ALifecom

Unlocking Connectivity Frontiers

Exploring IoT-NTN Innovations

ALifecom Insights

Introduction

With the increasing excitement surrounding 5G non-terrestrial networks (NTN), which promise broader coverage and greater resilience compared to terrestrial networks, satellites are poised to revolutionize telecommunications by addressing coverage gaps and enabling connectivity in remote or challenging environments. Leveraging the foundation of 3GPP NR-NTN and IoT-NTN standards, which build upon terrestrial 5G NR and IoT specifications, these networks aim to meet evolving requirements and unlock new growth opportunities in the NTN market. In this context, this paper aims to provide insight into the applications of IoT-NTN, the fundamental technology architecture, and details of the advanced test solutions from ALifecom.

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1 IoT-NTN Use Cases

IoT-NTN applications encompass a diverse range of use cases, harnessing the power of NTN to enable seamless communication and data transmission in remote and challenging environments. These applications include:

- **SOS and Two-way Messaging**: Devices like smartphones, wearables, and cars can leverage NTN NB-IoT chipsets to enable SOS and two-way messaging functionalities in regions without terrestrial access.
- **Agriculture and Farming**: Agricultural applications, including precision farming and livestock monitoring, remain viable even in rural or remote locations.
- **Asset Tracking**: The location of valuable assets, such as shipping containers or vehicles, can be continuously tracked, even when these assets traverse areas with limited cellular connectivity.
- **Disaster Response and Recovery**: IoT devices designed for search and rescue, damage assessment, and emergency response can operate in areas with limited or no connectivity, particularly in the aftermath of damaged infrastructure.
- **Remote Monitoring**: Equipment situated in remote locations, such as oil rigs or weather stations, can be effectively monitored.
- **Maritime/Airtime Applications**: Vessel tracking, and environmental monitoring become feasible in the open ocean or coastal areas with restricted connectivity.
- **Automotive Communications**: Ensuring continuity of service for low data rate automotive safety, as well as remote services like emergency calls, monitoring, and access control.

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2 NTN System Architecture

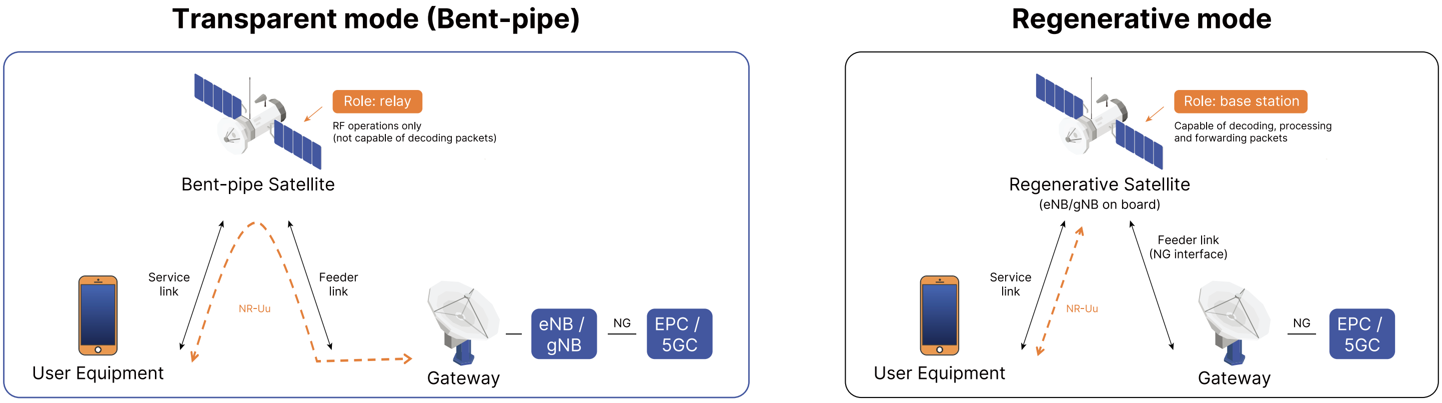

***Figure 1:** Transparent and regenerative mode NTN architectures*

Figure 1 depicts two distinct architectures utilized in satellite communication systems based on the 3GPP NTN architecture[1]. Typically, the satellite radio payload interfaces with the core network via a feeder link connected to a satellite ground station or gateway. Subsequently, the satellite delivers communication services to user equipment (UE) via the service link. While 3GPP Rel-17 specifies the transparent NTN architecture illustrated on the left side of Figure 1, the methodologies and enhancements are flexible and can be adjusted to accommodate the regenerative architecture depicted on the right side.

In the transparent architecture, the base station (eNB or gNB) is located on the ground behind the gateway, with the satellite primarily functioning as a repeater. Processing capabilities on the satellite are limited to radio frequency (RF) operations such as frequency conversion, amplification, and beam management.

Conversely, in the regenerative architecture, the satellite houses either a complete eNB/gNB or its constituent parts, such as the radio unit. This configuration enables packet decoding and processing directly on the satellite. The regenerative architecture offers greater flexibility, enhanced performance; however, this architecture increases system design dramatically. Currently various deployment options are under discussion within the 3GPP and consensus is expected to be reached within the next few releases.

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[1] 3GPP standardize the NTN requirements, architecture, and specifications in various docments. We refer to TS36.211, TS36.213, TS36.300 TS36.321, TS36.331, TR38.811 and TR38.821.

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***Table 1:** Three types of satellite orbits*

Orbits Parameters	**LEO** (Low Earth Orbit)	**MEO** (Medium Earth Orbit)	**GEO** (Geo-stationary)
Satellite Height	300-1500 km	5000-12000 km	35786 km
Orbital Period	90-120 min	2-8 hours	24 hours
Number of Satellites	>40	8-20	3
Satellite Life	short	long	long
Number of Handovers	high	low	non
Orbital Velocity	~ 8 km/s	~ 5 km/s	3 km/s
Propagation Delay	Few ms	>30 ms	119 ms

Normally, satellites can be classified into three categories: Low-Earth Orbit (LEO), Medium-Earth Orbit (MEO), and Geostationary Earth Orbit (GEO). As shown in Table 1, LEO satellites orbit at altitudes ranging from 300 to 1,500 kilometers, while MEO satellites operate between 5,000 and 12,000 kilometers above Earth. In contrast, GEO satellites maintain a much higher orbit at 35,786 kilometers above the equator. Each orbit type has distinct orbital periods, with LEO satellites completing one orbit every 90 to 120 minutes, MEO satellites taking 2 to 8 hours, and GEO satellites matching Earth‘s rotation with a 24-hour orbital period.

LEO constellations typically consist of over 40 satellites to ensure extensive coverage and redundancy. In comparison, MEO constellations require fewer satellites, typically ranging from 8 to 20, while GEO satellites are deployed in groups of three due to their fixed position relative to Earth. LEO satellites offer minimal propagation delays, resulting in communication delays of just a few milliseconds, whereas MEO and GEO satellites experience longer propagation delays due to their higher altitudes.

LEO and GEO orbits represent contrasting scenarios in terms of altitude and deployment characteristics. LEO satellites, positioned closer to Earth‘s surface, offer advantages such as lower launch costs but require a larger number of satellites and complex network infrastructure to maintain continuous coverage. In contrast, GEO satellites stationed at fixed positions above Earth provide continuous coverage over specific areas without the need for frequent handovers or complex relay systems. While GEO satellites entail higher initial deployment costs, they offer scalability and simplicity in network management, making them appealing for operators seeking gradual coverage expansion.

As a result, the choice between LEO and GEO satellite systems depends on factors such as coverage requirements, scalability needs, and budget considerations for network operators. LEO satellites offer cost-effective and flexible solutions but require complex infrastructure, while GEO satellites provide continuous coverage with simpler network management despite higher initial costs.

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3 Timing Relationship

The major challenges in IoT-NTN communications are caused by the satellite to Earth distance as well as the movement of the satellite relative to Earth. The distance to gives rise to unprecedented propagation delays and the high-velocity satellites introduces Doppler shifts of the carrier frequency. While propagation delays in terrestrial mobile communications are typically less than 1 ms, the propagation delays in satellite systems are several orders of magnitude longer, ranging from several to hundreds of milliseconds. This is especially felt by GEO satellites furthest away from Earth with round-trip delays of roughly 500 ms. The movement of the LEO satellite gives rise to Doppler shifts of 48 kHz and must be compensated by both the gateway and UE.

While both challenges are important for IoT-NTN communication, currently most IoT-NTN communication is based on GEO satellites due to their large coverage on Earth. In this section we focus on the challenges of the timing relationship required to implement effective communication with the large round-trip delays.

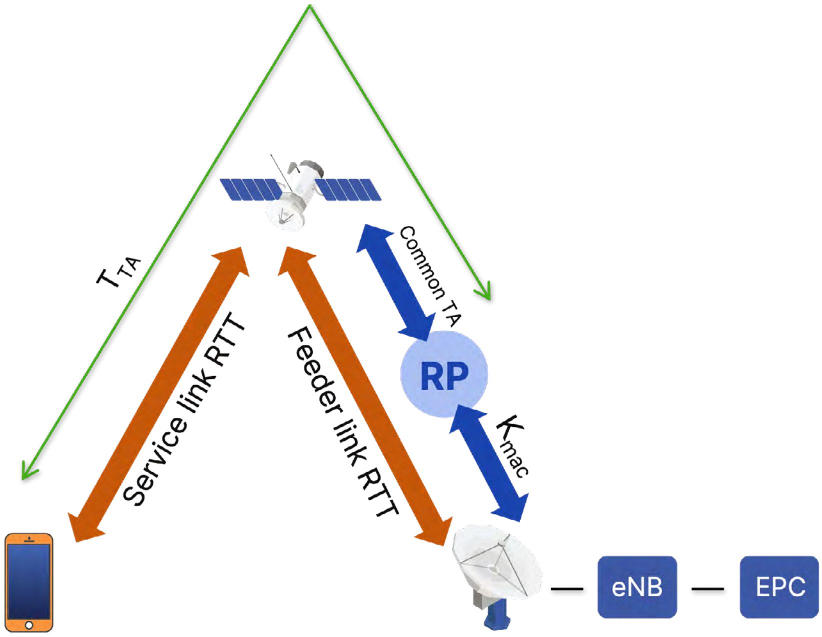

Figure 2: NTN Timing Relationship

According to TS36.300, K_{offset} represents a configured scheduling offset required to be greater or equal to the T_{TA} , which is the sum of the service link Round-Trip Time (RTT) and the Common TA as shown in Figure 2. Common TA, another configured timing offset, is defined as the RTT between the Reference Point (RP) and the NTN payload. It's noteworthy that DL and UL frames are synchronized at the Reference Point. Additionally, K_{mac} denotes a configured offset, approximately equal to the RTT between the RP and the eNB.

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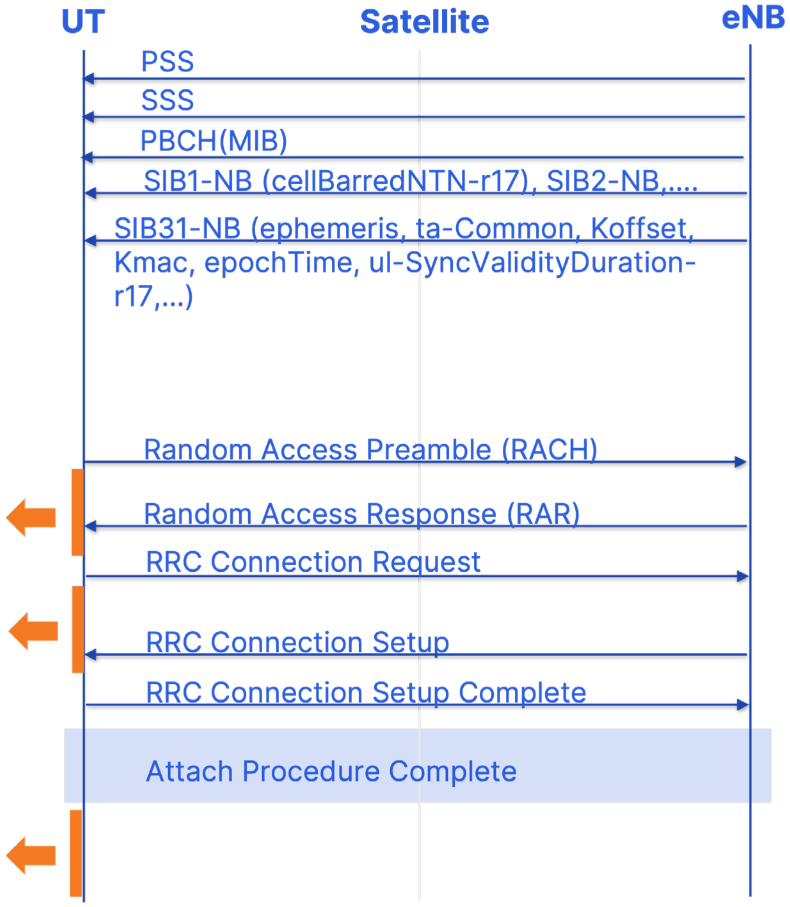

- UE shall have valid **GNSS position**
- **compute the RTT between UE and the RP (T_{TA})** based on the GNSS position, the ephemeris, and the Common TA
- **autonomously pre-compensate the T_{TA}**
- **compute the frequency Doppler shift of the service link**, and autonomously pre-compensate for it in UL
- UE listen PDCCH to get RA-RNTI in **ra-response-window**
- UE listen PDCCH to get T-CRNTI in **ra-ContentionResolutionTimer-window**
- re-acquire SIB31 within duration of **T317** Timer (**ul-SyncValidityDuration**)

Figure 3: *IoT-NTN random access procedure and related time-window*

One crucial aspect of IoT-NTN involves the random access procedure, facilitating the initial communication establishment between the UE and the eNB, as shown in Figure 3. In NB-IoT NTN, the eNB initiates communication by broadcasting the Primary Synchronization Signal (PSS) and Secondary Synchronization Signal (SSS), enabling UE synchronization with the eNB's timing and frequency. Following successful synchronization, the UE proceeds to decode the Physical Broadcast Channel (PBCH) to retrieve essential network information such as Master Information Block (MIB) and System Information Blocks (SIBs). Of particular importance of the system information is SIB1-NB, encompassing critical data like cell barring configuration tailored for IoT-NTN deployment.

Furthermore, SIB31-NB contains key parameters essential for IoT-NTN operation. These parameters encompass various crucial elements including ephemeris data, ta-Common, Koffset, Kmac, epochTime, ul-SyncValidityDuration-r17, etc.

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From the UE perspective, modifications are necessary to adapt to IoT-NTN requirements:

- UE shall have valid GNSS position
- Compute the T_{TA} (RTT between the UE and the RP) based on the GNSS position, the ephemeris, and the Common TA
- Autonomously pre-compensate the T_{TA}
- Compute the frequency Doppler shift of the service link, and autonomously pre-compensate for it in UL
- Due to the long propagation delay, the UE may miss messages as a result of delayed reception outside the designated time windows. It is essential to either delay the start of the time window or extend its duration. These time windows include ra-response-window for Random Access Response (RAR), and ra-ContensionResolutionTimer-window for RRC Connection Setup.
- ul-SyncValidityDuration (T317 Timer) is a newly introduced timer for IoT-NTN. The UE must receive SIB31-NB within ul-SyncValidityDuration to obtain the latest NTN parameters and confirm its presence within the cell coverage area.

TS36.211 presents $T_{TA} = (N_{TA} + N_{TA,offset} + N_{TA,adj}^{common} + N_{TA,adj}^{UE})\ T_s$, N_{TA} and $N_{TA,offset}$ are derived from terrestrial network, $N_{TA,adj}^{common}$ and $N_{TA,adj}^{UE}$ are new parameters introduced for NTN.

- N_{TA} and $N_{TA,offset}$ are derived from terrestrial network parameters
- The quantity $N_{TA,adj}^{common}$ is derived from the higher-layer parameters *TACommon*, *TACommonDrift*, and *TACommonDriftVariation* if configured, otherwise $N_{TA,adj}^{common} = 0$.
- The quantity $N_{TA,adj}^{UE}$ is computed by the UE based on UE position and serving satellite-ephemeris-related higher-layers parameters if configured, otherwise $N_{TA,adj}^{UE} = 0$.
- T_s represents basic time unit

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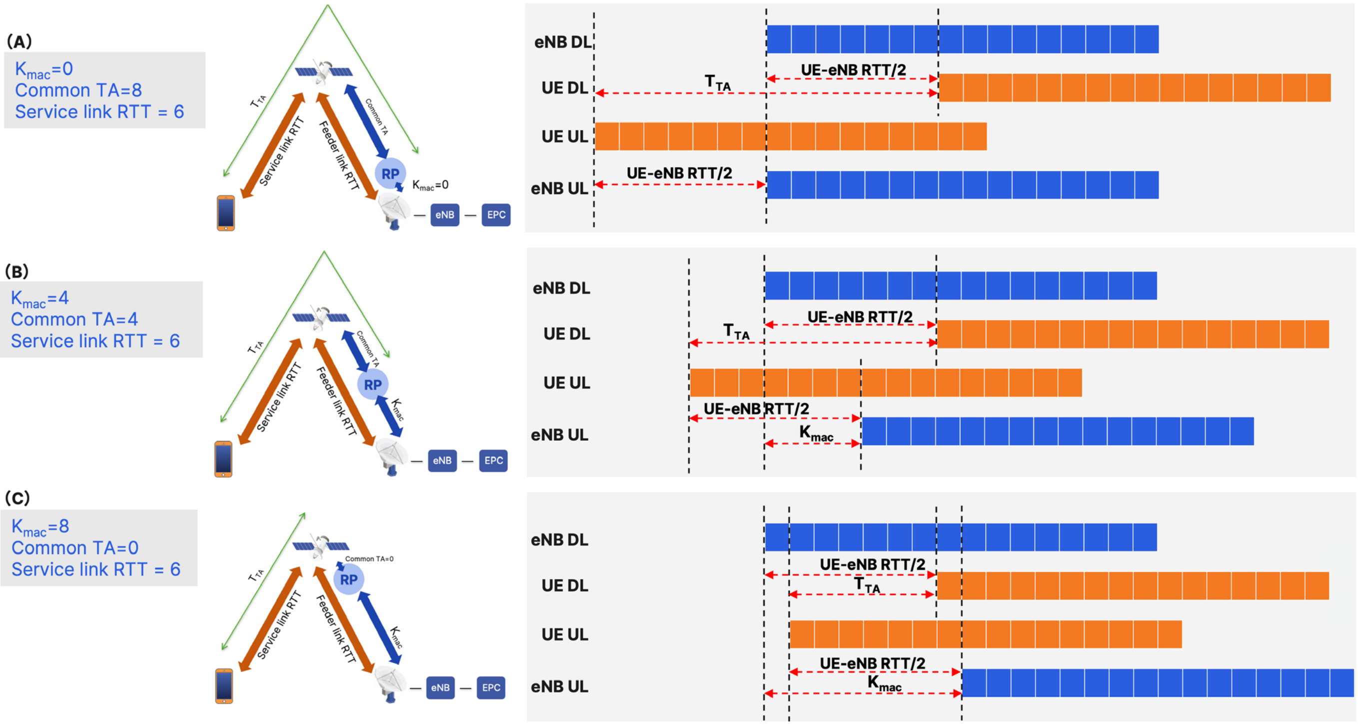

Figure 4: *Critical challenge for eNB scheduling for timing discrepancies and network performance optimization*

In Figure 4.(A), where K_{mac} is set to zero and Common TA is significantly large, DL and UL subframes are aligned at the eNB, yet a notable timing discrepancy exists for UE DL and UL subframes, posing challenges for UE design. Conversely, Figure 4.(C) depicts a configuration with an exceptionally large K_{mac} and zero Common TA, resulting in a substantial DL and UL subframe timing difference at the eNB, while UE DL and UL timing differences are comparatively smaller. This highlights the critical challenge for eNB scheduling schemes to address timing discrepancies and optimize network performance.

The challenge of testing NTN networks comes to mimicking the long delay timings and accurately implementing the timing relationship. At ALifecom, we have worked intensively on implementing these items in the NE6000 Network Emulator.

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4 ALifecom NE6000 IoT-NTN Test Solutions

NE6000 IoT-NTN signaling test solution emulates a complete NB-IoT non-terrestrial network, including the eNodeB and EPC, and features a channel emulator that accurately replicates real-world signal propagation conditions for comprehensive testing and validation of IoT-NTN devices. The channel emulator is fully integrated in the NE6000 and is responsible for implementing the propagation delay and timing relationships as described in the previous section.

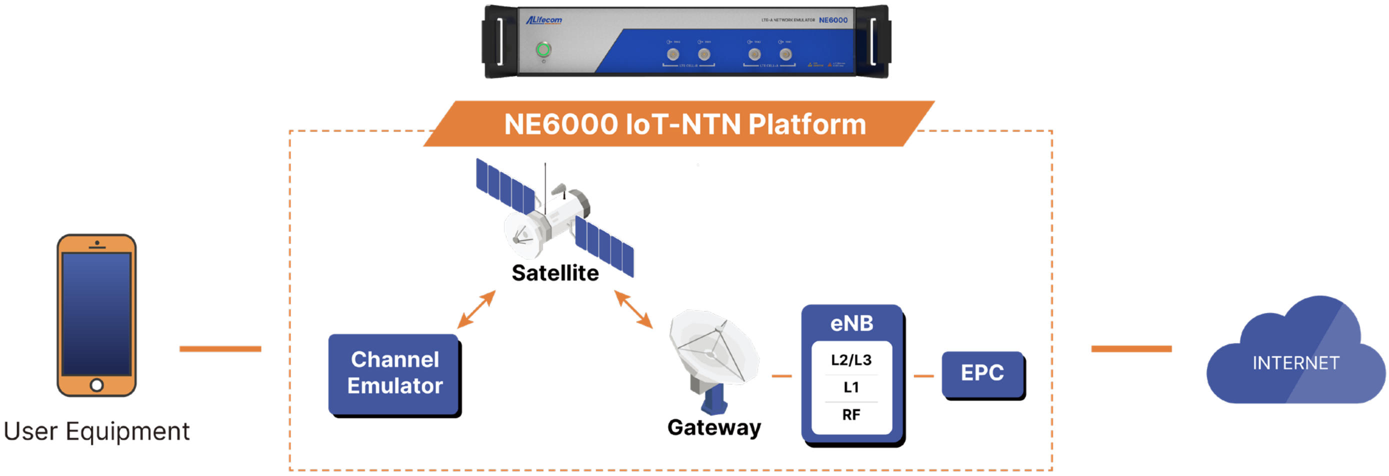

Figure 5: The Key components of ALifecom NE6000

ALifecom IoT-NTN network emulator stands as a cutting-edge FPGA/DSP-based hardware platform. It hosts a 3GPP Rel.17 compliant eNB base station and EPC core network software, ensuring compatibility with industry standards. It is fully integrated within a compact single-box solution minimizing usage of valuable lab-space for our customers.

The NE6000 IoT-NTN network emulator is a versatile platform, meticulously crafted to serve various purposes including academic research, early R&D, functional testing and verification, and Proof-of-Concept demonstrations. The setup and configuration are effortless, and we help the user with pre-loaded default parameters to get started quickly. Its flexibility extends to facilitating the verification and measurement of user terminal product designs, RF transmit/receive functionalities, performance metrics, and run-time behavior post-connection to the NB-IoT NTN.

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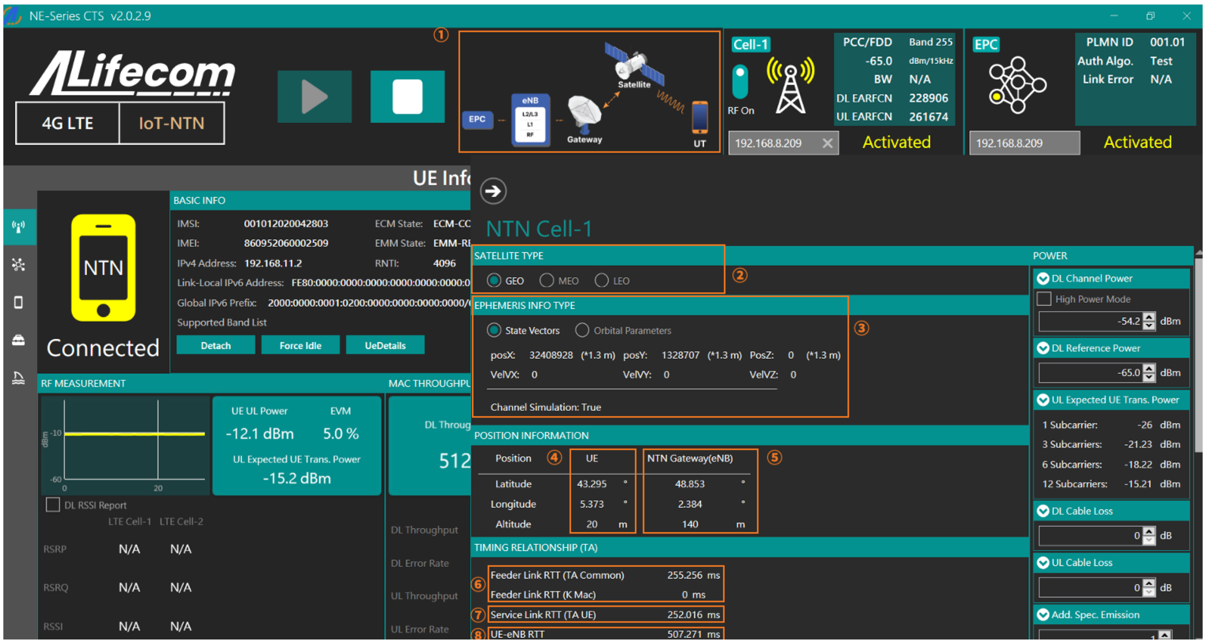
① **Transparent**
(Bent-pipe)
② **Satellite: GEO**
③ **Ephemeris info**
④ **UE Position**
⑤ **eNB Position**
⑥ **Feeder link RTT**
⑦ **Service link RTT**
⑧ **UE-eNB RTT**



PCC/FDD Band 255
-65.0 dBm/15kHz
BW N/A
DL EARFCN 228906
UL EARFCN 261674
192.168.8.209 Activated

PLMN ID 001.01
Auth Algo. Test
Link Error N/A
192.168.8.209 Activated

Connected

BASIC INFO
IMSI: 001012020042803
ECM State: ECM-CC
IMEI: 860952060002509
EMM State: EMM-RE
IPv4 Address: 192.168.11.2
RNTI: 4096
Link-Local IPv6 Address: FE80:0000:0000:0000:0000:0000:0000:0
Global IPv6 Prefix: 2000:0000:0001:0200:0000:0000:0000:0000/
Supported Band List

RF MEASUREMENT
UE UL Power -12.1 dBm
EVM 5.0 %
UL Expected UE Trans. Power -15.2 dBm
☐ DL RSSI Report

	LTE Cell-1	LTE Cell-2
RSRP	N/A	N/A
RSRQ	N/A	N/A
RSSI	N/A	N/A

MAC THROUGHPU
DL Throughput
DL Error Rate
UL Throughput
UL Error Rate

NTN Cell-1

SATELLITE TYPE
● GEO ○ MEO ○ LEO

EPHEMERIS INFO TYPE
● State Vectors ○ Orbital Parameters
posX: 32408928 (*1.3 m) posY: 1328707 (*1.3 m) PosZ: 0 (*1.3 m)
VelVX: 0 VelVY: 0 VelVZ: 0
Channel Simulation: True

POSITION INFORMATION

Position	UE		NTN Gateway(eNB)	
Latitude	43.295	°	48.853	°
Longitude	5.373	°	2.384	°
Altitude	20	m	140	m

TIMING RELATIONSHIP (TA)
Feeder Link RTT (TA Common) 255.256 ms
Feeder Link RTT (K Mac) 0 ms
Service Link RTT (TA UE) 252.016 ms
UE-eNB RTT 507.271 ms

POWER
DL Channel Power
☐ High Power Mode
-54.2 dBm
DL Reference Power
-65.0 dBm
UL Expected UE Trans. Power
1 Subcarrier: -26 dBm
3 Subcarriers: -21.23 dBm
6 Subcarriers: -18.22 dBm
12 Subcarriers: -15.21 dBm
DL Cable Loss
0 dB
UL Cable Loss
0 dB
Add. Spec. Emission

Figure 6: *NE6000 Easy-to-Use GUI*

The NE6000 GUI has been developed with the end-user first in mind. It offers a simple and user-friendly interface, enabling quick setup and utilization, which allows both novice and experienced users to use the platform. Within the GUI, essential NTN parameters such as ephemeris information, Feeder Link RTT, Service Link RTT, and UE band details are presented clearly, facilitating easy access, and understanding.

Additionally, the NE6000 platform features an integrated protocol analyzer that facilitates real-time diagnosis of protocol message handshakes between user terminals and base stations. This invaluable tool enhances troubleshooting capabilities by providing insights into network communication dynamics during operation.

Overall, the ALifecom NE6000 IoT-NTN network emulator offers a comprehensive solution tailored to the needs of researchers, developers, and engineers in the IoT-NTN domain.

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5 About ALifecom Services

ALifecom offers a suite of IP services, including extensive technical expertise in FPGA, DSP, and MCU/NPU development, self-developed eNB and EPC core network software tailored for non-terrestrial networks, FPGA/DSP-based payload platform design services, robust system integration capabilities, and a commitment to continuous technological advancements in line with 3GPP developments.

Extensive Technical Expertise

- ALifecom brings a wealth of technical expertise in FPGA, DSP, and MCU/NPU development.
- Deep understanding of the specific requirements of payload companies.
- Strong stack record in successfully addressing complex technical challenges and delivering tailored solutions.

Self-Developed eNB Software

- ALifecom has developed its own eNB software.
- Leverages in-house expertise and experience for high customization and adaptability.
- Ability to meet the unique needs and requirements of non-terrestrial networks.

FPGA/DSP-based Payload Platform Design Services

- Years of experience in working on FPGA/DSP platforms with Different RFICs.
- Tremendous expertise in architecture design, spec determination, component selection, IP integration, and fast prototyping.
- Offers complete system design services with unprecedented speed and quality.

System Integration Capability

- Beyond eNB software services, ALifecom possesses extensive system integration capabilities.
- Understands intricacies and potential challenges in system-level integration.
- Provides comprehensive solutions seamlessly integrating with existing infrastructures.

Continuous Technological Advancements

- ALifecom remains at the forefront of 3GPP developments and updates.
- Constantly tracks the latest technologies.
- Ensures eNB software incorporates the most advanced features for cutting-edge capabilities in the non-terrestrial network.

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6 Conclusions

The evolution of NTN heralds a transformative era in telecommunications, presenting unprecedented opportunities for ubiquitous connectivity. With ALifecom‘s comprehensive technical expertise in FPGA/DSP-based systems, self-developed eNB and EPC software, and innovative test solutions, the full potential of NTN is within reach. ALifecom stands at the forefront, empowering the future of connectivity with confidence and ingenuity.

Looking ahead, NTN holds immense promise for revolutionizing various industries and sectors. From enabling seamless communication in remote and underserved regions to facilitating the deployment of IoT devices in challenging environments, NTN is poised to drive significant advancements across the telecommunications landscape. With its ability to extend network coverage beyond terrestrial boundaries, NTN opens doors to new possibilities in areas such as disaster response, environmental monitoring, and maritime communication.

Moreover, as technological advancements continue to accelerate, the capabilities of NTN are expected to expand exponentially. From leveraging advanced satellite constellations to optimizing network protocols for enhanced efficiency, the future of NTN is characterized by innovation and progress. ALifecom remains committed to leading this charge, pushing the boundaries of what is possible and shaping the future of connectivity for generations to come.

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7 References

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Established in 2009, ALifecom has been dedicated to algorithm development, hardware design and software implementations to develop innovative communication testing solutions. The high-quality testing solutions from ALifecom support a range of communication protocols from 5G and NTN to WiFi and Bluetooth. ALifecom provides customers with a customized one-stop solution for functional testing, communication protocols, and RF measurements.

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