Non-Terrestrial Networks: Architecture and Implementation Challenges

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Presenter

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- Work as Software Analyst in 5G, 6G and IoT projects at Eldorado Research Institute.

Agenda

- Introduction
- NTN Standardization and Architectures
- Challenges of the NTN
- Conclusion and Future Work

Introduction

- NTNs use LEO, MEO, GEO satellites and HAPS to extend 5G/6G services beyond terrestrial reach.
- They address gaps in connectivity in remote, maritime, polar and disaster-affected regions.
- Key advantage: support for legacy devices through 3GPP standardization enabling seamless interoperability.
- Integration with 5G Core enables resource management and mobility support across terrestrial and non-terrestrial links.
- Major challenges: Doppler effects, long propagation delays, robust handovers, and service continuity.

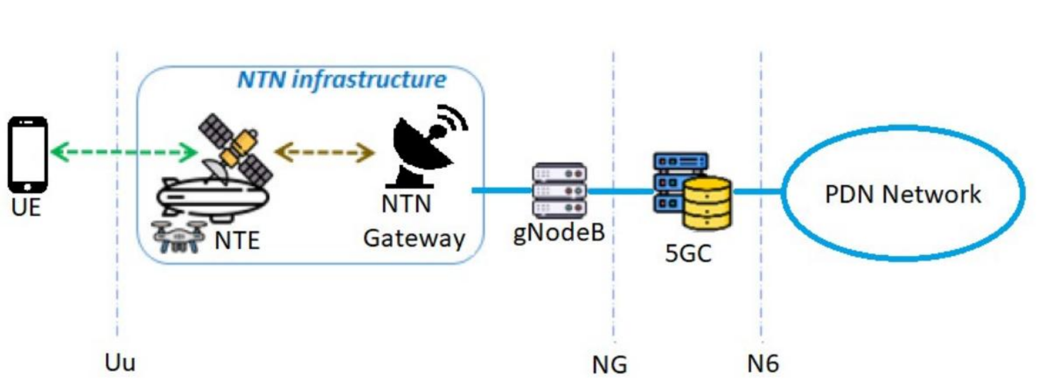
NTN Standardization and Architectures

- 3GPP Releases 15–20 define NTN evolution:
  - R15–R17: foundational support for IoT, NR adaptation, mobility and latency management.
  - R18–R19: HAPS integration, AI/ML for resource optimization, secure protocols.
  - R20: focus on scalability, sustainability, and real-time communications for 6G.

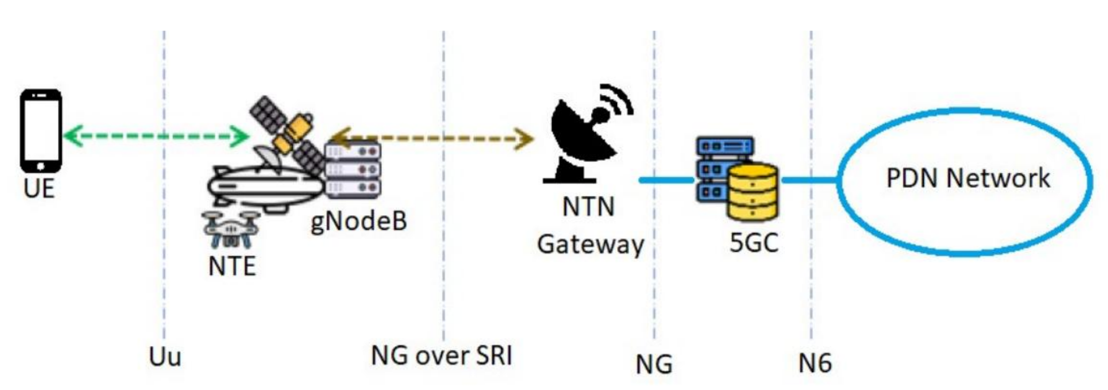
- Architecture types:
  - Transparent: Ground-based gNodeB, low satellite complexity.
  - Regenerative: Satellite processes signal, lower latency.
  - Distributed: Split gNodeB (DU in satellite, CU on ground), flexible and efficient.

- Protocol stacks differ by architecture (User & Control Plane split).

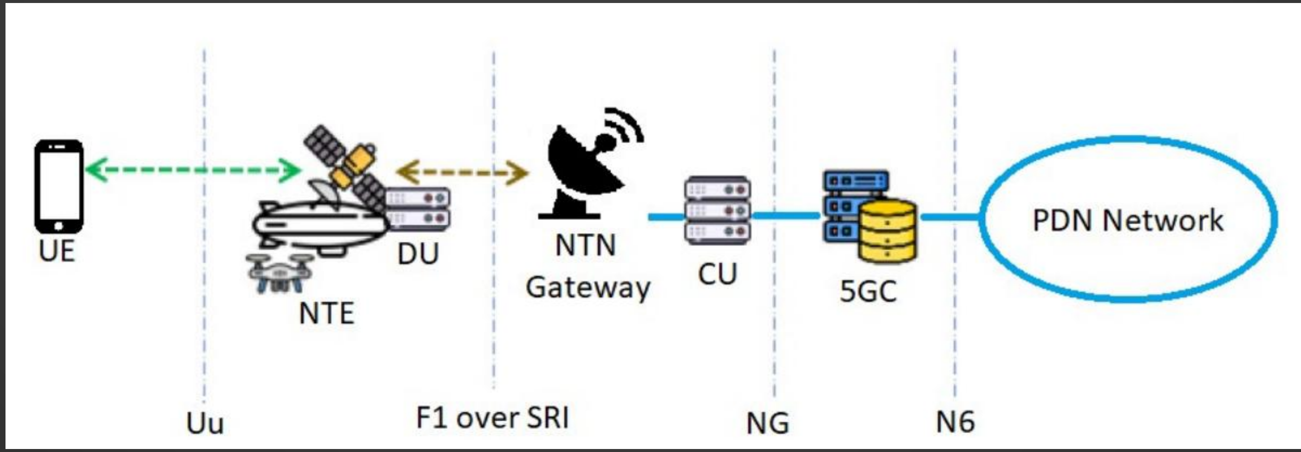
Architectures



Transparent Architecture



Regenerative Architecture



Distributed Architecture

Challenges of the NTN

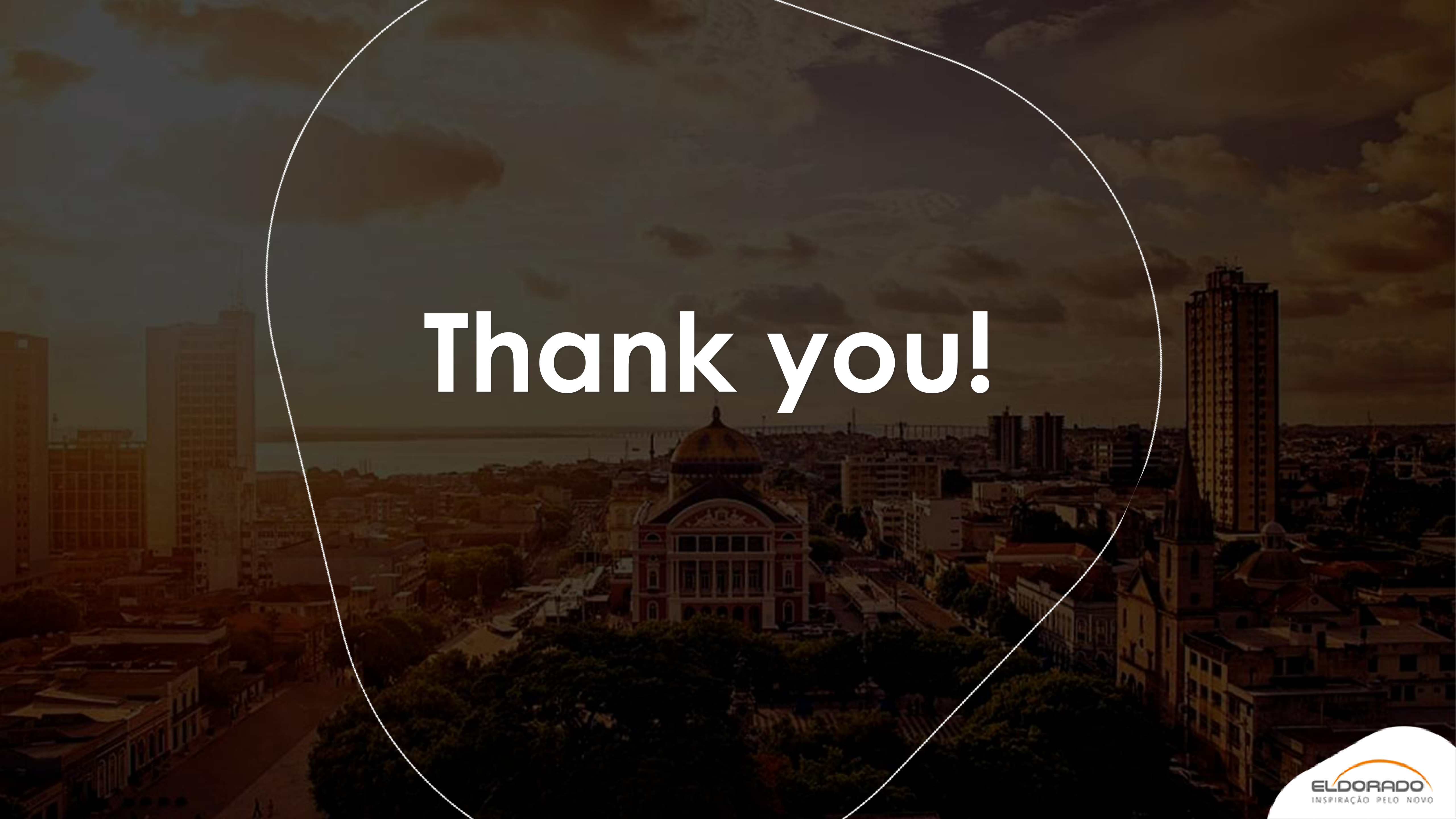
- **Backhaul:**
  - 38 GHz band viability with rain attenuation ~27 dB/km.
  - Use of portable base stations, HAPS, ATPC & ACM techniques.
- **Handover:**
  - Frequent due to satellite motion, latency heterogeneity.
  - Requires AI-based real-time adaptation and channel prediction.
- **Radio Link Failure:**
  - Triggered by low SNR, satellite movement, interference.
  - Need for robust AS and NAS recovery mechanisms.
- **Reconfigurable Intelligent Surfaces (RIS):**
  - Enhances coverage, reduces energy use, but requires AI for real-time optimization.
  - Hardware complexity and dynamic environment challenges persist.

Conclusion and Future Work

- NTNs are pivotal for 5G/6G global coverage, resilience and remote connectivity.

- Key enablers:
  - AI/ML for dynamic handover and resource allocation.
  - RIS to enhance signal strength, reduce power and improve security.
  - Edge computing on satellites to reduce latency.

- Future Work:
  - Secure, adaptive handover protocols for high-mobility.
  - Smart spectrum sharing strategies.
  - NTN-optimized architectures for autonomous vehicles, IoT, and smart cities.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