CLUSTERSAT

Bringing Cellular Power to Space.

Optimizing MSS architecture for Direct-to-Device services

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Dr. Santanu Dutta

CO-CEO & CTO

Dr. Santanu Dutta is a veteran of the wireless industry with over 40 years of experience spanning satellites, cellular networks, HF radio, and mobile payments. He has held senior technology leadership roles at Ligado Networks, as Chief Engineer and Head of Technology Research; at Ericsson, where he led satellite and mobile-payments standardization efforts; and at Rockwell, contributing to military HF systems and Mobile Satellite Services (MSS).

He holds a PhD in Electrical Engineering from the University of Manchester, M.SC from the University of Bradford and B.Tech (Hons) from IIT Kharagpur and is a named inventor in more than 75 patents. Dr. Dutta's career bridges deep technical innovation and real-world implementation, with a lasting impact on both commercial and defense wireless technologies.

Market Need

A mobile satellite system offering high Capacity-Density – Net Capacity is less important

- Satellite and cellular stakeholders are united to introduce **hybrid, satellite-cellular networks providing D2D service** to
  - **improve user retention in urban/suburban areas by filling 5G coverage gaps,** thereby improving user roaming experience
  - **harvest additional revenues from remotes areas** with poor cellular coverage
  - In all use cases**, the need is for at least 4G service to clusters of randomly distributed users**
- **Billions of dollars have been invested** by the largest technology companies.

Limitations of currently planned systems

Very large satellite antennas that drive up cost.

Spectrally inefficient radio access technologies

Present first movers—**AST SpaceMobile (AST) and Starlink**—are driving satellites toward **higher cost/risk** by **maximizing antenna aperture**, while relying on **inefficient, space architectures.**

Antenna size is the biggest risk in a satellite

- AST and Starlink employ apertures of approximately 8 m and 40 m. Nominal aperture for a < 3 GHz LEO system is typically ~1–2 m.

Inefficient, traditional space architectures

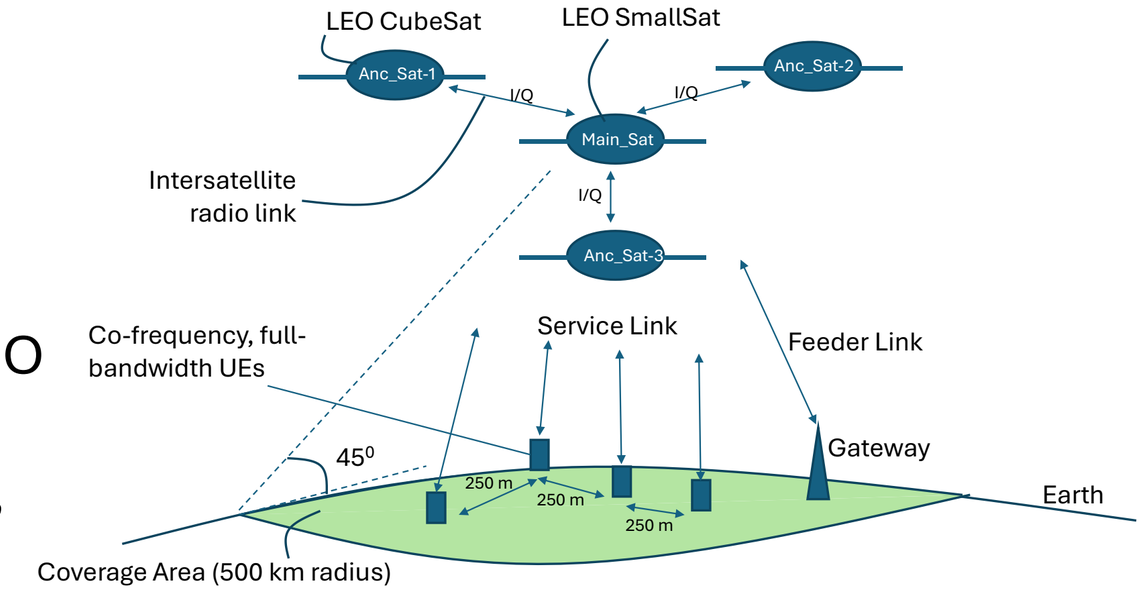
- Satellite user are typically clustered, not numerous, requiring high Capacity-Density, not high Capacity.
- Existing satellites use traditional beamforming, which link Capacity-Density and Capacity -- not possible to provide one without the other.

ClusterSat's offering

High capacity-density at low cost via high resolution MU MIMO from space

Enabling means

- Fractionated satellite (cluster of 9-17, low-cost small satellites acting as one, adaptive phased array antenna)
- Synthetic aperture of ~ 400 m
- Hybrid of traditional beamforming and MU MIMO
- Frequency reuse distance of 250 m
- Patented, validated by Monte Carlo simulation, PoC field trial planned



Differences from traditional MSS:
(1) Power focused on desired users
(2) Frequency reuse distance of 250 m

Combination of very high synthetic aperture and MU MIMO from space

ClusterSat uses multi-user MIMO (MU-MIMO) to focus power on desired users.

- MU-MIMO steers desired signal power toward scheduled users while avoiding unscheduled users -- results in substantially **superior power and spectrum efficiency** than traditional beamforming.

ClusterSat's fractionated satellite creates a **synthetic aperture spanning several hundred meters**

- Results in a **frequency-reuse distance of ~250 m, compared to 21 km for AST,** and **a capacity-density exceeding those of AST and Starlink**.

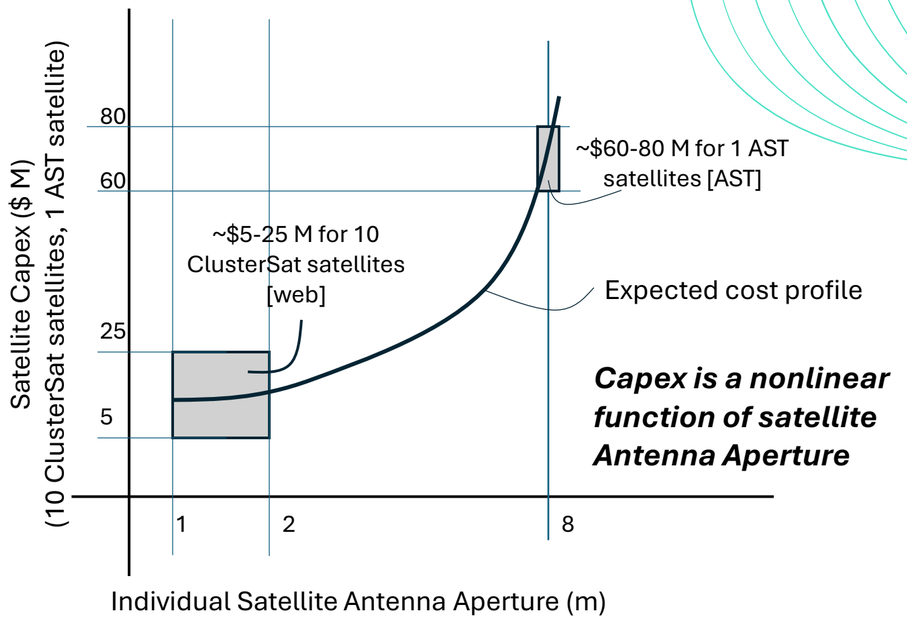
Differences from traditional MSS:
(3) Small satellites

Satellite cost increases non-linearly with size.

Satellite antenna aperture is a prime driver of satellite capex/launch cost

- Antenna aperture drives satellite size, which drives development and launch costs

ClusterSat's patented **fractionated satellite replaces an expensive, large satellite by a cluster of inexpensive small satellites,** each with an aperture of approximately ~1-2 m.



Differences from traditional MSS: (4) High spectral efficiency, interference rejection

MIMO increases spectral efficiency and provides interference immunity

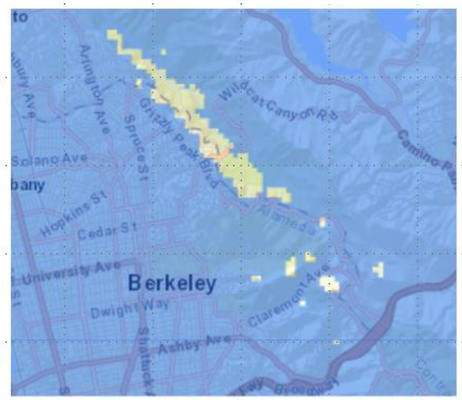
- Spectrum scarcity is a major challenge for D2D deployment
- By using **Space Division Multiple Access (SDM) implicit in MIMO,** in addition to TDMA/FDMA, ClusterSat **substantially increases spectral efficiency** relative to existing systems.
- Through **over-provisioning the number of satellites, MIMO introduces AJ capabilities to the radio access system**. Can be exploited to aid regulatory compliance as well as jamming protection in military applications

What should a D2D KPI be?

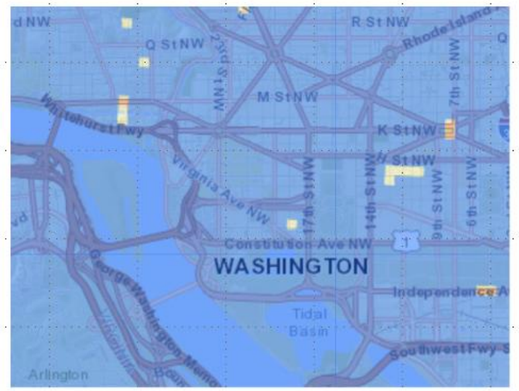
Per-user throughput, or capacity density, is the prime KPI for D2D

Urban

AT&T's LTE(5/1) Berkely, CA Coverage Map (as of Dec. 15, 2021)

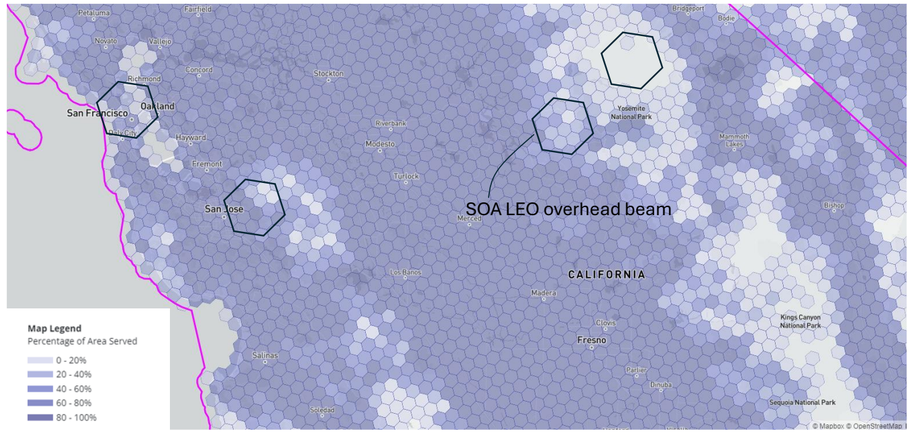


AT&T's LTE(5/1) Washington D.C. Coverage Map (as of Dec. 15, 2021)



Rural

AT&T's LTE(5/1) N. California Coverage Map (as of Dec. 31, 2022) [FCC database]



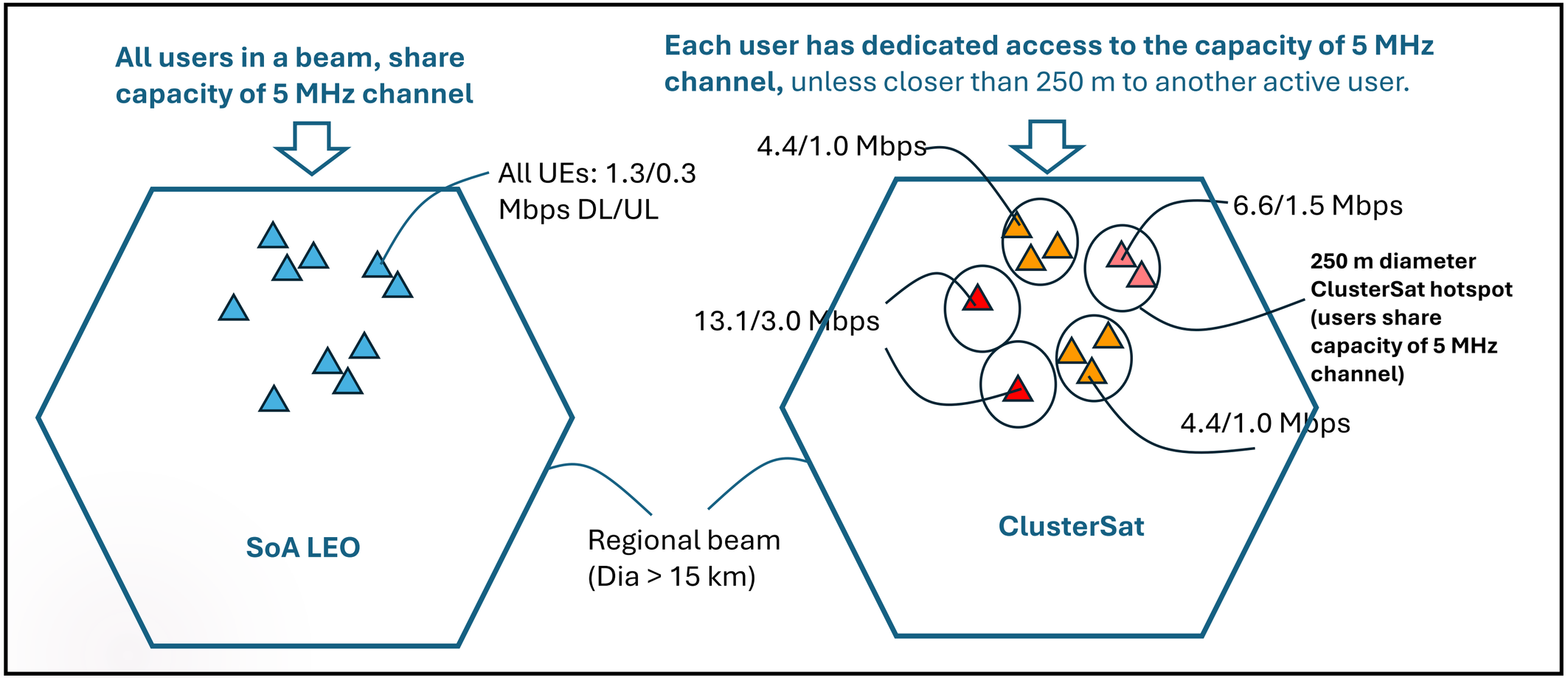
Note: Each cell (small hexagon) has a diameter of approx. 4 km. The large hexagon has a diameter of approx. 15 km and represents a SOA LEO beam with overhead satellite.

Capacity Density Comparisons

Per-user throughput, or capacity density, is the prime KPI for D2D

- The capacity density of ClusterSat and AST were compared using
  - Link budgets guided by 3GPP NTN assumptions/methods
  - Extensive Monte Carlo simulations of ClusterSat's PHY layer and satellite channels to validate MIMO processing gains
  - Use cases
    - Urban environment (fill coverage gaps in deployed cellular networks), throughputs 5/1 Mbps (DL/UL) per user
    - Rural environment, throughputs 1/0.2 Mbps (DL/UL)
      i. uniform user distribution (harvest greenfield cellular market covered from space)
      ii. non-uniform user distribution (serve remote areas with partial cellular coverage)

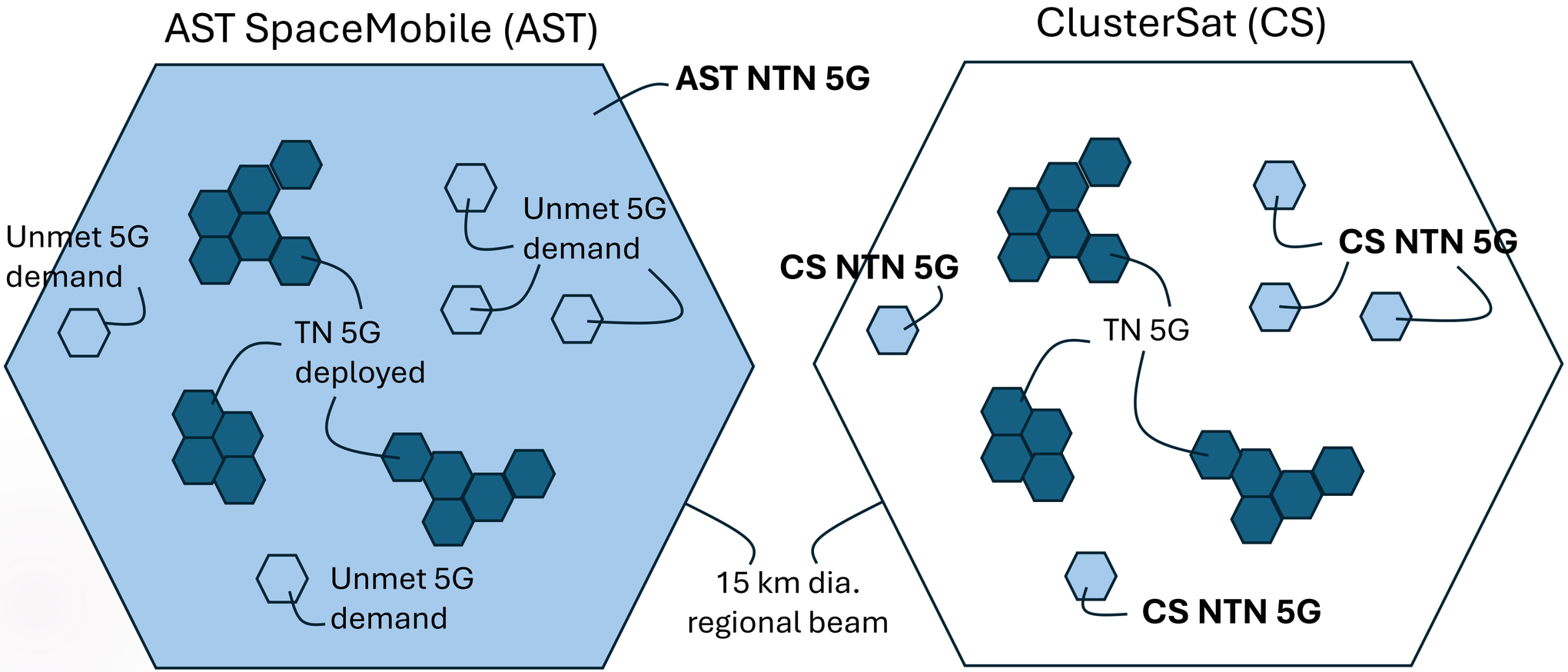
Example analysis for Urban environment



Notes

- *For SOA LEO, traditional beamforming dilutes per-user throughput with increasing number of active users.*
- *ClusterSat, by leveraging SDM, enables every active user to experience a lightly loaded channel.*

Example of Rural case, non-uniform & sparse user distribution



7 satellites are sufficient for CS to provided 13/3 Mbps (DL/UL) in the above scenario

Conclusions

Conclusions

- **Capacity Density** is a more meaningful KPI for D2D services than **Net Capacity**
- A **fractionated satellite with MU MIMO** can deliver **substantially higher capacity density and at much lower cost** than a monolithic satellite using traditional beamforming.
- **High Capacity-Density leads to transparent handovers** as users transition from terrestrial 5G to satellite-delivered 4G, making the **user experience similar to present roaming in and out of terrestrial 5G**.

Future Work

Furture Work

- Proof-of-concept, **over the air tests using a single cluster**, embodying the present innovations, planned.
- **Development of a baseband ASIC embodying the proprietary lower PHY layer** is planned to allow 3GPP NTN compliant base stations to use the technology with the least disruption.
  - ASIC could be **sold/licensed to mobile satellite or terrestrial cellular operators.**
- **Promote ClusterSat's technology for 3GPP NTN standardization**
  - Interwork with existing 3GPP NTN standards above the lower PHY layer. Interface with BS upper layers via ORAN-affine standards.
  - Long-term goal requiring collaboration with major 3GPP stakeholders.