



International Network Generations Roadmap (INGR) Virtual Workshop Satellite

> Sastri Kota, Giovanni Giambene, Prashant Pillai 15 October 2020



Introduction

- Recent studies estimate that about 51% of the world's population still lack high-speed Internet access. Moreover, terrestrial networks cannot guarantee the access to the Internet to passengers on aircrafts or high-speed trains, as well as users on highways, rural and remote areas besides urban areas.
- It is the evident that there is definite need of satellite infrastructure complementing 5G and B5G terrestrial wireless networks.
- Satellites by nature provide multicast and broadcast and highly reliable communications.
- Satellites will also support M2M/IoT, paving the way to new applications, ranging from smart agriculture, environmental monitoring, remote plant control, transportation, etc.
- Non-Terrestrial Networks (NTN), are expected to be an integral part of the 5G infrastructure and 3GPP standardization work is in progress on this subject. NTN will include not only satellites of GEO and mega-constellations of LEOs, but also High-Altitude Platforms (HAPs), Unmanned Aerial Vehicles (UAVs), commonly known as drones.



International Network Generations Roadmap | FutureNetworks.ieee.org/roadmap



1st Edition of the Satellite WG Chapter



International Network Generations Roadmap (INGR) An IEEE 5G and Beyond Technology Roadmap

Satellite

1st Edition FutureNetworks.ieee.org/Roadmap





https://futurenetworks.ieee.org/roadmap/i ngr-edition-1-2019/

Published on December 2019

(Available for free for Members of IEEE ComSoc)



International Network Generations Roadmap | FutureNetworks.ieee.org/roadmap



10-year Vision from Satellite Report 1st Edition

There is the need of R&D to address the UN Sustainable Development Goals (SDGs) besides technological drivers.

- New network systems requirements include high-date rates, spectral efficiency, low-latency, and system management.
- New technology developments are needed for MIMO PHY, advanced digital payload (regenerative vs. bent-pipe), phased arrays antennas, optical cross-links, pervasive AI and ML applications for resource management, and global optimization.
- Virtualization and softwarization of satellite networks and integration with the terrestrial systems.
- Design of new satellite/aerial component architectures with special emphasis on LEO, HAPs, and UAVs.



International Network Generations Roadmap| FutureNetworks.ieee.org/roadmap



A Vision of the Future Integrated System (UAV/HAP/LEO/MEO/GEO)

Future network generations, leveraging software-defined networks, will drive towards the solution of a seamlessly integrated heterogeneous network, between the terrestrial and non-terrestrial networks.

The new 5G system will be an umbrella system, enabling **different radio access networks (RANs)** to operate together, including terrestrial base stations, aerial platforms of different types, such as UAVs, HAPs, and satellites at different altitudes.







Topics Addressed in the 1st Edition of the Satellite WG Chapter

Topics considered in the first edition of our roadmap document are:

- Applications and scenarios
- Reference architectures
- Antennas
- Waveforms
- Machine learning applications & AI self-awareness needs
- NFV/SDN for satellite networks
- Optical techniques (e.g., intersatellite links)
- Protocols and interfaces for integrated satellite and terrestrial RANs
- QoS/QoE
- Security
- Standardization





Main Outcomes of 1st Edition (1/2)

Communications Applications and Scenarios

- Several scenarios involving the satellite in the 5G system (eMBB, mMTC, URLLC) have been considered

Reference Satellite Architectures

- Preliminary study on reference system architectures and orbit types

Antennas

- Metamaterials, optimized mechatronics, switching matrices for beam-hopping, and full electronic steering

Waveforms

- Significant gains with MIMO, precoding, and NOMA

Machine Learning and AI Self-Awareness

AI and ML techniques can play an important role since these techniques can learn extracting (automatically) information from data to take optimized decisions.

Optics in Space and Intersatellite links

 Optical intersatellite links are used to allow increased bandwidths and traffic routing in the sky as made possible by the mega-LEO constellations.



7

Main Outcomes of 1st Edition (2/2)

• Network Function Virtualization and Software-defined Networking for Satellite Nets.

 Software Define Networking (SDN) and Network Function Virtualization (NFV) are being considered by both ETSI Satellite Earth Station (SES) working group and in the Non-Terrestrial Network (NTN) work item of the 3GPP standardization.

Integrated Protocols and Interfaces

 Protocol integration of satellite 5G with terrestrial 5G systems is essential. This is important for resource management, traffic offloading, path optimization, etc.

Quality of Service/Quality of Experience

Satellite 5G system should cope with QoS requirements as close as possible to those of the terrestrial RAN; URLLC service case has very critical latency requirements to be met in the satellite case (e.g., impossible with GEOs)

Security

 Data confidentially (encryption) and data integrity are important features required along with data origin authentication.

Standardization

 3GPP has provided a lot of standards for satellite 5G, dealing with use cases, architecture, and new radio. ETSI has specifications dealing with the integration. ITU-R is also addressing the integration of satellites into the terrestrial systems.





Scope of the 2nd Edition

- Develop further detailed analysis of the reference or baseline architectures(s) and various topics, based on the first-year efforts.
- Investigate the next 10 years maturity and challenges of the technology of the subsystems.
- To address new aspects like, network management and Mobile Edge Computing (MEC), and their impact on the satellite system design.
- The key topics and the sub-working groups are detailed in the next slides.





5G Satellite Roadmap Topics (1/2)

Торіс	Lead / Principal	Contributors
1. Applications and scenarios	Ray Sperber	
 Reference architectures (LEO/MEO/GEO, aerial platforms, UAVs, and drones) 	B. S. Manoj	Joan Bas, Debabrata Dalai, Marco Giordani, Sastri Kota, Seema Verma, Kanglian Zhao
3. A new MIMO-based PHY	Joan Bas	Thomas Delamotte, Andreas Knopp, Ray Sperber
4. Antenna design	Ray Sperber	Avinash Sharma, Andreas Knopp, Thomas Delamotte
5. Machine Learning & Artificial Intelligence	Paresh Saxena	Alberto Gotta, Sastri Kota





5G Satellite Roadmap Topics (2/2)

Торіс	Lead / Principal	Contributors
6. EDGE Computing	Tomaso de Cola	Thomas Delamotte, Alberto Gotta, Andreas Knopp, Liang Zhao, Kanglian Zhao
7. QoS/QoE	Giovanni Giambene	Alberto Gotta, Tomaso de Cola, Mario Marchese
8. Security	Prashant Pillai	Joan Bas, Thomas Delamotte, Andreas Knopp
 Network management (ground to satellite and satellite to satellite) 	Tasneem Darwish	Mohammed Abdelsadek, Jean- Daniel Medjo
10. Standardization	Sastri Kota	Avinash Sharma, Seema Verma, Giovanni Giambene





Today's Landscape

- Mega-constellations (LEO and MEO):
 - Space X is in the deployment phase The FCC approved Starlink global network consists of 4425 satellites about 700 miles up and another 7518 around 210 miles up. Space X has applied to FCC for further 40000 satellites.
 - Other LEO systems in the advanced design phase: LeoSat (108 satellites), OneWeb (588 satellites), Telesat (117 satellites), and Kuiper (3236 satellites)
 - As for MEO, we can consider the O3B system that is operational, using 20 satellites in a single MEO equatorial ring.
- Criticalities are related to the need of large capacity and the exploitation of high-frequency bands (impact of meteorological events).
- Current state of the technology has been presented by WG members with 2 presentations at every WG meeting.



International Network Generations Roadmap | FutureNetworks.ieee.org/roadmap



Activity in Progress

- Pramud Rawat, "5G satellite for border control"
- B. S. Manoj, "Small satellite missions and 5G satellite related research activities at IIST"
- Paresh Saxena, "AI/ML for B5G satellite networks"
- Prashant Pillai, "Security issues for future networks"
- Kanglian Zao, "Architecture and testbed for future space terrestrial integrated networks"
- Joan Bas, "Satcom CTTC activities and security data rate tradeoff in IoT over satellite"
- Tasneem Darwish, "Network management"
- Tomaso de Cola, "MEC over Satellite overview for IEEE INGR roadmap"
- Andreas Knopp and Thomas Delamotte, "5G satellite PHY-layer activities"
- Ray Sperber, "Application scenarios and antenna design"
- B. S. Manoj, "Some use cases for 5G-satellite Integration"
- Alberto Gotta, "IoT via satellite"
- Marco Giordani, "Non-terrestrial networks in the 6G era"







Challenges and Solutions – Current Group Activities

• Architecture(s):

- Providing a 3D coverage where different layers are involved (including UAVs, HAPs, LEOs) for a multi-connectivity scenario.
- The reference architectures investigated in this second edition will consider the satellite network as a backhaul network.
- GEO satellites cannot be easily part of the data plane but can be considered for the control plane and for feeding caches.
- System interoperability is a challenge.











Architecture: 5G-Satellite Integration



Architecture: HAPs 5G-Satellite integration



Challenges and Solutions – Current Group Activities

• A new MIMO-based PHY:

- MIMO communications will increase the capacity as well as improve the physical layer security
- Complexities in exploiting mmWave communications (70 and 150 GHz) via LEO satellite due to large Doppler shifts.

Antennas Design:

There is the need of multi-feed antennas with reflectors on the satellites to generate multiple beams. Use of
reconfigurable phased antennas with electronic beam-steering.

• AI/ML:

 Mega-LEO constellations entail a significant complexity to be managed. AI/ML can help providing new methods to solve complex problems such as routing, resource allocation, cross-layer optimization, and handover decision.

Security:

5G will be based on new approaches, like MEC, SDN, NFV, and network slicing. However, many of these technologies are not yet mature, when considering their security implications.



International Network Generations Roadmap | FutureNetworks.ieee.org/roadmap



Challenges and Solutions – Current Group Activities

Network management:

- There is the need for a realistic simulation platform to test satellite network management solutions based on SDV/NFV.

MEC:

 The satellite has to support new low-latency applications (e.g., gaming, tactile internet, AR/VR applications, IoT data, etc.). MEC can help on this aspect by elaborating large amount of data closer to users to reduce the satellite delay.

Standardization:

 Current mega-LEO systems are not well aligned with 3GPP standardization. This situation could lead to interoperability issues with terrestrial 5G systems.



International Network Generations Roadmap| FutureNetworks.ieee.org/roadmap



Top Needs for 10-year Vision

- Identification of baseline architectures for a 3D system with interconnected layers: UAVs + HAPs + LEOs
 - Use of mmWaves and possible use of optical links
 - Space connectivity
 - Exploitation of pervasive AI/ML for a real-time optimized management of satellite resources
 - Adoption of SDN/NFV for the satellite network
 - Interoperability among different systems
 - Supporting the QoS/QoE requirements of 5G and B5G







Stakeholders

- Manufacturers
 - Looked, Loral, Interdigital, Space-X, SES, Catapult, Thales Alenia, etc.
- Operators
- Users' communities
- Regulators
 - FCC, governments
- Space agencies
 - NASA, ESA, ISRO
- Standards Development Organizations (SDOs)
 - IEEE, Internet Engineering Task Force (IETF), 3GPP, 5GPPP, International Telecommunication Union Radiocommunication Sector (ITU-R), ITU Telecommunication Standardization Sector (ITU-T), European Telecommunications Standards Institute (ETSI), etc.)
- Research institutions and Universities





List of Satellite WG Members (1/3)

• Co-chairs:

- Sastri Kota, University of Oulu, Finland, <u>sastri.kota@gmail.com</u>
- Giovanni Giambene, University of Siena, Italy, giambene@unisi.it
- Prashant Pillai, University of Wolverhampton, UK, <u>P.Pillai@wlv.ac.uk</u>
- IEEE:
 - Brad Kloza, <u>b.kloza@ieee.org</u>
 - Matthew Borst, <u>m.borst@ieee.org</u>
- Team members:
 - Carlos A. Astudillo, University of Campinas, Brazil, <u>castudillo@lrc.ic.unicamp.br</u>
 - Mohamed-Slim Alouini, King Abdullah University of Science and Technology (KAUST), Kingdom of Saudi Arabia, email: <u>alouini@gmail.com</u>
 - Mohammed Abdelsadek, Carleton University, Canada, <u>mabdelsadek@mun.ca</u>
 - Joan Bas, CTTC, Spain, joan.bas@cttc.es
 - Anirban Bandyopadhyay, Global Foundries, USA, <u>anirban.bandyopadhyay@globalfoundries.com</u>
 - Aizaz ul Haque Chaudhry, Carleton University, Canada, <u>auhchaud@sce.carleton.ca</u>
 - Tomaso de Cola, DLR, Germany, <u>Tomaso.deCola@dlr.de</u>
 - David J. Copeland, Johns Hopkins University, USA, <u>David.Copeland@jhuapl.edu</u>
 - Debabrata Dalai, Indian Institute of Space Science and Technology, India, email: <u>ddalai937@gmail.com</u>
 - Tasneem Darwish, Carleton University, Canada, <u>tasneemdarwish@sce.carleton.ca</u>
 - Ashutosh Dutta, Johns Hopkins University, USA, <u>d37@caa.columbia.edu</u>
 - Ayush Dwivedi, International Institute of Information Technology Hyderabad, India, ayush.dwivedi@research.iiit.ac.in





List of Satellite WG Members (2/3)

Team members:

- Michael A. Enright, Quantum Dimension, USA, email: <u>michael.enright.17@quantumdimension.com</u>
- Ramon Ferrús, UPC, Spain, <u>ferrus@tsc.upc.edu</u>
- Samah Ghanem, University of Aveiro, Portugal, samah.ghanem@gmail.com
- Marco Giordani, University of Padova, Italy, giordani@dei.unipd.it
- Alberto Gotta, ISTI-CNR, Pisa, Italy, email: <u>alberto.gotta@isti.cnr.it</u>
- Atefeh Hajijamali, University of Waterloo, ON, Canada, <u>a.hajijamali@gmail.com</u>
- Shuai Han, Harbin Institute of Technology, China, <u>hanshuai@hit.edu.cn</u>
- Cunqing Hua, School of Cyber Science and Engineering, Shanghai Jiao Tong University, China, cqhua@sjtu.edu.cn
- Francisco J. Escribano, Universidad de Alcala', francisco.escribano@ieee.org
- Tamer Khattab, Qatar University, Qatar, <u>tkhattab@ieee.org</u>
- Andreas Knopp, Bundeswehr University Munich, Germany, <u>andreas.knopp@unibw.de</u>
- Min Lin, College of Telecommunications and Information Engineering, Nanjing University of Posts and Telecommunications, <u>linmin@njupt.edu.cn</u>
- Rongke Liu, School of Eletronics and Information Engineering, Beihang University, <u>rongke_liu@buaa.edu.cn</u>
- Kumar Vijay Mishra, United States Army Research Laboratory (ARL), USA, <u>vizziee@gmail.com</u>
- B. S. Manoj, Indian Institute of Space Science and Technology, India, <u>bsmanoj@iist.ac.in</u>
- Jean-Daniel Medjo Me Biomo, Carleton University, Canada, email: jemeda@sce.carleton.ca





List of Satellite WG Members (3/3)

• Team members:

- Mario Marchese, University of Genova, Italy, <u>mario.marchese@unige.it</u>
- Antonella Molinaro, University Mediterranea of Reggio Calabria, Italy, <u>antonella.molinaro@unirc.it</u>
- Pramud Rawat, Consultant, US, <u>prawat@aol.com</u>
- Paresh Saxena, BITS Pilani, Hyderabad Campus, India, <u>psaxena@hyderabad.bits-pilani.ac.in</u>
- Pat Scanlan, Consulting at Scanlanavia, Ireland, email: <u>scanlanavia@ieee.org</u>
- Avinash Sharma, Johns Hopkins University, USA, <u>Avinash.Sharma@jhuapl.edu</u>
- Ray Sperber, Consultant, Luxembourg, <u>brsperber@gmail.com</u>
- Seema Verma, School of Aviation, Banasthali Vidyapith, Rajasthan, India, seemaverma3@yahoo.com
- Simon Watts, Avanti Communications, UK, simon.watts@avantiplc.com
- Jihong Yu, School of Information and Electronics, Beijing Institute of Technology, China, <u>jihong.yu@bit.edu.cn</u>
- Yuma Abe, Space Communication Laboratory, NICT, Japan, email: <u>yuma.abe@nict.go.jp</u>
- Kanglian Zhao, Nanjing University, China, <u>zhaokanglian@nju.edu.cn</u>
- Liang Zhao, Shenyang Aerospace University, China, <u>leonedin@gmail.com</u>





Get involved!

Please contact the Satellite WG co-Chairs by email:

sastri.kota@gmail.com

giovanni.giambene@unisi.it

P.Pillai@wlv.ac.uk

QUESTIONS?



Enabling 5G and Beyond | FutureNetworks.ieee.org/roadmap

