White Paper

Non-Terrestrial Networks: A Position Paper on Why These Networks are Important to the Federal Government

ATARC Secure 5G Working Group

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Executive Summary

This paper, developed by the ATARC Secure 5G Working Group, discusses the strategic importance of 5G Non-Terrestrial Networks (NTN) emphasizing the significance for government stakeholders. It begins with a foundational background on 5G NTN, explaining how this innovative technology extends the capabilities of terrestrial 5G networks through the use of satellites thereby ensuring global coverage, including remote and underserved areas. The paper covers key technological considerations crucial for the successful implementation and integration of 5G NTN, such as the architecture that supports seamless connectivity between terrestrial and non-terrestrial components, and spectrum management, which is vital to optimize bandwidth and minimize interference among users.

The paper identifies gaps and challenges, including technological hurdles, highlighting the importance of addressing these to harness 5G NTN's full potential. It underscores the critical nature of robust transmission security measures to safeguard against increasing cyber threats in an ever-more connected world.

Highlighting the evolutionary path of 5G NTN, the paper posits that this technology is pivotal for achieving ubiquitous connectivity, supporting economic growth, enhancing national security, and fostering technological innovation. It calls on government bodies to proactively engage in the development and deployment of 5G NTN by setting clear policies and leading international collaboration efforts. The overarching message is clear: 5G NTN represents a transformative opportunity for global connectivity and security that requires governments attention, positioning 5G NTN as a critical infrastructure component for future-proofing telecommunications.

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Background

The government sees 5G technology as a true game changer for military and civilian agencies. The Department of Defense (DoD) and multiple other civilian agencies are already aggressively pursuing 5G Strategy Implementation Plan.[1] The plan includes promoting 5G technology development, testing both the advantages and potential vulnerabilities of 5G, engaging with private-sector partners, and actively influencing industry as policies and standards are developed and put in place. The government sees the following lines of effort as necessary in the adoption and enablement of 5G technology with government:

1. Promote technology development,
2. Assess, mitigate, and operate through 5G vulnerabilities,
3. Influence 5G standards and policies, and
4. Engage industry partners.

These are generalized 5G adoption techniques for government. The purpose of this document is to give high level background on what Non-Terrestrial Networks (NTN) are and how NTN can be integrated into 5G Terrestrial networks and beyond 5G networks to best benefit the government.

Overview

Third Generation Partnership Project (3GPP) has defined a standards-based NTN framework that enables economies of scale, a multi-vendor, interoperable, continuous service, backwards compatible capabilities between generations, for NTN. It is designed to support any device, orbit, service, frequency bands, beam size/type natively 5G features, global connectivity, improved QoE, and reliability through multiple connectivity across terrestrial and satellite access, with spectrum coexistence between satellite and terrestrial systems.

As per 3GPP TS 38.821, “A non-terrestrial network refers to a network, or segment of networks using RF resources on board a satellite (or Uncrewed Aerial System [UAS] platform)”. There is NTN and 3GPP 5G NTN. Protocols of NTN do not always comply with 3GPP.

[1] https://www.cto.mil/wp-content/uploads/2020/12/DOD-5G-Strategy-Implementation-Plan.pdf

Architecture

Satellite systems typically use a bent-pipe architecture or an intersatellite architecture to provide connectivity. In a bent-pipe architecture, a device transmits directly to a satellite that relays the communications back down to a ground station without on-board processing capabilities. Regenerative satellites would include on-board processing capabilities. The call or session is then routed through terrestrial networks to the recipient or destination ground station that transmits to the serving satellite that immediately relays the call or session to the receiving mobile device.

In an intersatellite architecture, a device transmits to a satellite that relays the communication across satellites until the call or session reaches its destination. The intersatellite network bypasses the terrestrial communications network to reach its destination. Both the bent-pipe and intersatellite network architecture are shown in Figure 1. Both architectures have tradeoffs associated with performance, security across communication links, deployment costs, etc. Intersatellite links have the potential for improved latency performance and specific end-to-end security. However, the latency performance depends on the distance between satellites and the number of satellites that are deployed.

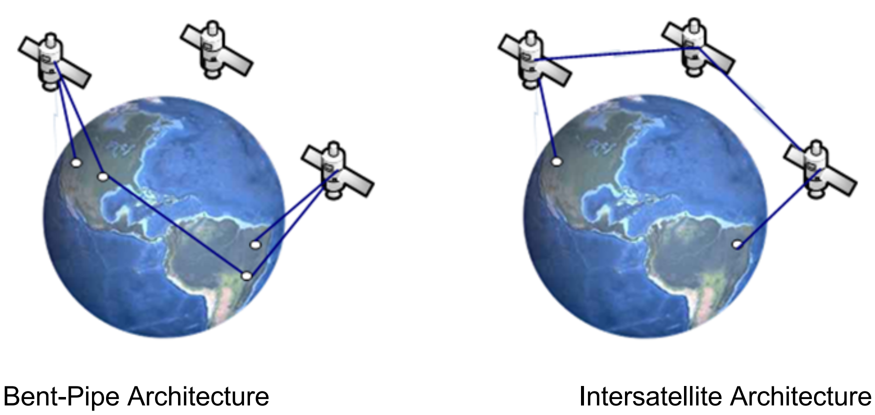

Figure 1 – Bent-Pipe and Intersatellite Conceptual Architecture for a single point-to-point connection.

NTN Satellite and Aerial Platforms

Satellite and aerial networks complement existing terrestrial service areas by extending service access and backhaul capabilities for permanent, temporary, and deployable communications platforms as depicted in Figure 2. They provide the necessary communications capabilities for underserved or unserved service areas, e.g., tribal lands, rural and remote communities, maritime communications, etc. It should be noted that 3GPP release 17 did not address Aerial vehicle NTN operation and integration.

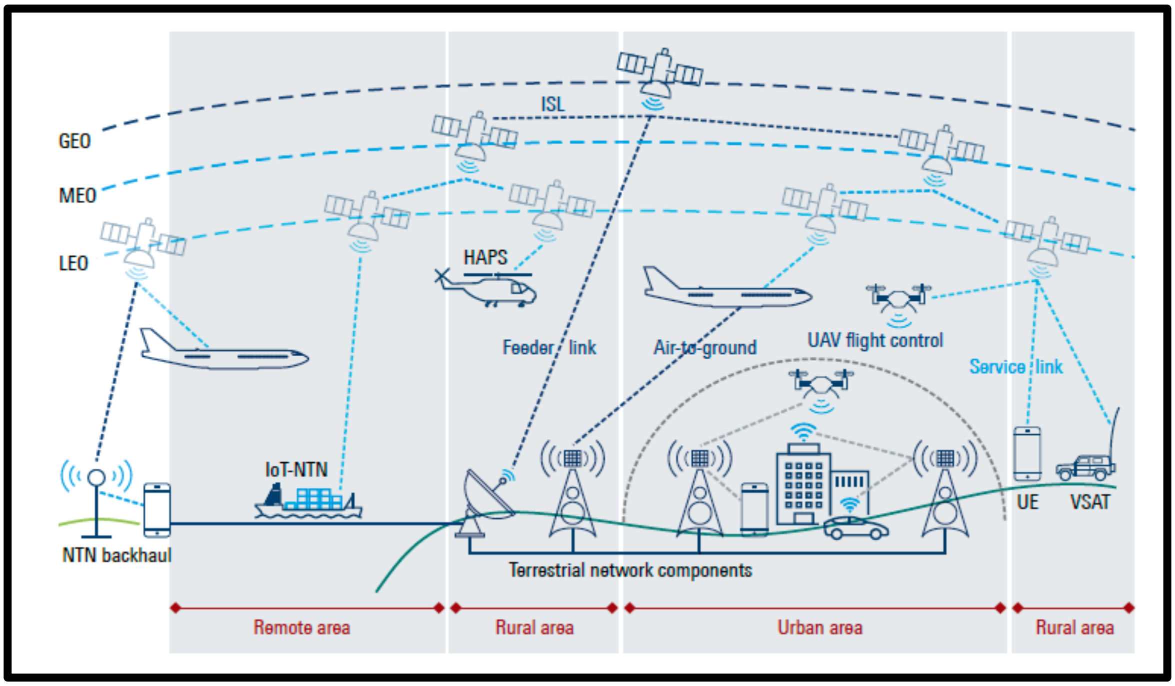

Figure 2 Satellite and aerial platforms complimenting an existing cellular network

NTN networks can be classified based on the orbital altitude[2] as shown in Table 1. The altitude determines the number of satellites required for the potential service area, capacity, and performance capabilities that influence the types of services that may be offered.

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[2] Non-terrestrial networks (NTN) | Rohde & Schwarz

NTN Types	Name	Approximate orbital altitude
LAP	Low Altitude Platforms (includes UAS)	100 m - 1 km
HAP	High Altitude Platforms	1 km - 100 km
LEO	Low Earth Orbit satellites	100 km - 1000 km
MEO	Medium Earth Orbit satellites	1000 km - 2000 km
GEO	Geostationary Orbit Satellites	36000 km
HEO	Highly Elliptical Orbit satellites	100 km to > 36000 km

Table 1 Satellite Orbit Types

The use of satellites introduces propagation delay associated with Low Earth Orbit (LEO), Medium Earth Orbit (MEO), and Geostationary Orbit (GEO) to the User Equipment (UE), which are shown in the Table 2.

	UE to satellite Delay [ms]		One-Way Max propagation delay [ms]
	Min	Max	
LEO	3	15	30
MEO	27	43	90
GEO	120	140	280

Table 2 UE to Satellite Propagation Delay[3]

The proposed future release of 5G specifications calls for the following latency specifications that the use of NTN would need to meet

- GEO based satellite: 285 ms end-to-end latency (inc 5ms network delay)
- MEO based satellite: 95 ms end-to-end latency (inc 5ms network delay)
- LEO based satellite: 35 ms end-to-end latency (inc 5ms network delay)

[3] 3GPP TR 22.822 - Study on using satellite access in 5G

The Quality of Service (QoS) requirements are shown in the Table 3.

Scenario	Experienced data rate (DL)	Experienced data rate (UL)	Area traffic capacity (DL)	Area traffic capacity (UL)	Overall user density	UE speed	UE type
Pedestrian	1 Mbps	100 kbit/s	1.5 Mbps/km 2	150 kbps/km 2	100/km 2	Pedestrian	Handheld
Public safety	[3, 5] Mbps	[3, 5] Mbps	TBD	TBD	TBD	100 km/h	Handheld
Vehicular connectivity	50 Mbps	25 Mbps	TBD	TBD	TBD	Up to 250 km/h	Vehicle-mounted
Airplane connectivity	360 Mbps / plane	180 Mbps / plane	TBD	TBD	TBD	Up to 1000 km/h	Airplane-mounted
Stationary	50 Mbps	25 Mbps	TBD	TBD	TBD	Stationary	Building-mounted
Video surveillance	[0, 5] Mbps	3 Mbps	TBD	TBD	TBD	Up to 120 km/h or stationary	Vehicle-mounted or fixed installation
Narrowband IoT connectivity	2 kbit/s	10 kbps	8 kbps/km2	40 kbps/km 2	400/km 2	Up to 100 km/h	IoT

Table 3 Performance Requirements for Satellite Access[4]

Key Technology Considerations

Implementing and adopting NTN in 5G introduces several unique technology considerations that differentiate them from traditional terrestrial networks. One of the primary technical challenges is the higher end-to-end latency and its variations. Unlike terrestrial networks, where data transmission occurs over relatively short distances with minimal delays, NTN involves communication via satellites or high-altitude platforms, which inherently increases the distance the signals must travel. This additional distance can lead to increased latency, affecting the performance of real-time applications, such as video conferencing or any other

[4] 3GPP TR 22.261 - Service requirements for the 5G system; Stage 1

service requiring near-instantaneous response times. The variation in latency can fluctuate due to the dynamic nature of the satellite orbits and atmospheric conditions, necessitating advanced techniques for latency management and optimization.

Another significant consideration is the doppler shift and its variation caused by mobility. In NTN environments, both the satellites (or other non-terrestrial elements) and user equipment are often in motion. This mobility introduces doppler shifts, causing changes in the frequency of the transmitted signals, which can impact the reliability and quality of the communication links. Terrestrial networks typically experience minimal doppler effects due to the relatively stationary nature of cell towers. However, in NTN, continuous adjustments and calibrations are required to compensate for these frequency shifts, which adds to the complexity of network management. Additionally, the larger cell sizes in NTNs, compared to terrestrial networks, pose challenges in terms of coverage, capacity, and power management. Larger cells mean that signals must cover greater distances, which can lead to signal degradation and reduced data rates, especially at the edges of the coverage area. To address these challenges, advanced technologies such as beamforming, adaptive modulation, and coding techniques have to be explored to enhance signal strength and maintain robust communication links.

The adoption of NTN in 5G networks requires careful consideration of these technical challenges. Solutions must be tailored to address the increased latency, manage doppler effects, and optimize performance over larger cell sizes. Successfully overcoming these obstacles will be crucial for leveraging the full potential of non-terrestrial networks in delivering ubiquitous, high-quality 5G services, particularly in remote or underserved areas where traditional terrestrial infrastructure may be impractical or cost-prohibitive.

Government Use-Cases

As 5G cellular communications and NTN continue to advance, the following use cases are examples how these technologies converge in support of government operations.

- Satellite-Based Intelligence: Leveraging NTN for intelligence gathering through enhanced satellite communications. This includes real-time data transmission from intelligence sensors deployed in remote areas, improving situational awareness and operational effectiveness.

- Disaster Response: Facilitating communication and coordination during disaster response efforts where terrestrial infrastructure may be compromised. NTN can provide crucial connectivity for first responders and relief organizations, enabling efficient resource allocation and emergency management.

- Remote Operations and Maintenance: Supporting remote operations such as equipment maintenance in isolated locations. NTN enables direct access to cloud-based instructions and data, facilitating efficient maintenance procedures without the need for extensive ground-based infrastructure.

- Cost-Effective Solutions: Taking advantage of the low-cost nature of cellular connected devices and technologies to optimize government expenditures. This includes adapting commercial off-the-shelf products for mission-focused use cases, reducing development costs and enhancing operational efficiency.

- Interoperability Improvement: Addressing interoperability challenges within government agencies by adopting standardized 3GPP technologies. This initiative aims to unify communication protocols across different branches and agencies, enhancing coordination and information sharing.

- Future-Proofing with 6G: Planning for the future integration of 6G technologies with NTN to further enhance performance and capabilities. This includes preparing for advancements in satellite constellation deployment and ensuring readiness for upcoming technological evolutions.

NTN Gaps and Challenges

NTN promises unparalleled connectivity from the skies above, integrating seamlessly with terrestrial 5G networks to provide global coverage but gaps and challenges exist. The latency introduced by long and varying propagation delays complicates real-time communication, a crucial factor for both civilian agencies and military operations. The high speeds of LEO satellites induce significant Doppler shifts, affecting signal integrity. Additionally, the vast coverage area of NTN satellites means fewer resources are available per user, leading to potential bottlenecks in data transmission.

The architecture of NTN involves constantly moving cells, necessitating frequent handovers that are far from trivial. The movement challenges conventional handover mechanisms, demanding a reevaluation of how we maintain seamless connectivity. The elliptical shape of satellite beams introduces additional complexity to signal reception, diverging from the traditional circular beam patterns of terrestrial cells.

Addressing these technical challenges is only part of the challenge. On the operational front, the current reliance on Global Navigation Satellite System (GNSS) capabilities for user equipment poses a significant gap. In contested or battlefield environments, where GNSS signals might be jammed or unavailable, alternative solutions are necessary. The DoD requires support for devices lacking GNSS capabilities, including low-cost or low-power mobile devices and sensors for Internet of Things (IoT) applications.

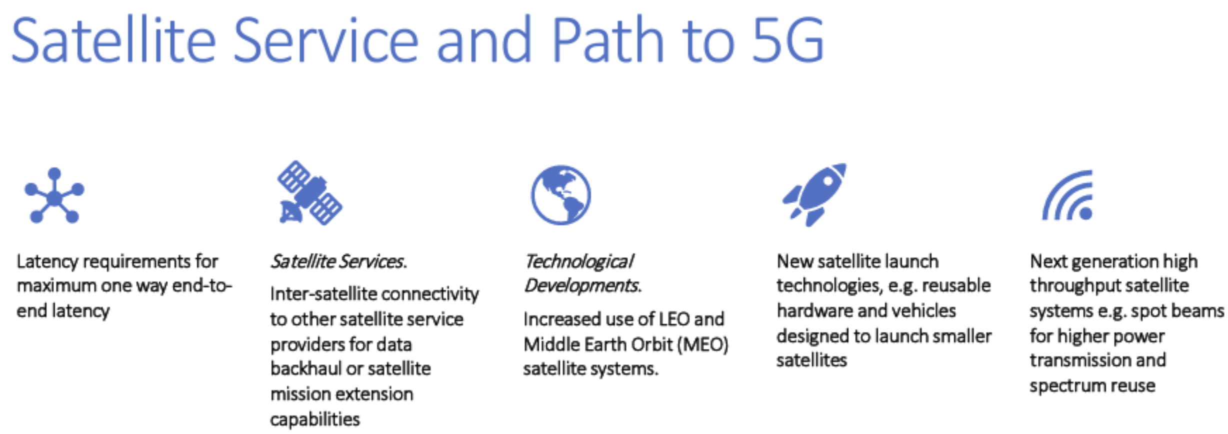

Figure 3 Satellite ecosystem innovations and services[5]

Security remains a paramount concern, especially for DoD applications. The military demands robust, uncompromising security measures, beyond what current 5G terrestrial standards offer. Several security features considered optional in commercial 5G implementations must be mandatory and reinforced in military contexts.

One significant challenge in NTN is adapting the Hybrid Automatic Repeat reQuest (HARQ) processes, essential for error correction in data transmission. HARQ in NTN must contend with the long propagation delays and Doppler shifts inherent in satellite communication, necessitating new approaches to ensure timely and accurate data recovery.

Finally, the quest for efficiency extends to the realm of energy consumption. NTN operations, particularly in NB-IoT applications, must overcome the inherent energy challenges posed by long-distance communication and the Doppler effect.

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[5] Broadband Communications Industry and Path to 5G, Narendra Mangra, IEEE Future Networks Winter School for Young Professionals, March 2019 – https://futurenetworks.ieee.org/education/ieee-5g-summer-school/winter-school-for-yp-2019

Security Aspects

Security is a critical concern when it comes NTN in 5G communications, particularly for government and military applications. Transmission security is vital for ensuring that all transmission waveforms, whether terrestrial or non-terrestrial—such as satellite communications in the space layer—are safeguarded against various threats, especially in sensitive environments like tactical deployments. Given the unique vulnerabilities of NTNs, such as longer signal paths and exposure to a broader range of interception risks, robust security measures must be integrated to protect data integrity and confidentiality.

Several tactics have been proposed to enhance the security of 5G systems in different threat environments. These include leveraging native 3GPP 5G interference mitigation techniques, which help reduce the risk of signal jamming and eavesdropping. Physical layer modifications can offer more robust protection against sophisticated attacks by making it harder for adversaries to intercept or disrupt communications. Integrating NTN with established hardened waveforms and employing spectrum and network path diversity further strengthens the resilience of 5G networks by ensuring multiple, secure paths for data transmission, reducing the risk of a single point of failure.

Encryption is another cornerstone of securing NTN in 5G communications, especially when dealing with sensitive government and military data. The use of advanced encryption methods will be necessary to comply with Federal Information Processing Standards (FIPS), which mandate stringent security requirements for cryptographic modules. For DoD applications, adherence to these standards is non-negotiable, ensuring that all data transmitted via NTN is protected against unauthorized access and potential cyber threats. Implementing FIPS-compliant encryption will not only secure data but also aligns with the broader security framework required for government communications, providing a reliable foundation for the secure adoption of NTN in 5G networks. This multi-layered approach to security ensures that NTN can operate securely even in high-risk environments, supporting mission-critical operations while mitigating potential threats.

NTN Evolution to 6G

6G will bring evolution into standards-based NTN with four basic agenda items – global coverage (space-air-ground-sea), all spectrum (includes THz, optical bands) all applications including those driven by Artificial Intelligence/Machine Learning, and security beyond 5G.

The evolution from NTN to 6G represents a significant advancement in global connectivity and technological integration. 6G aims to establish a standards-based NTN framework with several key priorities to enable global coverage across diverse environments including space, air, ground, and sea. This expansion not only broadens geographical reach but also supports a wide array of applications, leveraging all spectrums from traditional to Terahertz and optical bands. These advancements are crucial for accommodating future technologies driven by artificial intelligence and machine learning and ensuring robust security measures that surpass those of current 5G systems.

The integration of aerial vehicles into the 5G/6G ecosystem is an example of the innovative approach to network expansion. The use of AI could play a pivotal role, enabling functions such as interference detection, dynamic spectrum management, and resource allocation across satellite and aerial platforms. This application of AI extends to optimizing device performance, network efficiency, and hybrid configurations, thereby enhancing overall operational effectiveness.

In terms of network architecture, 6G necessitates a shift towards decentralization and intelligence. Each network node is envisioned to possess autonomous reconfiguration capabilities and advanced computational abilities. This Reconfigurable, Open, and Intelligent (ROI) network concept underscores the need for new architectures, protocols, and APIs that facilitate seamless integration of NTN elements into a unified global network. This integration is critical for implementing advanced network orchestration schemes such as network slicing and software-defined networking with network function virtualization.

The development of multi-protocol radio stacks and advanced spectrum management techniques reflects the potential 6G has in optimizing spectrum usage, including the exploration of terahertz frequencies for cross-link communications. Security should also be a primary driver in 6G design, ensuring it is an intrinsic component of the system architecture. This shift ensures that robust security measures are embedded throughout the network infrastructure, safeguarding against emerging threats in an increasingly interconnected world.

Conclusion

The last decade or so of progress in the telecommunications field has highlighted by the rapid proliferation of smart phones and devices providing ubiquitous internet connectivity, advancements in wireless technologies, and exponential growth and demand for new internet services. Telecom services have advanced from a nice to have to a mission essential business model. The government depends on telecom services to conduct their mobility missions. Non-Terrestrial Networks have the potential to be another highly important and dependable tool in the toolkit to provide mission-essential services for government and industry. NTN has the potential to provide global, rural, remote, maritime, and hotspot connectivity, which can become a mission-essential, cost-effective, and dependable service for governments. NTN is also less susceptible to natural disasters, which can improve resiliency.

NTN does have some technical challenges to overcome such as large distances between user equipment and satellite, the amount of data rate that can be transmitted, and spectrum use. HAPS, MEC functionality in satellites, and architecture improvements, will help alleviate some of those challenges. However, NTN cannot achieve the same latency and throughput as a terrestrial or small cell architecture.

6G promises to bring improvements to NTN via 3GPP standardization and non-standards-based implementations. NTN is a technology that government will remain interested in to fulfill its mobility missions domestically and overseas.

Appendix 1: Standards

3GPP NR NTN started in 2017 with a Rel-15 study focused on deployment scenarios and channel models. The study was documented in 3GPP TR 38.811. It identified two frequency ranges: K-band and S-band. After completing the Rel-15 study on scenarios and channel models for NR to support NTN, 3GPP continued with a follow-up Rel-16 study on solutions for adapting NR to support NTN. Rel-16 identified necessary features for NTN with proprietary satellite access; High Altitude Platform Station (HAPS) was limited.

In Rel-17's normative phase, 3GPP developed an enhancement in all the relevant technical specifications of NR protocols. Specifically, enhancements were necessary for LEO- and GEO-based NTNs to target HAPS and air-to-ground networks. This involves physical layer aspects, protocols, and architecture as well as radio resource management (RRM), radio frequency (RF) requirements, and frequency bands. The focus is on transparent payload architecture with earth-fixed tracking areas and frequency-division duplexing (FDD) systems, where all user equipment (UE) is assumed to have global navigation satellite system (GNSS) capabilities.

Rel-18 features non-geostationary Earth orbiting satellites, transparent, and regenerative payload architecture. It addresses issues such as extended and variable propagation delays and Doppler, spectrum issues, and wide and/or moving radio cells in NTN. Implicit combability to support HAPS and Air to Ground (ATG) scenarios.

Some constraints include, propagation delay due to the extremely large distance between the gNB (gNodeB), the radio base station for 5G networks, and the UE, the propagation delay can be up to a few hundred milliseconds for GEO satellites, especially for bent pipe scenarios. Current NR specifications are mainly designed for cell systems and not meant to handle propagation delay or Doppler effect.

Timing and uplink time synchronization could have impact of firmware of user equipment whereas others could impact software. This is a consideration. We want to have software as opposed to hardware updates. Design NTN to avoid updates. Overall, want variable bandwidth and latency for sat conn to cell phone – as part of Rel-18 and more reliable UE communications to help "lawful intercept and emergency communications". As for Rel-19, that is to be determined. 6G activities will start in the coming year. Already, satellite integration is possible with release of 5G NTN.

- Cybersecurity considerations (TranSec)
- How developed is this technology for govt use
- Gaps in govt's use of this technology