Uplink zone-based scheduling for LEO satellite based Non-Terrestrial Networks

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***Abstract*—To provide coverage to the network devices distributed all over the globe, non-terrestrial networks (NTNs) have been recognized to complement and extend the terrestrial network to remote areas. The Low Earth Orbit (LEO) NTNs face several unprecedented challenges over 5G-NR protocol due to high differential delay and Doppler shifts which drastically impacts the performance of NR-NTN users. In this work, we investigate the impact of large differential delay and Doppler shifts within a NTN cell on the 5G-NR resource allocation and medium access control (MAC) protocol. We then propose an uplink zone-based scheduling technique to address the high differential delay and Doppler shifts for LEO satellites for LEO satellite-based NTNs. Finally, we validate the performance of the proposed strategy by comparing it with the conventional 5G-NR protocol through numerical simulations over the recently developed Samsung's NR-NTN System Level Simulator.**

I. Introduction

In recent years, non-terrestrial networks (NTNs) have emerged as a promising solution to complement terrestrial networks (TNs) for global coverage extension. The Low Earth Orbit (LEO) NTNs face several unprecedented challenges over 5G-NR protocol. In satellite systems, the propagation delays are long when compared to TN's delays due to large propagation distances between the user and the satellite. Moreover, since NTN cells are expected to cover an area as wide 1000 Kms in diameter, each NTN cell may have users with vastly different propagation delays. The maximum differential delay within one NTN cell is 10.3 ms for geosynchronous equatorial orbit (GEO) and 3.18 ms for LEO satellites, respectively [2]. For LEO-satellites at 600 km, the minimum and maximum round trip delays at 30 degrees and 90 degrees elevation are 7.17 ms and 4 ms, respectively. Due to high speed of the LEO satellites, high Doppler variation also impacts the performance of LEO-NTN users. The performance degradation due to Doppler shift comes from differential Doppler part which in uplink, can be compensated for if each individual NTN-user can also estimate and compensate its differential Doppler shift appropriately before transmitting the signal. However, this would significantly raise the complexity on the user side since it would require a continuous estimation of the satellite position [6] and would not be possible for low complexity devices.

In the current work, we study the impact of high differential delay and Doppler shifts on the resource allocation and 5G-NR medium access control (MAC) protocol for NTN users. In particular, for uplink transmissions, the user must have the time to prepare the data to send, and therefore, the gNodeB takes the uplink scheduler decision in advance and then sends the uplink grant taking into account these timings. For example, consider that the downlink control information (DCI) for downlink is usually prepared two slots in advance with respect to when the MAC Protocol Data Unit (PDU) is actually over the air i.e, the uplink (UL) grant must be prepared four slots before the actual time in which the user transmission is over the air: i.e. after two slots, the UL grant will be sent to the user, and after two more slots, the gNodeB is expected to receive the uplink data. For 5G NR NTNs, the uplink scheduling-offset would be determined to satisfy the above-mentioned timings for all users within the same spot-beam which may have drastically different propagation delays. Such a design methodology would impact the performance of low-propagation delay users within the same satellite beam drastically.

The **main contributions** of this work are articulated below:
1) We investigate the impact of high differential delay and Doppler shifts within NTN cells on the 5G NR-NTN MAC protocol in detail. We also bring out the impact of a common scheduling-offset (conventional strategy in 5G-NR) and explore strategies to support multiple scheduling offsets within the same cell.
2) We propose a novel uplink zone-based scheduling (ZBS) technique for a LEO satellite system, which is able to mitigate the impact of the differential delay and Doppler shifts on the 5G-NR MAC protocol.
3) We finally validate the performance of the proposed scheme for 3GPP-specified NTN layouts via simulations over the recently-developed 5G-NR uplink LEO-NTN simulator. *We have recently developed an uplink system-level simulator with basic NR PHY and MAC features to simulate 3GPP-specified NTN scenarios in MATLAB.* For obtaining realistic radio channel impulse responses for system-level simulations, the NR-NTN simulator uses Fraunhofer's channel-model named QuaDRiGa, short for Quasi Deterministic Radio channel Generator. The list of features supported by NR-NTN simulator is given in Table. I. In the current work, we use the uplink NR-NTN simulator to generate 3GPP-compliant NTN scenarios to evaluate the performance of the proposed ZBS scheme.

TABLE I: List of Features – Samsung's NR-NTN Simulator

Features		**Description**
Antenna Modelling	Antenna Pattern	[QuadRiGa] Based on TR-36.873, TR-38.901
Channel Modelling	Large-Scale Path-Loss, Shadow-Fading Model	[QuadRiGa] Based on TR-38.901, TR-38.811
Channel Modelling	Fast-Fading Model	[QuadRiGa] Based on TR-38.901, TR-38.811 (realistic channel evolution with spatial consistency, drifting)
Satellite Modelling	Satellite Beam-Pattern Modelling	Based on TR-38.811
Satellite Modelling	Satellite Trajectory Modelling	[QuadRiGa] Based on ITU-R documents
PHY Abstraction	-	Uses NR-specific SINR vs BLER curves
MAC	SR, BSR signaling	TR-38.821, TS-38.214
MAC	Resource Allocation	Proportional Fair Scheduling, Homogenous Power Allocation. Based on TS-38.214
MAC	Support for NTN-delays, Timing advance	Supports slot-level timing-advance
MAC	NR-scheduling timings (K1, K2 delays)	Supports K2-delay for uplink protocol
Traffic Modelling	Data-Traffic Model	Supports VoIP. Video, Gaming, IoT traffic models

II. System Model

In the 3GPP framework, six reference scenarios have been specified [1], [2]. We consider the scenario referred to as D2 in [1], [2] which targets the LEO satellite communication with S-band users.

TABLE II: 3GPP NTN scenarios.

	Set-1	**Set-2**
Altitude	600 Kms	600 Kms
Payload	Regenerative	Regenerative
Operating Band	S-band (2 GHz)	S-band (2 GHz)
Satellite Beam Diameter (at nadir)	50 Km	90 Km
3dB beam-width	4.4127 deg	8.832 degrees
G/T	1.1 dB K-1	-4.9 dB K-1
Satellite Rx Max Gain	30 dBi	24 dBi

A. Doppler-Shift Characterization

The Doppler's shift for both static and mobile NTN users have been analyzed in the 3GPP specification, TR-38.811 [1]. We note that the Doppler shift for a user connected to a LEO satellite at a height of 600 Kms can vary between $+/-4200$ kHz [1]. We now discuss the signal reception model for uplink in 5G-NR to understand the impact of differential Doppler on user- performance [6]. For 5G-NR, the transmitted signal by the k-th UE to the satellite can be given as:

$$s_k(t) = \frac{1}{\sqrt{N_k}} \sum_{n=0}^{N_k-1} b_k[n] e^{j2\pi f_s n t} \cdot u_T(t) \tag{1}$$

where $b_k[n]$ are the symbols mapped onto the subcarriers after applying DFT by k-th user, N_k is the number of subcarriers assigned for transmission for the k-th UE, $u_T(t) = 1 \; \forall t \in [0, T]$ where $T = T_s + T_{cp}$. T_s is the symbol-length, $f_s = 1/T_s$ is the sub-carrier spacing and T_{cp} is cyclic-prefix length. The received baseband signal is given by the superposition of each signal from UEs as $r(t) = \sum_{k=1}^{M} \cdot h_k(t) \cdot s_k(t) + w_k(t) = \underbrace{e^{j2\pi f_d^c(t)t}}_{\text{Common Doppler Shift}} \sum_{k=1}^{M} \underbrace{e^{j2\pi \Delta f_d^k(t)t}}_{\text{Diff. Doppler Effect}} h_k(t) s_k(t) + w_k(t)$ where $w_k(t)$ is the additive white gaussian noise (AWGN), M is the total number of UEs transmitting at a certain time, $f_d^k(t)$ is the time-dependent Doppler shift for the kth user, and $f_d^k(t) = f_d^c(t) + \Delta f_d^k(t)$, where $f_d^c(t)$ is the common Doppler-effect experienced by all users whereas $\Delta f_d^k(t)$ is the differential Doppler experienced by the k-th user.

The common part of the Doppler shift can be ideally pre-compensated in the downlink, or post compensated at the receiver in uplink i.e. at the satellite or gateway. Though, in uplink transmissions, the subcarriers assigned to different NTN-users will arrive at the satellite with different Doppler shifts, negating the orthogonality in the final OFDM signal and degrading the performance of the NTN users. This performance degradation coming from the differential Doppler part of the Doppler shift in uplink can be compensated for if each individual NTN-user can also estimate and compensate its differential Doppler shift appropriately before transmitting the signal. However, this would significantly raise the complexity on the user side, since it would require a continuous estimation of the satellite position [6] and would not be possible for low complexity devices.

In the conventional terrestrial 5G-NR networks, the differential Doppler shift is caused by the velocity of users. Based on 3GPP specifications, for mobile UEs, at a carrier frequency of 2 GHz and 15 kHz SCS, a maximum speed of 500 km/h can be considered, and therefore, it can be derived that the current 5G-NR standard can support up to 950 Hz of Doppler shift among subcarriers [6].

B. Differential Delay Characterization

The maximum differential delay within one cell is 10.3 ms for GEO and 3.18 ms for LEO satellites, respectively [1]. On investigating, we found that the round-trip differential delay for a LEO satellite spot-beam can be as high as 1.96 ms and 2.8 ms for the scenarios Set-1 and Set-2 described in Table II.

III. 5G-NR Resource Allocation Protocol

A. 5G-NR Grant Allocation Protocol

For scheduled access, once data arrives at user's Radio Link Control (RLC) queues, the user requests for an UL grant by sending a scheduling request (SR) to the gNB over the physical uplink control channel, PUCCH. Then, the gNB sends the UL grant (Downlink Control Information (DCI) in PDCCH) to indicate the scheduling decision to the UE. DCI formats 0_0 and 0_1 carry 4-bit field named 'time domain resource assignment' which points to one of the rows of a look-up table citespec3. Each row in the look-up table provides the following parameters; (i) **Slot-offset K2.** Upon reception of

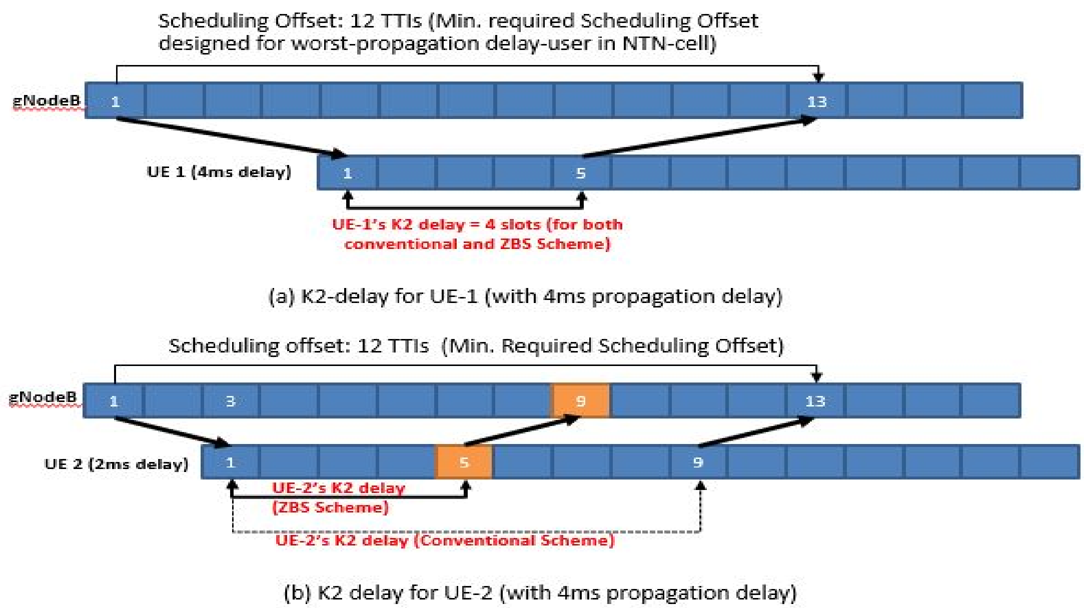


Fig. 1: Impact of scheduling-offset on K2-delay (for conventional and ZBS scheme) for (a) UE-1 with 4 ms. propagation delay and (b) UE-2 (with 2 ms propagation delay

an UL grant by the UE, the UL transmission (e.g., data and/or BSR) is sent after $K2$ slots, (ii) **SLIV** (jointly coded Start and Length Indicator Values), or individual values for the start symbol 'S' and the allocation length 'L'. These parameters indicate the first symbol and the length to be transmitted by the UE and (iii) **'PUSCH mapping type'** to be applied on the PUSCH transmission which helps in determining the demodulation reference signals' (DM-RS) starting position. After receiving the UL grant, the UE performs the data transmission in the allocated resources over PUSCH, which may contain UL data and/or buffer status report (BSR). If a BSR is received, the gNodeB knows the user's buffer status and can provide the user with another UL grant to transmit for the remaining data.

Minimum Required Scheduling Offset: For uplink transmissions, the UE must have the time to prepare the data to send, and therefore, the gNodeB takes the uplink scheduling decisions in advance (referred to as scheduling-offset) and then sends the uplink grant taking these timings into account. For example, consider that the DCIs for downlink are usually prepared two slots in advance with respect to when the MAC PDU is actually over the air i.e, the UL grant must be prepared four slots before the actual time in which the user transmission is over the air i.e. after two slots, the UL grant will be sent to the user, and after two more slots, the gNodeB is expected to receive the uplink data. The waiting-time for the UE after receiving the grants and actual transmission is K2-delay [3].

Due to the high propagation delay in NTN cells, the scheduling decisions have to be taken many transmission time intervals (TTIs) in advance. For example, if the worst-case propagation delay within a NTN cell is N TTIs, the minimum required scheduling-offset for a feasile transmission is N (For gNodeB-to-UE DCI transmission) + Processing-Delay + N (For UE-to-gNodeB data transmission). Note that the scheduling-offset within the NTN cell directly impacts the $K2$ delay indicated in the UL grant, which is the waiting time for the UE before the actual UL transmission (e.g., data and/or BSR).

B. Impact of Differential delay and worst-case scheduling-offset in NR on NTN users

For 5G NR NTNs, the uplink scheduling-offset would be determined to meet the timing-restrictions discussed in the previous section for all users within the same spot-beam. For an example, consider the system with two users with propagation delays of 2ms and 4ms, as shown in Fig. 1, to be served by the same satellite spot-beam. In such a case, the uplink scheduling-offset can be best set as 12ms (4ms worst-case propagation delay to send grants + 4ms to process the received grants + 4ms worst-case propagation-delay for gNodeB to receive user data). Note that in this example,

- From Fig.1a, we note that the K2-delay of the 4ms user is same for both conventional 5G-NR protocol and ZBS scheme. Also note that since the scheduling-offset was designed considering the propagation-delay for this user, the K2-delay can not be reduced for this UE.
- On the other hand, from Fig.1b, we observe that the K2-delay for the 2 ms user is being un-necessarily increased by 4 ms in the conventional 5G-NR protocol

because the scheduling-offset was designed for the worst-propagation-delay user i.e. the 4 ms user.

Therefore, for uplink NTN transmissions, the latency for the low propagation-delay users in the satellite spot-beam is being severely and rather un-necessarily impacted because the scheduling-offset is being designed for the worst-propagtion-delay users within the satellite beam. **To resolve this, in this work we propose the novel Zone-based Scheduling scheme wherein different scheduling-offsets can be considered for different zones within the same satellite beam which will radically improve the latency of NTN users. Besides this, the ZBS scheme, will also alleviate the performance degradation of NTN users due to large differential doppler doppler shift.** In the next section, we discuss the ZBS scheme in detail.

IV. Zone-Based Scheduling Scheme

In the ZBS scheme, we divide the coverage area into zones and allocate independent scheduling-offsets for each of the zones. Therefore, the ZBS scheme improves upon the overall user latency by reducing the K2 delay for low-propagation delay users within the NTN cells. At the same time, the impact of differential doppler can also be mitigated with such a zone-based allcoation strategy (similar to the work in [6]). Note that with the ZBS scheme, the users will use the same techniques as in the terrestrial network since the uplink scheduling and resource block allocation is done at the gNodeB with no explicit indication to the users about the zone-allocation required. Though, the gNodeB would need to continuously track and estimate the differential delays within each zone in an NTN cell and reallocate users accordingly.

A. Zone-Allocation for ZBS Scheme

We propose to divide the coverage area of each spot-beam into multiple NTN-zones in such a way that

1) The differential Doppler among users within the same NTN-zone should be below an allowed threshold.
2) The differential delay within each NTN-zone can be minimized and K2-delays for each user can be reduced given a pre-determined maximum number of allowed NTN-zones per beam.

Here, the number of NTN-zones that we need will depend on the variance in propagation delay and doppler shifts in the system. This is because larger NTN -zones can be created with smaller differential delay and doppler shifts within satellite coverage. For example, for the spot-beam at 90^o elevation angle with a beam-diameter of 50 Kms, we may need very few NTN-zones compared to a spot-beam at 10^o, with a beam-diameter of upto 1000 Kms. Besides this, also note that, we may not have any advantage if we increase the number of zones indefinitely. This is because, in such cases, though we are decreasing the differential delay within NTN zones by increasing the number of NTN-zones, the scheduling offset and the K2 delays cannot be reduced further at all. Therefore, it is crucial to determine appropriate number of NTN-zones for each spot-beam to gain an advantage from ZBS scheme.

Finally, we now discuss the ZBS scheme in detail.

B. Resource Allocation for ZBS Scheme

For ZBS scheme, there are two requirements:

1) **To address the impact of differential doppler shift in the satellite coverage area**
   To alleviate this problem, the resources can be allocated to NTN-zones in time-domain such that only NTN-zones with differential doppler shift within the allowed limit i.e. 950 Hz are allocated resources in the same time-slot i.e. different NTN-zones may be allocated resources in orthogonal time slots.
2) **To address the scheduling-offset issue arising due to differential delay in satellite coverage area** In a conventional system, all users have to be allocated resources with a common scheduling-offset but with NTN-zone based strategy, a different sheduling offset suited to the differential delay within that zone may be determined.

Before proposing the zone-based resource-allocation scheduling logic, we first discuss the conventional scheduling logics in the following sub-section.

1) Conventional Resource Allocation Algorithms: The conventional proportional-fair (PF) scheduler aims to provide a fair distribution of resources among the set of UEs that are served by the gNodeB. To obtain a fair allocation of resources among all UEs, the PF scheduler gives priority to the UEs that have the highest ratio between the feasible rate at the current time-slot and the average rate over former successive time-slots. The PF scheduler policy to assign the user u^* in the time-slot t can be expressed as

$$u^* = \arg\max_u \frac{r_u(t)}{\bar{r}_u(t-1)} \tag{2}$$

where $\bar{r}_u(t)$ is the average rate of user u in the time slot t, and is calculated based on an exponential moving average $\bar{r}_u(t) = (1-w)\bar{r}_u(t-1) + wr_u(t)$ where $w \in [0,1]$ is a system parameter that weights the importance of the current feasible rate with respect to the average rate when computing the average rate metric. On the other hand, the Maximise Minimum Rate (MaxMin) scheduler aims to maximise the minimum rate of the UEs. This is done by prioritising the UE with the lowest average rate. The MaxMin scheduler policy to assign the user u^* in the time-slot t can be expressed as $u^* = \arg\max_u \frac{1}{\bar{r}_u(t-1)}$.

2) Proposed Zone-Based Resource Allocation: Overall, the resource allocation for ZBS scheme can be divided into two-stages:

1) **Resource allocation at zone-level:**
   The users within each zone will have a common scheduling offset to alleviate the scheduling-offset issue for NTN cells. This ensures that the latency of the low-propagation delay users is not un-necessarily impacted. In ZBS scheme, the available uplink resources are first allocated among the NTN-zones considering the worst-case scheduling-offset and then allocated among the users within each zone based on the individual scheduling-offset selected independently for each NTN zone. For

resource allocation at zone-level, zone-based scheduling logics need to be defined.

Buffer-Length Based Scheduling Logic:

Let the candidate NTN zone-set to be scheduled this TTI be Z_c, and $BL(t, z_k)$ be the summation of buffer-length for the NTN-zone z_k at slot time t. The buffer-length for each NTN-zone is obtained based on the buffer status report by the UEs i.e., $BL(t, z_k) = \sum BL_i(t), \forall$ users $i \in z_k$, where $BL_i(t)$ is buffer-length of user i at slot time t. The scheduler calculates the buffer-length based utility function of each NTN-zone in Z_c. Given a total of M RBs in each slot time, the proposed function for zone z_k for m^{th}RB in scheduling time-slot t is,

$$\mathrm{ZBBL}(t, z_k) = \frac{BL(t, z_k) \Big/ \sum_{\forall z_k \in Z_c} BL(t, z_k)}{\bar{\beta}_{z_k}(t-1)}$$

where

$$\bar{\beta}_{z_k}(t) = \left(1-\frac{1}{T_w}\right) \cdot \bar{\beta}_{z_k}(t-1) + \frac{1}{T_w} \cdot \sum_{m=1}^{M} x_{z_k}(t, m)$$

where, $x_{z_k}(t, m)$ is a boolean to check whether the RB_m is or is not occupied by the NTN-zone z_k , $\bar{\beta}_{z_k}(t)$, is the average number of RB usage per time slot for NTN-zone z_k at time t. The proposed function allocates more resources to zones with higher buffer-length and at the same time, penalizes those NTN-zones which have higher average number of RB usage per time slot.

Zone-Based Proportional-Fair Scheduling Logic:

The proposed function fpr proportional fair scheduling for zone z_k for m^{th}RB in scheduling time-slot t is,

$$\mathrm{ZBPF}^{(1)}(t, z_k) = \frac{D_{z_k}(t)}{\bar{R}_{z_k}(t-1)}$$

where

$$\bar{R}_{z_k}(t) = \left(1-\frac{1}{T_w}\right) \cdot \bar{R}_{z_k}(t-1) + \frac{D_{z_k}(t)}{T_w} \cdot \sum_{m=1}^{M} x_{z_k}(t, m),$$

where $\bar{R}_{z_k}(t)$ is calculated as the moving average rate over a window size of T_w time slots for the NTN-zone z_k at time t. Note that for the trivial case, i.e. when z_k contains only one user, the proposed ZBPF function becomes equivalent to conventional PF function given in (2). Finally, we select the NTN-zone z_k^* with the best ZBPF utility function values, $z_k^* = \mathrm{argmax}\,\mathrm{ZBPF}(t, z_k)$.

Zone-Based Max-Min Fair Scheduling Logic:

For zone-based Max-Min Fair scheduling, we assign the RBs zone z_k^* in the time-slot t s.t. $z_k^* = \arg\max_{z_k} \frac{1}{R_{z_k}(t-1)}$

Besides the above scheduling logics, several strategies can be devised to allocate resources for ZBS scheme.

2) **Resource-allocation within zones:**
Finally, the resources are allocated among the users within each zone in a round-robin or random or priority based manner. Resource allocation within zones cane be done on the basis of conventional scheduling logics.

We now provide the overall algorithm for ZBS scheme in Algorithm 1.

Algorithm 1: ZBS Scheme

Result: Resource Block (RB) allocation for each user

Step 1: Re-allocate zones to NTN users and update each zone's scheduling-offset such that (i) the differential Doppler within each zone is below the maximum value tolerable by the 3GPP standard, (ii) The differential delay within each NTN-zone can be minimized.

Step 2: Update the scheduling-offset for each zone.

Step 3: Allocate uplink resource blocks at the zone level considering worst-case scheduling-offset within NTN cell. Resources can be allocated based on above described zone-based PF, zone-based max-min fair allocation strategies.

Step 4: Schedule users within each zone considering different scheduling-offset for each zone. Resourcrs can be allocated each time-slot based on round-robin, random etc scheduling logics)

Step 5: Determine K2-delays for each NTN user.

Step 6: Indicate the scheduling decision and the K2-delays accounting for different scheduling offsets to the users in the DCI.

Step 7: Update the utility criterion and historical information required for zone-based allocation.

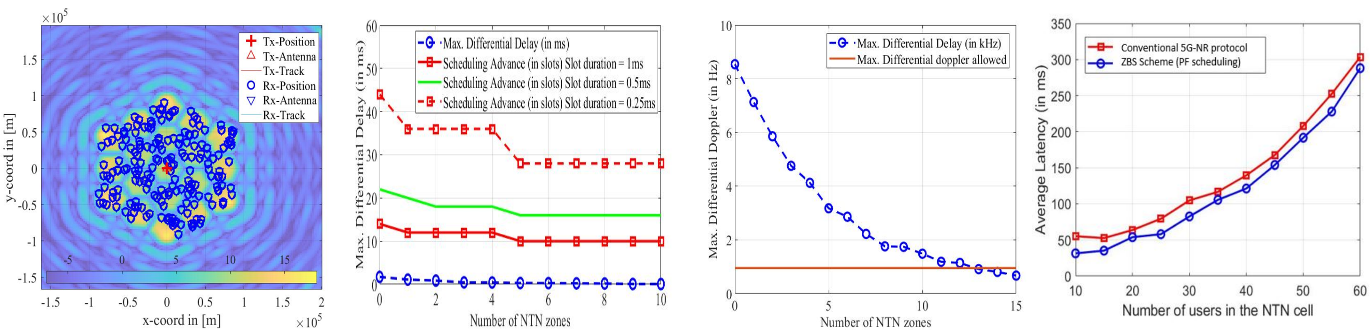
In the next section, we study the impact of high differential delay and Doppler shifts within NTN cells on the performance of NTN users and also compare the performance of conventional NR MAC protocol with the proposed ZBS scheme.

V. Simulation Results

We consider the following set-up: (i) A single LEO satellite with three-tiers i.e. 19 spot-beams (3GPP baseline layout for LEO NTNs) at an altitude of 600 Kms. We deploy 10 users per satellite spot-beam randomly within the satellite visibility region. We assume that the channel between the gNodeB and the satellite is ideal, (ii) SLS parameters; SR-prohibit-Timer = 20ms, Worst-case scheduling-offset = 16 TTIs, Scheduler averaging window , T_w= 25 TTIs, and (iii) the users are fixed on Earth with no terrestrial gNodeB within visiblity.

A. System Characterization

TR-38.811 specifies the 3-tier, 19-beam layout as the baseline for NTN scenarios. In Fig 2a, we show the beam-layout for the 19-beam pattern LEO satellite (in 2-D) considered in the Samsung's NR-NTN simulator. For the NTN scenario considered in Fig. 2a, we first investigated the differential delay in the NTN cell and found that the minimum differential delay was in the spot-beam pointed towards nadir point (the point on earth just below satellite) and was equal to 0.2 ms whereas the maximum differential delay was for the satellite-edge spot-beam (in the outer-most tier) and was found to be 1.6 ms for Set-I 3GPP layout. For Set-II, the maximum differential delay was 2.8 ms. We next investigated the differential-Doppler shift for a LEO satellite, and observed that the maximum



(a) (b) (c) (d)

Fig. 2: (a) LEO-satellite Beam-Layout, (b) Max. Differential Delay vs Number of Zones, (c) Max. Differential Doppler vs Number of Zones and (d) Performance of ZBS Scheme.

differential Doppler shift was as high as 8kHz for the NTN users.

B. Performance of ZBS Scheme

We now study the performance of the ZBS scheme with the help of numerical simulations in this section.

A. Zone Allocation:
In the ZBS scheme, we first allocate zones to each of the NTN users such that the differential delay and Doppler-shifts can be minimized within each zone. To illustrate the impact of optimal zone-allocation for ZBS Scheme, in the current work we employ agglomerative hierarchical zone allocation strategy described in the following algorithm.

Algorithm 2: Agglomerative Heriarchical Zone-Allocation for ZBS Scheme

Input: Number of user (N), Users i.e. $\{\mathrm{UE}_i\}\ \forall i$
Output: Max-diff.-delay/Doppler-shift versus number of zones, N_z
Step 1: Allocate all users to different NTN-zones i.e. $Z_i = \mathrm{UE}_i \forall i$. Set number of zones i.e. $N_z = N$.
Step 2: for $N_z = N$ **to** 1; $N_z = N_z - 1$ **do**
  Step 2.1: For all i, j, Obtain Diff[i][j] = Max-Diff-Delay/Doppler-shift in $Z_i \cup Z_j$
  Step 2.2: Merge Z_i and Z_j such that $\{i, j\} = \arg\min$ Diff[i][j]
end

For this study, we consider a single LEO-satellite spot-beam at an elevation of 30 degrees from the LEO satellite and spot-beam diameter of 256 Kms. In Fig. 2b, we plot the maximum differential delay within a NTN zone versus number of NTN-zones (N_z) using Algorithm 2, and observe that even with a small reduction in differential delay in an NTN zone, the min. required scheduling-offset is impacted significantly. We also note that for higher numerologies (i.e. small slot-length, larger sub-carrier spacing), the min. required scheduling-offset is impacted more severely. We can therefore conclude that with zone-based NTN deployment, the scheduling-offset can be brought down significantly improving upon the latency of NTN users. Next, in Fig. 2c, we plot the maximum differential delay within a NTN zone versus number of zones. We note that for the considered simulation scenario, we need at least 12 zones to meet the standard requirement of maximum differential Doppler of 950 Hz (as in terrestrial scenarios).

B. Resource Allocation:
Finally, we investigate in Fig. 2d, the latency versus number of users in NTN cell using the NR-NTN System Level simulator for the proposed zone-based proportional-fair scheduling scheme. We observe that the latency rises radically with an increase in number of users within an NTN cell due to limited number of resources. We also note the proposed zone-based resource allocation scheme significantly outperforms conventional proportional-fair resource allocation scheme.

VI. Conclusion

In the present work, we investigated the impact of high differential-delay and Doppler effects on 3GPP specified NTN scenarios in detail. We studied its impacts on the NR-NTN user performance and then proposed zone-based resource allocation strategy wherein the entire coverage area is split into multiple zones and showed that the proposed scheme can improve upon the latency of NTN users without increasing complexity at the user-side or requirement of any additional signalling overhead. We then finally validated the performance of the proposed zone-based resource allocation strategy with the help of system-level simulations.

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