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Research, Development and Standardization of Terrestrial and Non-Terrestrial Network Integration

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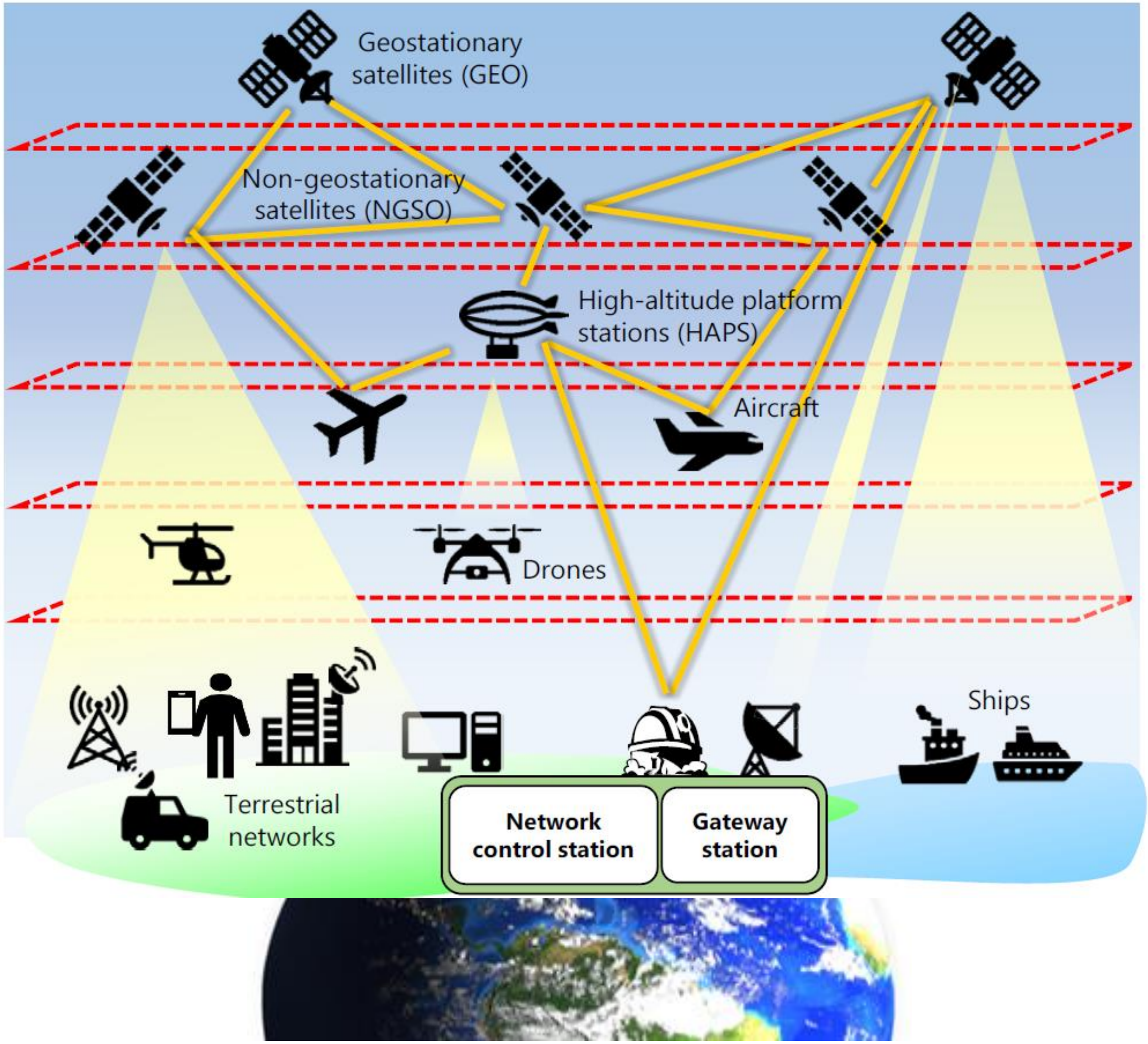
Outline

- NTN integration scenario
- Satellite communication overview
- TN-NTN convergence scenarios
- Related research projects and forums
- Related standardization works
- TN-NTN integrated network control architecture (INCA)
- INCA requirements and features
- INCA experimental system (work-in-progress)
- Conclusion and some research topics

TN: Terrestrial network
NTN: Non-terrestrial network

NTN integration scenario in beyond-5G/6G network

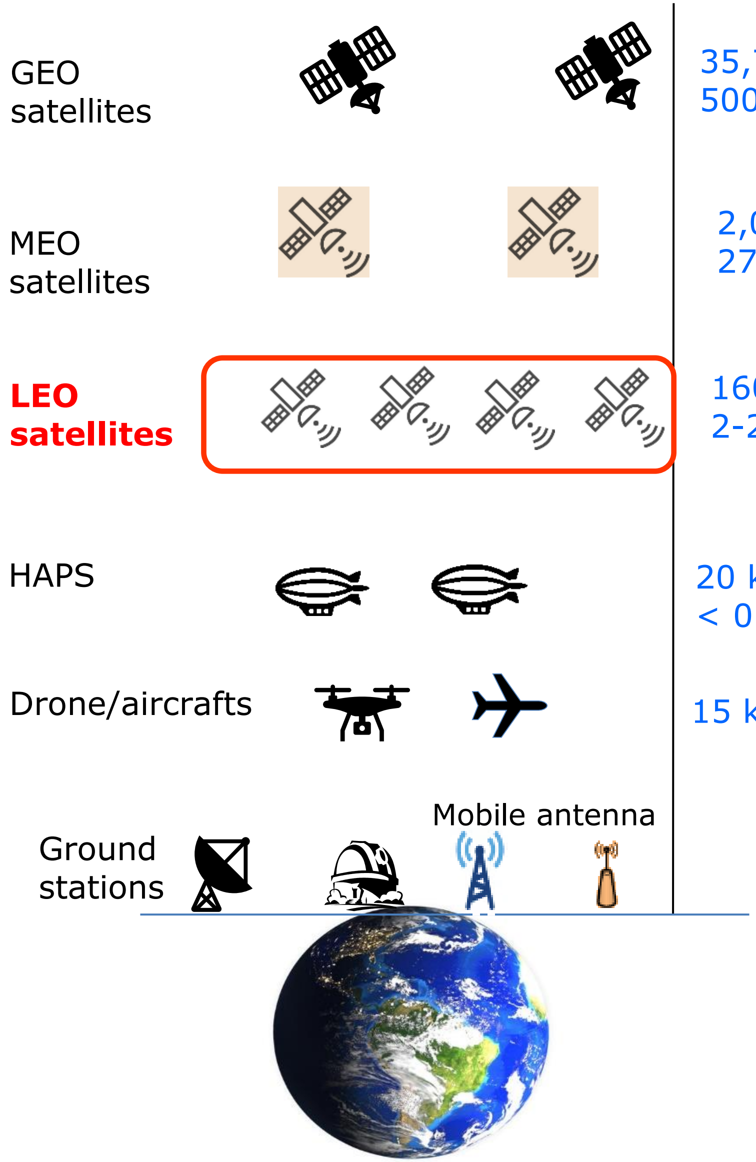


Non-terrestrial networks (Satellites and HAPS)

Satellite classification according to altitude:

1. GEO satellites
2. NGSO satellites:
   a. MEO (Mid-earth orbit)
   b. LEO (Low-earth orbit) satellites

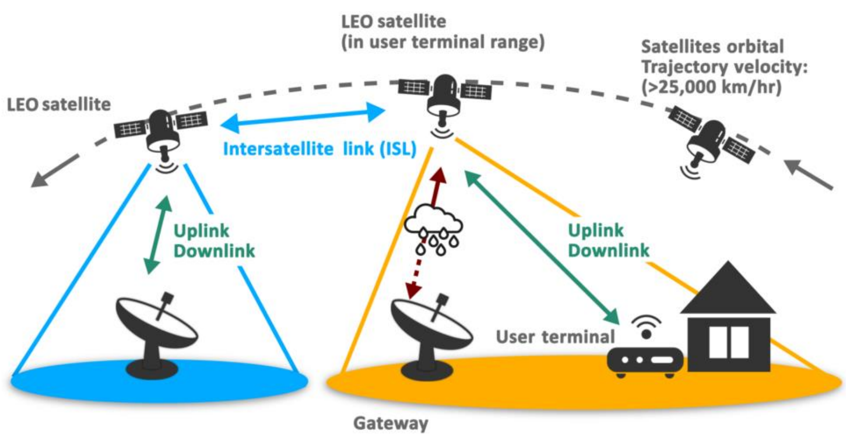
Altitude and latency of NTN nodes (satellites)



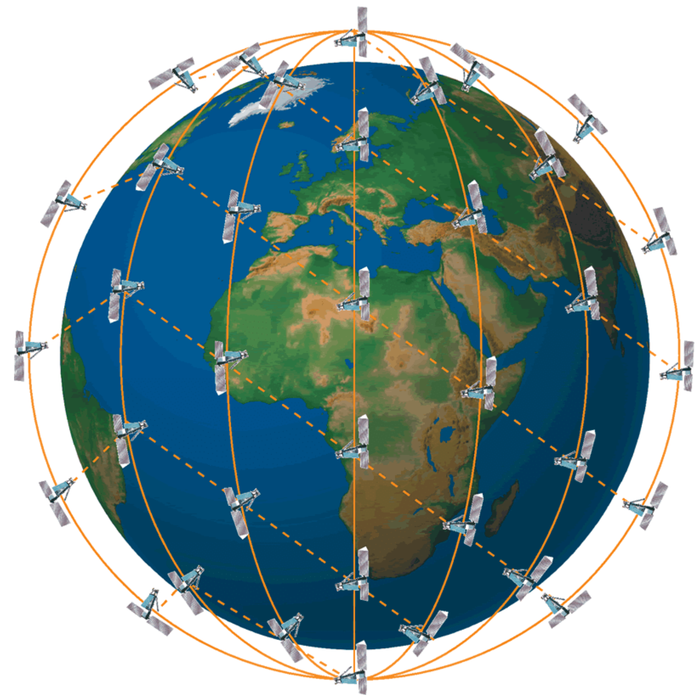
- Low Earth Orbit (LEO) satellites, the latest generation of satellites providing broadband Internet access
- LEO are smaller, lighter and less expensive than GEO satellites
  - LEO satellite weigh 1kg – 200 kg vs. GEO 6,500 kg
  - Cost: USD 7k vs. 150m – 200m
  - LEO satellites are mass-produced and launched 100~ at once

LEO constellation

- LEO satellites exist in constellations
  - Satellites orbiting earth ~16 times a day
  - Thousands of satellites for networks in space
    - Satellites interconnected through inter-satellite links (ISL)



Ref: https://www.testandmeasurementtips.com/

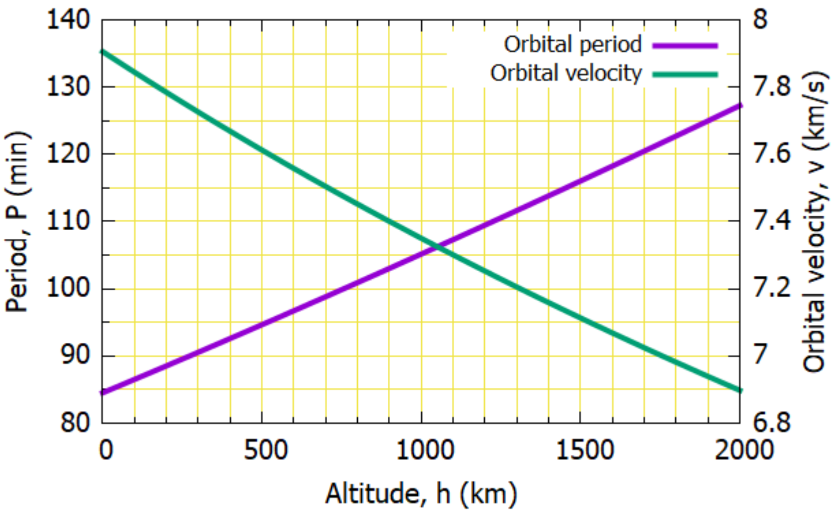


Ref: E. Sag et al, JoC, Vol. 13(10), 2018

- Earth surface coverage by multiple satellites
  - Satellite with best link accessible from earth station and user terminals

LEO satellite orbital period (velocity) and latency

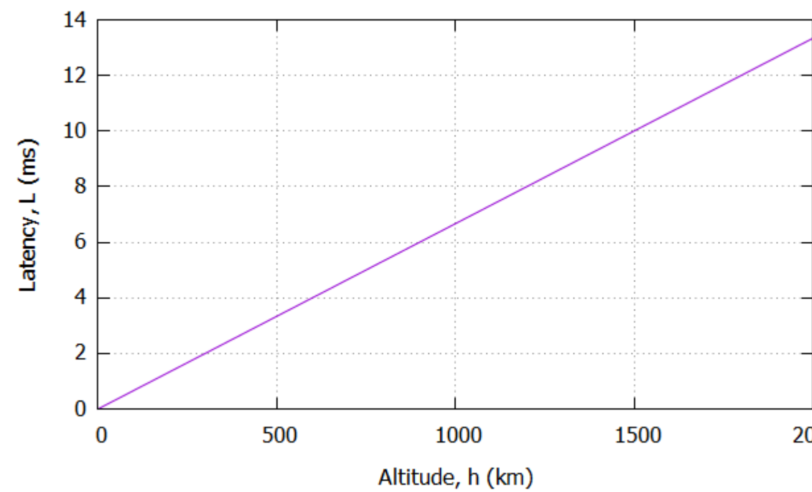
Orbital velocity and period for various satellite altitudes (based on Kepler's third law of planetary motion i.e., centripetal force = gravitational force)



- Orbital velocity, $v = \sqrt{GM/(R+h)}$; where R = radius of earth; h = satellite altitude
- Orbital period, P = perimeter / velocity $= 2\pi(R+h)/v$

$$= \frac{2\Pi}{\sqrt{GM}}(R+h)^{3/2}$$

One way communication latency between two endpoints in ground via (one-hope) satellite



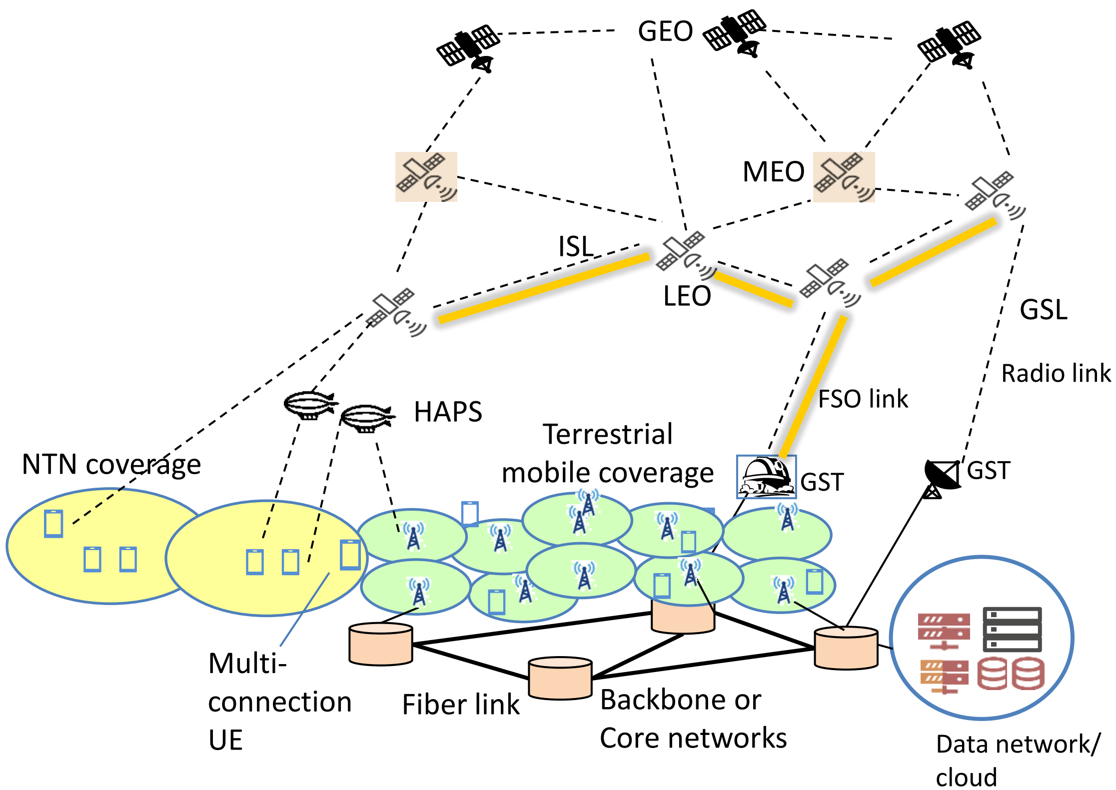
L = one-way latency via a satellite in milliseconds

h = Satellite altitude in km

c = light/RF velocity in space in km/s (3×10^5)

$$L = \frac{2h}{c} \text{ x } 1000$$

TN and NTN integration scenario overview



GEO: Geostationary earth orbit;
MEO: Medium earth orbit;
LEO: Low earth orbit

GST: Ground station;
HAPS: High altitude platform system
GSL: Ground-to-satellite link;
ISL: Inter-satellite link;
FSO: Free space optical

- TN are composed of data networks and mobile system (5G/Byond-5G)
- NTN are composed of GEO/MEO/LEO (and HAPS)
  - HAPS can also be considered as TN in terms of mobile radio frequency allocations
- Both TN and NTN can be operated as a single administrative domain (i.e., by a single operator) or as multiple administrative domains (i.e., by two or more operators).

Related research projects and forums

- European Commission (EC) funded projects
  - Sat5G: Satellite and terrestrial networks for 5G
    https://5g-ppp.eu/sat5g/
  - 5G- ALLSTAR: 5G agile and flexible integration of satellite and cellular
    https://5g-allstar.eu/
  - VITAL: Virtualized hybrid satellite-terrestrial systems for resilient and flexible future networks
    https://cordis.europa.eu/project/id/644843

- European Space Agency funded project
  - SATis5: Demonstrator for satellite-terrestrial integration in the 5G context
    https://satis5.eurescom.eu/

- Research activities in Japan
  - NICT's Beyond 5G/6G White paper; Space ICT Promotion Initiative Forum

Ongoing standardization works

- 3GPP and ETSI
  - TR 22.822 Study on using satellite access in 5G
  - TR 28.802 Study on management aspects of satellite in 5G
  - TR 23.737 Study on architecture aspects for using satellite access in 5G (Release 16)
  - TR 28.808 Study on management and orchestration aspects of integrated satellite components in a 5G network
  - Updated architecture (Release 17):
    - TS 23.501 (System architecture for 5G – integrated NR satellite access),
    - TS 23.502 (Procedure and flows)
    - TS 23.503 (Policy control and charging)
  - ETSI TR 103 611Satellite Earth Stations and Systems (SES); Seamless integration of satellite and/or systems into 5G and related architecture options, June 2020
- ITU standardization activities
  - ITU-T SG13 (non-radio aspects of FMSC architecture), ITU-R W5D

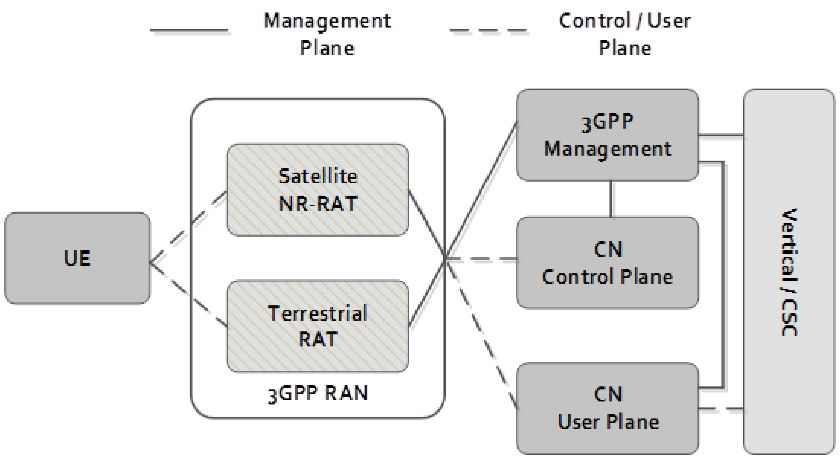
3GPP standardization work – examples (1/3)

3GPP TR 28.802 Study on management aspects of satellite in 5G (1/2)

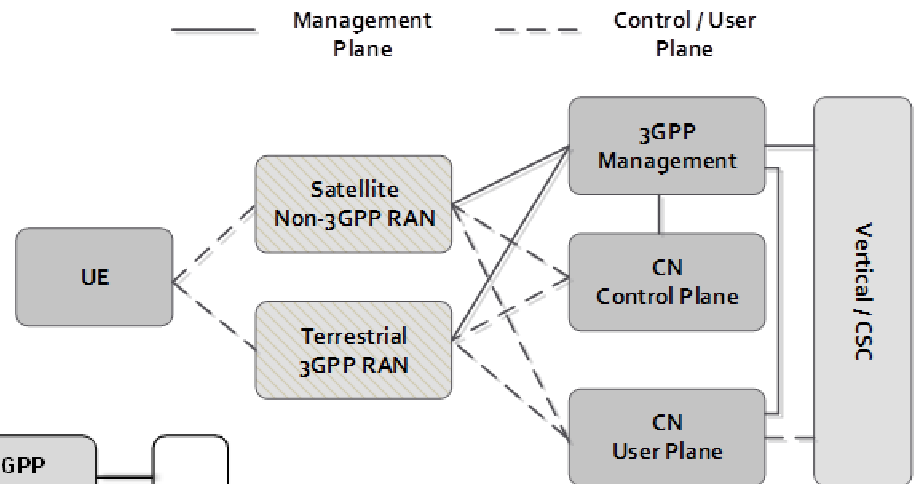
Scope:

- Identify issues associated with service and network management
- Study the associated solutions.

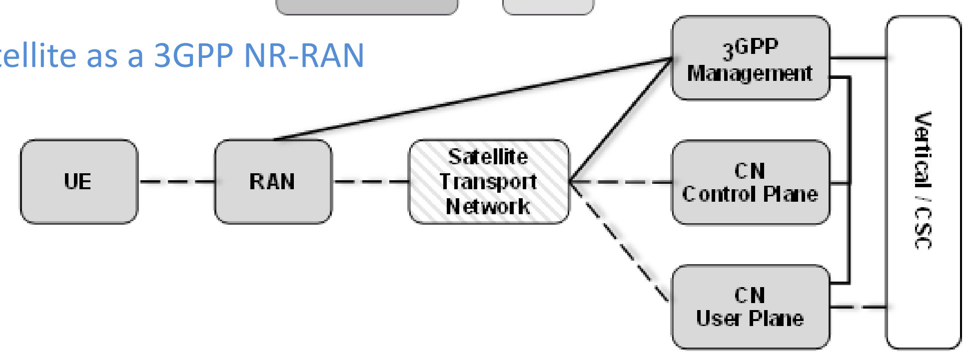
Reference architecture for the management of a satellite integrated 5G (3 cases)



(a) Satellite as a 3GPP NR-RAN



(b) Satellite as non-3GPP RAN



(c) Satellite as backhaul transport network

3GPP standardization work – examples (2/3)

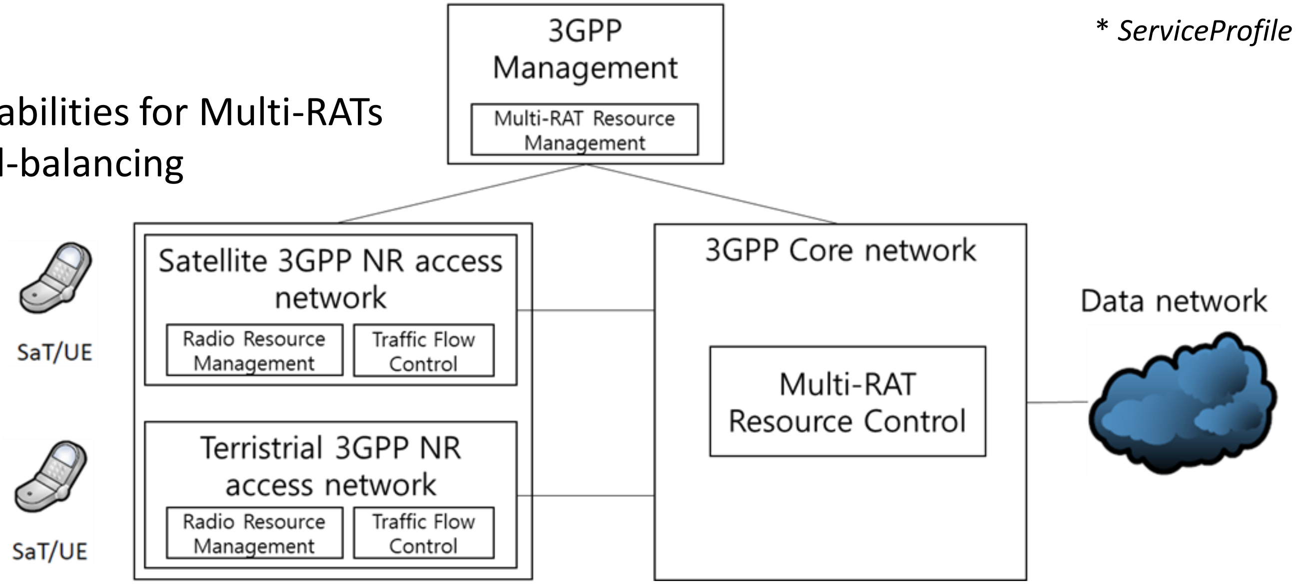
3GPP TR 28.802 Study on management aspects of satellite in 5G (2/2)

Management use cases and solutions

	Use cases	Potential solutions
1	Network slice management : Slice creation in both TN and NTN RAN sharing with satellite components	Adapt *ServiceProfile** to support a network slice instance associated with satellite components
2	Management of satellite components MEO/LEO regenerative satellite components	Extend *SliceProfile* to specify separate service requirements for Satellite RAN and Terrestrial RAN
3	Monitoring of satellite components Performance Delay Multi-RAT load balancing	Adapt the Average delay DL air-interface measurement and Distribution of delay DL air-interface measurement Switch/split traffic from currently active RAT to another RAT

* *ServiceProfile* defined in 3GPP TS 28.541

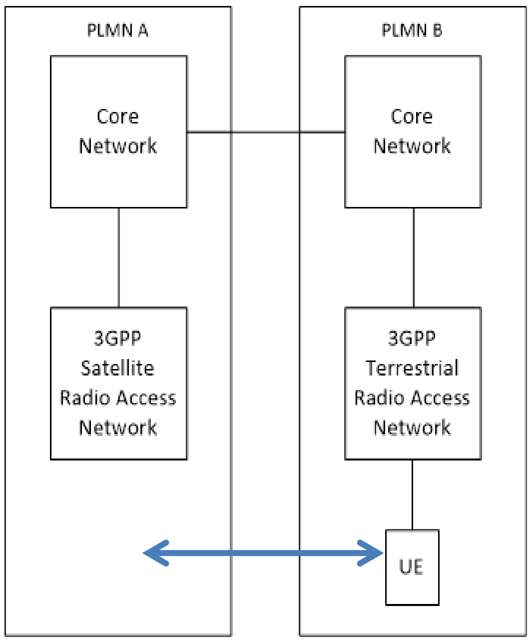
Capabilities for Multi-RATs load-balancing



3GPP standardization work – examples (3/3)

TR 23.737 Satellite access in 5G: Scope

- Identification of impact areas of satellite integration in 5G
- Solutions to adjust 5G system (roaming, satellite New Radio (NR)-radio access network (RAN), etc.)
- Resolution of RAN & core network (CN) inter-related issues



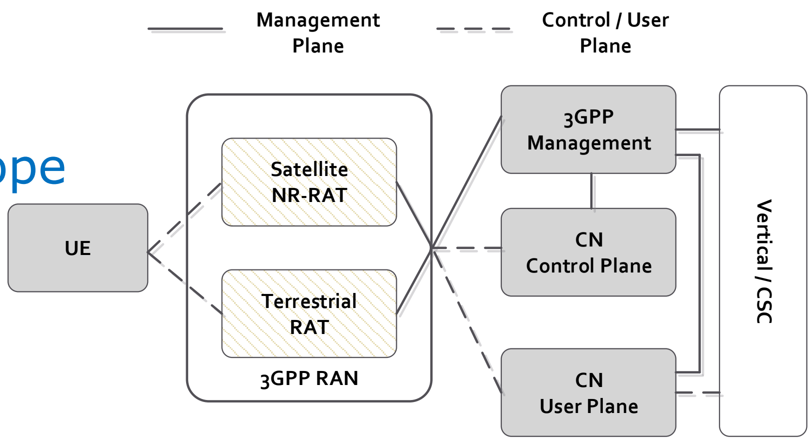
Roaming (scenario 3)

Various architectural scenarios considered:

1. Satellite and terrestrial RAN managed by a CN
2. Multi-operator CNs sharing a satellite RAN
3. Roaming between satellite RAN and terrestrial RAN (connected to multiple CNs)
4. Satellite backhaul

TR 28.808 Management and orchestration aspects of satellites integration in 5G: Scope

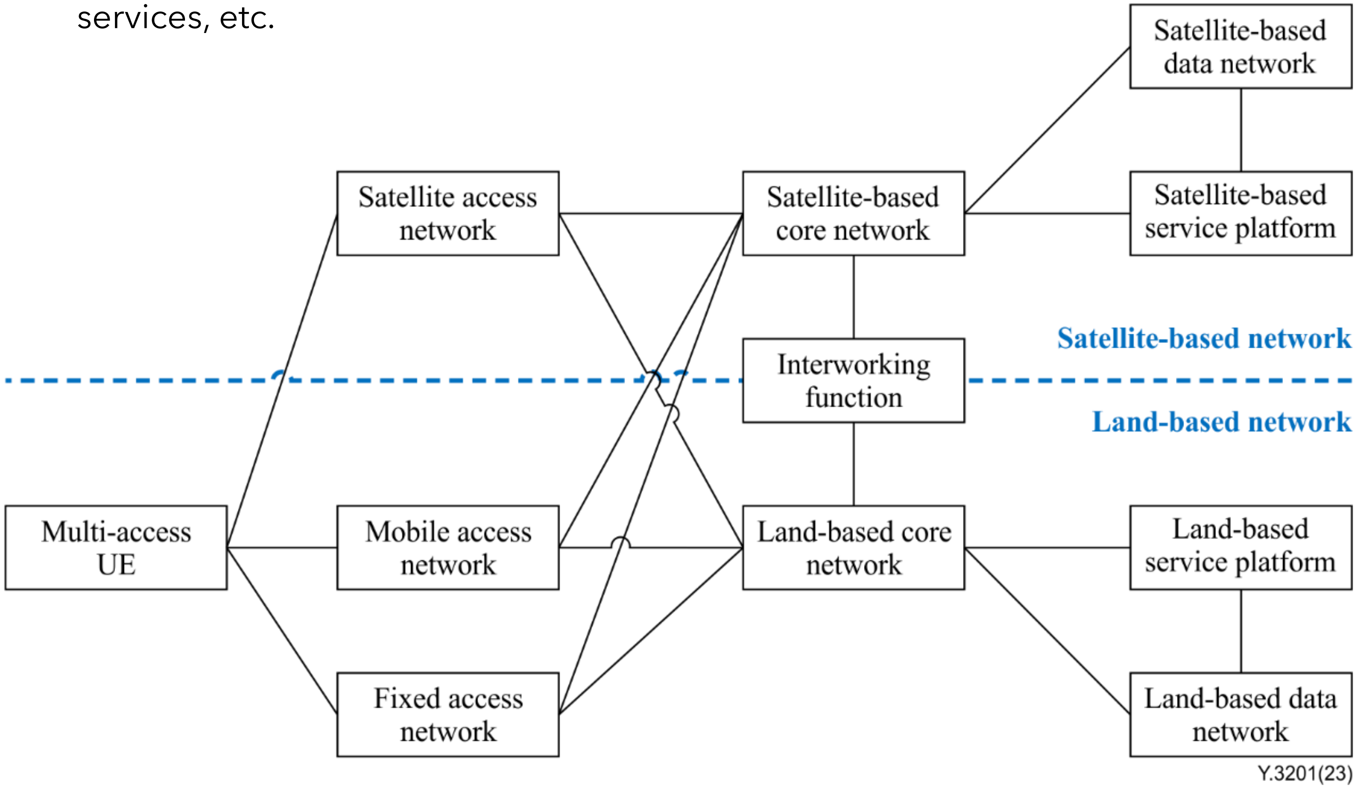
- Identification of key issues service/network management/orchestration
- Study of associated solutions



Reference architecture for management of satellite NR-RAN

ITU-T standardization work - example

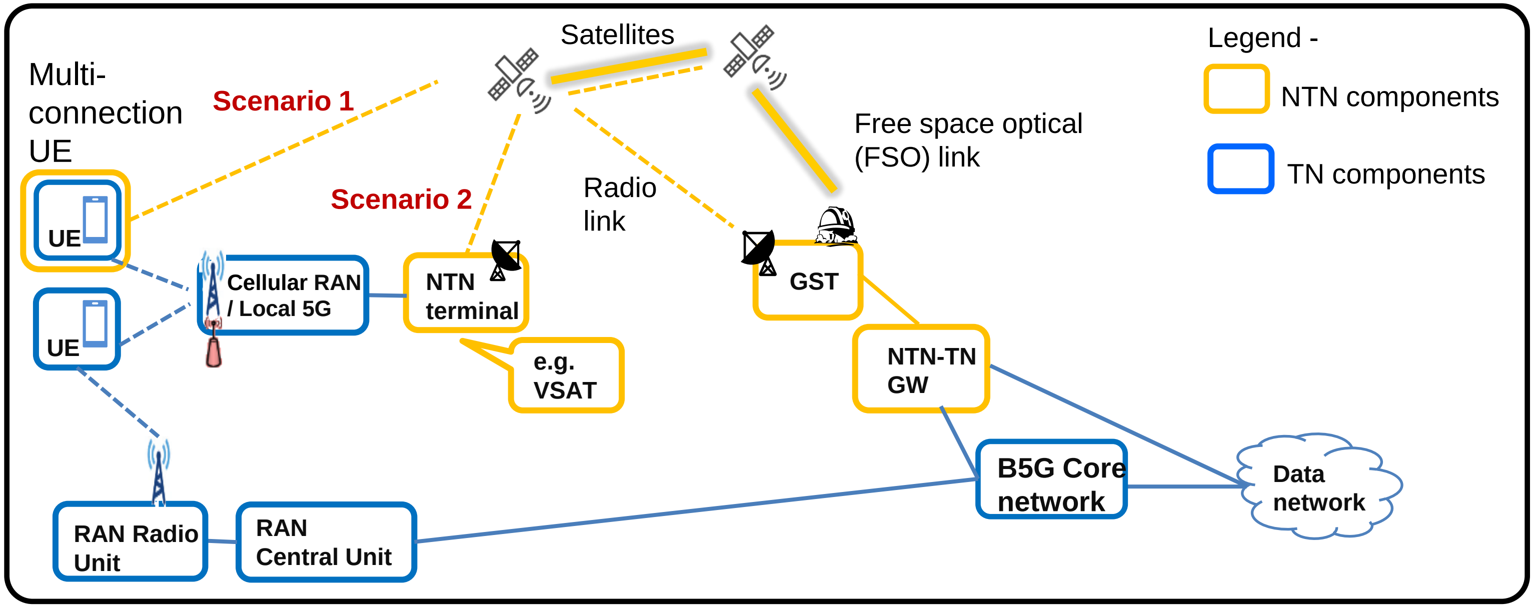
- ITU-T SG13 developing several Recommendations under the topic of fixed, mobile, satellite convergence (FMSC):
  - Y.3201: FMSC – Framework
  - Y.3202: FMSC – Mobility management
  - Y.3203: FMSC – Connection management
  - Y.3204: FMSC – Service continuity
  - Several work-in-progress drafts on multi-access edge computing, traffic scheduling, location-aware services, etc.



Framework of fixed, mobile and satellite convergence (ITU-T Y.3201)

Research issues: TN-NTN integration scenarios

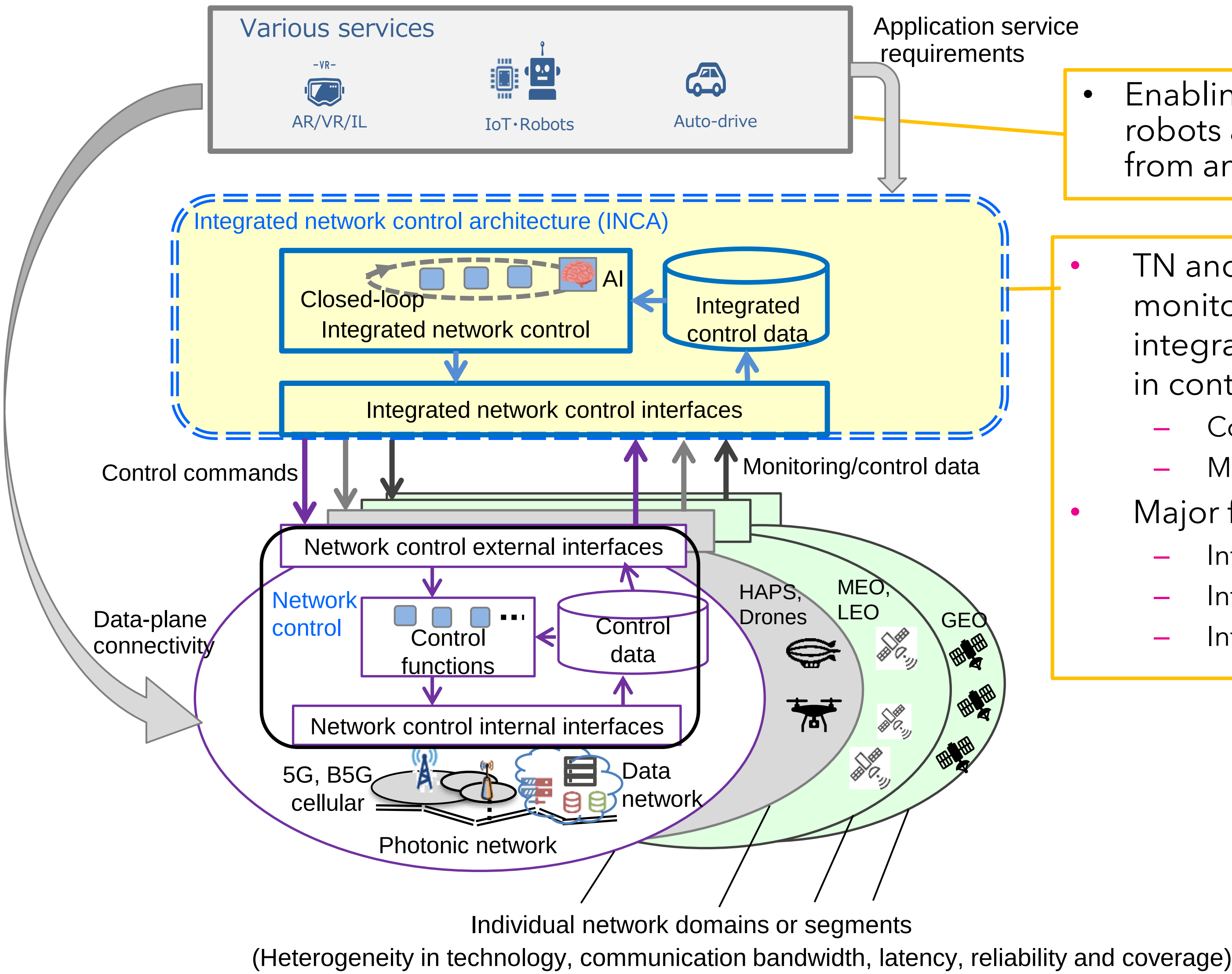
- NTN can be used as
  - End user's radio access network (RAN) -- Scenario 1 (satellite access)
  - Backhaul network in between B5G core and RAN -- Scenario 2 (satellite backhaul)
  - Backhaul links between split B5G core (e.g., in between Central 5G Core and Edge 5G core (extension of Scenario 2)



GST: Ground station, GW: Gateway, RAN: Radio access network, UE: User equipment

- End-to-end integrated network control-system architecture (INCA) still missing

TN-NTN convergence through INCA – overview

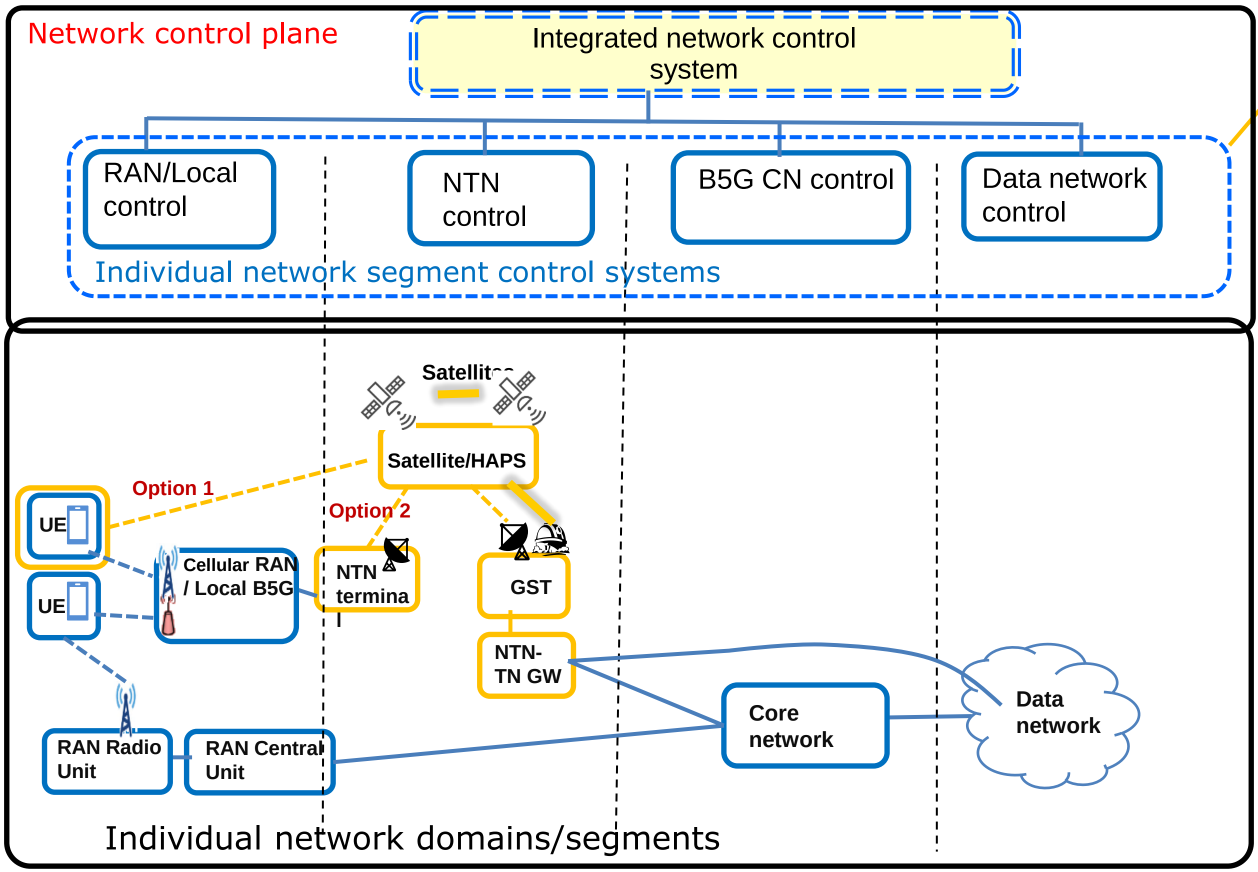


- Enabling AR/VR/IL, IoT, connected robots and auto-driving services from anywhere at any time

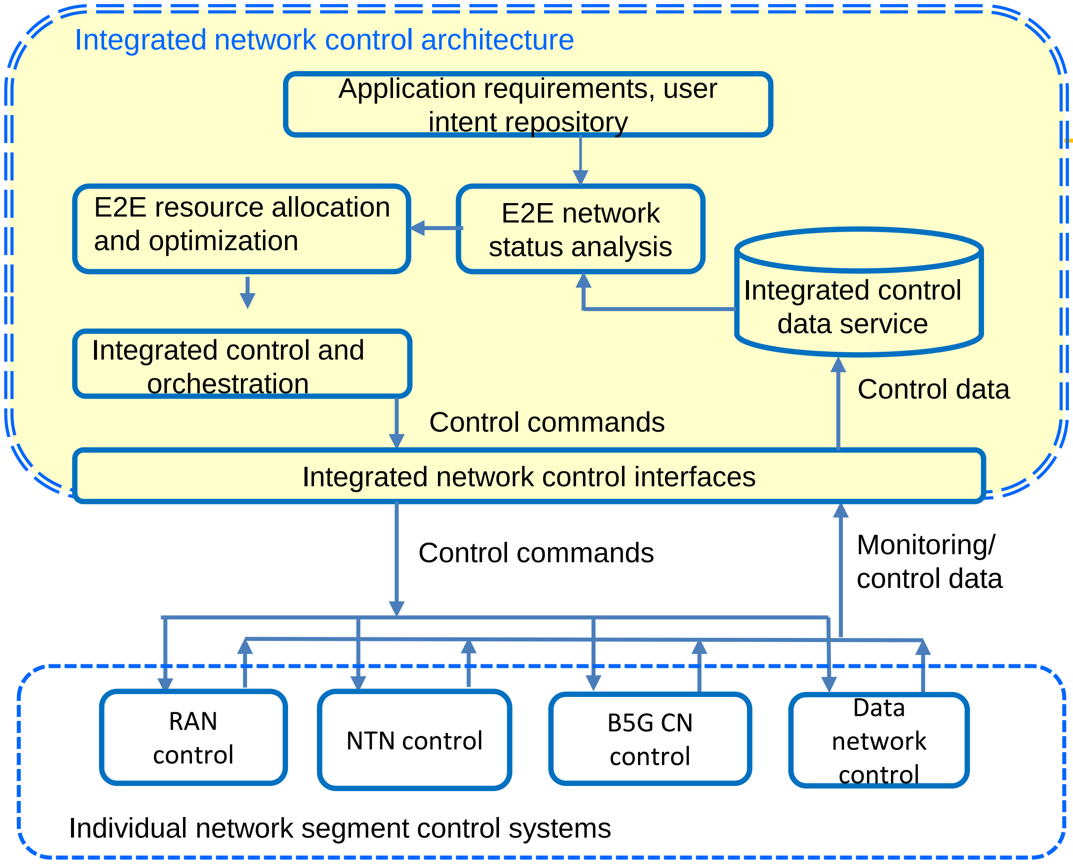
- TN and NTN collectively monitored and controlled from the integrated network control system in control plane
  - Controlling resources
  - Monitoring performance
- Major functional components
  - Integrated network ctrl functions
  - Integrated ctrl data service
  - Integrated network ctrl interfaces

Scenario of individual network segment control components with integrated network control system

- In control plane, each network domain/segment is managed by its own control system.
- The functional architecture framework of individual network control, assuming NTN domain is shown in next slide



TN/NTN integrated network control architecture (INCA) functions



E2E: End-to-end

- Integrated network control architecture – functional components:
  - App requirements, user intent repository
  - E2E resource allocation and optimization
  - E2E network status analysis
  - Integrated control data service
  - Integrated control and orchestration
- Integrated network control interfaces
  - Receiving control data from and sending control commands to individual network segment control systems

References:

[1] V.P. Kafle, M. Sekiguchi, H. Asaeda, and H. Harai, "Integrated network control architecture for terrestrial and non-terrestrial networks convergence in beyond 5G systems," ITU Kaleidoscope Academic Conference, Accra, Ghana, Dec. 2022.

[2] ITU-T Draft Recommendation Y.FMSC-INCA "Fixed, mobile and satellite convergence - Integrated network control architecture framework for IMT-2020 networks and beyond," ITU-T SG13-TD431/WP1, July 2023

INCA requirements and features

Requirements

- Virtualization of both TN and NTN resources and software-based control
- Unified representation of TN and NTN resources
- Existence of control data sharing platform
- Provision of E2E network resource sharing
- Availability of intelligent data processing and control tools

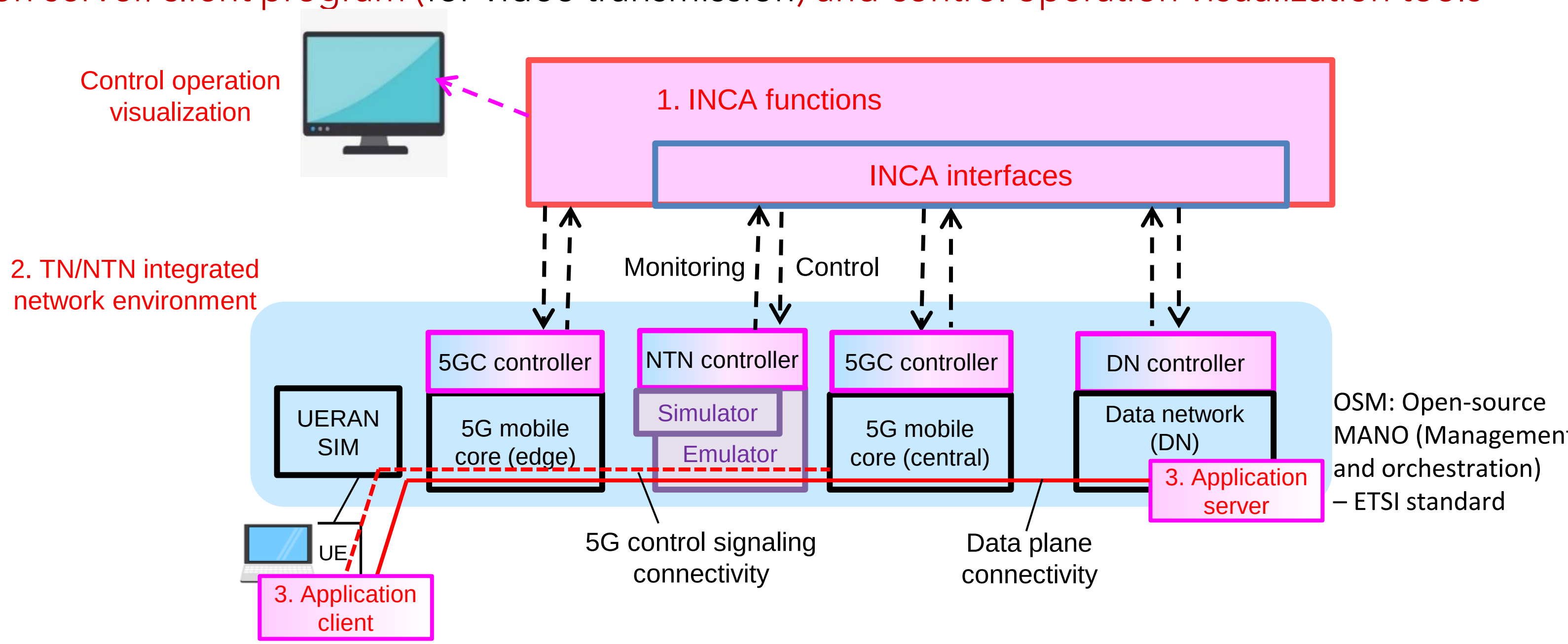
Beneficial features

- Technology-agnostic control and orchestration
- Promoting network control automation

INCA experimental system work-in-progress (1/2)

Consisting to three subsystems:

1. INCA functions and interfaces
   - Perform three tasks: (a) mapping of QoS requirements to network resource requirements, (b) analysis of integrated monitoring/control data using statistical/machine learning tools, and (c) setting of resource control parameter values
2. TN/NTN integrated network environment: contains 5G RAN and 5G core (5GC) platforms, NTN simulator/emulator, and DN platforms
   - 5G RAN: based on Opensource UERANSIM software
   - 5GC: based on opensource free5GC software, split into two segments: 5GC (central) and 5GC (edge)
   - NTN: composed of satellite simulator in control plane, emulator in data plane
   - Openstack/OSM-based data network (DN) contain application server programs installed VMs.
   - All segments (expect RAN) have respective controllers to monitor resource utilization and performance, collect control data, and execute resource control commands.
3. Application server/client program (for video transmission) and control operation visualization tools



INCA experimental system development (2/2)

Challenges to be addressed

- Developing common interfaces between INCA and individual network segment controllers
  - Using RESTful API to exchange control data and control commands in de facto standard formats (e.g., JSON)
- Collecting control data from diverse platforms of TN and NTN
  - Leveraging monitoring and control tools of resource virtualization platforms such as Docker containers, OpenStack, and Open-Source MANO (OSM)
  - Expecting that NTN components will also be developed in virtualization platforms soon, availability the functions of network slicing control
- Configuring end-to-end communication services over TN and NTN infrastructure leased from different infrastructure operators
  - This issue requires additional standardization work as it has not become a common practice yet that a single company owns/operates all TN and NTN infrastructures.

Conclusion and additional research topics

- TN-NTN integration is going to be major innovation in Beyond-5G or 6G networks.
- R&D and standardization works progressing rapidly.
- Presented the design for TN and NTN integrated network control architecture (INCA)
  - Enabling end-to-end network monitoring and control for offering reliable services in any place at anytime
- Development (work-in-progress) of an experimental system for the verification of INCA functionalities in NTN (simulator/emulator), 5G, and DN integrated environment
- Additional research topics:
  - Optimal path setup in TN-TNN virtualized network platform
  - Dynamic update of paths to maintain QoS when NTN link quality changes or number of users increases suddenly
  - Automation of monitoring and control operation