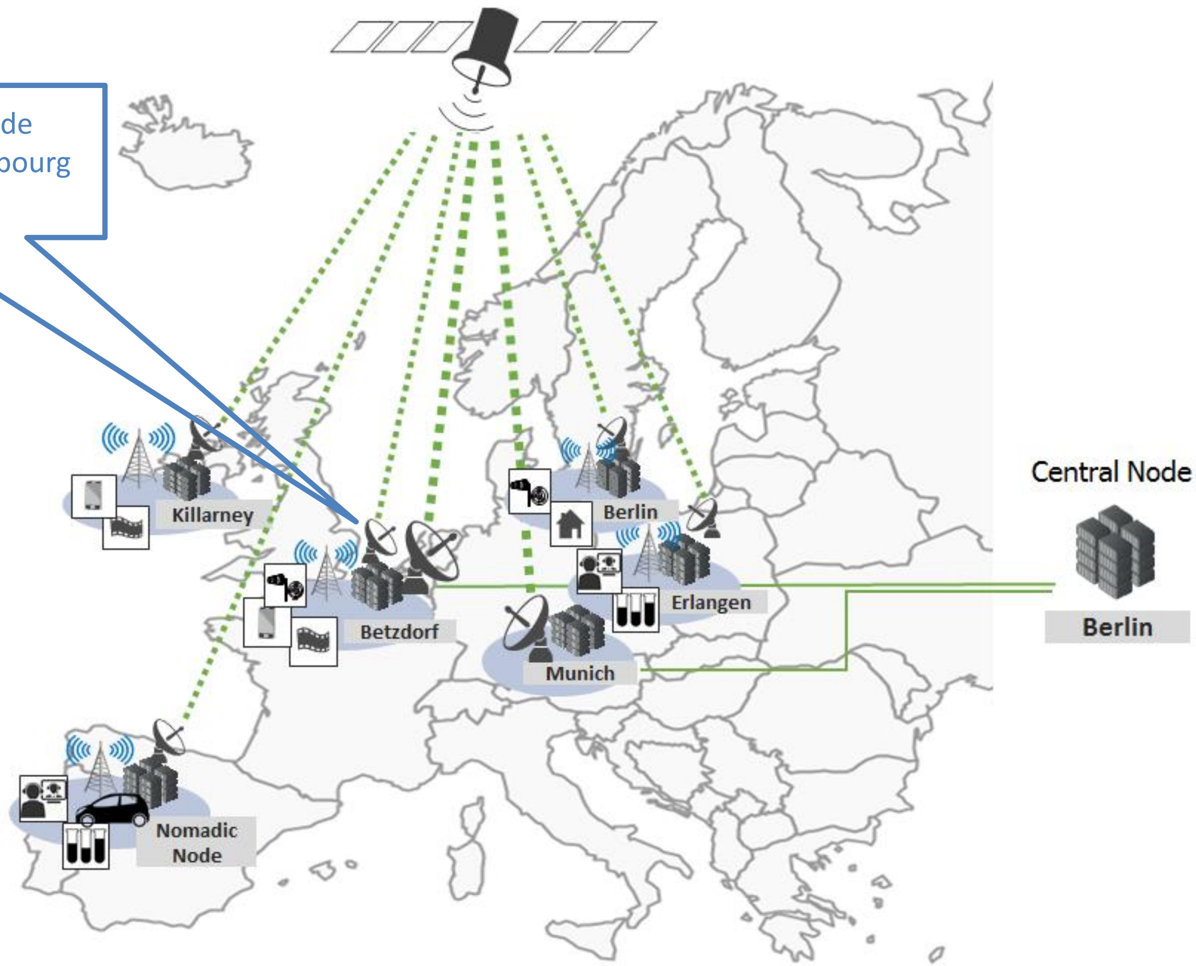
Architecture in line with "*Scenario A3 - Indirect Mixed 3GPP NTN Access with Bent-Pipe Payload*" in ETSI TR 103 611 "Seamless integration of satellite and/or HAPS (High Altitude Platform Station) systems into 5G system and related architecture options"

Edge-Central Functionality Split Model



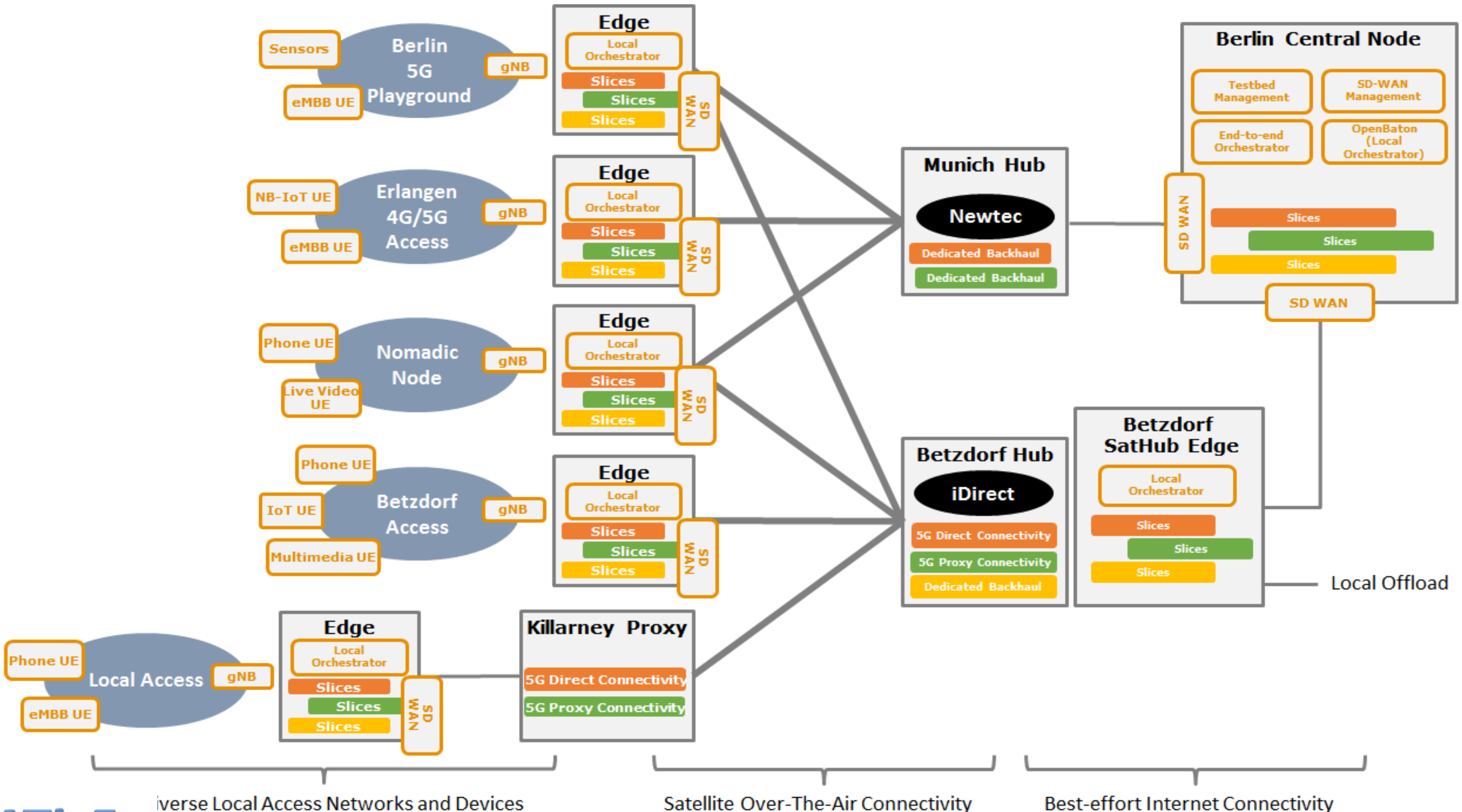
SATis5 Testbed Deployment Overview

Central Node and Edge Node hosted in Betzdorf, Luxembourg operated by SES



SATis5

SATis5 Testbed Topology



Slice Models selection for Use Cases

5G Usage Scenario	Satellite Use Case Category	SATis5 Use Case	Satellite Network Placement	Implementation solution	Slice implemented
eMBB	Trunking and Head-end Feed	**Broadband connectivity to areas where it is difficult or not (yet) possible to deploy terrestrial connections**	Between gNB and Core	Any type of application with satellite backhaul	**Local offload**
	Backhauling and Tower Feed	**Providing efficient multicast/ broadcast delivery to network edges**	Broacast over satellite, DASH server at edge	DASH server at local offload, broadcasting content to DASH server	**Local offload**
	Communications on the Move	**Broadband and content multicast connectivity to moving platforms**	Backhaul and proxy connectivity of edge network	Any type of application with satellite backhaul	**Autonomous edge**
		Direct content delivery to devices	Direct connectivity	Direct connectivity emulation using non-3GPP RAN	**Direct connectivity**
	Hybrid Multiplay	**Connectivity complementing terrestrial networks**	Backhaul of edge network	Media delivery to different UEs using selected backhauls	**Local offload**
mMTC	Backhauling and Tower Feed	**Support of low bit-rate broadcast service**	Backhaul to edge node	LWM2M based syncronization of end devices	**Local offload**
	Communications on the Move	**Aggregation of device information**	Backhaul to the IoT server in the nomadic edge	Libellium server on edge	**Autonomous edge**
		Cyber and Managed Security Services	Direct and backhaul connectivity	Downloading broadcasted firewall rules/checking security status of devices	**Direct connectivity + Autonomus edge**

EdgeSAT Project at a Glance

EdgeSAT: Edge Network Computing Capabilities For Satellite Remote Terminals

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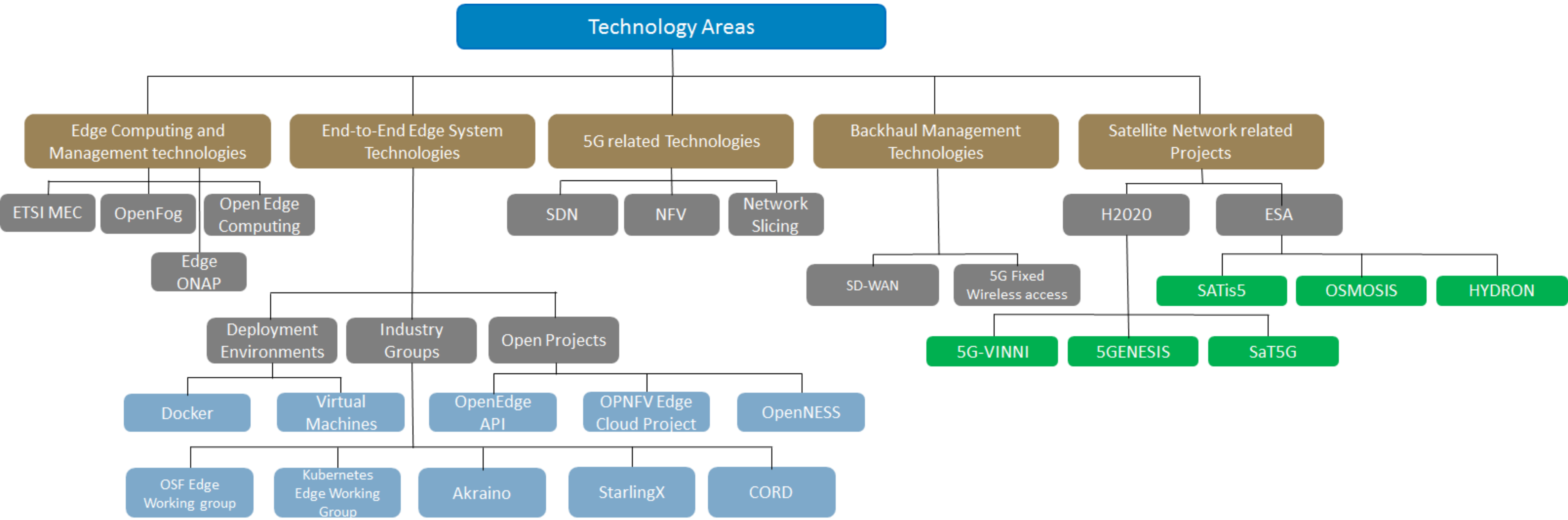
Further info: https://artes.esa.int/projects/edgesat

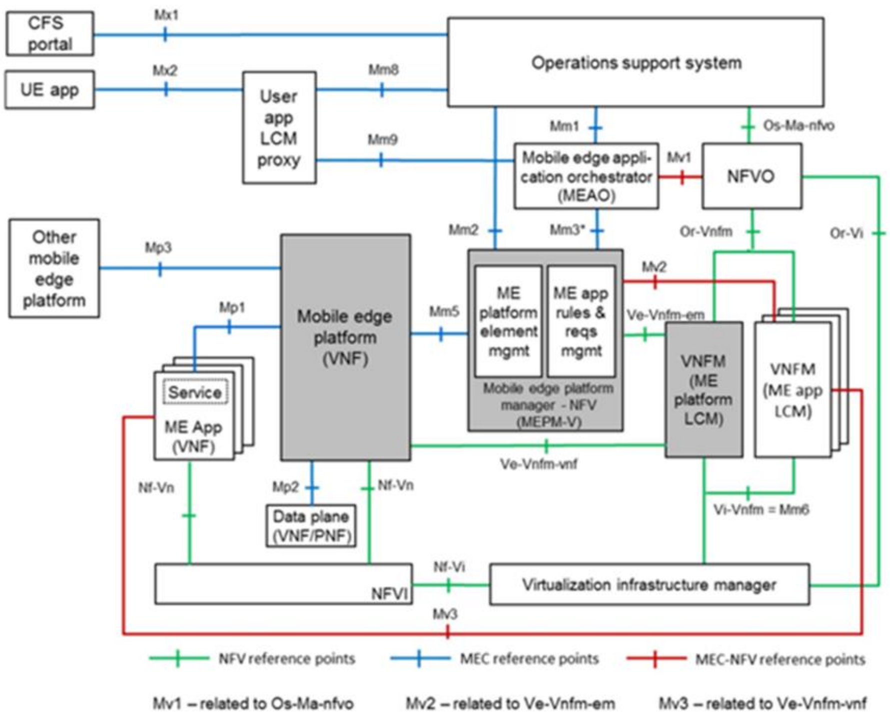
- Customer: European Space Agency (ESA)
- Funding Programme: ESA ARTES Future Preparations
- Total Budget: 300 KEUR (100% funded)
- Duration: April 2019 – March 2020 (12 months)
- Main Objective:
  - To explore the applicability and implementation of edge networking concepts in satellite networks
  - To extend existing capabilities of SATis5 5G testbed with MEC (Multi-access Edge Computing) capabilities
  - To specify and validate a SatCom MEC-enabled edge node through GEO demos
- Consortium:
  - EU consortium comprising 4 partners based in DE, IRL, LU
  - **SES**: Consortium Partner, WP Leader

State of the Art Review
Edge Computing Technologies



EdgeSAT Main Approach

- Two direction, service oriented approach is taken:
  - ETSI MEC approach – implementing added value services for the edge and orchestrating them
    - Base for the ETSI MEC part is the Intel's NEV (Network Edge Virtualization) SDK (precursor of the OpenNESS toolkit, used in Akraino and LF Edge)
    - Extensions: implementation of edge services, their management and orchestration
  - 3GPP Edge approach – imported directly from SATis5 and extended depending on the value added services (including 3GPP services such as backhaul management and location services)
    - Base: the SATis5 testbed (see Edge-Central Functionality Split Model)
    - Extensions: implementation of edge services and their local exposure, integration with ETSI MEC

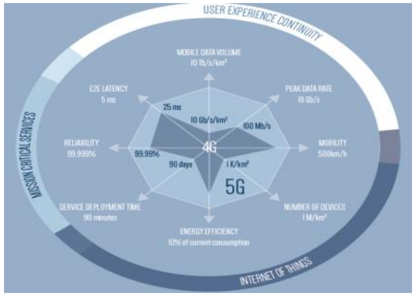


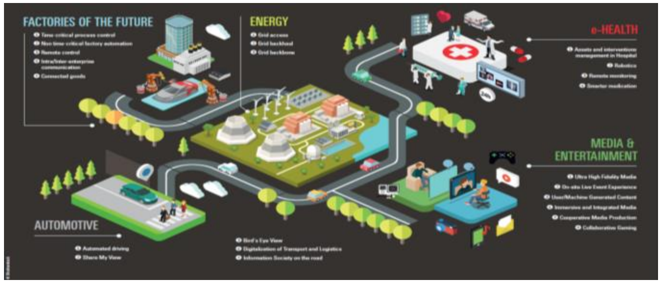
5G-VINNI Project at a Glance

5G-VINNI: 5G Verticals Innovation Infrastructure

Further info: https://www.5g-vinni.eu/

- Customer: European Commission (EC)
- Funding Programme: EC H2020 5G PPP Phase 3
- Total Budget: 20 MEUR (100% funded)
- Duration: July 2018 – June 2021 (36 months)
- Main Objective:
  - Build an open large scale 5G End-to-end facility that can:
    - demonstrate that key 5G network KPIs can be met
    - be validated, accessed and used by vertical industries (H2020 ICT-19 projects) to test use cases and validate 5G KPIs
- Consortium:
  - Project Coordinator: Telenor (NO)
  - Large industrial EU consortium comprising 23 partners, incl. Major MNOs and Mobile Industry Vendors
  - **SES**: Consortium Partner, Experimentation Facility Site Owner & Operator





5G-VINNI Facility Sites

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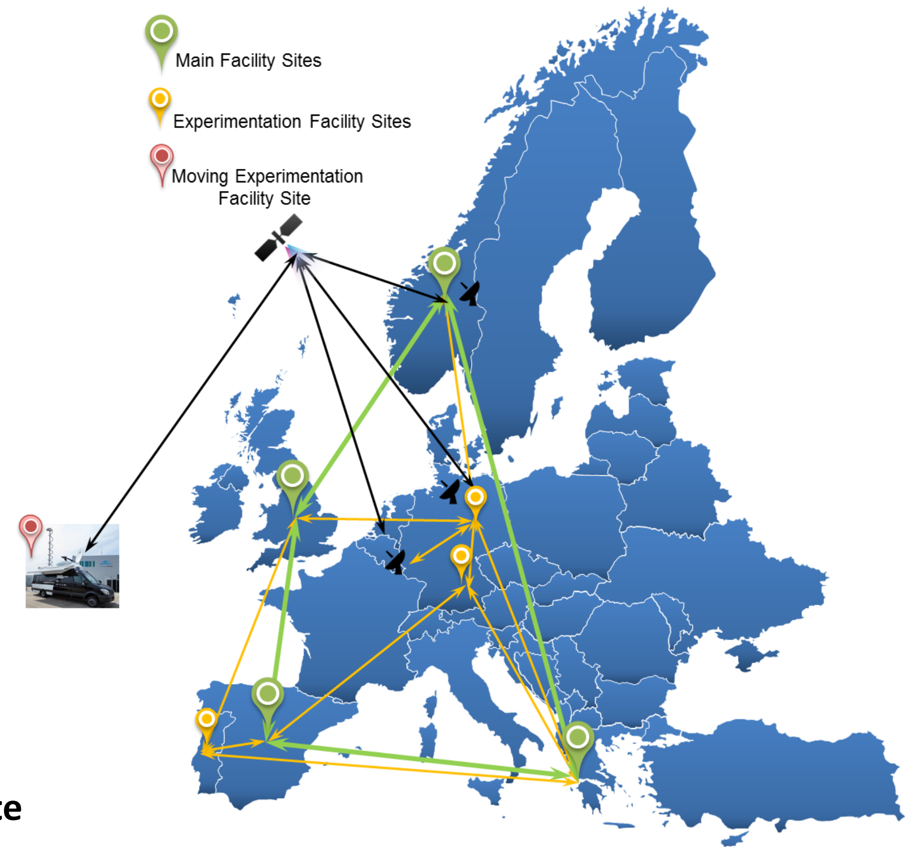
- **Main Facility sites:** E2E 5G-VINNI facility that offers services to ICT-18-19-22 projects with well-defined Service Level Agreements (SLAs)
  - Norway (Oslo, Kongsberg)
  - UK (Martlesham)
  - Spain (Madrid)
  - Greece (Patras)
- **Experimentation Facility sites:** provide environments for advanced focused experimentation & testing possibilities on elements & combinations of elements of the E2E model
  - Portugal (Aveiro)
  - Germany (Berlin)
  - Germany (Munich)
  - **Moving Experimentation Facility site: Satellite Connected Vehicle (SES's owned RRV - Rapid Response Vehicle)**



5G-VINNI Facility Sites
Capabilities Summary

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Main Facility sites

Norway (Oslo, Kongsberg)	UK (Martlesham)	Spain (Leganes)	Greece (Patras)
• Slicing (eMMB, URLLC, mMTC) • E2E Service Orchestration (Nokia) • NFVI (OpenStack) and MANO (Nokia) • MEC (Nokia) • Four 5G gNBs (Ericsson, Huawei) – 3.5GHz, 90MHz BW – 26GHz, 800MHz BW • 5G Core (Ericsson) • 3GPP compliance – Rel'15 in 2019, Rel'16 in 2021 – NSA in 2019, SA in 2021 • Satellite backhaul option (GEO)	• Slicing (eMMB, URLLC, mMTC) • Service Orchestration (Nokia) • NFV MANO, NFVI and vEMS (Samsung) • MEC • 5G RAN incl. 3.5 and 26GHz (Samsung) • 5G Core (Samsung) • 3GPP compliance – Rel'15 in 2019, Rel'16 in 2021 – NSA in 2019, SA in 2021	• Slicing (OSM extension) • Service Orchestration (OSM NBI) • NFV MANO (OSM) and NFVI (OpenStack) • SDN (ODL/ONOS) • Support for micro-VNFs • 5G RAN (SDR), low frequencies and 30-300GHz • Advanced monitoring and data-driven management • Edge computing (MEC and non-MEC) • 5G Core (possibly SBA-based)	• Slicing (eMMB, URLLC, mMTC, via OSM) • Service Orchestration (via OSM NBI services) • NFV MANO (OSM) and NFVI (OpenStack)+DPDK • 5G RAN open source radio (Lime, SRS)-700-800MHz, 3.5.-3.8GHz • 5G Core (Open5GCore) • NB-IoT, LTE-M (FhG NB-IOT core) • mmWave backhaul (Intracom) • GEANT connectivity • MEC

Experimentation Facility sites

Portugal (Aveiro)	Germany (Berlin)	Germany (Munich)	Luxembourg (Satellite Connected Vehicle)
• Service Orchestration (Alticelabs) • NG-PON2-based 5G front/backhaul (Alticelabs) • NFVI (OpenStack) • SDN (ODL) • Cloud RAN • MEC	• 5G RAN prototype(s) • 5G Core (Open5GCore) • Edge cloud/e2e Orchestration (OpenBaton) • mmWave backhaul • Interconnection with remote islands in Betzdorf and Tokyo • Large scale events, Nomadic networks, Disaster Relief	•5G NR SA RAN (Huawei) 3.5 GHz •5G Core (Huawei) •MANO and NFVI (Huawei) •SDN (Floodlight) •V2I, V2P •MEC, Edge Computing •URLLC targeting Rel16/17 •Sensor fusion enabled by 5G	• GEO/MEO satellites (SES) • C/X/Ku/Ka-band (SES) • Satellite teleport (SES) • Satellite backhauling (SES) • Satellite 5G testbed node with SDN/NFV/MEC (SES) • Satellite interconnection with Berlin Facility site (SES) • eMBB, mMTC use cases (SES)

SES's Rapid Response Vehicle (RRV)

… enabling the 5G-VINNI Moving Experimentation Facility Site

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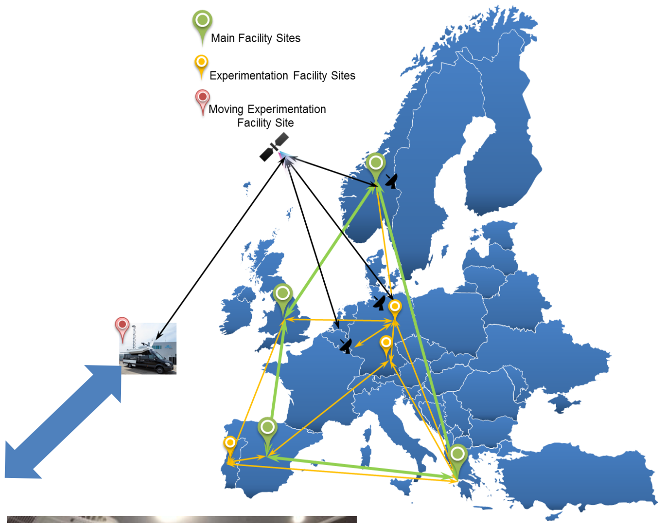
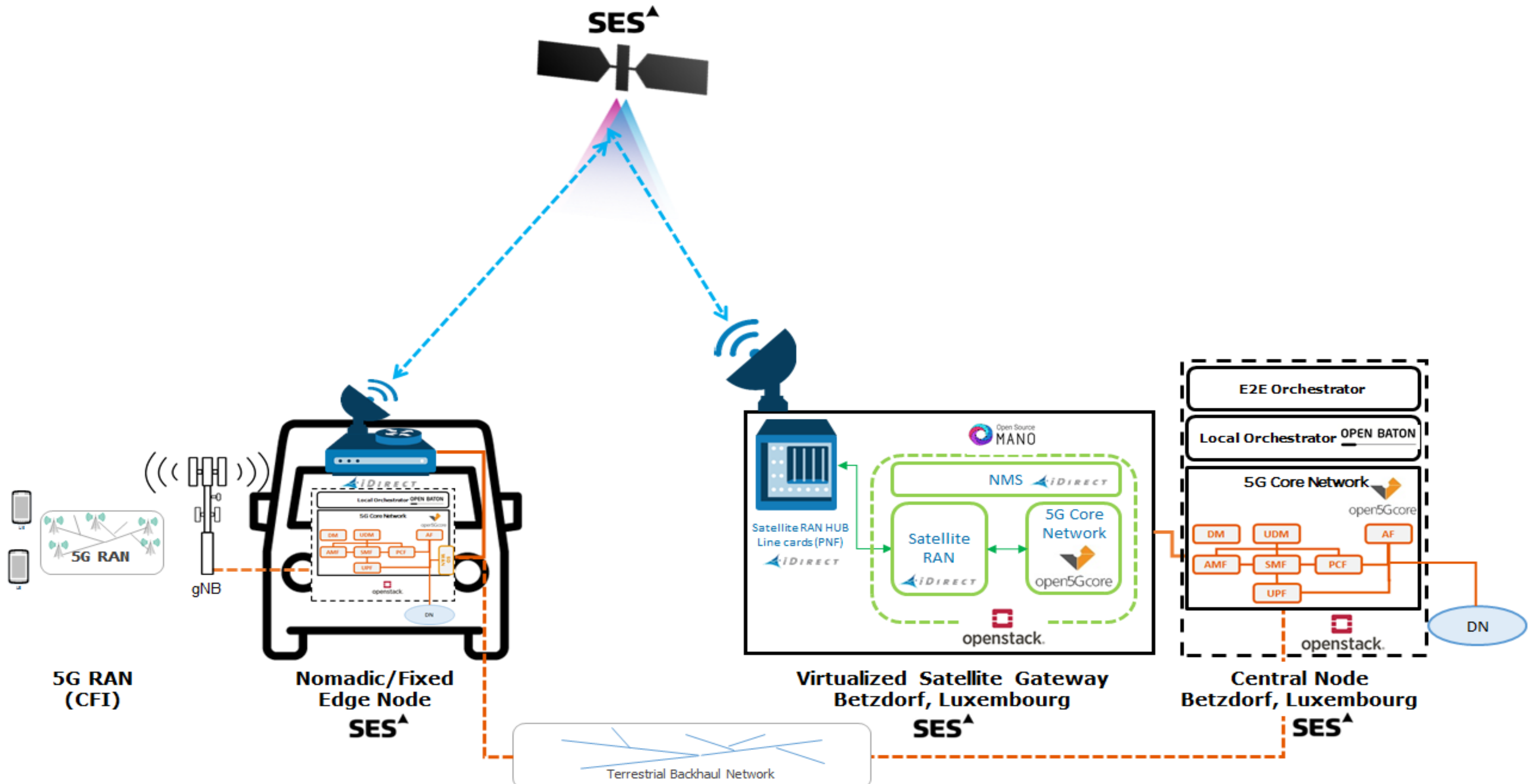
- RRV is a multi-purpose communications platform mainly for governmental and PPDR use cases
- Architecture is modular and supports evolution
- Highly resilient due to its multiband capability (X, mil-Ka, Ka, Ku)
- A rolling lab for mission specific solutions
- Designed to be easily configured, even remotely
- Quickly deployed and operational in minutes
- Built for client showcases and demonstrations



SES's Satellite 5G Testbed Node

… enabling the 5G-VINNI Moving Experimentation Facility Site

- Synergies with ESA ARTES project "SATis5" in collaboration with Fraunhofer FOKUS & iDirect



Relevent Reference:

[1] C. Politis, K. Liolis, M. Corici, E. Troudt, Z. Szabó J. Cahill, "Design of Moving Experimentation Facility to Showcase Satellite Integration into 5G", in Proc. ***28th European Conference on Networks and Communications (EuCNC 2019)***, Valencia, Spain, June 2019.

Over-the-Air Satellite 5G Demos

Successful Live Over-The-Air Demos Conducted in 2018-2019 Validating Key Technologies for Satellite Integration into 5G

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Demonstrated key benefits of satellite backhaul integration into standard 3GPP core network architecture using SDN/NFV/MEC-enabled 5G testbed as proof-of-concept for satellite integration into 5G

SDN | NFV | MEC | eMBB | mMTC | Network Slicing | 5G Core Network Integration

EUCNC 2018 June 18-21
European Conference on Networks and Communications | Ljubljana, Slovenia

FUSECO Forum 2018
FUTURE SEAMLESS COMMUNICATION

GSMA MWC19 Barcelona
25-28 February 2019

Relevent Reference:

[1] K. Liolis, "Milestone Over-the-Air Demonstrations Showcasing Satellite's Strategic Role in 5G", in Proc. ***28th European Conference on Networks and Communications (EuCNC 2019)***, Valencia, Spain, June 2019.

EuCNC 2018 Demo Overview

First-of-its-kind over-the-air live demo towards satellite integration into 5G

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Demonstrated key benefits of satellite integration with an SDN / NFV / MEC-enabled pre-5G construction testbed, with an SES GEO in-orbit satellite system as a proof-of-concept for integration of those features into a full 5G network

European Conference on Networks and Communications | Ljubljana, Slovenia

Objectives

- Satellite integration into standard 3GPP network architecture
- SDN and NFV integration into satellite communications
- Content delivery over Satellite
- Multi-access Edge Computing (MEC)

Satellite and Terrestrial Network for 5G

Relevent Reference:

[1] C. Ge, N. Wang, I. Selinis, J. Cahill, M. Kavanagh, K. Liolis, C. Politis, B. Evans, Y. Rahulan, N. Nouwell, M. Boutin, J. Desmauts, F. Arnal, S. Watts, G. Poziopoulou, “QoE-Assured Mobile Live Streaming through Satellite-backhaul in 5G Networks,” ***IEEE Transactions on Broadcasting***, Volume: 65, Issue: 2, June 2019, DOI: 10.1109/TBC.2019.2901397, https://ieeexplore.ieee.org/document/8666159

FUSECO Forum 2018 Demo Overview

First over-the-air live demo of SATis5 testbed

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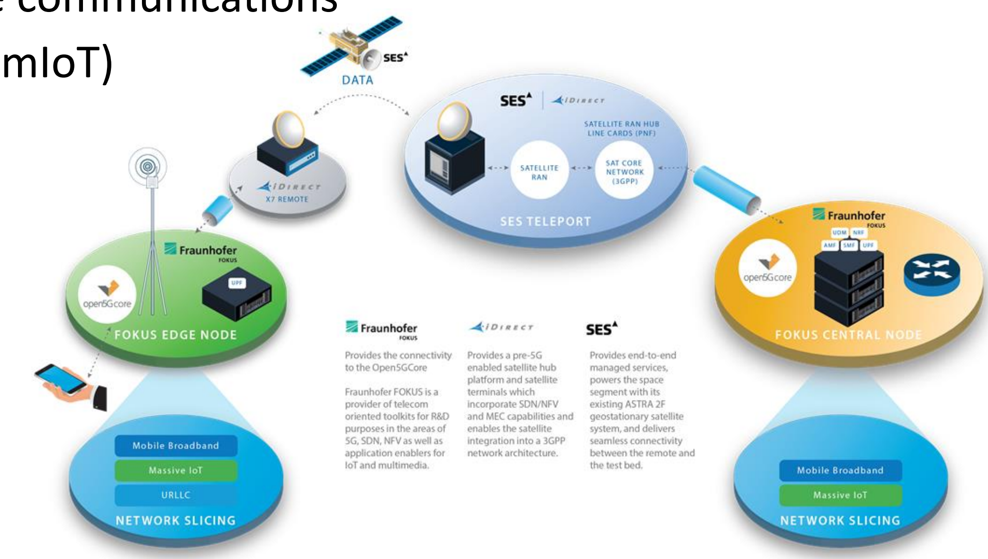
Demonstrated key benefits of satellite integration with an SDN / NFV / MEC-enabled 5G testbed as a proof-of-concept for integration of those features into a full 5G network

FUSECO Forum 2018
FUTURE SEAMLESS COMMUNICATION

Objectives

- Satellite integration into standard 3GPP network architecture
- SDN and NFV integration into satellite communications
- Network Slicing of eMBB and mMTC (mIoT) Use Cases over Satellite
- Multi-access Edge Computing (MEC)



SATis5

Relevent Reference:

[1] F. Völk, K. Liolis, M. Corici, J. Cahill, T. Schlichter, and A. Knopp, "Satellite Integration into 5G: Accent on First Over-The-Air Tests of an Edge Node Concept with Integrated Satellite Backhaul", *MDPI Future Internet Journal – Special Issue*, 2019, 11, 193; doi:10.3390/fi11090193.

MWC 2019 Demo Overview

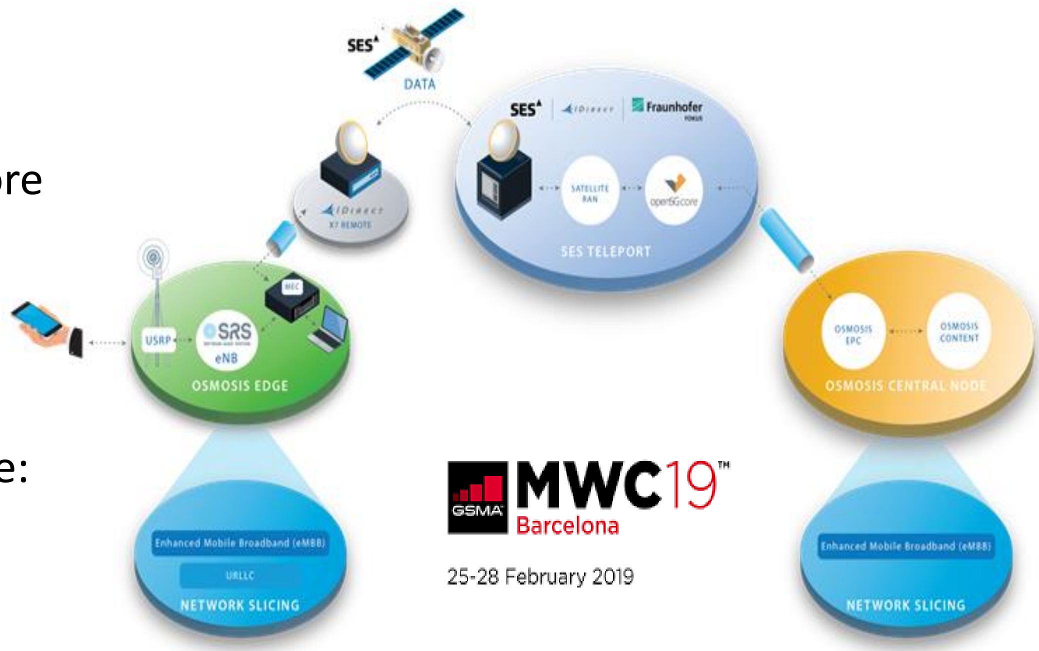
OSMOSIS edge computing run as overlay on SATis5 satellite 5G testbed

SES SnT securityandtrust.lu

Demonstrated integration of GEO satellite backhauling into standard 3GPP 5G Core Network and versatility of SATis5 testbed for “customer” use cases to run as overlay

Objectives

- Satellite backhaul integration into latest 3GPP Rel’15 compliant 5G Core Network
- SDN, NFV and MEC technologies integration into satellite communications
- OSMOSIS Edge Computing Use Case:
  - eMBB and URLLC network slicing use cases over satellite
  - Efficient multi-access content delivery and edge caching over satellite
  - ABR streaming and CDN integration



SATis5

Relevent Reference:

[1] K. Liolis, J. Cahill, E. Higgings, M. Corici, E. Troudt, P. Sutton, “Over-the-Air Demonstration of Satellite Integration with 5G Core Network and Multi-Access Edge Computing Use Case”, in Proc. ***IEEE 5G World Forum 2019***, Dresden, Germany, September-October 2019.

MWC 2019 Demo Overview

OSMOSIS edge computing run as overlay on SATis5 satellite 5G testbed

Some Proof of Concept Test Results & Statistics

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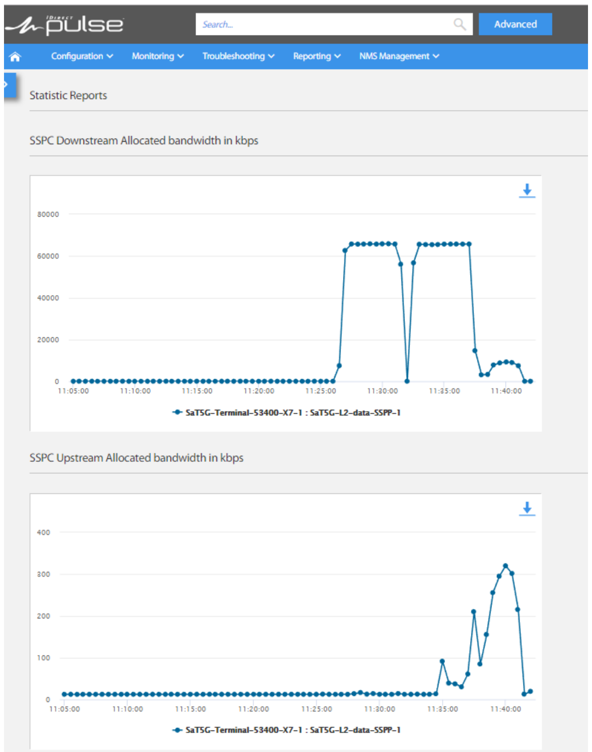

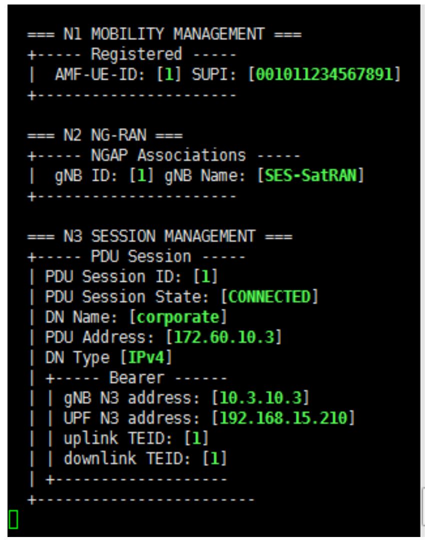

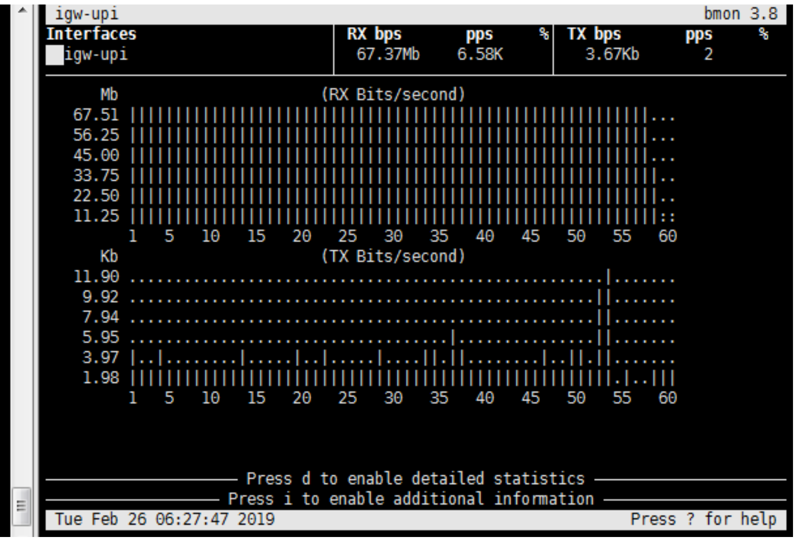


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[1551178458.057123] 64 bytes from 192.168.252.5: icmp_seq=15274 ttl=64 time=560 ms
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SATis5

Relevent Reference:

[1] K. Liolis, J. Cahill, E. Higgings, M. Corici, E. Troudt, P. Sutton, “Over-the-Air Demonstration of Satellite Integration with 5G Core Network and Multi-Access Edge Computing Use Case”, in Proc. ***IEEE 5G World Forum 2019***, Dresden, Germany, September-October 2019.

IEEE 5G World Forum 2019 Demo Overview

Over-the-air demo planned for SEP/OCT-2019

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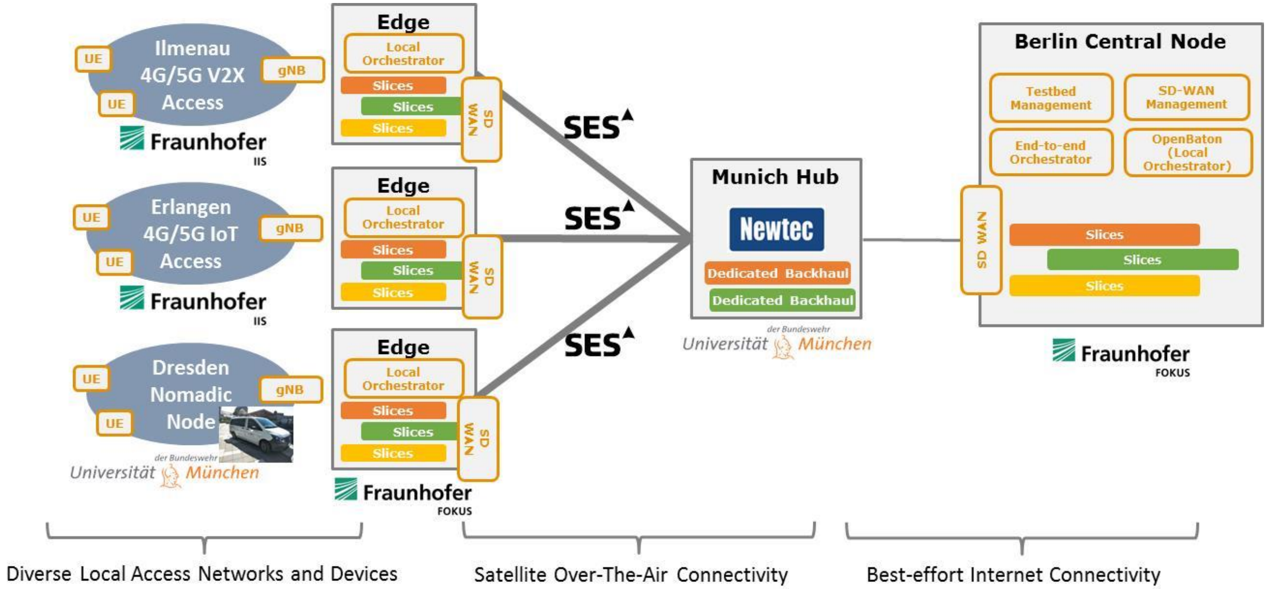
Main Focus

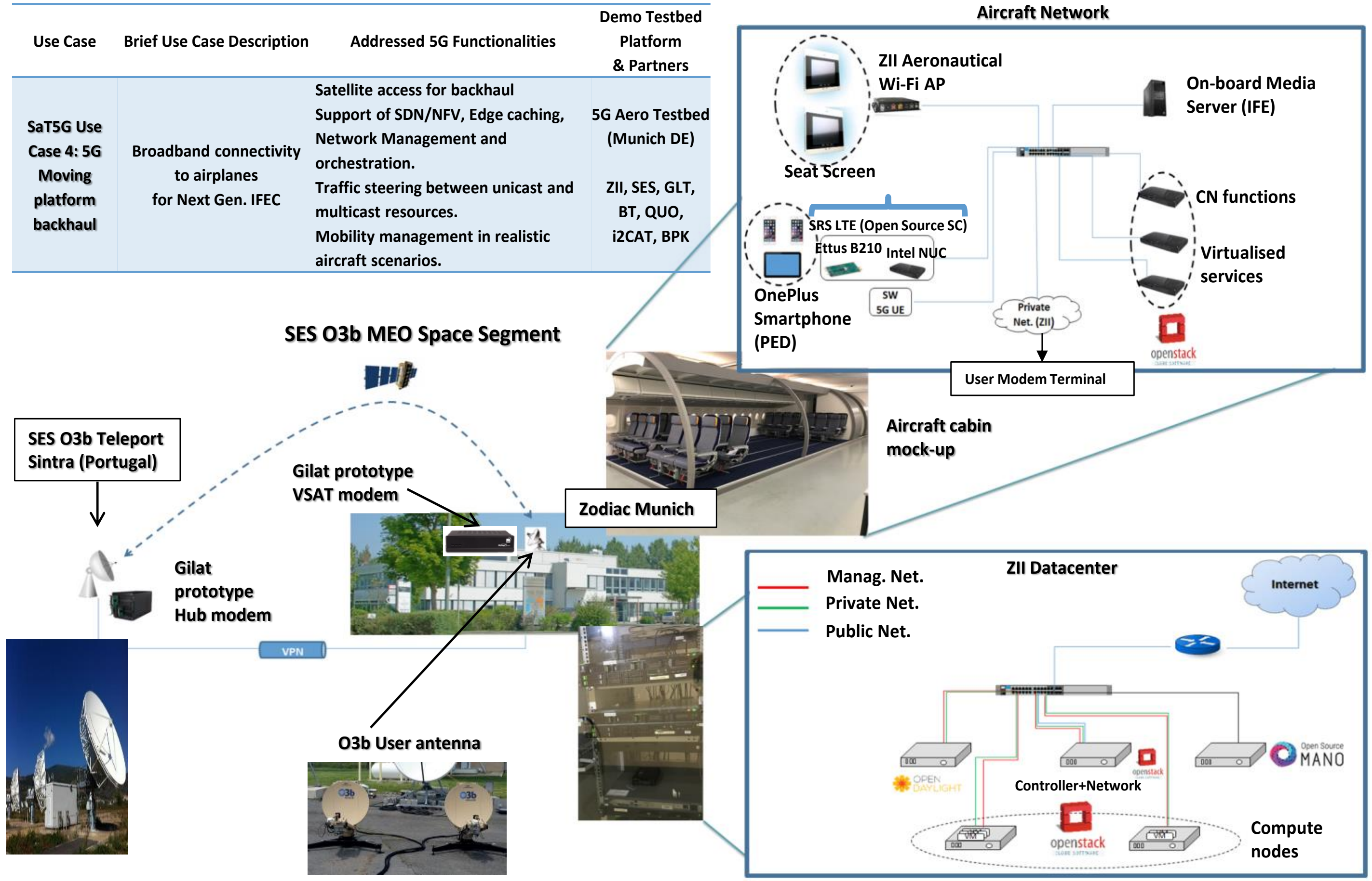
- NB-IoT
- Comms on the Move
- Edge Node
- SATis5 Testbed



5G Aero Backhaul Demo Overview

Over-the-air demo over O3b MEO HTS planned for DEC-2019

Use Case	Brief Use Case Description	Addressed 5G Functionalities	Demo Testbed Platform & Partners
SaT5G Use Case 4: 5G Moving platform backhaul	Broadband connectivity to airplanes for Next Gen. IFEC	Satellite access for backhaul Support of SDN/NFV, Edge caching, Network Management and orchestration. Traffic steering between unicast and multicast resources. Mobility management in realistic aircraft scenarios.	5G Aero Testbed (Munich DE) ZII, SES, GLT, BT, QUO, i2CAT, BPK



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Questions ?

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Acknowledgements

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- Part of the work presented has been conducted as part of the SaT5G project, which has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement no. 761413. *(Website: https://www.sat5g-project.eu/)*
- Part of the presented has been conducted as part of the ESA ARTES project SATis5 – ESA Contract No.: 4000120663/17/NL/CLP. The views expressed herein can in no way be taken to reflect the official opinion of the European Space Agency. *(Website: https://artes.esa.int/projects/satis5-0)*
- Part of the work presented has been conducted as part of the ESA ARTES project EdgeSAT– ESA Contract No.: 4000126382/19/NL/MM. The views expressed herein can in no way be taken to reflect the official opinion of the European Space Agency. *(Website: https://artes.esa.int/projects/edgesat)*
- Part of the work presented has been conducted as part of the 5G-VINNI project, which has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement no. 815279. *(Website: https://5g-vinni.eu/)*

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