Air and satellite networks overview

Course program

- Elements of an air and satellite network
- Orbits and constellations
- Digital transmission techniques
- Multiple Access Techniques
- Satellite Networks and Standards
- Architectures and protocols
- Terrestrial Non Terrestrial Networks for IoT
- Evolving Context of 5G, Beyond 5G and 6G.

Materiale del corso

- Il materiale didattico è parzialmente accessibile sul sito web moodle2.units.it. Chiave d'accesso: RAS24

- Il corso è visibile su MS Teams.

- Matlab.
  - Il corso farà ampio uso del programma Matlab. Per scaricarlo e installarlo sul tuo computer, segui le istruzioni al link:

    https://dia.units.it/it/dipartimento/node/32619

- Orario

Lunedì	9.15 – 10.45	(Aula A [Edificio C8])
Martedì	12.15 – 13.00	(Aula A [Edificio C8])
Mercoledì	8.30 – 10.00	(Aula B [Edificio C9])

Modalità d'esame

- La prova consiste in un esame orale in cui verranno esaminati i principali argomenti del corso.

- L'esame propone un esempio di applicazione della teoria relativa ai sistemi satellitari, oltre a valutare la conoscenza dei principali standard e delle loro proprietà.

- Sono previste sette sessioni d'esame durante l'anno, ma l'esame può essere sostenuto anche su appuntamento.

Textbooks and References

BOOKS

- Gerard Maral, Michel Bousquet, Zhili Sun, "Satellite Communications Systems: Systems, Techniques and Technology ", Wiley, 2020.
- Alessandro Vanelli-Coralli, Nicolas Chuberre, Gino Masini, Alessandro Guidotti, Mohamed El Jaafari, "5G Non-Terrestrial Networks: Technologies, Standards, and System Design", Wiley-IEEE Press, 2024

FURTHER REFERENCES

- R. Stuhlfauth, "5G NTN Takes Flight: Technical Overview Of 5G Non-terrestrial Networks", Rohde & Schwarz, 2023
- ETSI EN 301 545-2 V1.4.1, "Digital Video Broadcasting (DVB); Second Generation DVB Interactive Satellite System (DVB-RCS2); Part 2: Lower Layers for Satellite standard (2024-01)

Introduction (1)

- This course aims at providing an introduction to the aerial and space context, taking into account various types of satellites based on the different categorizations.
- Main focus is on aerial and space communication, and on the use of artificial satellites to establish communication links between various points on the Earth's surface.
- The first phase of satellite communication deployment was mainly based large platforms at high altitudes, to cover a portion of the Earth as large as possible with few satellites.
- Recently, taking into account the novel requirements of Service Types and Quality of Service, and given the significant improvements in terms of on-board capabilities and cost reduction, the interest on smaller satellites at lower altitudes is demonstrated by the rapid deployment of low altitude mega-constellations.

Introduction (2)

- More recently, the Non Terrestrial Networks (NTN) show significant advancements related to Air-to-Ground (ATG) systems, drones, and High-Altitude Platform Stations (HAPS), initially to support the connectivity to on-ground users in critical scenarios, but now also for many other applications.

- Today NTN, which include the use of airborne and spaceborne nodes to establish communication links between various points on the Earth's surface, form a continuum of layers/orbits.

A reference scenario (1)

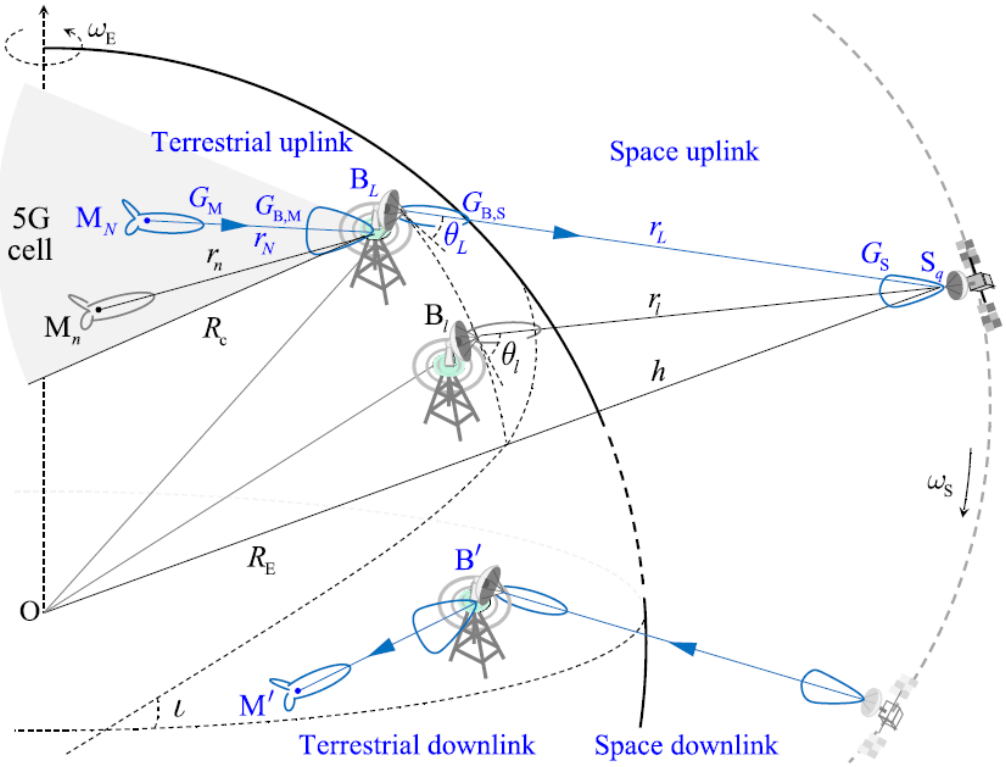
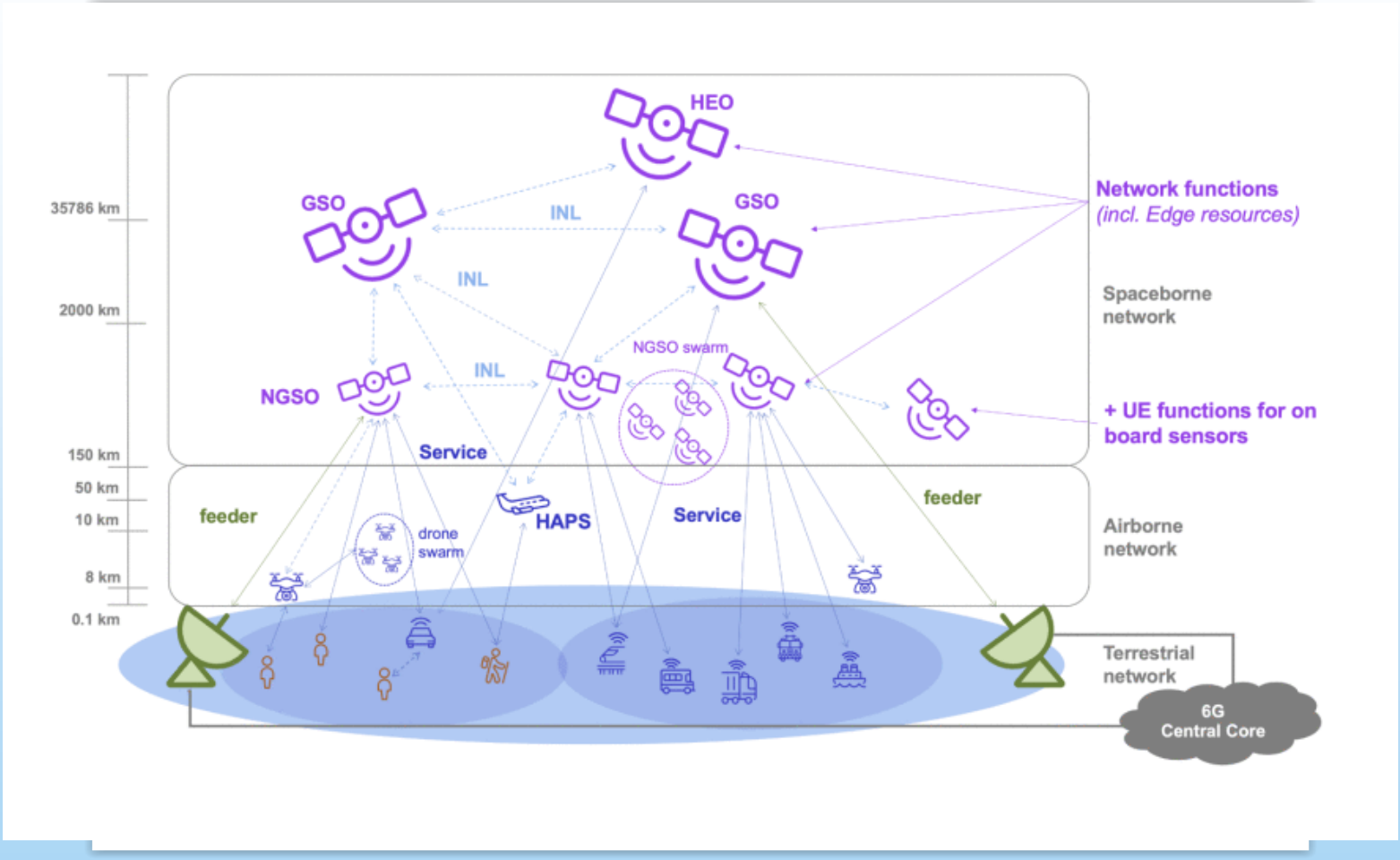


Fig. 1. End-to-end communication scenario.

F. Babich, M. Comisso, A. Cuttin, M. Marchese, and F. Patrone, "Nanosatellite-5G Integration in the Millimeter Wave Domain: A Full Top-Down Approach", *IEEE Transactions on Mobile Computing*, Vol. 19, N. 2, February 2020, pp. 390-404.

A reference scenario (2)



A. Guidotti; A. Vanelli-Coralli, V. Schena, N. Chuberre, M. El Jaafari, J. Puttonen, S. Cioni, "The path to 5G-Advanced and 6G Non-Terrestrial Network systems", *2022 11th Advanced Satellite Multimedia Systems Conference and the 17th Signal Processing for Space Communications Workshop (ASMS/SPSC)*.

6G Vision

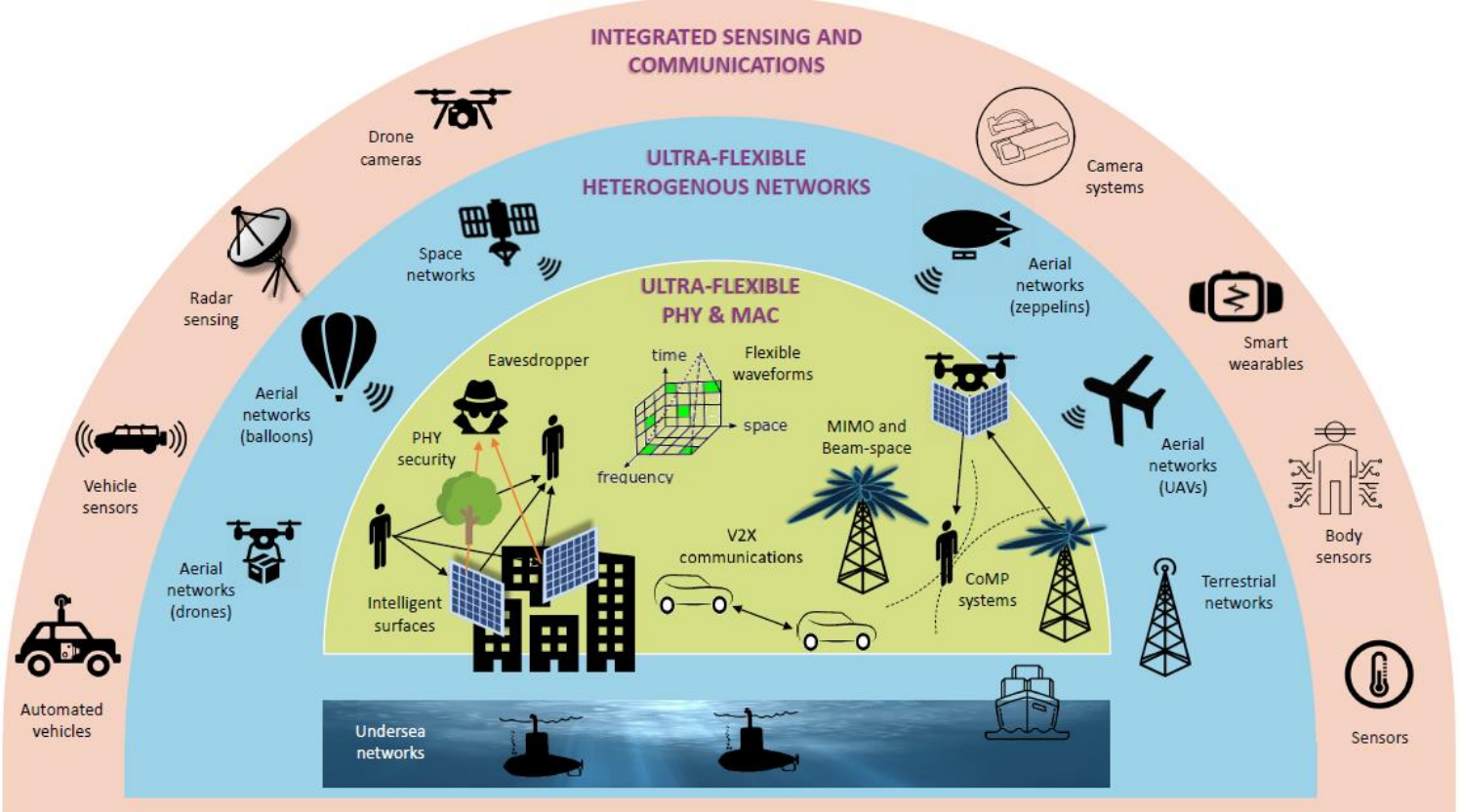


Fig. 5 – The integration of many different sensor hardware with the heterogeneous communications networks under 6G systems.

A. Yazar, S. D. Tusha, H. Arslan, "6G VISION: AN ULTRA-FLEXIBLE PERSPECTIVE",
ITU Journal on Future and Evolving Technologies - Volume 2020.

Classification

- Satellite: an object that orbits around a celestial body.
- Artificial satellite: a man-made device, regardless of the category of the celestial body around which it orbits (star, planet, natural satellite, ...)
- An artificial satellite can be classified according to three criteria.
  - Use: the artificial satellites can be divided into two families
    - scientific satellites: used for purposes related to technical-scientific research,
    - applicative satellites: used for civil, commercial or military purposes.
  - Orbit: the trajectory described by the satellite around the Earth. This trajectory is generally elliptical, with the Earth occupying one of the two foci, although, for simplicity, it is often assumed to be circular.
  - Mass: directly linked to their volume, since the internal space of any satellite is exploited to the maximum for reasons of efficiency.

Use examples (1)

- Telecommunications satellites. Aimed at providing an information transfer service (telephony, radio broadcasting, TV broadcasting, data transmission, ...) via links between satellite and Earth station (space wave), between two satellites (intersatellite link), or via double Earth station-satellite and satellite-Earth station links (satellite radio link).

- Meteorological satellites. Aimed at collecting information on weather conditions to send to Earth via space wave for the formulation of real-time weather forecasts.

- Remote sensing satellites. Aimed at systematic observation of the earth's surface to extract information on the presence of natural resources, orography and pollution, which are sent to Earth via space wave and used in various fields, such as precision cartography.

Use examples (2)

- Navigation satellites. Aimed at providing a positioning service that allows a dedicated electronic receiver to determine its geographic coordinates on the Earth's surface or in the atmosphere by exploiting the space waves corresponding to multiple satellites.

- Military satellites. Aimed at espionage, monitoring of installations and support of the army, navy and air force, via space wave, intersatellite link and satellite radio link.

- Orbiting stations. Aimed at allowing humans to remain in space for long periods of time (weeks, months, years), in order to carry out scientific experiments and study the effects of the absence of gravity on living beings. Communications with the Earth are carried out via space wave.

A classification based on distance

- Depending on distance and orbit characteristics some different satellite types may be identified.
- Geostationary earth orbit (GEO) operating in a circular orbit around the earth with an altitude of 35786 km above the equator resulting in a notional station keeping its position fixed in terms of elevation and azimuth angle with respect to a given point on the earth.
- Medium earth orbit (MEO) satellites operate in a circular orbit around the earth with an altitude between 7000 km to 25000 km.
- Low earth orbit (LEO) satellites operate in a circular orbit around the earth, with an altitude between roughly 500 km to 2000 km.
- High elliptical orbit (HEO) satellite operate in an elliptical orbit around the earth. With such an orbit shape, a longer satellite visibility from the earth point can be obtained, e.g. when the desired coverage service area is a remote area e.g. the pole regions such a HEO would be more beneficial.
- High altitude platform systems (HAPS) is a generic term covering all devices (airplanes, balloons, helicopters or drones (UAV)), which operate very flexibly at altitudes from several hundred meters up to about 15 km.

A classification based on mass

- The mass is directly linked to the volume, since the internal space of anysatellite is exploited to the maximum for reasons of efficiency.
- Artificial satellites can be divided into the categories reported in Table. All categories of satellites can operate both individually and in constellations, with the last five that, together, form the family of so-called small satellites, with a mass of less than 500 kg.

Category	Mass
Large satellites - LSat	>1 t
Medium satellites - MSat	500 kg÷1 t
Minisatellites - mSat	100 kg÷500 kg
Microsatellites - μSat	10 kg÷100 kg
Nanosatellites - nSat	1 kg÷10 kg
Picosatellites - pSat	100 g÷1 kg
Femtosatellites - fSat	<100 g

CubeSat

- The last three categories can sometimes refer to a larger satellite, called mother satellite, which performs the coordination and monitoring function of the constellation.
- For small satellites, there are further definitions, normally referring to volume, which lead to types of vehicles straddling multiple categories.
- The best-known type is that of CubeSats, so called because they can be created by composing one or more U units, each consisting of a cube with a side of 10 cm, in order to obtain structures with form factors from 1U up to 27U.
- The same construction logic, with the same form factors allowed from 1x to 27x, is adopted for PocketQubes and SunCubes, created starting from *x=p* and *x=f* units, with sides of 5 cm and 3 cm, respectively. Thanks to the possibility of composing the units, small satellites of different categories can be obtained.
- For example, CubeSats can be both μSats and nSats. As regards specific applications in the scientific and commercial fields, the general trend, mainly due to the continuous miniaturization of electronics, leads to directing attention towards the categories of lower mass, which have the notable advantage of requiring lower costs for launch into orbit.