IEEE Future NETWORKS

Enabling 5G and Beyond

International Network Generations Roadmap (INGR)

Virtual Workshop

Satellite

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IEEE

Introduction

- Recent studies estimate that about billion people of the world's population still lack of a 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 vehicles on highways or in the countryside.
- Under these challenging operational conditions, there is the evident need of a satellite infrastructure complementing the terrestrial 5G system.
- Satellites will also support machine-type communications, paving the way to new applications, ranging from smart agriculture, environmental monitoring, 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 ofGEO and LEO types, but also High Altitude Platforms (HAPs), Unmanned Aerial Vehicles (UAVs), and drones.

10-year Vision

There is the need of R&D progress to address the following aspects:

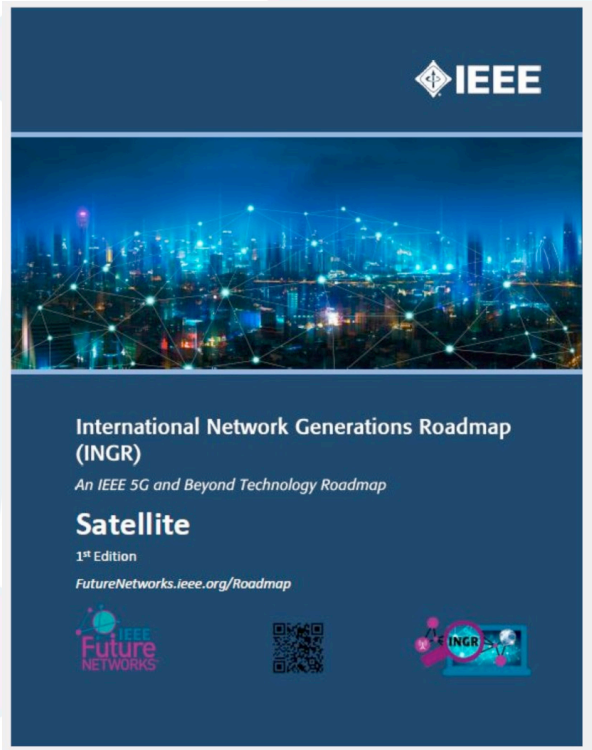
- Design of the new satellite/aerial component architecture with special emphasis on LEO, HAPs, UAVs, and cooperation with drones as well.
- New technology developments are needed for MIMO PHY, advanced digital payload, phased arrays antennas, AI-driven satellites, optical communications.
- Virtualization of satellite networks and integration with the terrestrial systems.
- Develop systems to meet the new KPIs for 5G and B5G requirements.
- New network systems meet the requirement such as densification, date rates, spectral efficiency, latency, and system management of the future wireless networks.

First Edition of the Satellite WG Chapter

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

- Applications and scenarios
- Reference architectures (LEO/MEO/GEO + aerial platforms)
- 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

First Edition of the Satellite WG Chapter



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

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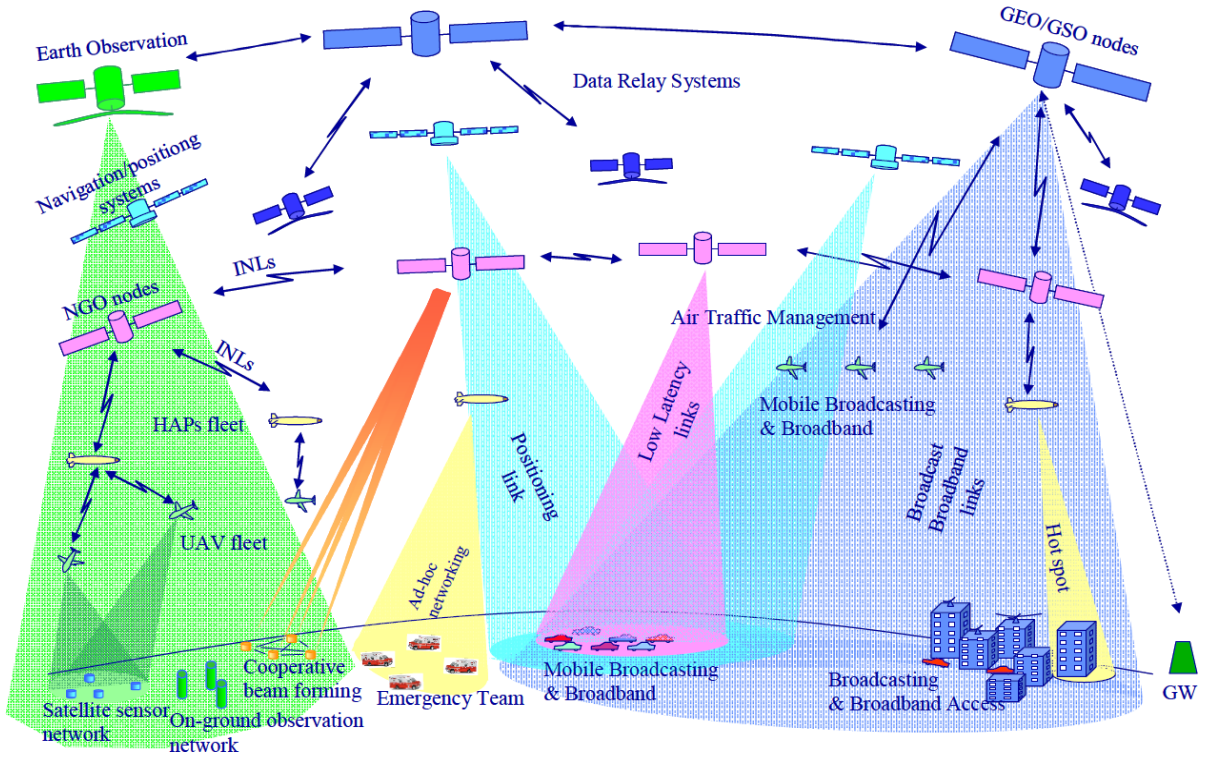
Reference Architectures (LEO/MEO/GEO + aerial platforms, including UAVs)

- 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 drones (UAVs), HAPs, and satellites at different altitudes.



Main Outcomes of Our Chapter (1/2)

- **Communications Applications and Scenarios**
  - Several scenarios involving the satellite in the 5G system (eMBB, mMTC, URLLC) have been considered
- **Reference Satellite Architectures**
  - 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 schemes enable the spatial multiplexing; NOMA outperforms orthogonal schemes
- **Machine Learning and AI Self-Awareness**
  - AI and ML techniques can play an important role since such techniques can analyze and extract information from data automatically, learn to take optimized decisions.
- **Optics in Space and Intersatellite links**
  - Optical intersatellite links are used to allow increased bandwidths and the routing of traffic in the sky as made possible by the mega-LEO constellations.

Main Outcomes of Our Chapter (2/2)

- **Network Function Virtualization and Software-defined Networking for Satellite Nets.**
  - Management and orchestration (MANO) framework defined within ETSI offers building blocks for virtualized functions. SDN/NFV is 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 (satellite+terrestrial)**
  - Protocol integration of satellite 5G with terrestrial 5G systems is essential. This is important for resource management, traffic offloading, SDN/NFV, etc.
- **Quality of Service/Quality of Experience**
  - Satellite 5G system should cope with the same QoS architecture and requirements as close as possible to those of the terrestrial RAN; URLLC service case has critical latency requirements to meet.
- **Security**
  - Data confidentially (encryption) and data integrity are important features required along with data origin authentication. Many of the 5G technologies are not mature, when considering their security implications.
- **Standardization**
  - 3GPP has approved study items on Non-Terrestrial Networks; 3GPP Release 17 5G New radio will also include the satellite component.

Scope of the 2nd Edition

Key topics to be considered for the second edition of the satellite chapter are:

- Applications and scenarios based on connecting the unconnected
- Reference architectures (LEO/MEO/GEO, aerial platforms, UAVs, and drones)
- A new MIMO-based PHY
- Machine Learning & Artificial Intelligence (e.g., resource allocation)
- Network management (ground to satellite and satellite to satellite)
- QoS/QoE
- Security
- Standardization (reference architecture)
- As and when beyond 5G, 6G, and beyond future networks are well understood issues such as Terahertz band communications, quantum communications, and the new architectures with cubesats and Starlink systems will be focused.

Today's Landscape

- GEO-based High Throughput Satellite systems (HTS) ViaSat 1 with 697000 subscribers, ViaSat 2 launched in 2017, and ViaSat 3 to be launched by May 29, 2021.
- Mega-constellations (MEO and LEO): Space X – Starlink a global network of 12000 Internet LEO satellites have been approved. 4425 satellites about 700 miles up and another 7518 around 210 miles up.
- Criticalities are related to the exploitation of high-frequency bands (impact of meteorological events).
- Challenges include: the complexity of the architectures and the investments.

Top Needs for 10-year Vision

- There is the need to identify a baseline architecture for the following satellite systems cases: LEO, LEO + HAPs, LEO + UAVs, LEO + drones.
- To progress on massive MIMO investigation.
- Exploitation of pervasive AI, ML real-time optimizers (supervised, unsupervised, and reinforcement learning).
- Integration of non-terrestrial networks, protocol definition and development for access and intersatellite links.
- Development of efficient handover protocols for LEO networks.
- Designs to meet the QoS and QoE requirements of the future networks.

Challenges and Solutions to Meet Needs
Reference Architecture Example

	Current State (2019)	3 years (2022)	5 years (2024)	Future State 10-years (2029)
Need #1: Satellite for eMBB	Current GEO HTS 500–1000Gbps solutions in production, Ku/Ka band implementations Limited flexibility in current systems Testbeds incorporating new satellite and terminal technology	50% availability of some eMBB services Next wave of HTS solutions will bring higher frequency Ka to V/Q/W/E and Optical, to increase throughput to multi Tbps capability Incorporating digital payload technology for flexible solutions Spectrum allocations to SatCom application	75% availability of some eMBB services Next wave of integrated HTS GEO and LEO/MEO solutions, to provide network capability across orbital platforms Incorporating network management solutions for reconfigurability and optimization	Complete availability of eMBB services Next wave of integrated terrestrial and non-terrestrial satellite networks, achieving full seamless eMBB services Incorporating HAP solutions with space solutions, integrated software-defined networks
Challenge(s) for Need 1	Limited standardization, manufacturer and proprietary operator solutions Satellite technology development limited investment	Satellite available throughput a function of available bandwidth, being encroached for terrestrial applications	Constellation solutions will try to push for global proprietary network exclusivity	
Possible Solution for Challenge	Business environment changing, standardization for new satellite leverage applications favored New technology leveraging terrestrial and radio development, can be leveraged into satellite solutions	5G standardization, industry alignment, will drive the satellite industry to adopt supporting architectures Will need to turn to high frequencies V/Q/W/E and optical	Integrated solutions across LEO and GEO platforms will drive for standardized interfaces, should help in adopting common interface standards to meeting 5G standards	Integrated solutions across HAP, LEO, MEO, HEO, and GEO platforms, will drive for standardized interfaces, should help in adopting common interface standards, to meeting 5G standard

Challenges and Solutions to Meet Needs Standardization Example

Name	Current State (2019)	3 years (2022)	5 years (2024)	Future State 10-years (2029)
Need #1: Reference Architecture				
Challenge(s) for Need 1	Definition of an architecture covering different use cases for NTN in 5G	Full definition of the architecture with the NTN component	Multi-layer architecture for the NTN (aerial) component	
Possible Solution for Challenge	Industries and main stakeholder working together for the identification of a standard			
Need #2: Integration				
Challenge(s) for Need 2	Update some standards of the 5G air interface to be able to work on both the terrestrial component and the aerial one. Big impact may have the larger propagation delays of the satellite component and the peculiarities of the propagation.	Full definition of a revised set of air interface protocols able to operate for the different segments		
Possible Solution for Challenge		Solutions are expected as standard are approved	Solutions are expected as standard are approved	Standard are approved and available
Need #3: QoS/QoE	QoS architecture for the 5G terrestrial segment			
Challenge(s) for Need 3	To identify QoS/QoE requirements suitable for services via the satellite component			
Possible Solution for Challenge		Solutions are expected as standard are approved	Solutions are expected as standard are approved	Standard are approved and available

Stakeholders

- Manufacturers (industry)
- Operators
- Users communities
- Regulators (governments)
- Space agencies (e.g., NASA, ESA)
- Governments
- Standards Development Organizations (SDOs) (e.g., 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
- Key projects: We have a value chain in the satellite area that involves manufacturers (those building the satellites), operators (those allowing the operation of satellites), service providers.

Satellite WG Members

- **Co-chairs:**
  - Sastri Kota, SoHum Consultants, USA and University of Oulu, Finland, sastri.kota@gmail.com
  - Giovanni Giambene, University of Siena, Italy, giambene@unisi.it
  - Prashant Pillai, University of Wolverhampton, UK, P.Pillai@wlv.ac.uk
- **IEEE:**
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- **Team members:**
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Topics of Interest of Participants (in Progress)

Participant	Topics of interest
Sastri Kota	Satellite networking, QoS/QoE, integration of satellite and terrestrial networks, standards
Giovanni Giambene	Satellite networks, network coding, radio resource management, aerial component integrating satellite, platforms, and drones
Prashant Pillai	Satellite cyber-security, video resource management, protocol integrations, Inmarsat projects, 5G integration with satellites
Joan Bas	Signal processing, IoT, 5G licenses
Aizaz ul Haque Chaudhry	Next-generation satellite networking, LEO satellite constellations, optical inter-satellite links, routing
David J. Copeland	Deep space communications, 5G networks, satellite architecture
Tasneem Darwish	Integration of 5G terrestrial systems with satellite ones, satellite routing for future mega-LEO systems
Andreas Knopp team	Advanced antenna concepts and MIMO Satcom, Integrated Satellite-Terrestrial Networks, IoT-mMTC for the Internet of Space, Physical Layer Security, Signal Processing for Digital Payloads, Channel Measurements and Modeling
Ayush Dwivedi	Signal processing, integration of satellite and terrestrial networks, Doppler effects for lower orbits,
Francisco J. Escribano	Channel coding, modulation and wireless communications, chaos-coded communications
Marco Giordani	Ns-3 simulator for 5G including the satellite segment
Tamer Khattab	PHY layer, Cubesta project, LEO satellites and integration with terrestrial systems, ML used in 5G
Jean-Daniel Medjo Me Biomo	Networks of UAVs, routing protocols,
B. S. Manoj	LEO satellites
Pramud Prawat	LEO satellites and platforms
Paresh Saxena	Multipath protocols for hybrid satellite systems
Avinash Sharma	Space exploration group, RF, scattering analysis
Ray Sperber	Satellite PHY layer, quantum key distribution
Kanglian Zhao	DTN, CCSDS protocols, free-space optical links for LEO constellations
Liang Zhao	Satellite communications, satellite networks

Telco Meetings

Telcos every alternate Friday for our Satellite WG.

Presentations of key topics by participants of different key areas at every meeting.

Schedule to meet at 11:00 AM PST via Webex:

https://ieeemeetings.webex.com/meet/Satellite
Access code: 597 446 783
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Get involved!

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QUESTIONS?