



Challenges in 6G Multi-Satellite Connectivity

SCSS 2023

Dr. Jorge Querol

12th October 2023

Challenges in 6G Multi-Satellite Connectivity

Outline

- ☐ Introduction
- ☐ Motivation
- ☐ MC Enabling Technologies
- ☐ Challenges
- ☐ Conclusions

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Introduction

Speaker Presentation

Dr. Jorge Querol



2013—2018 PhD Thesis, “**RFI Detection and Mitigation Techniques for GNSS and MW Radiometers**”, Polytechnic University of Catalonia, Spain

- Prof. Adriano Camps, Prof. Hyuk Park (special thanks!)



UNIVERSITAT POLITÈCNICA
DE CATALUNYA
BARCELONATECH

2018—2021 Research Associate, “**Multi-beam satellite live precoding demonstration**”, SnT, University of Luxembourg

- Prof. Bjorn Ottersten, Prof. Symeon Chatzinotas



2021—Today, Research Scientist, SnT, University of Luxembourg

- Head of the 6GSPACE Lab
- 5G/6G-NTN (SatCom)
- ML for PHY layer
- Deep Space communications



SnT SIGCOM Research Group



THE GOVERNMENT
OF THE GRAND DUCHY OF LUXEMBOURG
Ministry of State

Department of Media, Telecommunications
and Digital Policy



Fonds National de la
Recherche Luxembourg



Track Record

- **14** years in operation
- **80+** Researchers
- **60+** R&D projects
- **60M€+** Funding
- **6** Industrial Partnerships



NOKIA
Bell Labs



Research Areas

- 6G Communication Systems
- Non-Terrestrial Networks (SatCom-UAVs)
- Massive Antenna Arrays
- Quantum Communication Infrastructure



HEU TRANTOR



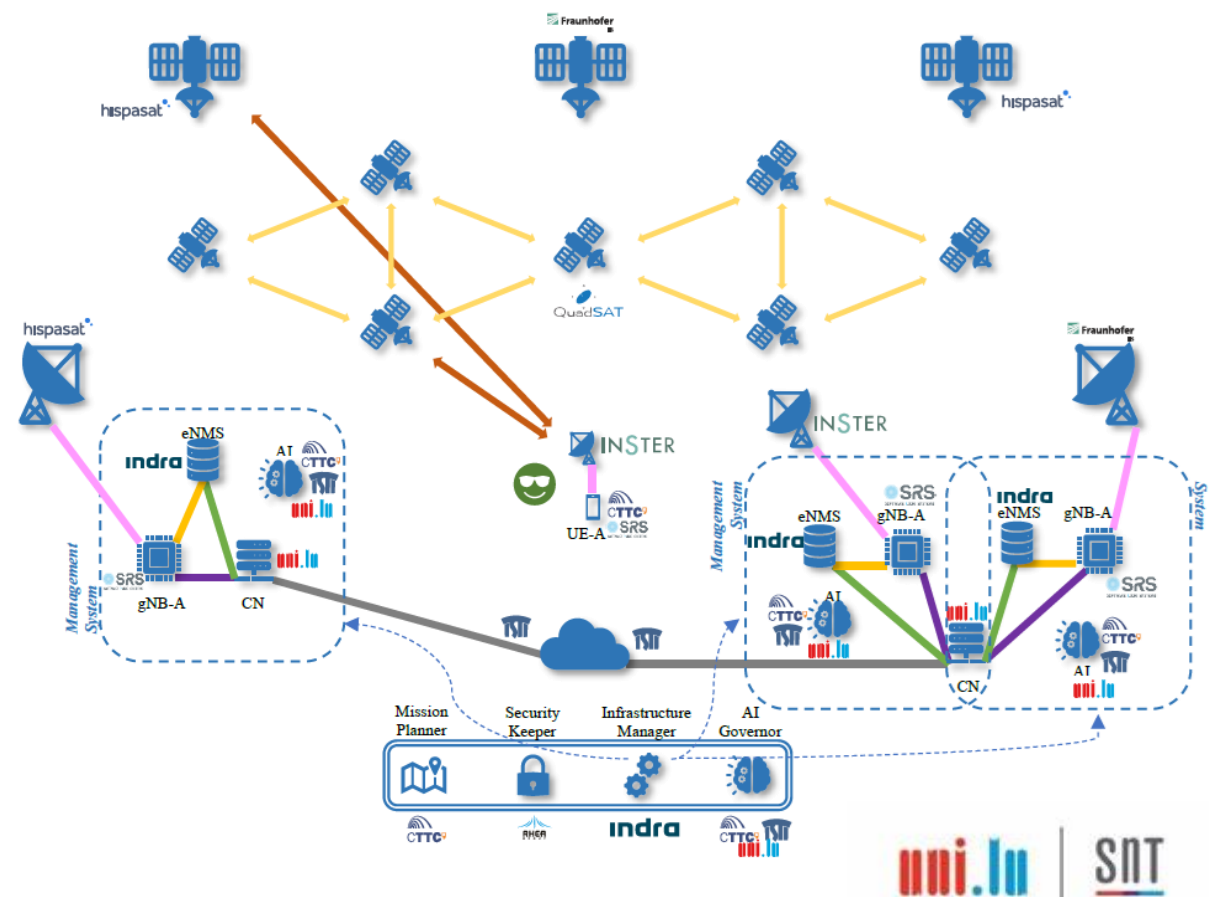
Commission
européenne



- Provide novel satellite components for 5G Advanced NTN that evolves low dynamic network single-orbital management to highly dynamic **multiorbital multiband connectivity services**
- Development of 5G Advanced NTN user equipment and gNB and extended capabilities for next generation **on-board processing payloads**
- Development of **AI governance modules** for efficient resource management and creation of a mission planner for the design of future satellite networks
- Develop a **Secure satellite operator network**
- **Demonstrate B5G NTN concepts via IOV**

□ **Duration:** 3 years

□ **Kick-Off Date:** 1st January 2023



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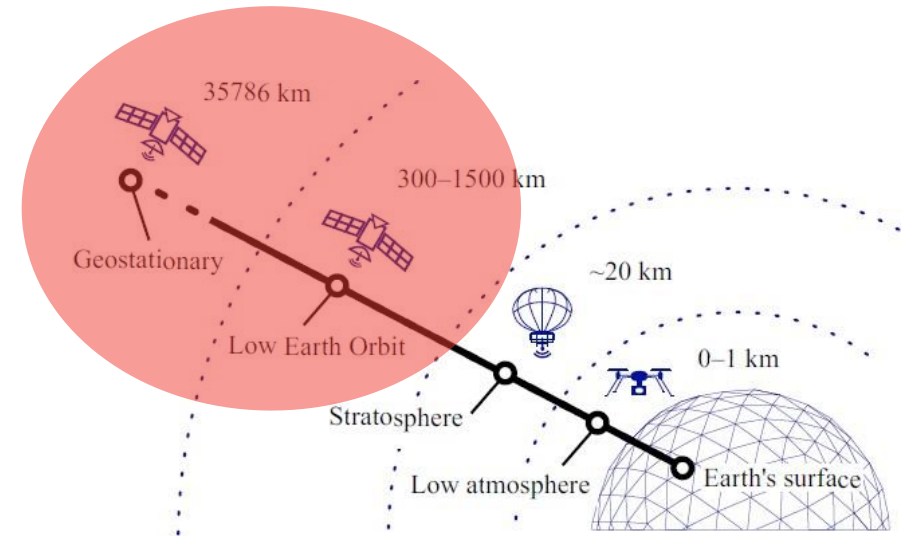
Motivation

Setting the Scene: NTN and SatComs



Expectations

- Ubiquitous coverage / Digital Divide
- Maritime/aeronautical/Rural areas
- Wide area content delivery / data collection
- Direct smartphone/vehicle access



SatComs vs HAPS vs UAVs

- **System Coverage Area**
- **System OPEX & CAPEX**
- **Regulations / Sovereignty**



Why multi-satellite connectivity?



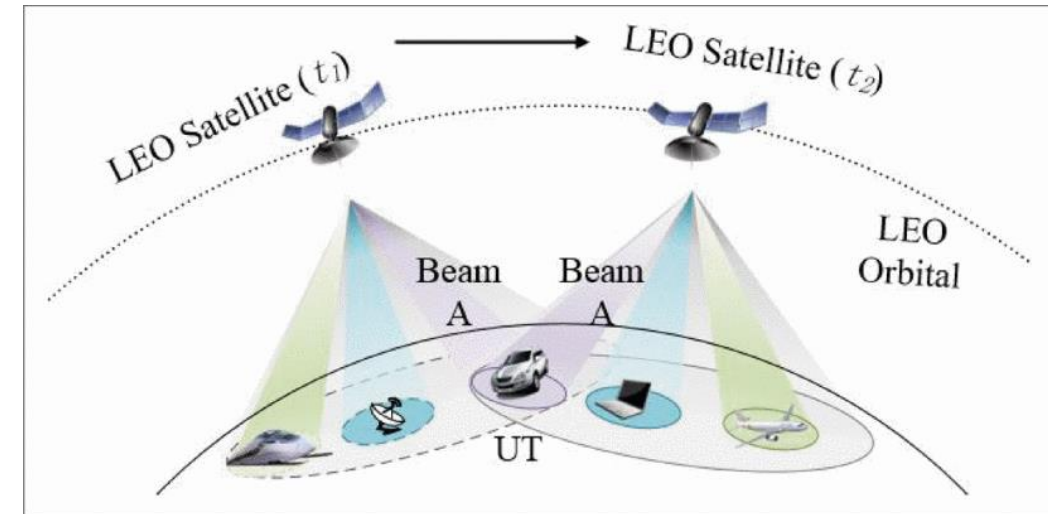
Advantages

- Enhanced coverage and increased throughput
- Overcome transmission flaws (blockages, weather)
- Link redundancy and smooth handover
- Enabled user self-localization

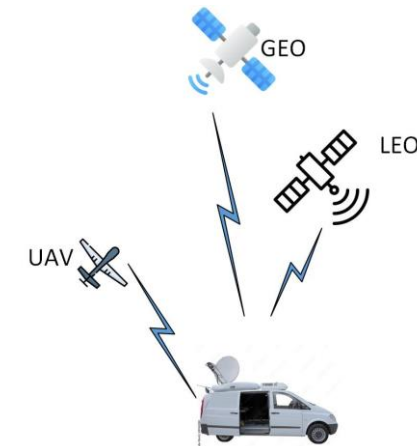


Specific Use cases

- Wide-Area Public Safety
- Disaster Management
- NTN-TN Service continuity for mobile UE
- Hybrid TN-NTN for Rural Connectivity
- Aerospace and Aviation Communication
- Mission Critical



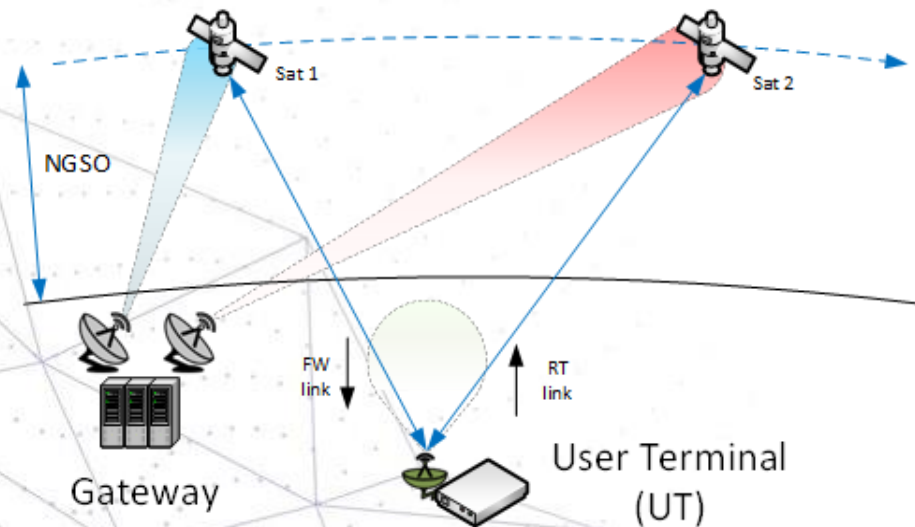
Y. Su, Y. Liu, Y. Zhou, J. Yuan, H. Cao and J. Shi, "Broadband LEO Satellite Communications: Architectures and Key Technologies," *IEEE Wireless Communications*, vol. 26, no. 2, pp. 55, April 2019.



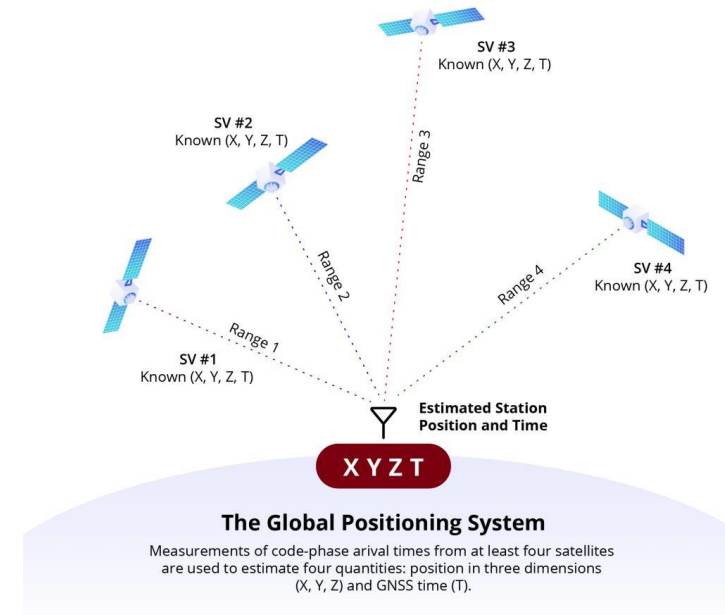
Examples of multi-satellite connectivity



Multi-feed Broadcast



MEO STBC Diversity (ESA Diversity)

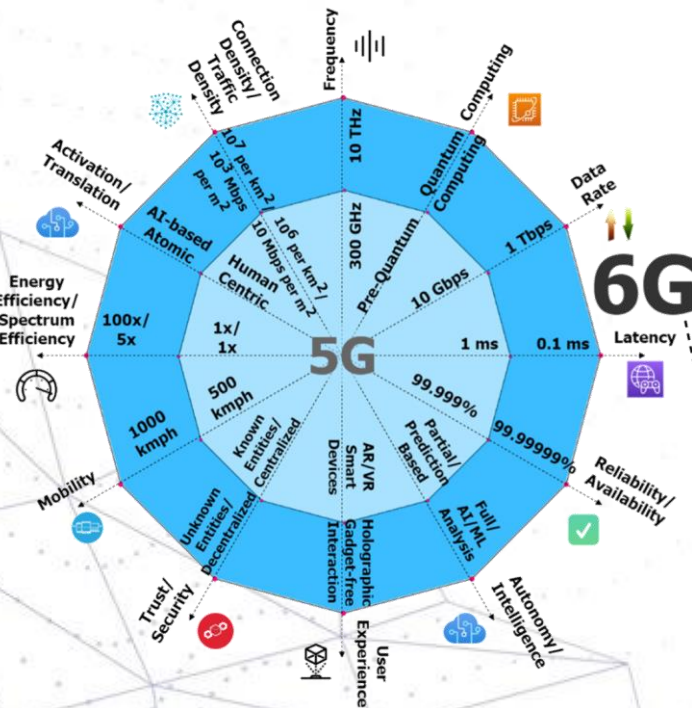
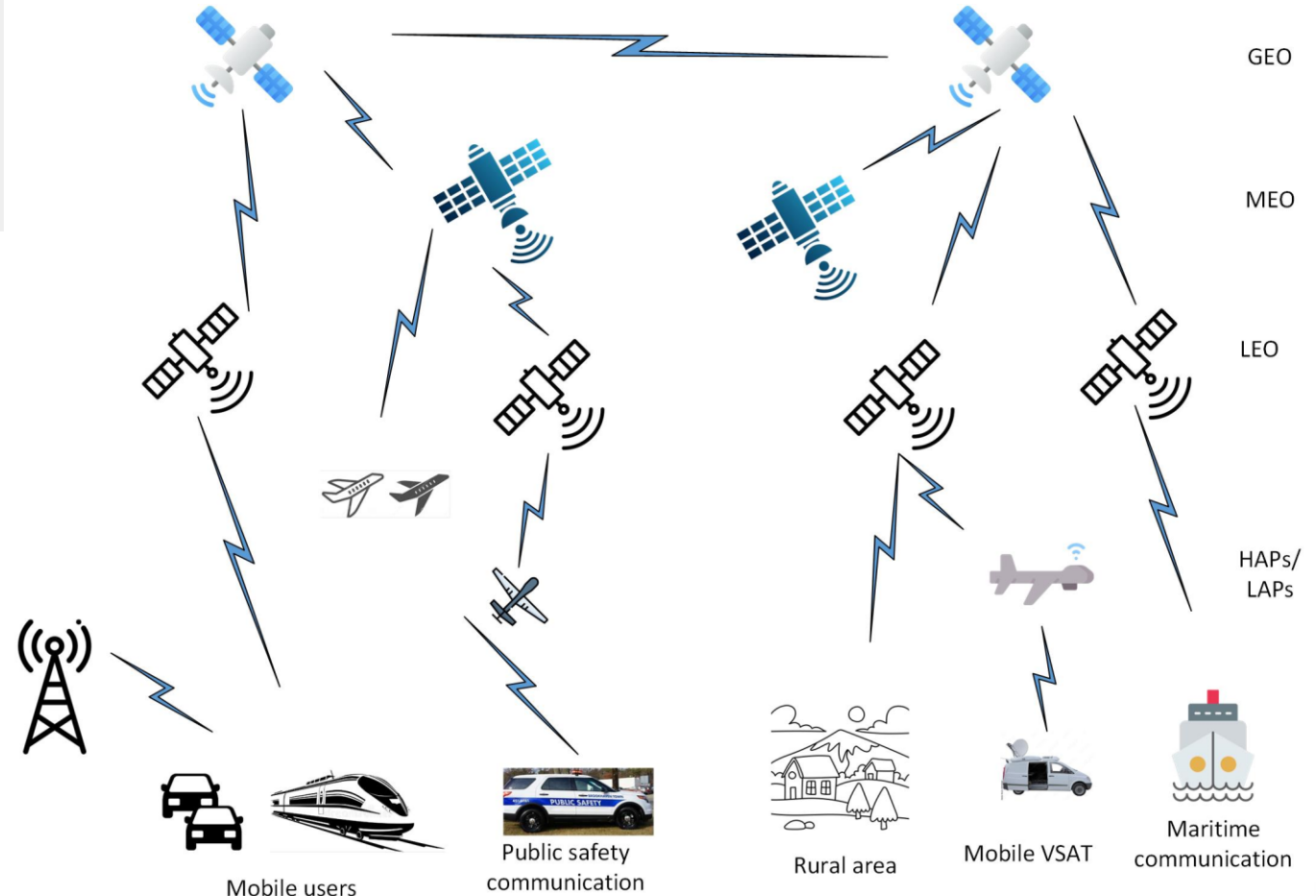


GNSS

<https://www.tallysman.com/>

From 5G-NTN towards 6G

- ❑ Evolution: 5G-NTN → 6G systems
- ❑ Satellite already embedded in 6G
- ❑ 3D multi-layer networks
- ❑ Regenerative payloads



3D Multi-Layer network

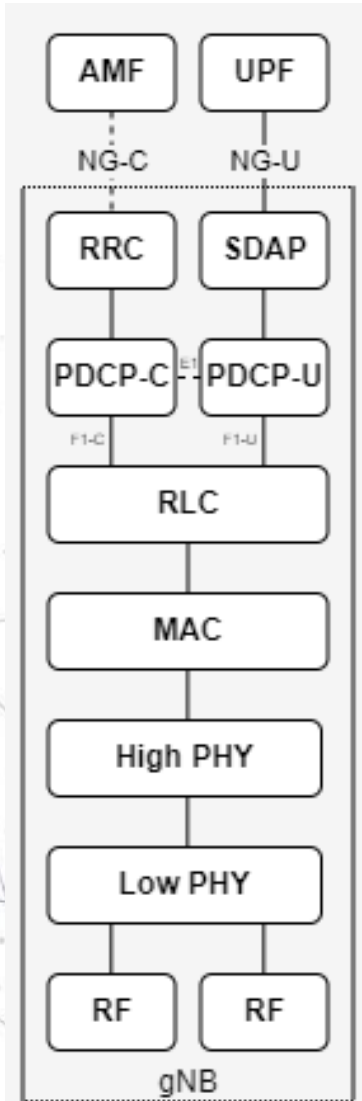
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MC Enabling Technologies

Standardized MC Technologies for 5G TN

User plane split point?



3 Layer 3

- **MA-PDU**: Enables PDU exchanges between UE and the Data Network
- **ATSSS**: Standardizes the functionality of Access Traffic Steering, Switching, and Splitting

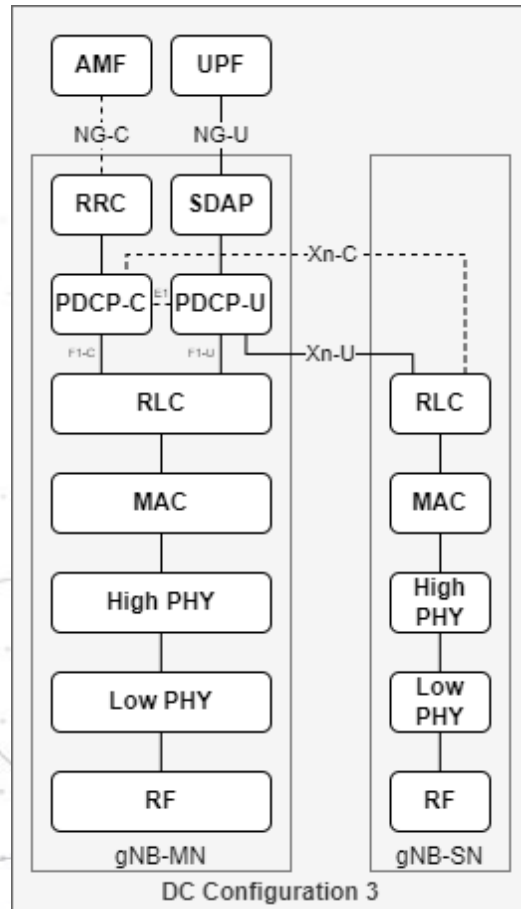
2 Layer 2

- **Dual Connectivity (DC)**: Allows UE to connect to multiple carriers from two base stations
- **Carrier Aggregation (CA)**: Aggregating carriers from connected cells

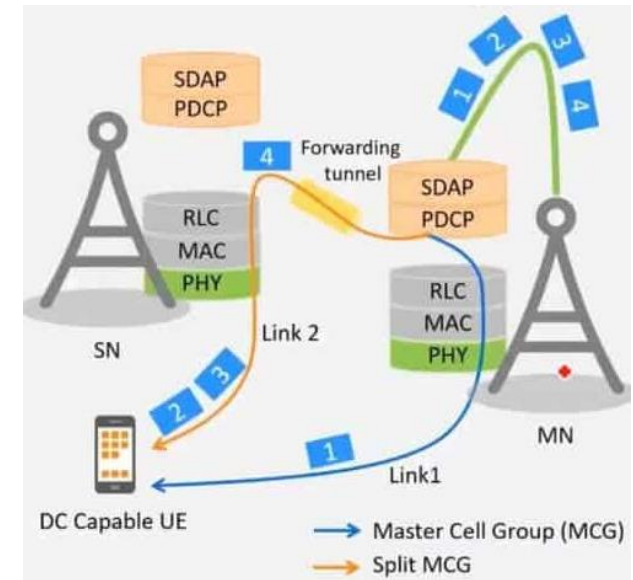
1 Layer 1

- **Multi-Transmission and Reception Points (mTRP)**: Improves QoS for users at cell edge
 - Phase coherent
 - Non-phase coherent

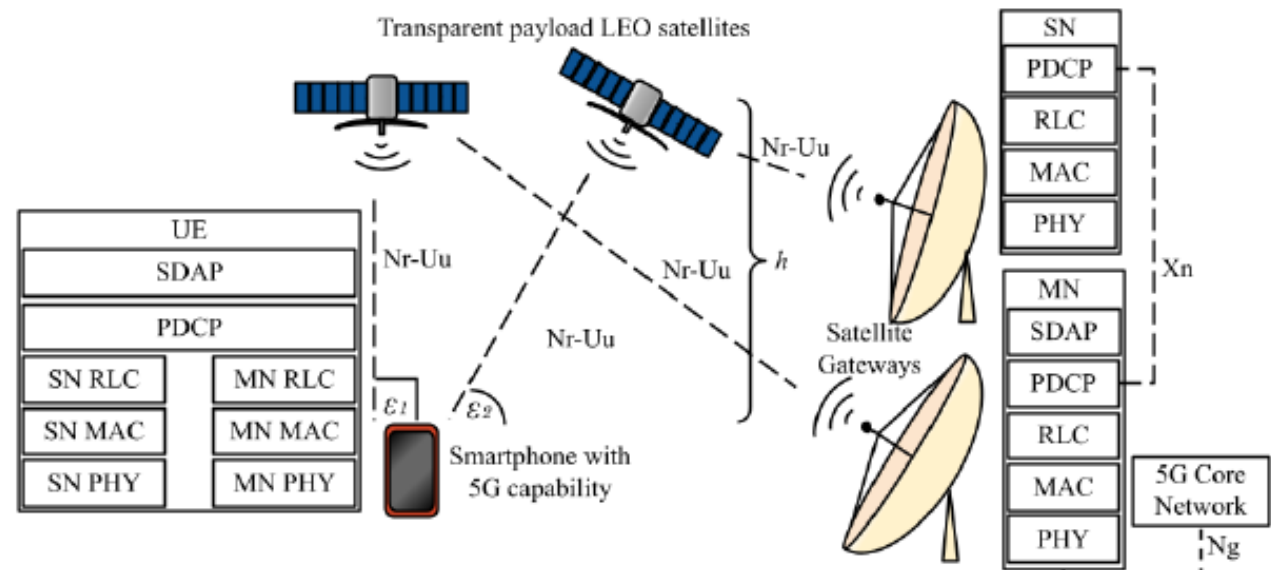
Dual-Connectivity (DC)



- Master/Secondary Nodes
- Split at Link Layer
- Independent link
- Larger UE complexity

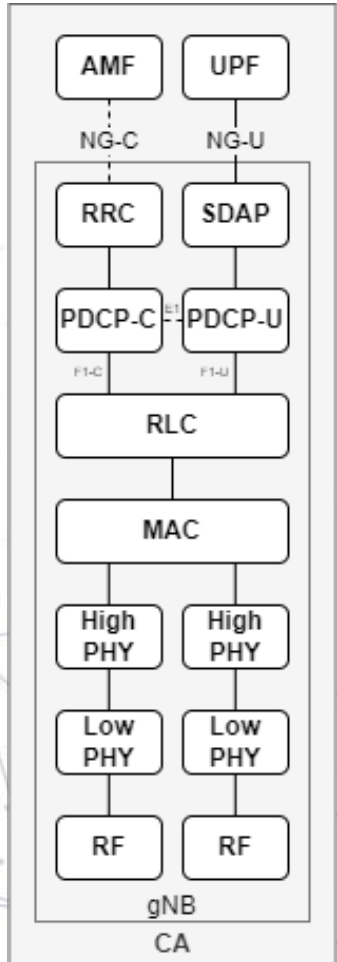


DC in Terrestrial Networks

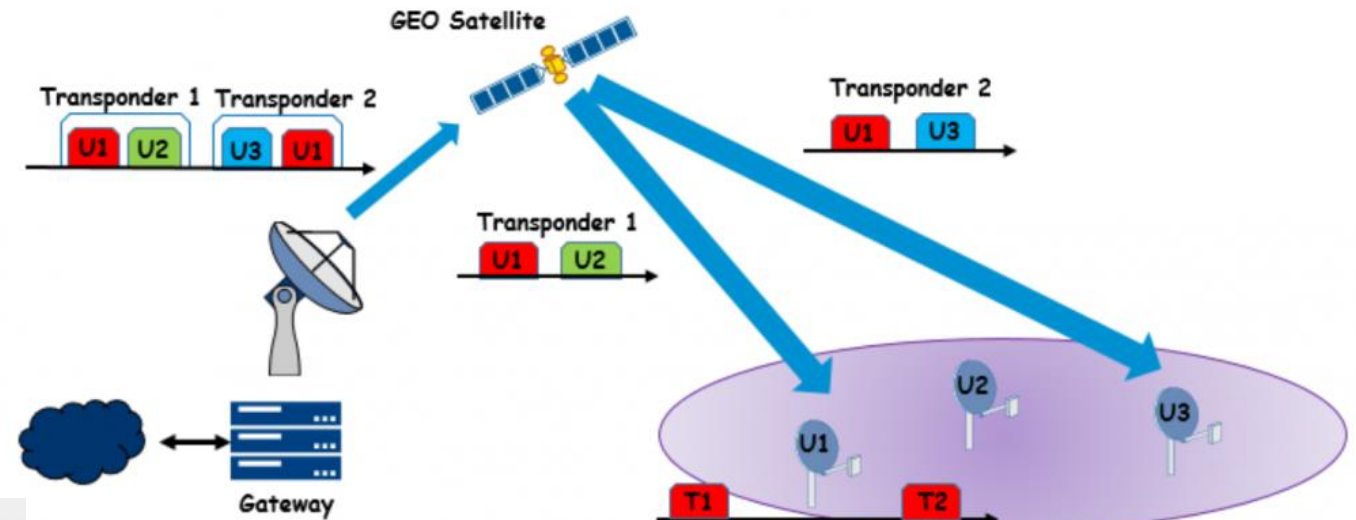


DC in NTN

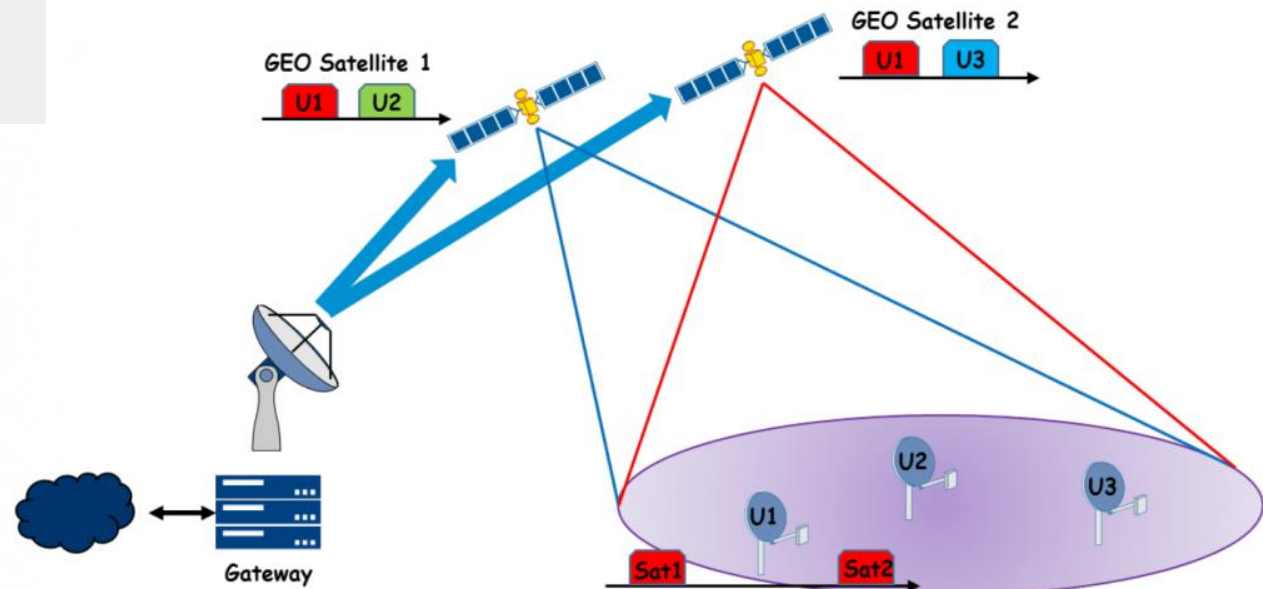
Carrier Aggregation (CA)



- Master/Secondary Cells
- Split at MAC Layer
- Independent cells
- Lower UE complexity

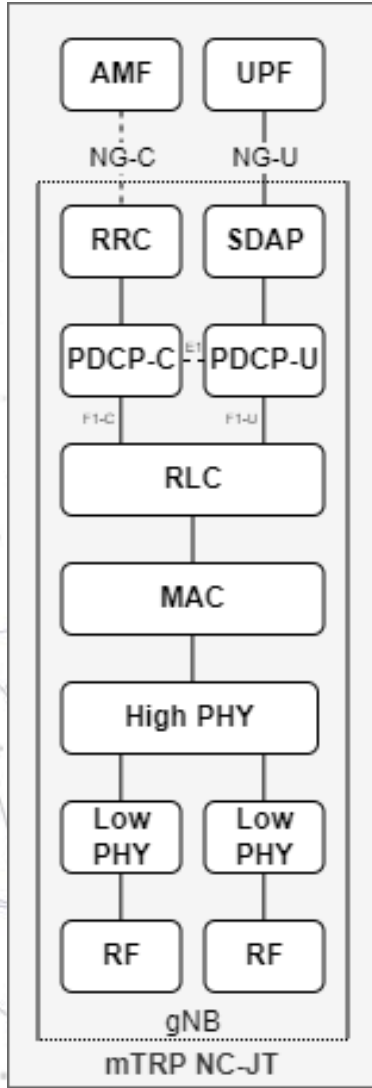


CA in single GEO forward link



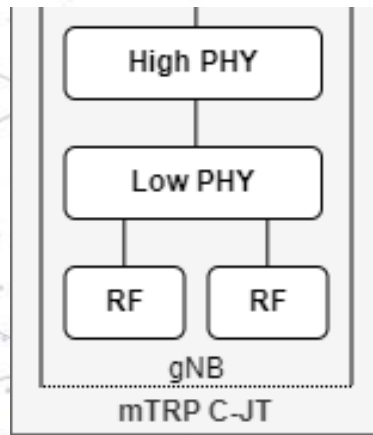
Multi-Satellite CA (GEO-GEO / MEO-MEO)

Multi-Transmission and Reception Points (mTRP)

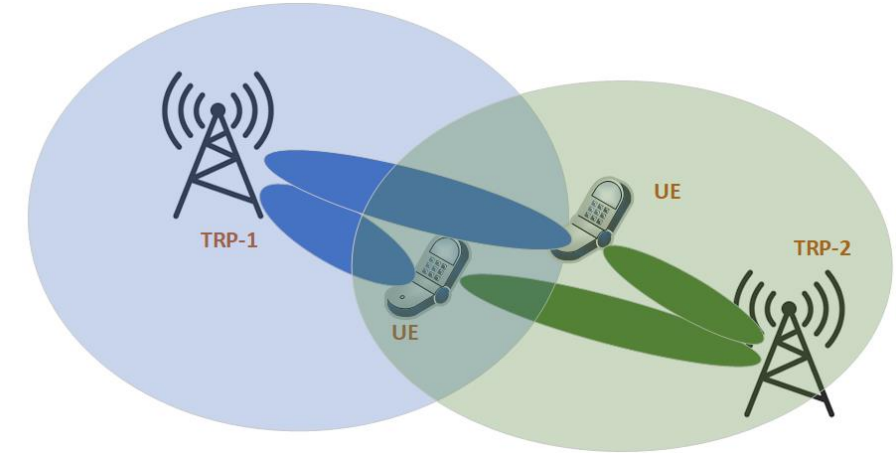


Non-coherent

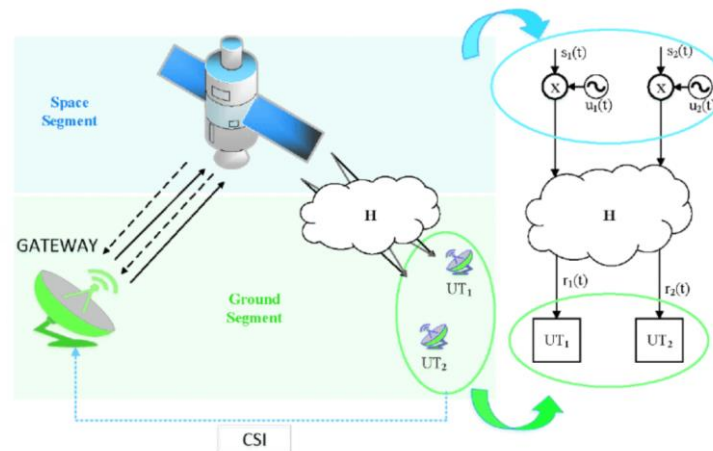
- Coordinated TX/RX
- Split at PHY Layer
- Network complexity
- Non-coherent
 - Time/Frequency BC
 - Polarization-based MIMO
- Coherent
 - Distributed Precoding
 - Distributed Beamforming



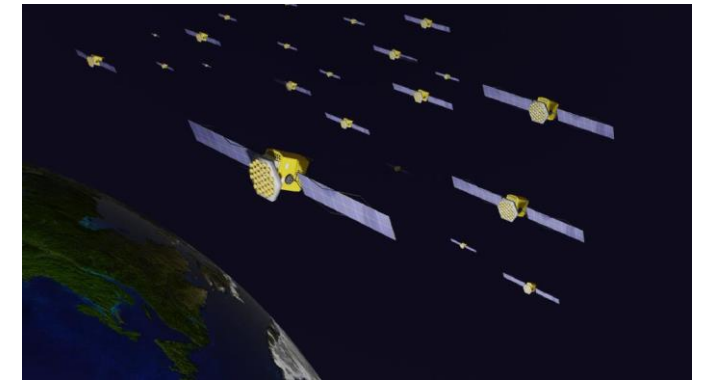
Coherent



mTRP in TNs



Satellite Precoding



Cell-free satellite MIMO?

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Challenges

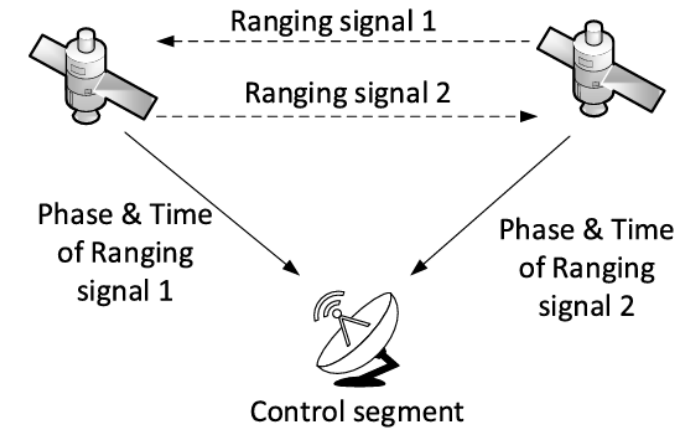
8 challenges for 6G Satellite Multiconnectivity

#	Challenge
1	Multi-satellite synchronization
2	Ground-satellite segment functional split
3	Front-/Mid-haul management
4	Handover & mobility management
5	Distributed resource management
6	Interference management
7	Packet reordering
8	UE antenna

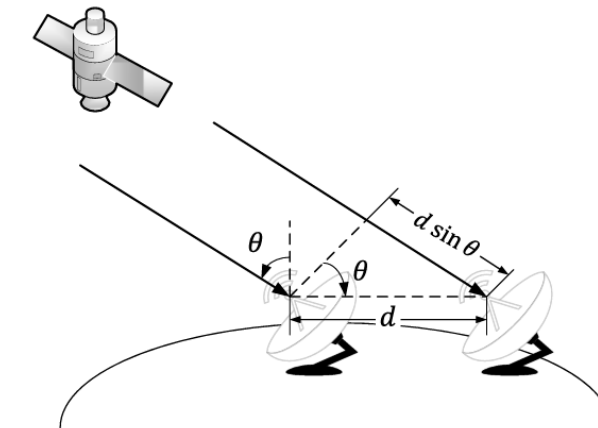
1. Multi-satellite synchronization

- ❑ High complexity and tight requirements
- ❑ Requires efficient signaling protocols and synchronization mechanisms

MC Technique	3GPP MRTD Requirement (TS 38.104)	Approximate MRTD Upper Bound
mTRP C-JT	65 ns (co-located)	$< \frac{1}{f_c}$
mTRP NC-JT	65 ns (co-located)	$< T_s$
CA Intra-band contiguous	260 ns	$< T_{slot}$
CA Intra-band non-contiguous	8 μ s (FR1) 260 ns (FR2-1)	$< T_{slot}$
CA Inter-band	33 μ s (FR1) 8 μ s (FR2-1)	$< T_{slot}$
DC	$T_{slot}/2$ (asynchronous)	PDCP reordering timer



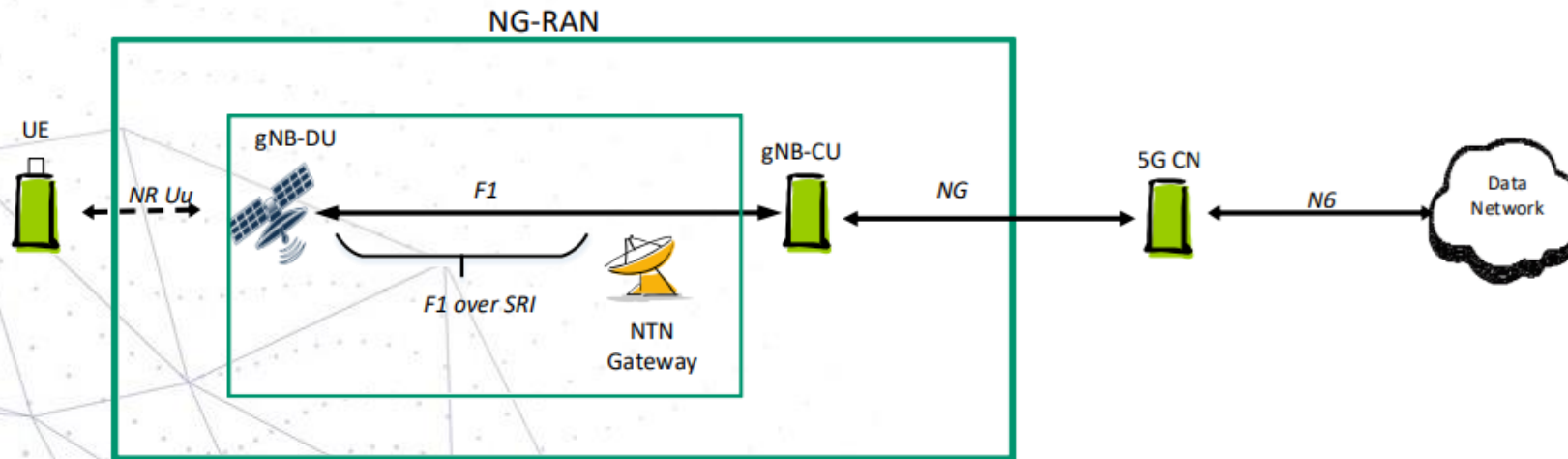
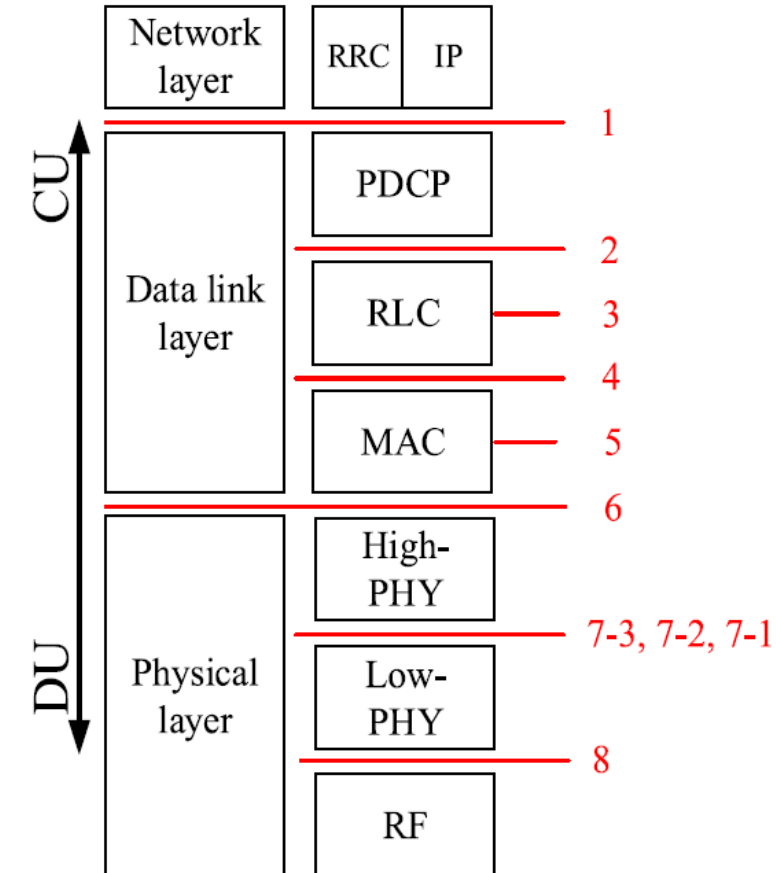
Time & Phase Synchronization



Precise Orbit Determination

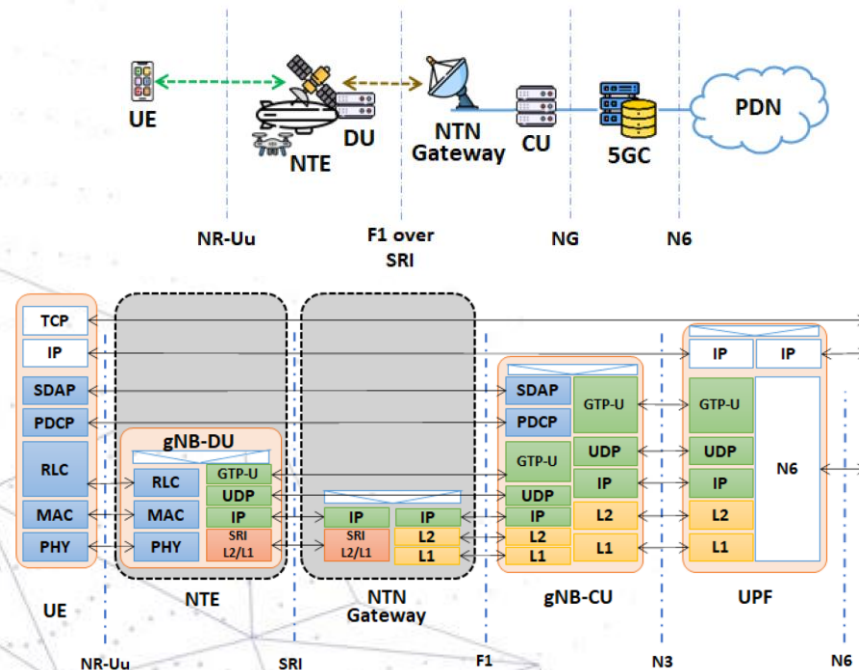
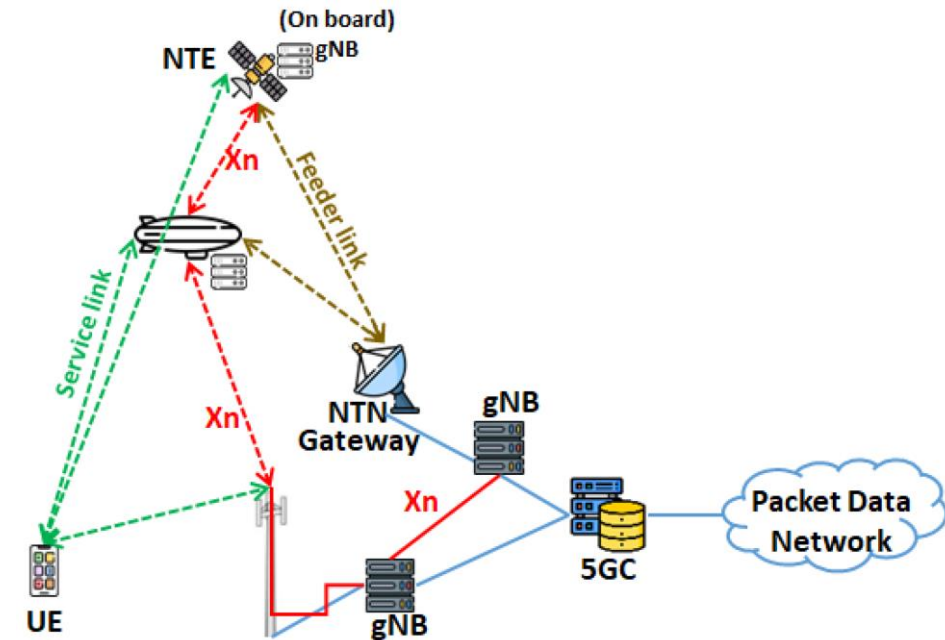
2. Ground-satellite segment functional split

- ❑ Optimal ground-satellite segment functional split
- ❑ Full range from transparent to (partially-)regenerative payload
- ❑ Balancing centralized administration and decentralized processing
- ❑ The split influences MC-enabling technologies applicability



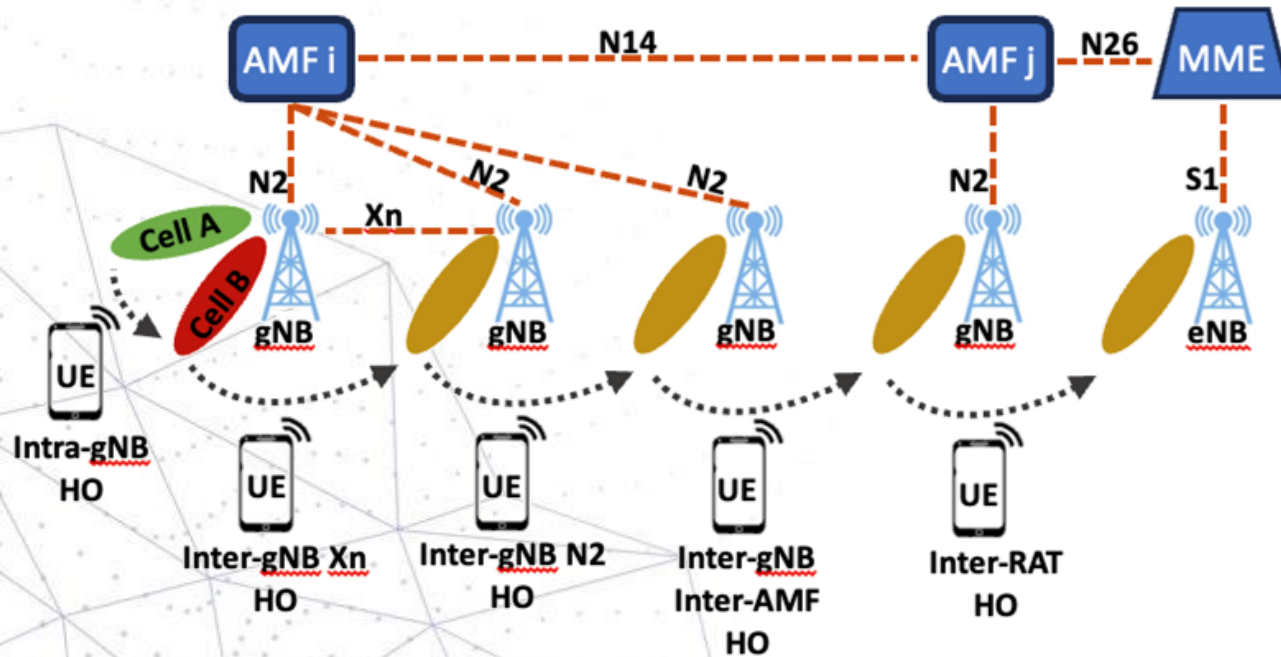
3. Front-/Mid-haul management

- ❑ Interface Management (SRI/Xn/NG)
- ❑ Bridges master and secondary TRPs/cells/nodes
- ❑ Challenges: latency, reliability, interference, adaptability to changing satellite structures
- ❑ Inter-satellite links: RF vs optical



4. Handover & mobility management

- ❑ Hand requirements increase with MC
- ❑ Mobility: satellite platform movement, terrestrial equipment motion, beam switching delays
- ❑ Ensuring smooth exchanges between satellites is key
- ❑ Seamless handover protocols and continuous connectivity

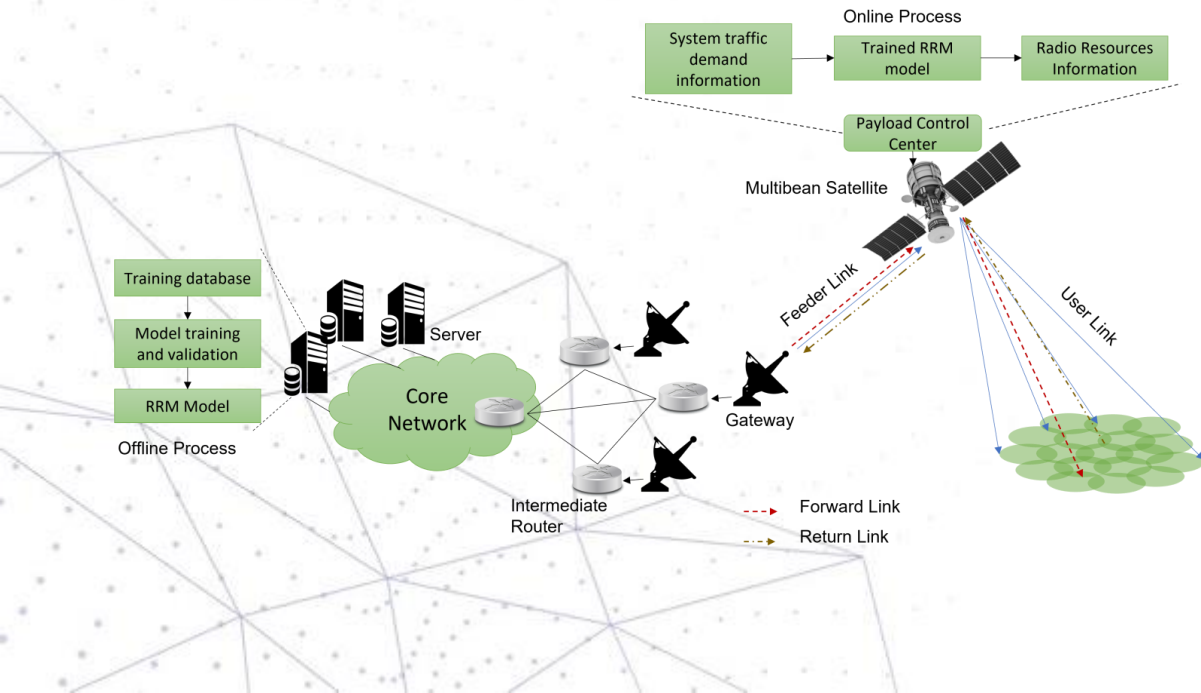
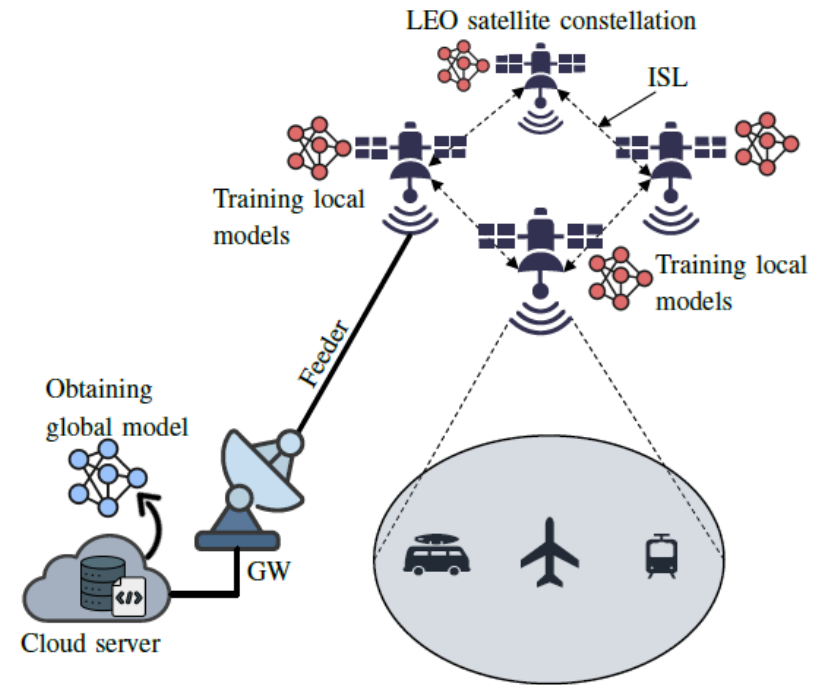


Conditional Handover

- Link quality-based
- Network-based
- Location-based
- Timer-based

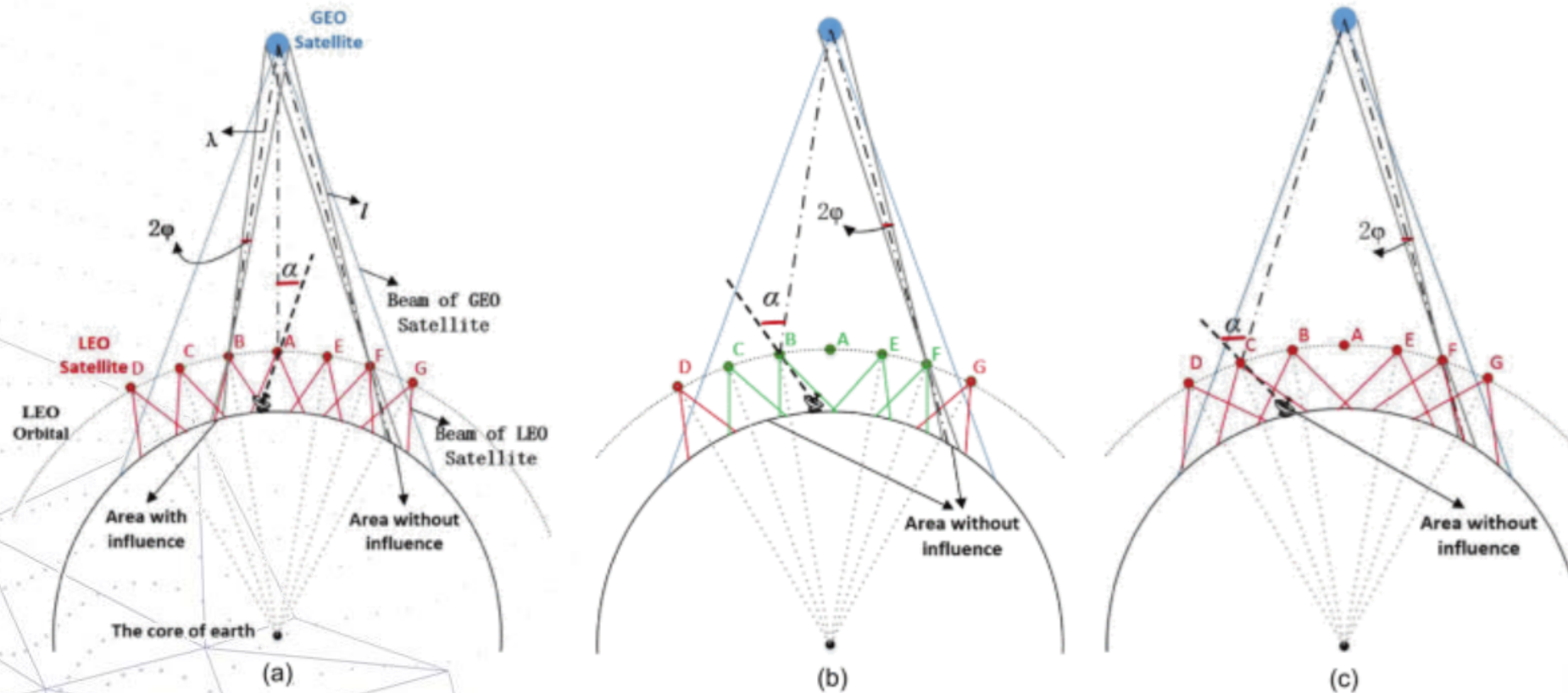
5. Distributed resource management

- ❑ Requires effective allocation algorithms for multiple nodes and bands
- ❑ Focus on spectrum efficiency, resource sharing, and dynamic strategies
- ❑ AI-based federated learning approaches gaining trend



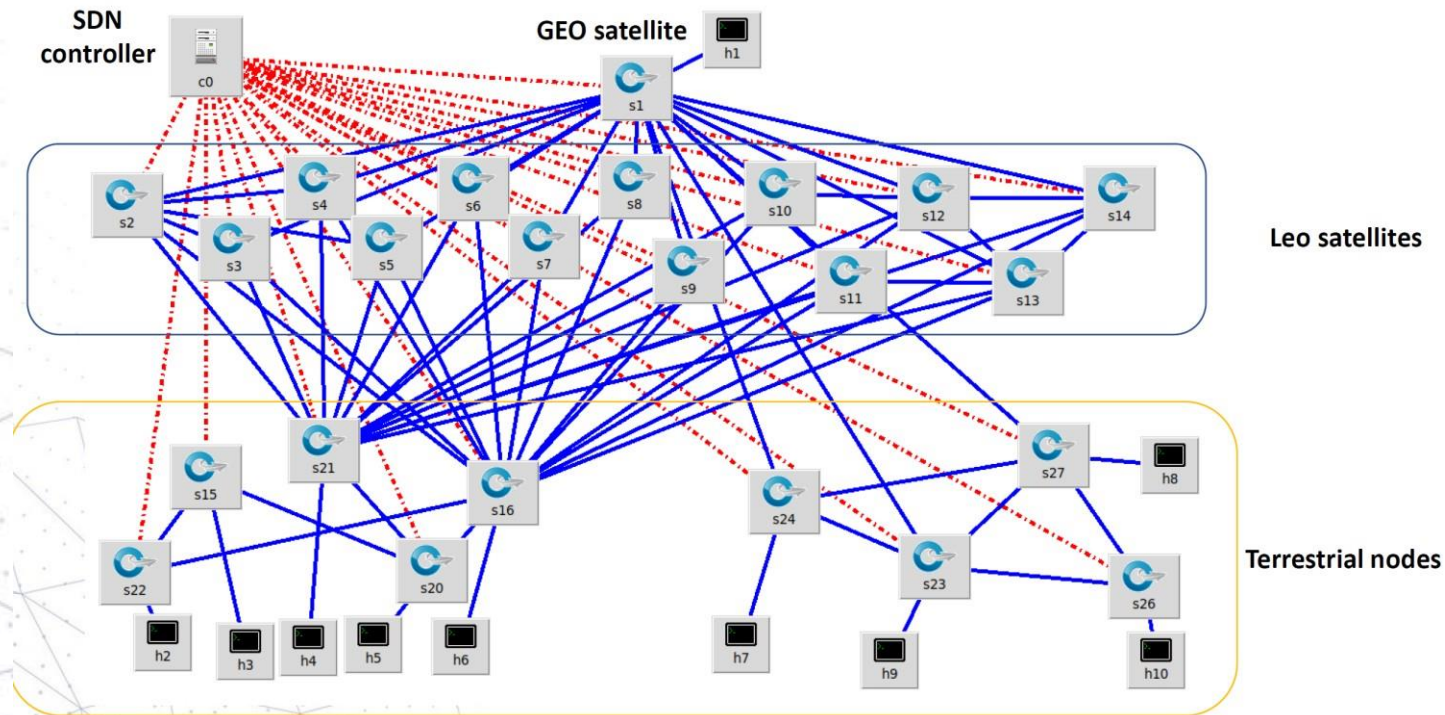
6. Interference management

- ❑ Interference between RANs (NTN and TNs) and frequency bands affects signal quality
- ❑ Solutions: adaptive beamforming, interference cancellation, spectrum coordination



7. Packet reordering

- ❑ Heterogeneous radio links cause variable delays
- ❑ Results in out-of-order PDU arrival
- ❑ Need innovative reordering methods for MC in NTN (Time-Sensitive Networking, SDN)
- ❑ Load-balancing vs packet splitting



8. UE antenna

Capable to close link budget?

- ☐ Low-directive / hemispheric antennas
- ☐ Multiple mechanically steerable reflector antennas
- ☐ Mechanically steerable antenna array
- ☐ Electrically steerable antenna array



Ku-Ka band convertible
antenna



Mechanically steerable antenna array dual
band



Electrically steerable
antenna

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Conclusions

Conclusions

- ❑ SatCom will be an integral part of 6G implementing 3D networks
- ❑ Multi-satellite connectivity can enhance throughput and reliability for selected use-cases
- ❑ Multiple MC enabling technologies under evaluation at different layers
- ❑ Multiple challenges need to be solved for effective implementation



Interdisciplinary Centre for Security, Reliability and Trust

Contact:



Jorge.Querol@uni.lu

Connect with us



@SnT_uni_lu



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