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NB-IoT random access procedure via NTN: system level performances

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***Abstract*—With the evolution process of the 5G into the 6G, there will be an exponential growth of the Internet of Things (IoT) devices, offering ubiquitous and continuous connectivity services in all areas of our life. In order to deal with such huge amount of IoT devices, and to satisfy the large capacity requirements of the most advanced of them, non-terrestrial networks (NTNs) will play a pivotal role to assist and complement the terrestrial systems. However, one of the major challenges of the NTN channel is represented by the large delay which hampers the different communication phases, such as the Random Access (RA) procedure. In this paper, we provide an assessment of the system level performances, in terms of access delay and access success probability, of the Narrowband IoT (NB-IoT) devices in typical satellite scenarios defined by the 3GPP. In particular, we provide a detailed analysis under different network densities, for various combinations of the related configuration parameters, and for different system architectures supporting the NB-IoT over NTN. The analysis led to a useful comparison of the RA performances obtained with 3GPP compliant configurations for access parameters and satellite configuration with the aim to maximize the access success probability and minimize the access time in a NB-IoT NTN system.**

***Index Terms*—NB-IoT, satellite communication systems, NPRACH collisions.**

I. Introduction

The fifth generation New Radio (NR) cellular network is driving the global economy and society, providing multi-service communications with highly heterogeneous requirements. At the same time the race towards Beyond 5G (B5G), or 6G, mobile communications has already started. Indeed, considering the extensive growth in the number of Internet-of-Things (IoT) and Narrowband IoT (NB-IoT) devices, the 6G communication systems aim to achieve high spectral and energy efficiency, low latency, and massive connectivity. Thanks to these devices, a plethora of different services will be offered, such as tele-medicine and smart transportation, environment monitoring and digital sensing. Market forecasts predict more than 25 billions IoT connections by 2025 [1], and therefore, it is very challenging for the existing multiple access techniques to support such massive number of terminals. Even NR communication systems, which are currently being deployed, are not able to provide connectivity to such huge amount of IoT devices spread all around the world. Therefore, to alleviate this kind of issue, the 6G communication systems foresee a multi-dimensional multi-layered integrated architecture, with the full integration of the Non Terrestrial (NT) component into the

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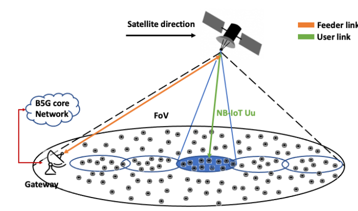


Fig. 1. System architecture

B5G infrastructure with no distinction between terrestrial and NT network (NTN) elements. By adding the third dimension to the already existing two terrestrial dimensions, this type of architecture will be able to satisfy the heterogeneous traffic requirements [2]. Indeed, the NTN elements will offer further connections to offload the terrestrial links, thus strongly supporting the scalability of the mobile communication systems. For these reasons, Satellite Communication (SatCom) systems result particularly effective for IoT scenarios. Moreover, the Third Generation Partnership Project (3GPP) has recently released a Study Item covering NTN's NB-IoT support [3]. This Study Item, which started at beginning of 2021, aims at evaluating the performance of NB-IoT over NTN and identifying the required adaptations. Indeed, the NTN channel imposes new challenges to be carefully addressed [4]. One of the main issue is represented by the high delay [5], which hampers different communication phases, such as the uplink synchronization achieved through the Random Access (RA) procedure. In this context, several scientific publications have analyzed the impact of the increased propagation delay over the NTN channel on the RA procedure. The authors in [6] investigate the effects of the differential Doppler and delay on the RA, while pointing out some solutions and research directions to overcome those challenges, such as the use of Global Navigation Satellite Systems (GNSS) aided solution and the removal of Hybrid Automatic Repeat Request (HARQ). A more general view of the NB-IoT via NTN systems is provided in [7], where the authors not only take into account the adaptations needed at the physical layer, but also at the higher layers, like Medium Access Control (MAC), Radio Link Control (RLC), Packet Data Convergence Control (PDCP), and Radio Resource Control (RRC) layers. A more practical approach is proposed in [4], where the authors design a testbed based on Open Air Interface (OAI) implementation for the 3GPP users and base station (BS), and hardware implementation for the NTN channel emulating the experienced delay in the communication link between the users and the BS. With this testbed, they measure and show the single user access time experienced by the terminal during the RA over NTN. The work in [8] presents a simulation tool, conceived as a new module for the open-source 5G-air-simulator, modeling NB-IoT cubeSat-based communication systems. Based on the preamble collisions, the End-to-End packet delays is computed. Although the authors test the performance of the system with a different number of cubeSats, the NB-IoT access parameters, such as the length of the back-off (BO) window and the random access occasion (RAO), are never changed.

The aim of this work is to test specific scenarios defined by the 3GPP in [9] where multiple users access the network at the same time within the same beam footprint. Varying the number of users, the probability of collisions changes, enabling us to obtain further results regarding the mean user access time as a function of the user density of NTN NB-IoT network and the time visibility of the beam. Overall, the contributions of our study can be summarized as follows: we model the random access procedure of a single coverage enhancement level as a multi-channel slotted Aloha system and we characterize the collision probability under the back-off mechanism, the number of sub-carriers reserved for the preamble transmission, and the RA periodicity, based on the satellite beam visibility window and the number of users. Performance analysis of the above-mentioned system is conducted for 3GPP-defined values of number of repetitions, periodicity, and back-off window size, which are the so called configurable access parameters. The result of this study is a comparison of the RA success probability and the users access time for different combinations of the configurable access parameters for a given user density and satellite configurations defined by the 3GPP. The users access time will act as an upper bound for future studies, where an efficient satellite constellation could be designed to fully serve all users, thereby reducing the high period during which a terminal is not served.

The remainder of the work is organized as follow: Section II gives an overview of the system architecture; in Section III the RA procedure is presented; Section IV provides a description of the simulation model, whose performances are, then, evaluated and discussed; finally Section V concludes this work.

II. System architecture

Referring to Fig. 1, the main elements of the high level system architecture are [10]: *i*) the terrestrial segment composed by the terrestrial network infrastructure, which is connected to the NTN segment through the Gateway (GW). *ii*) A satellite payload, transparent or regenerative, providing connectivity to the User Equipments (UEs) through the user link. Notably, with a transparent satellite, the BS is conceptually located at the GW, while with regenerative payloads it is implemented on-board. In both cases, the user access link between the satellite and the on-ground UEs is implemented by means of the traditional NB-IoT-Uu air interface. Regarding the feeder link between the satellite and the GW, the solution to be adopted depends on the position of the BS. Indeed, as detailed in [11], transparent payload only acts as a radio-frequency repeater, hence not terminating the NB-IoT protocols, which requires the feeder link to be implemented with a NB-IoT-Uu solution. While, in the regenerative payload, being the BS located on the satellite, the feeder link is implemented by means of the air interface between the BS and the Core Network. Depending on the payload, the satellite is able to serve a portion of the on-ground coverage area by means of a single-beam or multi-beam system. With respect to the satellite constellations, a further distinction is based on the type of on-ground coverage that is provided. In particular, on the one hand, the payload can be equipped so as to be able to steer the on-board antenna in order to always cover the same on-ground area, meaning that the on-ground beams are fixed. On the other hand, the area covered by each satellite will move accordingly with the satellite movement on its orbit, i.e., the on-ground beams are moving with the satellite since the coverage centre is always located at the sub-satellite point. This second case refers to the so called moving beams. *iii*) User segment, represented by a plethora of NB-IoT devices spread all over the world. It is worth noting that the devices do not have visibility of the satellites for the entire time. In particular, depending on the satellite's position along its orbit, for a given on-ground coverage area, only a subset of NB-IoT devices is able to communicate with the flying platform. In this paper, if not otherwise specified, we assume the following system configuration: direct access, i.e., the UE is directly connected to the satellite, regenerative payload, and a Low Earth Orbit (LEO) single-beam platform operating in S-band with a moving beam. In addition, we make the following assumptions: a standalone NB-IoT deployment is considered and the UEs are equipped with a GNSS receiver so as to pre-compensate the Doppler shift and the propagation delay due to the satellite distance.

III. NB-IoT Random access procedure

When a user wants to establish a connection with the network, it needs to achieve uplink synchronization and a permanent ID, through the RA procedure. As in the legacy LTE, this handshake procedure consists of four messages: the first one, also known as a preamble, is sent by the mobile device to the BS. If the latter detects the incoming message, replies with the Random Access Response (RAR or Msg2) and, then, two other messages are exchanged between the UE and the BS, the so called Radio Resource Control (RRC) messages, i.e., Msg3 and Msg4. Notably, the most critical part is represented by the preamble transmission, since the devices are not yet synchronized with the network and compete for the same resources. In the frequency domain, these resources are spread over 180 kHz, where are considered 48 sub-channels, each one 3.75 kHz wide. In the time domain, the minimum time frame is represented by four contiguous symbol groups (SGs), each one made by a Cyclic Prefix (CP) and five symbols [12]. Potentially, every UE can periodically send its preamble in the RAO configured by the network. Within a given interval, T_{max}, the number of RAO is defined as:

$$N_{RAO} = \left\lfloor \frac{T_{max}}{T_{RAO}} \right\rfloor \tag{1}$$

where T_{RAO} stands for the RAO duration. As per 3GPP specification, different values of T_{RAO} are defined to ensure that the device is aware of the procedure success. Therefore, $T_{RAO} > T_{msg1} + T_{RAR} + T_{CR}$.

In each RAO, the minimum preamble time frame could be repeated to increase the detection probability. Indicated as N_{rep} the number of preamble repetitions, its time duration is computed as follow: $T_{msg1} = 6.4 \cdot N_{rep}$ ms, where 6.4 ms is the length of four SGs. Regarding T_{RAR} and T_{CR}, they refer to the length of RAR window and the contention resolution timer, i.e., the timer between the first and the second message and between the third and the fourth message, respectively. Their duration depends on the number of repetitions configured in downlink. Moreover, as mentioned above, the satellite Round Trip Delay (RTD) is much higher than the one typical of the terrestrial communication. Therefore, since T_{RAR} and T_{CR} are procedure timers impacted by the single UE RTD, no pre-compensation can be implemented by exploiting the GNSS capabilities. It should be noted that the NB-IoT standard specifies two starting times for the RAR window, i.e., 4 ms and 41 ms after the last sub-frame containing the preamble [13]. Therefore, it is essential that these two starting times are long enough to absorb the RTD. As it is possible to see from Fig 2, which represents the RTD of a LEO satellite (set 3) with regenerative payload, the first one is not big enough to account for the increased delay of the NTN channel. Regarding the CRT, it starts as soon as Msg3 is sent, hence it is necessary to postpone it by a quantity equal to the RTD. Thus, if no modification of RA procedure are foreseen, the duration of the RAO needs to be able to satisfy the following condition: $T_{RAO} > T_{msg1} + T_{RAR} + T_{CR} + 41 + RTD$. When one of the two timers expires and the device does not receive Msg2 or Msg4, it re-attempts the procedure. In particular, the reasons for a RA failure are: *i*) worst channel condition: the BS is not able to detect the incoming preamble, because the signal power accumulated along the repetitions is not sufficient to exceed the receiver sensibility. Therefore, the BS does not send the RAR to UE, which, after waiting the expiration of the RAR window, extracts a BO value to be applied before the re-transmission. *ii*) Collision: if two or more devices choose the same preamble, they will receive the same RAR, and, therefore, will send the Msg 3 using the same resources. However, only one UE will receive the contention resolution message (i.e., Msg4), while the other will re-start the procedure after a BO time. The back-off mechanism represents a strategy to reduce the congestion in the RAO, by distributing the number of contending devices over the time. Indeed, the UEs which collide in an RAO will randomly choose a back-off value in the interval [0, BO]. Thus, the probability that a collided NB-IoT terminal in the $n-th$ RAO will transmit in the $k-th$ one is computed as follow:

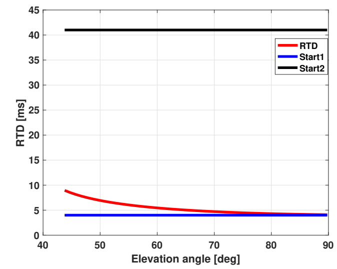


Fig. 2. RTD of LEO satellite varying the beam center elevation angle. Set 3

$$P_{BO} = \begin{cases} \frac{T_{RAO}}{BO} \text{ if } n + \lfloor \frac{BO}{T_{RAO}} \rfloor \leq k \\ 0 \text{ if } n + \lfloor \frac{BO}{T_{RAO}} \rfloor > k \end{cases} \tag{2}$$

The BO value has a great influence on the performance of the RA. Indeed, on the one hand a small BO allows devices to re-transmit the preamble after a short period of time, increasing the collision probability during burst arrivals. On the other hand, a large BO value may increase the access success probability causing high access time. Therefore, it is important to find the optimal BO value which increases the probability of concluding the RA procedure with a reasonable access delay. Moreover, another factor that impacts the RA performance is the number of sub-carriers dedicated to the preamble transmission. Indeed, based on the number of coverage enhancement (CE) zones and the traffic, the number of sub-carriers could be distributed among the CE zones with the aim to increase the detection probability of the terminals which experience worst channel conditions in the different sectors of the cell. Defined S as the total available sub-channels and N as the users attempting the access in the same RAO, the probability that each device randomly selects one of the available sub-carrier is $P_s = 1/S$. Therefore, the probability that *n* users select the same preamble is given by:

$$P_{n,s} = \binom{N}{n} \left(\frac{1}{S}\right)^n \left(\frac{S-1}{S}\right)^{(N-n)} \tag{3}$$

It should be noted that the transmission is considered successful if a preamble is chosen only from one user, thus this probability is equal to:

$$P_{1,s} = \frac{N}{S} e^{-\frac{N}{S}} \tag{4}$$

Therefore the number of UEs that re-attempt the procedure is:

$$N_{coll} = N(1 - e^{-\frac{N}{S}}) \tag{5}$$

Then, each of these N_{coll} devices randomly selects one of the available sub-carriers in the $k-th$ BO interval with probability $P_s \cdot P_{BO}$. Therefore, the probability mass function (pmf) obtained by distributing the N_{coll} UEs over the $(S \cdot \frac{BO}{T_{RAO}})$ sub-channels in the $k-th$ BO interval is:

$$P_{n,s,k} = \binom{N_{coll}}{n} (P_s \cdot P_{BO})^n \, (1 - P_s \cdot P_{BO})^{(N_{coll}-n)} \tag{6}$$

where $k \in [1, N_{RAO}]$. Therefore, the collision probability in the $k-th$ RAO is given by:

$$P_{coll,s,k} = 1 - e^{-(N_{coll} \cdot P_s \cdot P_{BO})} \tag{7}$$

IV. Simulation assessment

A. Simulation Model

In the proposed model, a LEO satellite covers a fixed area defined by its Field of View (FoV), where the stationary NB-UEs, equipped by an omnidirectional antenna, follow a uniform distribution. In order to evaluate the access success rate in the considered area, the satellite motion over the simulation duration, according to the Keplerian orbit parameters of the satellite, is computed. Starting from a reference epoch and given the Keplerian orbital elements, the state vectors, i.e., position and velocity, for the satellite are computed at each simulation step. Knowing the successive spacecraft positions at each simulation step, i.e., ephemerides, thus its trajectory, it is possible to compute the visibility period of the satellite with respect to the on ground UE. Thus, based on the satellite - User Terminal (UT) geometry, the uplink Carrier To Noise Ratio (CNR) is computed as follow:

$$\begin{aligned} CNR^{UL} = EIRP(\theta_s^u) + G_{max}^{RX} + \\ 10\log_{10}\Omega(\theta_u^s) - PL_s^u - 10\log_{10}(kTB) \end{aligned} \tag{8}$$

where the $EIRP(\theta_s^u)$ is the user's transmitted Equivalent Isotropically Radiated Power with θ_s^u indicating the angle between the boresight of the u-th user's antenna and the satellite. While the receiving gain of the satellite, $G^{RX}(\theta_u^s) = G_{max}^{RX} + 10\log_{10}\Omega(\theta_u^s)$, is computed according to the Bessel function in [14] and G_{max}^{RX} refers to the maximum receiving gain for the satellite. Notably, it is a function of the angle between the boresight of the antenna on the satellite and the u-th user (θ_u^s). The noise power in UL, $P_N = 10log10(kTB)$, depends on the satellite antenna equivalent noise temperature, T, and the user bandwidth, B. Finally, PL_s represents the overall path loss, which includes the free space loss, the shadowing losses and signal loss due to tropospheric or ionospheric scintillations. It is worth highlighting that the user is always in Line of Sight (LoS) condition and the shadowing loss is modelled as a lognormal random variable with zero mean and a variance related to the harshness of the shadowing environment (i.e., $PL_\sigma \sim (0, \sigma_s^2)$), whose values are provided by 3GPP as a function of the elevation angle in [10]. The UTs are able to communicate with the satellite, only if $\Omega(\theta_u^s) > \Omega(\theta_{edge}^s)$, where $\Omega(\theta_{edge}^s)$ is the value of the normalised radiation pattern at the beam edge. Therefore, all the users, whose radiation pattern is bigger than that at the beam edge, have the possibility to attach the network, by generating their own traffic. This means that the traffic is modeled as pick/bursty traffic, simulating a daily uplink report. The choice of the one shot arrival process is due to the fact that, under massive access scenario, it imposes more challenges at the network side with respect to other arrival process model, such as the beta distribution [15]. Finally, the

TABLE I
Satellite parameters

Satellite orbit	Set 2 LEO 600 km	Set 3 LEO 600 km	Set 4 LEO 600 km
Equivalent satellite antenna aperture	1 m	0.4 m	0.097 m
Sat EIRP density	28 dBW/MHz	28.3 dBW/MHz	21.45 dBW/MHz
Sat Tx max Gain	24 dBi	16.2 dBi	11 dBi
3dB beamwidth	8.8320 degrees	22.1 degree	104.7 degree
Sat beam diameter	90 km	234 km	1700 km
Equivalent satellite antenna aperture	1m	0.4 m	0.097 m
G/T	-4.9 dB K^{-1}	-12.8 dB K^{-1}	-18.6 dBK^{-1}
Sat Rx max Gain	24 dBi	16.2 dBi	11 dBi
Sat Visibility window (10° min el)	8.49 min	8.49 min	8.49 min
Beam visibility window = T_{max}	13.4 s	33.86 s	246.9 s

overall interference I_s^{uplink} in the uplink for the preamble S is

$$I_s^{uplink} = 10\log_{10}\left(\sum_{k=0}^{N_{int}-1} 10^{(0.1 \cdot I_{s,k})}\right) \tag{9}$$

with $k = 0, ..., N_{int}-1$, being N_{int} the number of interfering UTs with the same preamble. In order to solve the contention due to the multiple collisions, the Carrier to Interference plus Noise Ratio (CINR) of each UE is exploited to estimate the BLock Error Rate (BLER) of the received signal, using CNR-BLER curves of the Narrowband Physical Uplink Shared Channel (NPUSCH). Indeed, our model is based on the CNR level of the Msg3, since, thanks to this message, the contentions are solved. To this end, the BLER is estimated by considering the chosen Modulation and Coding Scheme (MCS), number of Resource Unit, number of NPUSCH repetitions, and the CINR experienced at the satellite during the reception. In case more than one UE has a CINR that exceeds the one providing a BLER of 10^{-1}, the highest one is selected.

B. Performance evaluation

In this section, we assess our proposed model by conducting a system level study, which highlights how the network parameters and the NTN configurations significantly impact the system performances. The numerical assessment is provided in terms of percentage of completed users, access delay, number of preamble transmissions per completed users and uncompleted users, and remaining time of beam visibility for the data transmission. To this aim, it is worthwhile highlighting that only one coverage enhancement zone is considered and all the preambles are available for the users, i.e., all the 48 sub-carriers. In our model, the T_{max} value represents the beam visibility window, which, in turn, defines the upper bound to the number of re-transmissions that a UT can perform to finalize the procedure. Notably, the wider the beam, the greater the number of users served and the greater the interference. Two user density values have been tested, i.e., $\alpha = 0.1$ $[users/km^2]$ and $\alpha = 1$ $[users/km^2]$. It should be noted that these are reasonable values in rural environments. Once fixed the RAO value for the different NTN configurations, the BO value is chosen based on the collision probability previously computed. The satellite parameters are reported in Table I and the access parameters in Table II.

1) Parameters configuration: Referring to Table III, as expected, a greater value of α leads to a higher number of collisions. Indeed, since more devices try to send a preamble in the same RAO, the collision probability increases accordingly.

TABLE II
ACCESS CONFIGURATION PARAMETERS [16]

Parameters	Value
N° repetitions	[1,2,4,8,16,32,64,128]
RA periodicity	[40,80,160,240,320,640,1280,2560]ms
Back-off	$[0, 256 \cdot 2^j]$ms, $j \in [0, 11]$

As a consequence, the percentage of users that finalizes the procedure decreases with the traffic load. Moreover, not all the configurations, given by the combination of the RA periodicity, number of repetitions and the BO index, perform in the same way. Indeed, as shown in Fig. 3a, only with a periodicity of 160 ms, more than 90% of the UEs finalize the RA. However, for the same RAO and number of repetitions (i.e.,4), a discriminating factor is represented by BO value in terms of percentage of completed users. Despite an increased BO value spreads the users over more RAOs, thus reducing the collision in the same opportunity, it increases the probability that a user is not served, being outside the beam visibility window. This behavior is reflected on the percentage of devices achieving the connection at the first attempt and on the percentage of users unable to attach the network. In fact, when the periodicity is fixed at 160 ms and the BO index is 8, 58% of the completing UEs has granted the network in the earliest RAO; while, in case of smaller BO value, this is reduced to 55%. On the contrary, with a lower BO index, the percentage of devices that are out of the system decreases. For the other two tested values of RAO, it is possible to observe the same behavior. Indeed, the performances worsen as the periodicity increases, as more UEs attempt the access causing a higher number of collisions. Therefore, being each RAO clogged, in both the cases, the highest BO index leads to the largest percentage of users that do not accomplish the procedure. The number of repetitions used for RAO equal to 320 ms and 640 ms are 8 and 16, respectively. Fig. 4a reports the cumulative distribution function (CDF) of the time taken by the devices to conclude the procedure. At first glance, it seems that the best performance is obtained with an opportunity of 640 ms and a BO index equal to 12, as the 87% of the UEs has a time access of the order of ms. However, a good trade-off, in terms of success access rate and access delay, is obtained with a periodicity of 160 ms and a BO index equal to 7. Indeed, its CDF in Fig. 4a has the steepest curve, allowing to 92% of the devices to have an access time smaller than 7 s. As a consequence, these users have more time for the data transmission, since their beam visibility window is higher. This trend is shown in Fig. 4b, where the curves on the right perform better in terms of remaining time of beam visibility for the data transmission. Fig. 3b shows the traffic overload, i.e., the total number of users trying to access the network, including the re-transmissions from same users. The worst performance is obtained with a RAO equal to 160 ms and BO index to 7, which is confirmed also from the CDF plots in 5a and in 5b. Indeed, for that configuration of parameters, both the users accomplishing the procedure and the ones that fail, must attempt the access several times. This translates into a high energy consumption of the device battery.

2) Impact of the number of repetitions: This parameter needs to guarantee a preamble detection probability at least of 99% (P_{d99}) at the BS [13]. In case of a smaller repetition value than the one providing P_{d99} is adopted, then the miss detection probability increases, worsening the overall performance of the system in terms of number of re-transmissions, and therefore of device's battery consumption. On the contrary, a better performance in terms of detection rate is not guaranteed with a higher number of repetitions and the access time increases due to an increased value of T_{msg1}.

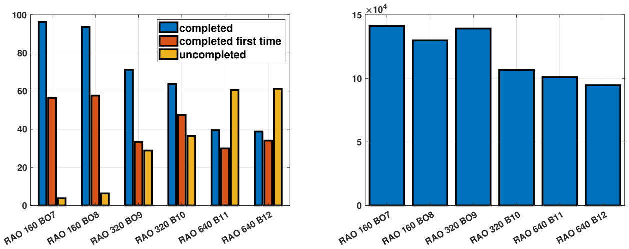
3) Impact of the beam visibility window: The satellite footprint diameter, and therefore the beam visibility window, has a great impact on the RA. As can be deduced from table III, a small radius reduces the number of terminals accessing the beam, thus reducing the NB-IoT preamble collisions and providing a lower mean access time with respect to the other NTN configurations. Also in terms of CNR it performs better, hence, a lower number of preamble repetitions is necessary to achieve P_{d99}. However, in addition to the low quantity of served users (34000 with $\alpha = 0.1$), the drawback of this configuration is the short satellite visibility window, which in turns, reduces the time for the data sending. In case of a wider beam, such as the one obtained in Set 3, a greater number of users can be served (89000 with $\alpha = 0.1$). In order to achieve a success rate higher than 90%, greater BO values and number of repetitions must be taken into account w.r.t the ones considered with a beam of 90 km, at the expense of the access time. The worst performance is obtained with a beam diameter of 1700 km, i.e., Set 4. As expected, the number of devices entering the beam is so high (839000 with $\alpha = 0.1$) that, even with the greatest BO value, the number of collisions is not reduced. In that case, it is necessary to implement other techniques to avoid that such excessive number of terminals transmit at the same time, e.g., the access barring.

4) Discussion: due to the long slant range typical of the NTN, it is not possible to use short periodicity of 40 ms and 80 ms. In contrast, when a long periodicity is taken into account, such as 1280ms, the number of RA occasion is drastically reduced. Thus, it is possible to observe a significant increase in the number of collisions, as more users compete for the access at the same period, requiring a high number of preamble repetitions and much longer time to gain random access. The latter has a negative effect both on the battery consumption, due to the high re-transmission factor, and on the remaining time of the beam visibility window for the data transmission. The utilization of medium-length periodicities, i.e., 160ms and 320ms, is recommended, especially if the beam diameters in Set 2 and Set3 are taken into account. Indeed, these RAOs provide a good balance between the resources dedicated to the preambles and the data with an acceptable number of collisions and a high number of correctly detected signals. In addition, a low number of preamble repetitions (2 and 4) can be sent. As longer periodicities are taken into account, a higher number of repetitions shows better performance. Finally, the simulation results demonstrate that an increase by a factor of 10 of the transmitting users significantly affect the NB-IoT

TABLE III

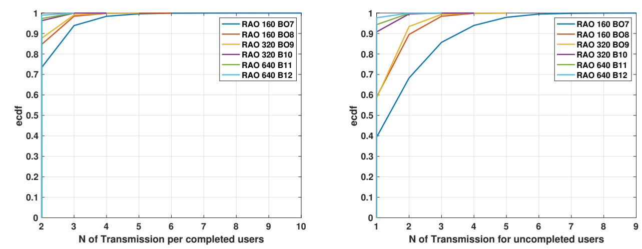
ACCESS PARAMETERS FOR SATELLITE CONFIGURATIONS. *s = success, f = failure, W = remaining time of beam visibility window*

Set	Density	Access parameters	Mean access delay	% of completed users	Mean N° of transmissions	Mean W
Set2	0.1$[users/km^2]$	$RAO = 160ms, BO_i = 4, N_{rep} = 2$	0.15 [s]	99.56 %, 85.85% (first attempt)	2 (s) - 3 (f)	1.67[s]
		$RAO = 320ms, BO_i = 5, N_{rep} = 8$	0.45 [s]	99.01 %, 71.91% (first attempt)	2(s) - 3 (f)	0.67[s]
		$RAO = 640ms, BO_i = 6, N_{rep} = 16$	1.95 [s]	92.44 %, 34.77% (first attempt)	3(s) - 3(f)	0.4[s]
	1 $[users/km^2]$	$RAO = 320ms, BO_i = 10, N_{rep} = 16$	2.12 [s]	22.44 %, 14.7% (first attempt)	2(s) - 1(f)	1.18[s]
		$RAO = 640ms, BO_i = 11, N_{rep} = 32$	2.1 [s]	11.25 %, 7.71% (first attempt)	2(s) - 1(f)	1.29[s]
Set3	0.1$[users/km^2]$	$RAO = 1280ms, BO_i = 12, N_{rep} = 64$	3.86 [s]	21.38 %, 16.53% (first attempt)	2(s) - 1(f)	2.5[s]
	1 $[users/km^2]$	$RAO = 320ms, BO_i = 11, N_{rep} = 16$	11.49 [s]	8.57%, 2.08% (first attempt)	2(s) - 2 (f)	6.67[s]
		$RAO = 640ms, BO_i = 12, N_{rep} = 32$	10.55 [s]	4.29%, 1.30% (first attempt)	2(s) - 1(f)	6.38[s]
Set4	0.1$[users/km^2]$	$RAO = 320ms, BO_i = 12, N_{rep} = 16$	103.38 [s]	9.01%, 0.07% (first attempt)	2(s) - 2 (f)	83.21[s]
		$RAO = 640ms, BO_i = 13, N_{rep} = 32$	100.66 [s]	4.55%, 0.09% (first attempt)	2(s) - 2(f)	80[s]



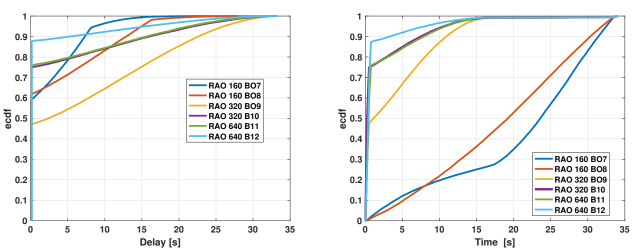
(a) Access rate (b) Channel overload

Fig. 3. Performances of the random access procedure. Set 3, $\alpha = 0.1$



(a) Completed users (b) Uncompleted users

Fig. 5. Number of transmissions. Set 3, $\alpha = 0.1$



(a) Access time of completed users (b) Remaining time of beam visibility

Fig. 4. Time analysis. Set 3, $\alpha = 0.1$

NTN system performance, even adopting different preamble repetition, RAO, and BO values. Hence the number of users is considered as a driving factor for choosing the RA parameters and implies the design of a satellite constellation able to serve all the terminals.

V. CONCLUSION

In this paper we provided a thorough study of the random access procedure performance for NB-IoT system over NTN, taking into account on the one hand the effect of configurable access parameters such as RAO periodicity, preamble repetitions, back-off values, and on the other hand the different satellite configurations proposed by the 3GPP for NB-IoT. This work aims at comparing the performances obtained with the different combination of these parameters in terms of the number of users which complete the procedure and the time taken by these devices to access the network. Based on the type of satellite configuration, the number of served users changes and, therefore, the combination of RAO and BO has a great influence on the performance of the RA. Future studies foresee the evaluation and the assessment of satellite constellation which provides global coverage to fully serve all of the UEs.

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