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# State of Satellite Access Network Standardization in 3GPP

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## Abstract

**This paper provides an overview of the current standardization progress in the 3rd Generation Partnership Project (3GPP) targeting integration of the satellite access network with New Radio (NR). It also discusses several impacted areas of NR, particularly in the physical layer and MAC layer, for incorporation of the satellite access network in NR.**

## 1. Introduction

Satellite communication networks use spaceborne platforms such as Low Earth Orbit (LEO) satellites, Medium Earth Orbit (MEO) satellites, and Geosynchronous Earth Orbit (GEO) satellites. Recently, there have been some (re)surging interests in providing broadband by LEO satellite mega-constellations (e.g., OneWeb, Lightspeed, Starlink, Kuiper). It is expected that the LEO satellite network will become a key factor in future integrated networks for providing universal Internet and communications services. Given the unprecedented growth of traffic—e.g., because of an exponential growth of the number of connected devices—the status quo of telecommunication industry and standardization, which usually considers satellite and terrestrial networks as two self-contained ecosystems, is losing ground.

There are various use cases for satellite access highlighting the significance of integration of the satellite access networks with 5G and beyond (5G+):

**1. Broadcasting and multicasting services such as TV broadcasting (e.g., to flight and train passengers) and video streaming.** One may also use the satellite access network for efficiently and timely broadcasting instantaneous alert signals to thousands of users before, during, and after emergency events and disasters. On the other hand, broadcast, and multicast services for edge network content delivery, via offloading popular media and entertainment contents from the mobile network infrastructure, seem to be a promising application of the satellite access in

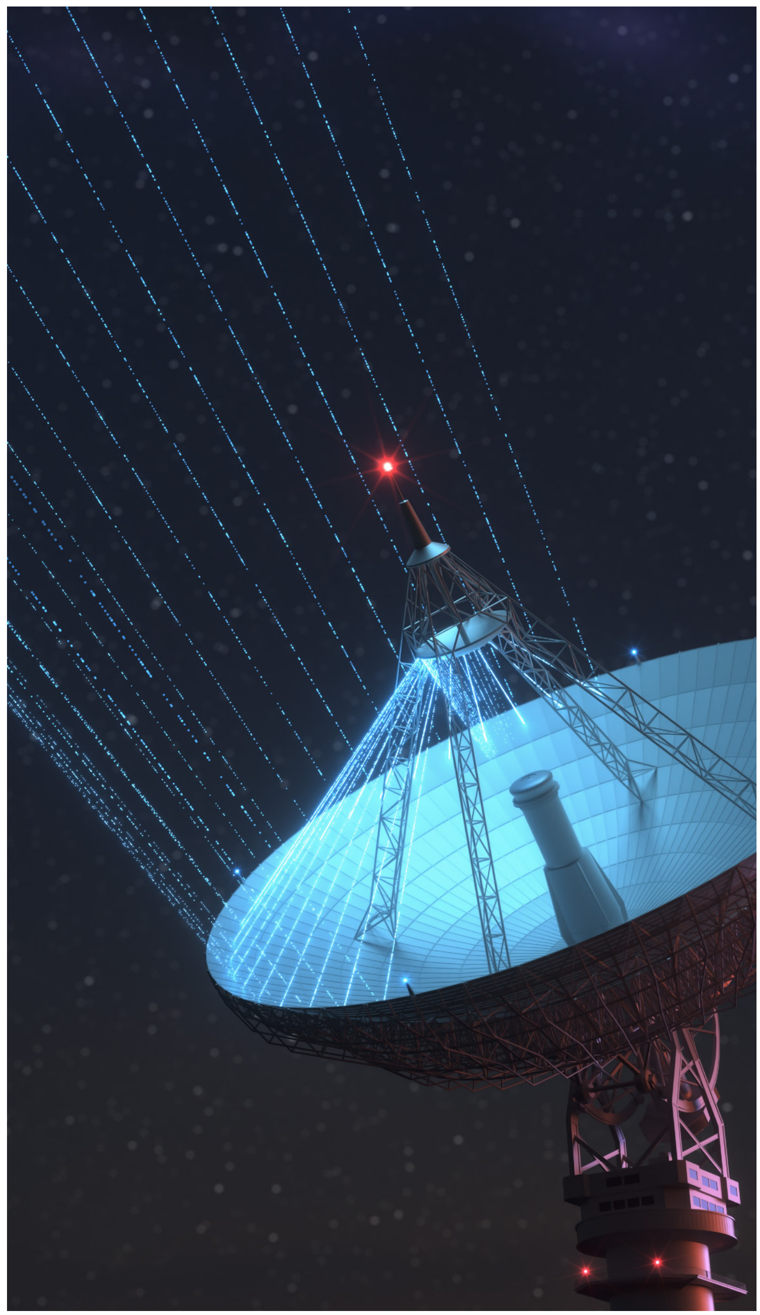
5G/5G+. Accordingly, 3GPP identifies the role of the satellite access in 5G/5G+ by enabling 5G network scalability for efficient broadcast and multicast resources.

**2. Internet of things (IoT) service providers can utilize the satellite mega-constellations for seamless global connectivity for wireless devices with restricted battery life and cicuitry.** Accordingly, 3GPP identifies the role of the satellite network in 5G/5G+ by supporting the reliability of 5G service for providing service continuity for machine-type communications and IoT devices. The satellite network in 5G/5G+ can also be used to ensure unrestricted service availability, especially for critical communications and railway, maritime, and aeronautical communications, and surveillance.

**3. Worldwide connectivity and global coverage through roaming between terrestrial 5G and satellite networks, suitable for timely tracking of shipping containers and robot/drone package delivery.** On the other hand, the robust global coverage is essential for public safety services and emergency responders, such as police, fire fighters, and medical personnel. In some cases, due to a disastrous event, terrestrial network may become unreliable or inaccessible. Access via satellite can compensate for the damaged terrestrial network. Accordingly, 3GPP defines the role of the satellite network in 5G/5G+ for providing 5G service in unserved areas that cannot be covered by terrestrial 5G networks (e.g., isolated and remote areas, on aircrafts and ships) and underserved areas (e.g., suburban and rural areas) or areas with damaged infrastructure.

**4. Coverage expansion of 5G terrestrial networks around countries' borders and remote areas.** Devices crossing borders may need to switch from one operator to another. A smooth transition from one operator to another via satellite access is beneficial. Furthermore, for remote areas, e.g., with low-density populations, a cost-efficient option for mobile operators is providing direct access via the satellite access or backhauling through satellite backhaul. Accordingly, 3GPP defines the role of the satellite network in 5G/5G+ for improving the performance of terrestrial networks in a cost-effective manner.

**4. Fast and secure end-to-end connectivity via a global satellite overlay for critical applications like banking, high frequency trading, and intra/inter corporation communications.** A satellite mega-constellation can be an alternative to conventional optical fiber transmission.



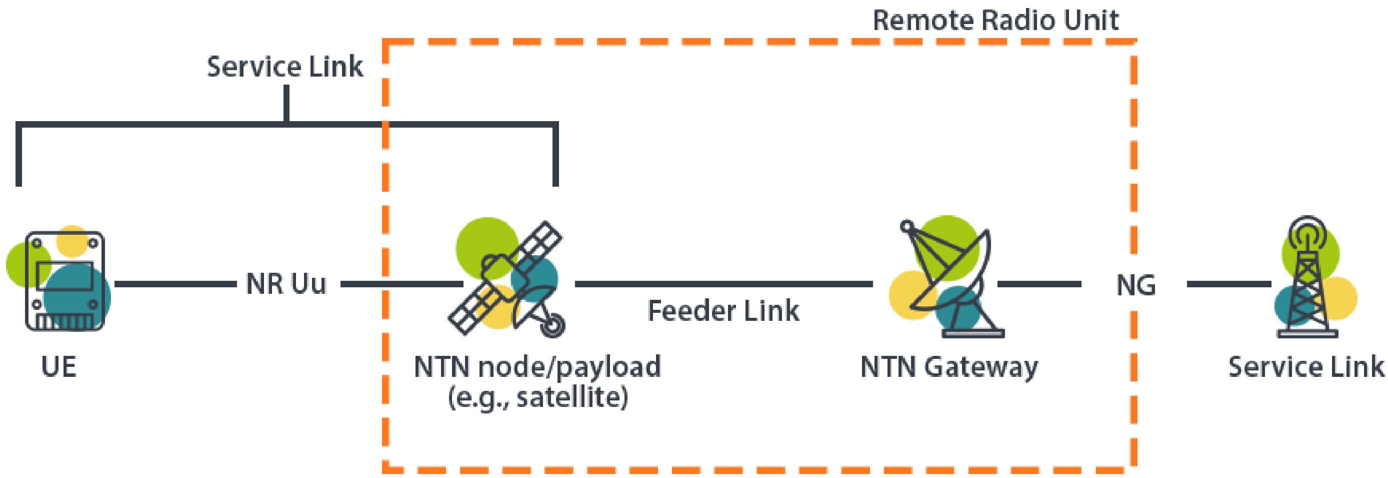



Figure 1: Networking-RAN architecture with transparent satellite

Satellite access in 5G/5G+ in 3GPP is collectively known as Non-Terrestrial Network (NTN). In a typical scenario, the NTN devices a network from spaceborne platforms (i.e., GEO, MEO, LEO satellites) or airborne platforms (i.e., pseudo satellites), performing either as a full-fledged base station or a repeater (relay) node.

From the 3GPP standardization perspective, a typical satellite access network may consist of the following components:

- A service link which is the radio link between the wireless device and the NTN platform.

- The NTN platform carrying a payload which may have one of these two configurations:

  o A transparent payload (or a bent-pipe payload) that performs radio frequency filtering, frequency conversion, and amplification. It is equivalent to a relay or a repeater node.

  o A regenerative payload offering radio frequency filtering, frequency conversion, and amplification as well as demodulation and decoding, switch and/or routing, coding and/or modulation. It provides the base station functions on-board a satellite.

- NTN Gateway for connecting the NTN payload to the ground base station or the core network.

- Feeder links which refer to the radio links between the NTN gateway and the NTN platform.

- Inter-satellite links (ISLs) for direct communication between NTN payloads. Usually, the ISL may operate in RF frequency or optical bands.

- User Equipment (UE) or a specialized terminal to the satellite system in case the satellite doesn't serve wireless devices directly.

**Figure 1 shows an example of the networking-RAN architecture with a transparent satellite. The communication between the NTN platform and the wireless device, via the service link, is based on NR Uu radio interface. Collectively, the NTN platform, the feeder link, and the NTN gateway may be known as the remote radio unit.**

## II. Release-15/16 NTN Standardization Proccess

Through Releases 15 and 16, 3GPP conducted several preliminary standardization efforts to support the integration of satellite access and 5G terrestrial networks. Refer to Table 1 for an overview of the standardization activities of the 3GPP through Release 15 and 16.

The outcome of the study items in Release 15 and 16 paves the road for a better understanding of the ecosystem of the NTN and identification of some unique characteristics of the NTN.

There are differences in propagation delay characteristics and cell/beam layout between the terrestrial network and NTN in NR. The differences are largely due to high altitude of the NTN platforms (e.g., 600 km in a LEO satellite or approximately 36000 km in GEO satellite), larger cell size in the NTN scenario (e.g., 200-to 3500 km) compared to a terrestrial network scenario (e.g., 500 m to 40 km), and fast movement of the LEO/MEO satellite (e.g., every 7-8 minutes a new LEO satellite may serve an Earth-fixed cell). In NTN, the propagation channel may have a different multipath delay and Doppler spectrum model compared to a typical terrestrial network scenario. Knowing the satellite orbits (e.g., satellite ephemeris), the delay variation at the wireless device is, to some extent, predictable. However, 3GPP acts cautiously in preventing revealing location information of the NTN gateways and/or location information of the wireless devices to the unintended entities and parties.

On the other hand, the allocated spectrum for the satellite system may be limited to frequencies below the mmWave spectrum, e.g., S band and Ka band. Already, frequency division duplexing (FDD) is the baseline duplexing operation in the NTN. Nevertheless, provisioning to accommodate TDD operation mode in NTN environment is important as it can reduce the signaling overhead for channel acquisition and improve the bandwidth efficiency. Further, efficient beam management to compensate the large pathloss attenuations in the NTN makes the higher frequencies (e.g., mmWave spectrum) accessible for the NTN, especially for access networks based on UAS and HAPS.

Note also that a frequent and rapid change of the cell/beam, due to the fast movement of the LEO satellite, may result in frequent and inefficient handover, paging, and tracking area adjustment. For other type of NTN platforms, such as HAPS, a slight location displacement of the NTN platform (e.g., due to wind or a drift of the NTN platform) may render displacement of the cell borders by couple of kilometers, causing unnecessary handover for many wireless devices in the affected regions around the cell boundary. Techniques that rely on location information of the wireless device for handover, paging, beam management, tracking area update is valuable to reduce the signaling overhead, complexity, and enhance the user experience.

| Item Code & Title | Scope & Goal(s) |
|---|---|
| TR 38.811 “Study on NR to support NTN” | 1) Defining the NTN deployment scenarios and related system parameters such as architecture, altitude, orbit etc.<br><br>2) Adapting the 3GPP channel models, such as propagation conditions and mobility, for NTN.<br><br>3) Identifying key impact areas on the NR interface that may need further evaluations. |
| TR 22.822 “Study on using satellite access in 5G” | 1) Identifying use cases for the provision of services when considering the integration of 5G satellite-based access components in the 5G system.<br><br>2) Addressing requirements on set-up, configuration, maintenance of the features of wireless device when using satellite components combined with other components from the 5G system.<br><br>3) Addressing regulatory requirements when moving to (or from) satellite from (or to) terrestrial networks. |
| TR 23.737 “Integration of satellite components in the 5G architecture” | 1) Identifying impact areas of satellite integration in the 5GS, when considering TR 22.822 use cases.<br><br>2) Identifying solutions to adjust the 5G system for the impact impacts areas for roaming between terrestrial and satellite networks, 5G Fixed Backhaul between Satellite Enabled NR-RAN and the 5G Core and RAN & CN inter-related issues. |
| TR 28.808 “Study on management and orchestration aspects with integrated satellite components in a 5G net- work” | 1) Identifying the main key issues associated with business roles, service and network management and orchestration of a 5G network with integrated satellite component(s) (whether as NG-RAN or non-3GPP access, or for transport).<br><br>2) Studying the associated solutions.<br><br>3) Minimizing the impacts and complexity of satellite integration in the existing business models and in management and orchestration aspects of the current 5G networks. |
| TR 38.821 “Solutions for NR to support NTN” | 1) Studying a set of necessary features/adaptations enabling the operation of the New Radio (NR) protocol in non-terrestrial networks for 3GPP Release 16 with a priority on satellite access. Access network based on Unmanned Aerial System (UAS) including High Altitude Platform Station (HAPS) could be considered as a special case of non-terrestrial access with lower delay/Doppler value and variation rate.<br><br>2) Consolidating potential impacts on the physical layer and definition of related solutions if needed.<br><br>3) Assessing performance of NR in selected deployment scenarios (LEO based satellite access, GEO based satellite access) through link level (Radio link) and system level (cell) simulations.<br><br>4) Studying and defining related solutions if needed on NR related Layer 2 and 3.<br><br>5) Studying and defining related solutions if needed on RAN architecture and related interface protocols. |

Table 1: 3GPP satellite standardization

## III. Some Aspects of Release-17 NIN Standardization

Compared to terrestrial network, communication between the wireless device and the base station may undergo a long propagation delay. In a transparent LEO satellite scenario, the round-trip transmission time (RTT) may be up to 50 milliseconds, approximately 50 times higher than a typical RTT in a terrestrial network scenario. The RTT, when the wireless device is communicating with the base station via a transparent GEO satellite, could grow to up to 600 milliseconds, approximately 600 times larger than a typical RTT in the terrestrial network scenario. These figures may even become larger proportional to the number of inter-satellite links that the signal should travers to reach the receiver (e.g., the ground base station). Hence, in Release 17, the chief focus of the 3GPP standardization was to provide solutions for the identified parts of the NR that require adjustment/update to properly accommodate the large RTT. In this section, we take a closer look into several solutions that the 3GPP adopted to coup with the impacts of the large RTT in the NTT.

### A. Uplink Timing Synchronization

In NR, the uplink timing synchronization is achieved via timing advance (TA) commands. During initial access and after transmission of a preamble, the wireless device may receive an absolute TA command that could cover up to 2 ms. After the wireless device gains access to the network, the base station constantly keeps the wireless device synchronized for uplink transmissions by transmitting TA commands that could cover up to 0.1 ms. Obviously, these values are not enough to cover the large RTT in NTN. Updating the structure of the TA commands (or introducing enhanced TA commands) for accommodating much larger values may not be suitable, due to substantial standardization effort and inefficiency. The 3GPP recognized that the incurred delay due to the feeder link and a portion of the service link is common across the cell and could be predictable or measurable at the wireless device. Therefore, broadcast system information can be used to deliver assistance information, such as satellite ephemeris data and the delay of the feeder link, to the wireless devices, equipping the wireless devices to measure the RTT. The wireless device may continuously measure the RTT by reading assistance information and receiving TA commands. The uplink synchronization in NTN is therefore based on the legacy approach when the wireless device is well equipped to measure and compensate the incurred delay due to the feeder link and the service link.

One issue, which caused intense debates, was the ramification of RTT pre-compensation on the UL/DL frame layout at the base station. Some contributors, mostly network vendors, preferred the UL/DL frames at the base station stay fully aligned, as the case of the terrestrial network. This allows a straightforward base station implementation when the base station simultaneously connects to both NTN and the terrestrial network. On one hand, some other contributors, notably mobile manufacturers, preferred the base station

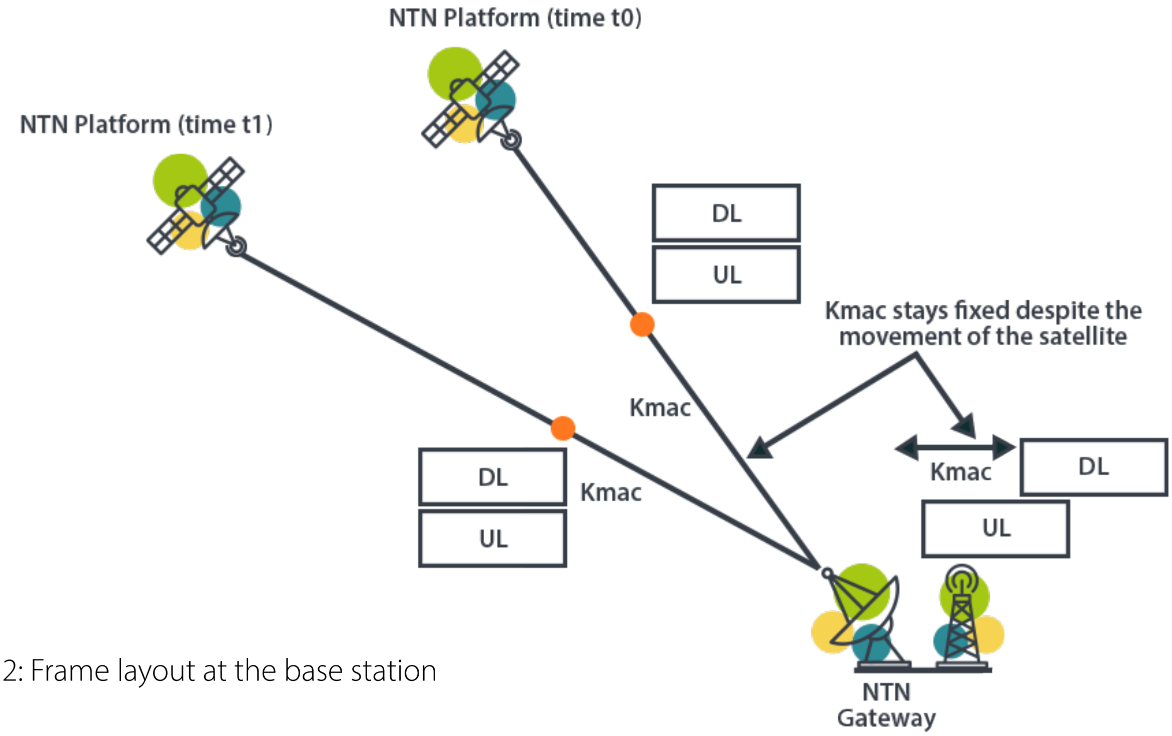



Figure 2: Frame layout at the base station

simultaneously connects to both NTN and the terrestrial network. On the other hand, some other contributors, notably mobile manufacturers, preferred the base station to pre-compensate all the RTT, as it substantially reduces the complexity of the wireless device. Eventually, to minimize the complexity of the base station and making the signaling overhead manageable, a middle ground design was chosen by agreeing that the base station pre-compensates a portion of the feeder link delay, leaving the wireless device with the pre-compensation of the service link delay and the reminded delay of the feeder link that is not pre-compensated by the base station. Importantly, the pre-compensated portion of the feeder link delay at the base station may stay fixed despite the movement of the satellite. This design choice strikes a balance between the complexity of the base station, the complexity of the wireless device, and the signaling overhead. See figure 2 for an example. As seen, the UL/DL frames may be unaligned at the base station, depending on what portion of the feeder link that is not pre-compensated by the base station.

## B. Random Access Response Timer

In a typical terrestrial network scenario, when the wireless device transmits an uplink signal (e.g., a preamble or a message A), the wireless device may start a corresponding timer (e.g., a random access response timer) after a last symbol of the transmission occasion of the uplink signal. While the timer is running, the wireless device may monitor physical downlink control channel (PDCCH) to receive the expected response. The current random access response timer, designed based on requirements of the terrestrial network, may not cover the long RTT (e.g., in a GEO satellite). Even, if the length of the timer is increased to accommodate the long RTT in the NTN, this legacy mechanism may not be efficient, as it increases the processing complexity, and therefore the consumed power, of the wireless device as the wireless device may monitor the PDCCH in vain. For example, when the wireless device is monitoring the PDCCH while the uplink signal has not yet received at the base station, or the response of the base station is still traversing the wireless medium to reach the wireless device, there is no need for the wireless device to monitor the PDCCH. To tackle this drawback, it is suggested to delay the start of the random access response timer by the RTT. For example, the wireless device may measure the RTT, transmit the preamble, and start the random access response timer after the RTT from the transmission of the preamble.

## C. Hybrid Automatic Repreat Request

Another major aspect of the NR that requires an update/adjustment to accommodate the large propagation delay of the NTN is HARQ operation in uplink and downlink. The 3GPP was quick to identify that the developed HARQ operation for small RTT values (e.g., smaller than 2 ms) may stall in NTN, as data corresponding to each HARQ process should be successfully received at the base station or the wireless device before the HARQ process become reusable for a new data transmission. The so-called HARQ stalling could reduce the spectral efficiency of the wireless device. One solution is to increase the number of HARQ processes. However, for the case of GEO satellite, up to 600 HARQ processes may be needed, which imposes a great memory and processing requirement on the wireless device, not mentioning the high signaling overhead for resource allocation.

Eventually, to tradeoff between complexity and performance, it is agreed to double the HARQ processes by increasing the number of the HARQ processes for downlink communication to 32 and for uplink communication to 16.

On the other hand, to reduce the impact of the HARQ stalling, part of RAN 1 and RAN 2 standardization effort was devoted to enhancing the HARQ procedure by disabling HARQ feedback of some downlink HARQ processes as well as disabling HARQ retransmission of some uplink HARQ processes. This allows the base station to have flexibility to reuse the feedback disabled HARQ processes during a time duration much shorter than RTT.

Nevertheless, having two modes of HARQ behavior in downlink (e.g., some downlink HARQ processes are feedback enabled and the rest of the downlink HARQ processes are feedback disabled) and/or in uplink (e.g., some uplink HARQ processes have activated retransmission mode and the rest of the uplink HARQ processes have deactivated retransmission mode) may affect the behavior of some MAC layer timers, particularly the MAC layer timers associated with discontinues reception (DRX) operation. An example shown in figure 3. As seen from figure 3, transport block 2 may not require retransmission, therefore, the wireless

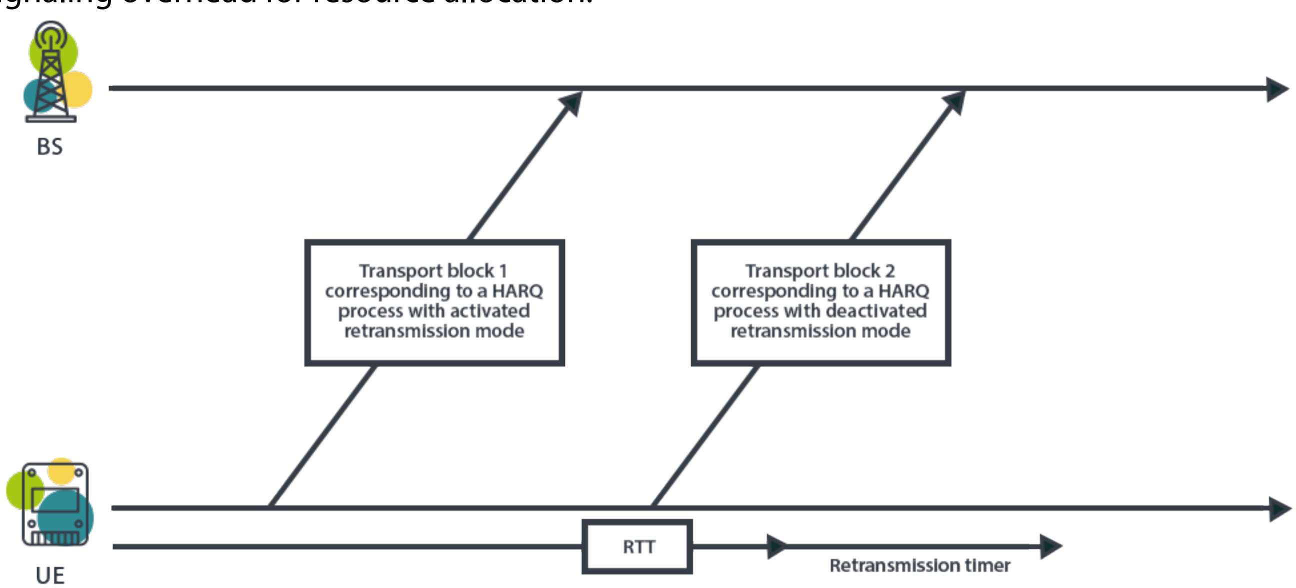



Figure 3: An ecample of DRX operation in NTN

device may not start the corresponding retransmission timer after transmitting the transport block 2. However, transport block 1 is associated with a HARQ process with activated retransmission, therefore the wireless device may start the corresponding retransmission timer after transmitting the transport block 1. Note that, as explained above, the start of the retransmission timer is delayed by the RTT to reduce the consumed power of the wireless device.

Furthermore, when UL HARQ processes are configured with two modes of HARQ mode A (e.g., activated retransmission mode) and HARQ mode B (e.g., deactivated retransmission mode), for each uplink data transmission, a modified logical channel prioritization (LCP) is introduced to align the QoS flow and UL HARQ operation. An example is shown in figure 4. As seen, the LCP procedure may conceptually group the logical channels based on whether their data require retransmission or not. For a given UL grant associated with a HARQ process, the LCP procedure selects data from those logical channels that support similar retransmission restriction as of the retransmission mode of the HARQ process.

## Logical Channel Prioritization (LCP)

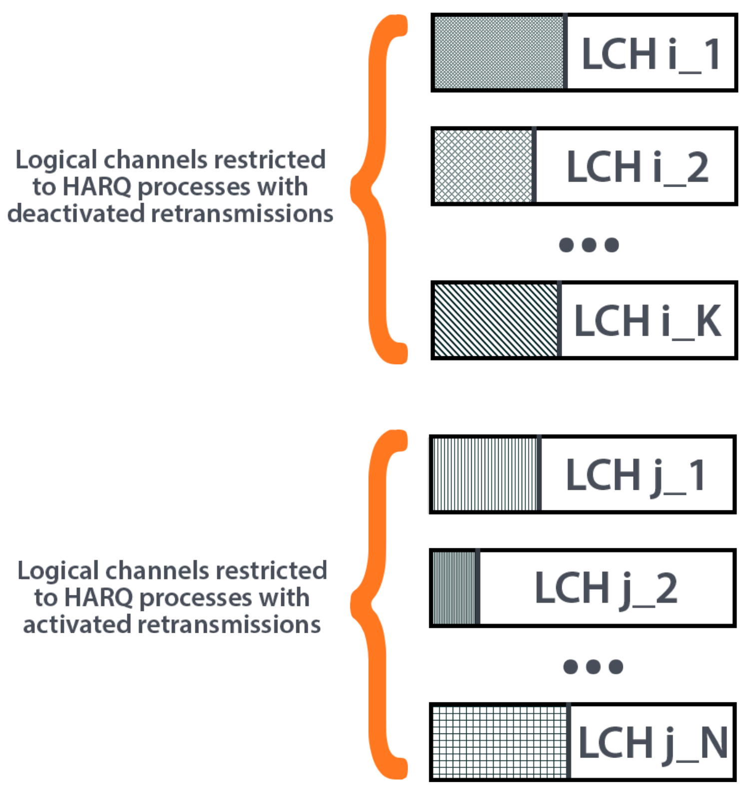



Figure 4: For transmitting a UL grant associated with a HARQ process with a configured retransmission mode (e.g., HARQ mode A or HARQ mode B), LCP selects data from logical channel(s) with the same retransmission restriction.

## About the Author

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Mohammad G. Khoshkholgh D. holds a Ph.D. from the University of British Columbia (UBC), Vancouver, Canada. Mohammad has authored 26 IEEE transactions papers and 22 IEEE conference papers. One of his journal papers was selected for IEEE ComSoc Best Readings on Cognitive Radio. In 2017, he was selected as Exemplary Reviewer IEEE Transactions on Wireless Communications. He was the holder of Vanier Canada Graduate from 2015 to 2018 and Four Year Fellowship from 2014 to 2015. His primary research interests include design and analysis of wireless communications systems, non-terrestrial networks, and machine learning and artificial intelligence.