Transport Optimization in Satellite Networks:
- 3GPP Use cases, Challenges & Considerations

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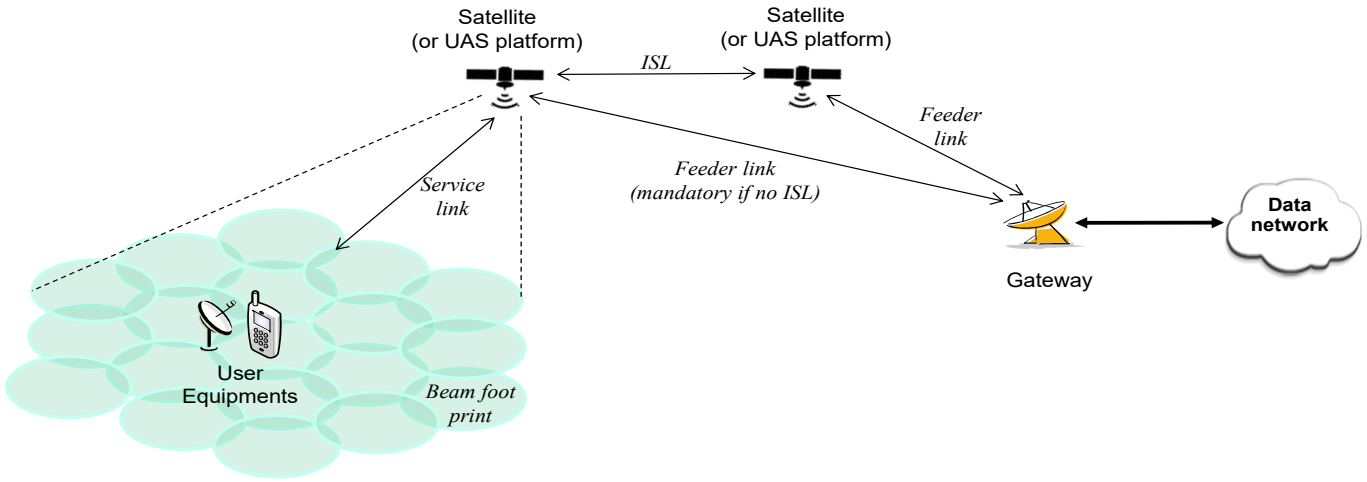
Agenda

- 3GPP NTN evolution & use cases
  - Rel-18 (Transparent), Rel-19 (Regenerative)
  - Rel-20 (A case: 5G VN group)
- Recaptures of IETF-122 discussions on transport optimization
- Satellite-Network: Problems, Challenges, Uniqueness, and Potential Optimization

3GPP Use Cases: Rel-18: Satellite as 'Transparent' Relay (2023/06)
3GPP Use Cases: Rel-19 Satellite w/ 'Regenerative' Forwarding (2025/03)

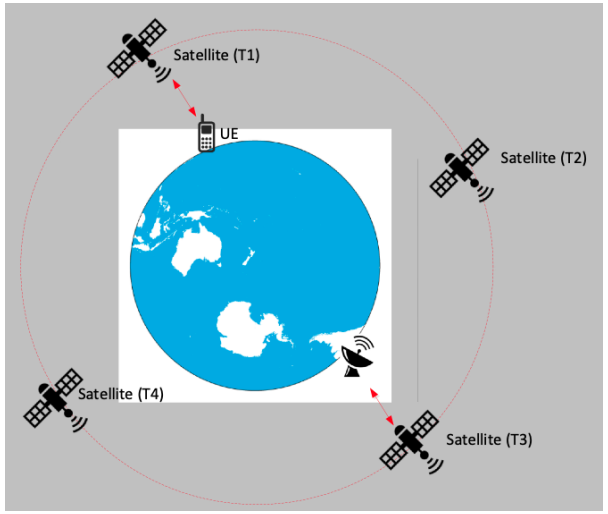
- Satellite constellation network being the infrastructure for wireless **access** and **backhaul**, it provides the transport functionalities for gNB, front haul and back haul.

- Satellite as a transparent relay
- No Inter-Satellite-Link (ISL), i.e., so-called 'bent-pipe'
- No layer-2/layer-3 packet processing, but only layer-1 functionalities like RF filtering, frequency conversion, etc.

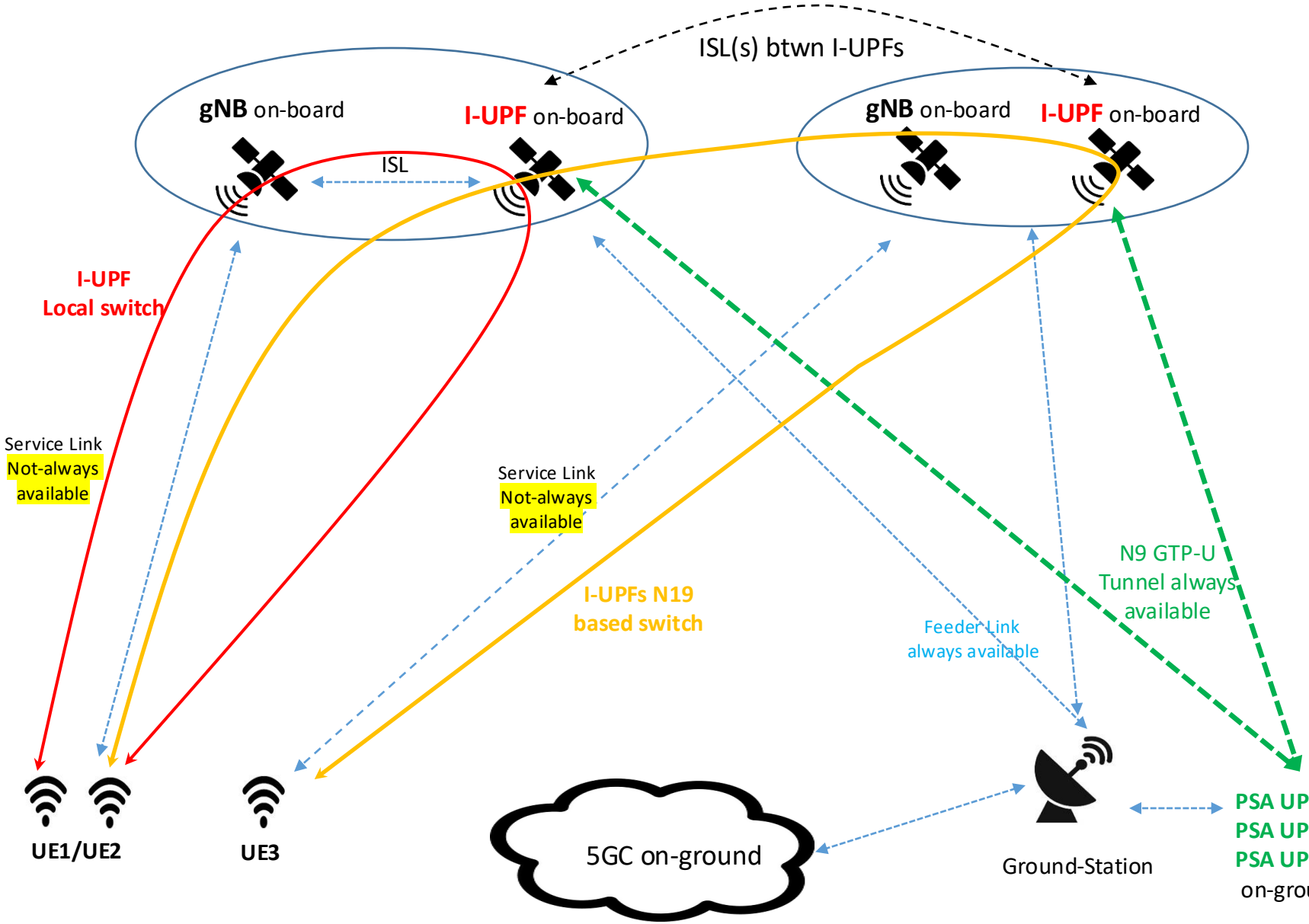


Field of view of the satellite (or UAS platform)

- Satellite w/ regenerative payload (gNB on-board)
- Multi-satellites with Inter-Satellite-Links (ISLs)
- High-layer functionalities:
  - Packet processing, L2 or L3 networking, Large scale networking
- Criticalness of **ISLs** & **SAT-Network**:
  - Note: ISLs *out of 3GPP scope*, but matter to IETF.



3GPP Rel-20: 5G VN Group Service via Satellite (Now on-going)



Pre-assumptions (of some solutions):

1. gNBs and I-UPFs could be on the same or different satellites
2. 5GC on-ground
3. All anchored PSA UPFs on-ground – for non UE-Sat-UE traffic: including UE sending UL to and receiving DL from other terrestrial-based UEs
4. Having on-board I-UPF(s) for UE-Sat-UE communication

3 scenarios for UE-Sat-UE:

1. UEs with corresponding PDU sessions anchored at the same on-ground PSA UPF – local switch;
2. UEs with corresponding PDU sessions anchored at different on-ground PSA UPFs, which are connected via share tunnel off N19;
3. UEs with corresponding PDU sessions anchored at different on-ground PSA UPFs, which are connected via share tunnel off N6;

(Rel-20) 5G VN Group service: Switch Types

- Local-switch type: for which the UL/DL traffic is locally forwarded by a single (on-board satellite) UPF (functioning like a router) if this UPF is the 'anchor' for all the participating UEs of the same 5G VN group;
- Inter-UPF type: for which the UL/DL traffic for the 5G VN group communication is forwarded between/among 'anchors' of different participating UEs.

5G VN Group service (*also in general*): Problems & Challenges

- **High latency**: thanks to potential long-distance satellite paths
- **High loss**: harsh environment in outer space impairing the transmission quality, e.g., radiation, solar storm, etc.
- **Path instability**: thanks to extremely dynamic topology of satellite network, leading to frequent ISLs break-up & reconnection between satellites, satellite handover, etc.
- **Path switchover & multi-path impacts**: related to equipment features and network design, e.g., frequent beam scanning of (phased array) antennas, peering changes between/among neighboring satellites, UE mobility, etc.

❖**Result in challenges & performance degradation in various aspects: e.g., challenges in the transport-layer protocols, like TCP.**

Recapture from IETF-122 @ Thailand (March 2025): - Varieties of Possible Optimization

Existing transport protocols (e.g., TCP) were not designed for satellite network (i.e., challenges):

- *Packet loss*: Fairly normal in satellite network, being an indication of network congestion in TCP
  - Losses subject to transmission errors leads to bursty re-transmission -- in congestion control.
- *High delay*: Variation of the end-to-end delay due to the extreme moving dynamics of satellites which results in the constant changing distances of different transmission paths.
- *High BER*: due to low signal-to-noise ratio, rain attenuation, multi-path distortion and shadowing, etc.

The enhancements of network performance have been studied in satellite communication. Some of the work has been done in transport layer. Some of them are listed below (not exhaustive though):

- Multi-path
- Packet-level Encoding
- Cross layer notification
- **Congestion control**

Satellite-Network: Uniqueness & Potential Optimization (1)

- **Uniqueness & Considerations**
  - Predictable & pre-determined satellite 'footprint' (i.e., trajectory, velocity, etc.)
  - Ephemeris: height, inclination, azimuth, time-changed track, etc.
  - Use case: (5G) 'Predictable' SAT-based QoS probing optimization for dynamic backhaul service

Potential optimization for transport-layer protocols, e.g., TCP

- Compared to the deployment over terrestrial networks (or TNs), the traditional transport-layer congestion control mechanism, e.g., TCP CUBIC, etc., when deployed over NTN, would perform much worse due to the adversarial factors in satellite networks. There are some literatures suggesting it be possible to adjust and optimize the traditional TCP congestion control schemes:
  - E.g., TCP CUBIC: To optimize the lost packet repair using Selective Acknowledgement (SACK) [RFC2883] if a packet loss event might occur at the time of a scheduled satellite handover or path switchover. Remember that SACK is a big reason why modern TCP protocols perform well over mobile services.
  - E.g., TCP New Reno: The paper [ACM-MACS] discusses how to tweak the TCP AIMD by modifying the TCP NewReno to emulate the behaviors of multiple concurrent connects in a TCP session.

[APNIC-blog] Geoff Huston, "A transport's view of Starlink', https://blog.apnic.net/2024/05/17/a-transport-protocols-view-of-starlink/, May 2024.
[ACM-MACS] Liz Izhikevich, et. al, "A Global Perspective on the Past, Present, and Future of Video Streaming over Starlink", ACM on Measurement and Analysis of Computing System, Dec. 2024.

Satellite-Network: Uniqueness & Potential Optimization (2)

Potential optimization for transport-layer protocols over 5G communications

– *to leverage the pre-previsioned satellite footprints*

- The 3GPP-based UE-Sat-UE 5G VN service does own the capability of knowing in advance satellite scheduled changes.
- In 5G network [TS.23.501], the 5GC NF AMF can get the satellite ephemeris information via different schemes and provide the satellite footprints to UEs for the optimization of transport services, i.e., UEs leveraging satellite scheduled events to optimize the communication during satellite handover.
- At UEs, these add-on information may help the TCP CC algorithm distinguish between isolated packet loss and continuous losses inducing levels of network congestion.

** 3GPP TS 23.501 (v19.4.0): System Architecture for the 5G System (5GS)", June 2025*

Summary

- 3GPP NTN Use cases & evolutions:
  - 3GPP Rel-18: Satellite as **transparent** relay
  - 3GPP Rel-19: Satellite with **regenerative** forwarding
  - 3GPP Rel-20: (A case) **5G VN Group service**

- Recaptures of IETF-122 discussions on transport optimization

- SAT-Network: Problems, Challenges, Uniqueness, and Potential Optimization
  - Problems & challenges
  - Uniqueness – predictable & pre-determined (e.g., Ephemeris)
  - Potential optimization for TCP

Thank you!