NB-IoT over GEO Satellite: Performance Analysis

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Abstract—**NB-IoT (Narrowband Internet of Things) has been introduced by 3GPP with the aim of meeting the 5G requirements for the IoT segment through coverage classes, repetitions, narrower subcarriers, user and control planes optimizations and power saving mechanisms. Recognizing the capability of satellite systems to offer wide coverage and enable cross-countries deployment, 3GPP is considering 5G technologies to support Non-Terrestrial Network (NTN). However, while studies have shown the capability of NB-IoT to meet the 5G latency and capacity expectations in terrestrial networks, the question remains open for the satellite context.**

In this paper, we consider the necessary mechanisms for adapting NB-IoT to the satellite context and provide a study of the delay of a communication as function of gNodeB parameters, cell specification (size, link budget, satellite altitude) and payload size. Our study adopts the configurations used for the simulation based on the link budget given in the 3GPP Study Item and considers not only the random access procedure but also the whole communication process, with signalling, uplink /downlink messages and connection release. We find that the optimal Block Error Rate for minimizing the delay of the communication and optimizing the spectral efficiency is lower that the one recommended in nominal 5G specification.

I. Introduction

The Internet of Things (IoT) is a new paradigm that has emerged in cellular networks. The predicted growth of the number of devices connected has already begun and is expected to continue - 25 billions devices today, 75 billions in 2025 ([1], [2]). In short, IoT solutions are aimed at a better performance than regular cellular networks (GSM, LTE) in terms of battery lifetime, coverage, device density, cost and complexity for low data rate communications. However, these improvements are done at the detriment of other metrics that are less critical to IoT communication such as latency, throughput and paging needs.

In the 2000's, cellular IoT applications were mainly using the GSM network (2G) because of the low cost (underused and already paid-for infrastructure) despite the low spectral and power efficiency. In 2013 Sigfox became one of the first large-scale cellular networks dedicated to IoT applications, along with the non-proprietary IoT technology LoRaWAN. Both Sigfox and LoRaWAN are deployed within the free ISM bands and are defined as Low Power Wide Area Networks (LPWAN). These LPWAN solutions demonstrated the huge potential market for IoT communications. Hence, 3GPP Long Term Evolution for Machine type communication (LTE-M), Extended-Coverage GSM (EC-GSM) and Narrowband IoT (NB-IoT) were first standardized in Release 13 - *Q1 2016*, improved in Releases 14 and 15 - *respectively mid-2017 and Q4 2018.*

In this paper, we focus on 3GPP NB-IoT, a solution that is expected to broaden the scope of 5G applications to include smart home - cities - grids - utilities - meters, object tracking and remote control among others. 5G-IoT aims to connect 5 billion devices by 2025. In parallel with the growth of IoT, satellite technologies have evolved and now allow the launch of low cost satellites and new kinds of services: nano-satellites, on-board payloads, regenerative payloads, etc. In addition to the current offerings of Orbcomm or Iridium (LEO) and Inmarsat, or Thuraya (GEO), new targeted IoT constellations are already being deployed: Astrocast, Fleet Space, Myriota, Kineis, ELO (Eutelsat) or Lacuna Space. Concerning NB-IoT, Ligado (formerly SkyTerra), a GEO operator, is partnering with Ericsson and Sequans for deploying a NB-IoT service over satellite in the United States [3]. On European side, ESA and GateHouse Telecom are partnering to develop space-based NB-IoT network [4]. The 3GPP Study Item [5] specifies the solutions considered so as to address the three challenges in the operation of 5G via satellite technologies:

- **Signal propagation delay and differential propagation delay:** In land deployments, the base station is located within a radius of 40 km. The propagation time is therefore less than one millisecond. For the satellite, a minimum signal propagation delay of 125 ms (GEO regenerative case) or 250 ms (GEO transparent case) must be taken into account for the geostationary case. The problems caused by this additional delay can usually be solved by increasing the protocol timers. However, as we show in Section II, the fact that intra-cellular delays can exceed milliseconds (up to 10 ms for the geostationary case) introduces the problem of collisions between different channels. This problem can be solved by adding guard times and increasing cyclic prefix durations, but at the expense of system performance.
- **Doppler frequency shift and drift:** Both 4G and 5G are technologies designed to support travel speeds of up to 500 km/h (high-speed trains). But LEO satellites have much higher velocities, measured in kilometers per second. Guard bands or the use of GPS positioning in conjunction with satellite ephemeris are considered for overcoming the Doppler shift. However, there is still the challenge of Doppler drift because the satellites at low altitude are passing by. The generated Doppler shift is therefore not constant, switching between positive and

negative values.

- **Moving cells:** In a constellation, the satellites along with the cells are in constant motion so the terminal must handover between cells / satellites on tens of seconds / few minutes basis to maintain communication. In 3GPP systems, these frequent handovers may cause not only reliability and latency problems, but also generate a large amount of control messages for maintaining the connection and keeping position information of the terminal.

In this work, we study the geostationary satellite case and therefore focus on studying the impact of signal propagation delay, intra-cell delay and coverage condition on the performance of NB-IoT communications and how to reduce this impact using existing configuration capabilities of the NB-IoT beam cell. To this end, we have implemented the entire communication process with both the random access and the allocated/connected phase.

The contributions of this paper can be summarized at two levels: first, we highlight the direct impact between beam size and spectral efficiency loss, second, we reveal an interresting finding about the targeted Block Error Rate, i.e. the trade-off between re-transmission and repetition.

The rest of the paper is organized as follows. Section II is a technical description of NB-IoT. Section III summarizes the mechanisms considered to allow NB-IoT satellite communications as well as their interaction with the features described in section II. In Section IV, we evaluate the performances of different cell configurations through simulations. We focused on the delay of the communcication and the cell capacity in term of aggregated throughput. Finally, we discover that the long-established terrestrial network optimum for Block Error Rate is challenged for the geostationary satellite context. Before to conclude this work, we underline the important related works on the performance of NB-IoT in section V.

II. NB-IoT

NB-IoT is organized in carriers of 180 kHz bandwidth, called Physical Resource Blocks (PRB). This is an heritage of legacy Long Term Evolution (LTE) technology (4G) which is deployed on a minimum of 6 PRBs. In this section, we focus on the functionality of one of these resource blocks. For scalability, PRBs can be stacked next to each other. 10 kHz guardbands are included on both sides of NB-IoT carriers to reduce interference with other technologies. As a technology designed at the end of the 4G era and the dawn of 5G, NB-IoT introduces three deployment modes:

- **Standalone**, using a dedicated frequency band.
- **Inband**, in a resource block of an LTE carrier, resulting in lower performance because of LTE broadcast symbols.
- **Guardband**, in the guardband between two LTE carriers which causes interference.

In this work, we consider a standalone deployment because of the satellite context.

In the following, we describe the different phases of an NB-IoT communication with a particular emphasis on the channels used.

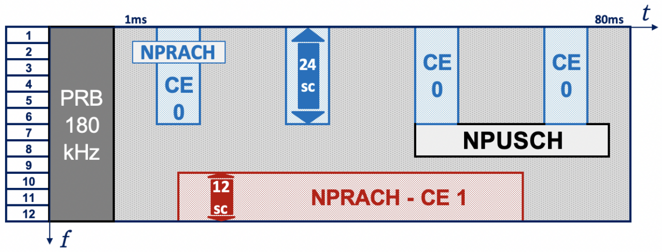

Fig. 1: NB-IoT - Uplink Frame

A. Synchronization Phase

When the User Equipment (UE) wants to transmit data after a period of inactivity (in idle state), it first synchronizes in time and frequency with the base station also called gNobeB. The UE does not transmit any data. Instead it uses the information broadcasted by the NB-IoT cell to know the useful information for the Access Phase. Synchronization signals and Broadcast make up 25% of the downlink PRB.

B. Access Phase

When the UE is synchronized, it sends a preamble to notify the base station that it wishes to transmit. Random Access Opportunities (RAO) are periodic in the UL PRB Fig. 1, offer from 12 to 48 different preamble indexes (3.75 kHz wide) and are associated to a given number of preamble repetitions. The UE randomly chooses an index on which to transmit its preamble. In order to avoid unnecessary repetitions, up to 3 coverage classes called CE (Coverage Enhancement) can be defined. A terminal derives its class based on the power threshold it receives from the base station. It deduces its RAO and therefore the number of preamble repetitions. The sum of the CEs constitutes the access channel - Narrowband Physical Random Access CHannel (NPRACH). All information about the NPRACH is available in the broadcast channel (periodicity, number of indexes, repetitions, timing offset, power thresholds). Note that preambles are deterministic symbols and do not contain particular data.

Figure 1 shows 2 CEs. The blue one corresponds to frequent opportunities (20 ms period) for devices in good coverage (1 repetition). And the red one is dedicated to devices in extreme coverage (8 repetitions) and offers far fewer opportunities (12 indexes every 80 ms). All other time-frequency slots are dedicated to allocated resources, referred to as the Narrowband Physical Uplink CHannel (NPUSCH).

If two or more UEs choose the same preamble index a collision occurs , in which case the UE will retransmit and send another preamble after some back-off time. After a number of unsuccessful retransmision attempts varying between one and several hundreds, depending on the cell configuration, the communication is definitively considered as having failed.

The first preamble that does not suffer a collision allows the UE to complete the connection process through the legacy LTE "hand-shake". After this "hand-shake", the UE enters the

Data Phase, without further additional signalling (User Plane Optimization).

C. Data Phase

Since in this work we consider uplink traffic only (from UE to satellite), two kinds of messages are needed during the data phase: **a)** Resource Grants in the Narrowband Downlink Control CHannel (NPDCCH) allocating **b)** Transport Block (TB) in NPUSCH containing payload and buffer status. Thus, the data phase is a succession of resource grants and transport blocks. Every time the base station receives a TB, it allocates new resources for the next one, according to the buffer size and the possible TB sizes (from 16 to 2536 bits [6]).

In case of reception errors, NB-IoT uses a Hybrid Automatic Repeat Request (HARQ) mechanism at the TB level. This is a typical ARQ process: each time a TB cannot be decoded successfully the grant message asks for a re-transmission (New Data Indicator not toggled). At the receiver side, the base station combines the re-transmissions of the same TB for increasing the chances of success.

In the Data Phase, messages are exchanged on allocated resources. Therefore no collisions should occur during NPUSCH. The base station allocates Resource Units (RUs) of different time-frequency shapes [7]. The different shapes of an RU make possible to play either on the flow rate or on the received SNR. Furthermore, there are two categories of RU: multitone, several symbols sent simultaneously, or singletone, only one symbol at a time. The key difference between multi-tone and single-tone is the number of symbols they carry $N_{symbols}$, 144 and 96, respectively.

The UL Grant specifies a number of useful bits to transmit, N_{bits}, from 16 to 2536 bits, and a number of RU, N_{RU}, from 1 to 10, depending on the coverage condition of the UE. Finally the UL grant contains the maximum number of repetitions, ranging from 1 to 128, R, necessary to improve the reliability of the communication in addition to the robustness already provided by turbo codes in RUs.

With all this information, one can compute the code rate associated to a TB as follows:

$$CR = \frac{N_{bits} + N_{CRC}}{N_{RU} \cdot N_{symbols} \cdot m \cdot R} \quad (1)$$

where $N_{bits}, N_{RU}, N_{symbols}, R$ are described above, N_{CRC} is the number of bits used for check code (24 for NB-IoT) and m is the order of the modulation used. The code rate is used to compute the probability of error on a given TB knowing the Signal to Noise Ratio (SNR).

III. MECHANISMS TO SUPPORT SATELLITE

This section summarizes the mechanisms considered to allow NB-IoT satellite communications as well as their interaction with the features described in the previous section.

A. Scenario definition

We consider the geostationary satellite case described in 3GPP Technical Report TR.38821 [5] i.e. a transparent multi-beam GEO satellite in S band (around 2 GHz). Each beam

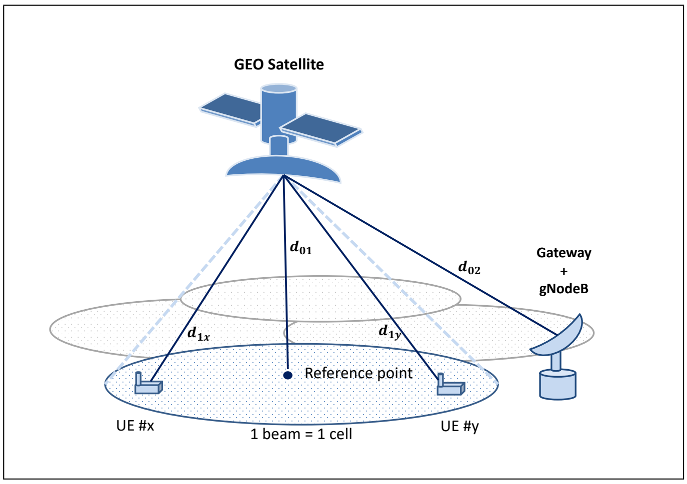

Fig. 2: Transparent GEO satellite scenario

(up to several hundreds beams per satellite) correspond to a NB-IoT cell. Within this context, the delay and the differential delay can be defined from the Figure 2.

UEs and satellite communicate using the NB-IoT radio interface. In transparent satellite mode, the satellite relay the raw signals (generally by transposing at higher frequencies) to/from the ground Gateway without any processing on the messages. The Gateway plays the role of gNobeB and performs the signal and message processing. From Figure 2, we get the following set of equations:

$$\begin{cases} \text{Minimum delay: } D_{min} = \frac{2\cdot(d_{01}+d_{02})}{c} \\ \text{UE specific differential delay: } D_{diff_x} = \frac{2\cdot(d_{1x}-d_{01})}{c} \\ \text{Full delay: } D = D_{min} + D_{diff_x} \end{cases} \quad (2)$$

In the literature on 3GPP cellular technologies, The base station compensates for the propagation delay with so-called Timing Advance (TA). These TAs are specific to each UEs and enable them to transmit or listen to time-shifted signals in order to be synchronized with the cell uplink (UL) and downlink (DL) frames. Typically the TA in the terrestrial environment is less than one millisecond - the maximum cell radius to be considered for NB-IoT is 40 km[1] (266μs cyclic prefix in preamble [7]). For the transparent geostationary case, the maximum delay is around 270 ms and the maximum differential delay should not exceed 10.3 ms [5] ($\approx$ 3500 km max beam foot print size regardless of the elevation angle).

In the following, we describe the effects of these unusual propagation delays on the performance of NB-IoT.

B. Differential delay effect

When the terminal wakes up, it does not know its position relative to the gNodeB. The preambles contain the connection request, and inform the gNobeB on each UE specific propagation time. The gNobeB then transmits the TA to the UEs in

[1]Rel. 15 enables a cell radius of up to 120 km through the use of 1.25 kHz preambles and 0.8 ms CPs.

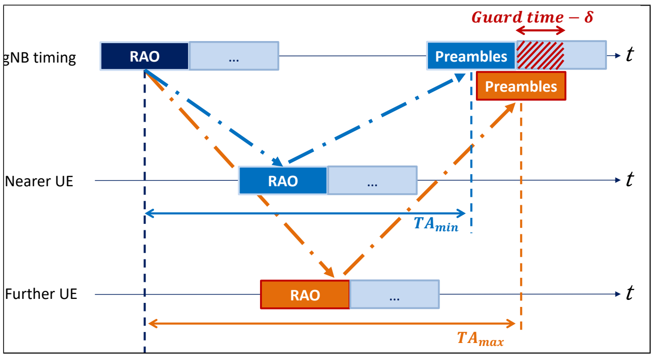

Fig. 3: Differential delay effect

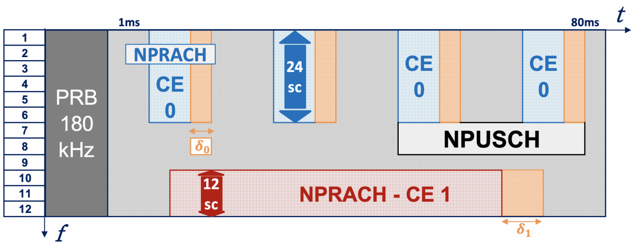

Fig. 4: Differential delay impact on UL Frame

its response. When sending preambles, the UEs assume that they are at the reference point with the associated minimum TA broadcasted by the gNodeB (null in terrestrial network), D_{min} in Equation 2.

The problem in the satellite case is that the differential delay within a single beam (= cell) is large enough to impact the resources allocated to NPUSCH that follow the RAOs, see Figure 3. The solution considered in the technical report [5] is to use guard times to avoid allocating NPUSCH following the NPRACH based on cell size (maximum differential delay). It is also necessary to increase the CP size of the preambles, which must be at least equal to the maximum differential delay in order to guarantee the orthogonality of preamble transmissions on different subcarriers [8]. Thus each RAO of CE n°i is extended by δ_i ms (Eq.3).

$$\delta_i = \delta + \delta \cdot 4 \cdot Nrep_i \tag{3}$$

with δ the maximum differential delay within the beam, 4 the number of CPs per preamble repetition and $Nrep_i$ the number of repetition for the i^{th} CE. In the satellite context, the uplink frame (from UE through satellite to the Gateway) received by gNodeB is impacted by the effect of the differential delay as shown in the Figure 4. Ratio of uplink resources lost due to differential delay, R_{loss} , is then:

$$R_{loss} = \sum_{i \in CEs} \frac{3.75 \cdot N_{sc,i}}{180} \cdot \frac{\delta_i}{period_i} \tag{4}$$

with 3.75 the width of the preamble subcarrier (kHz), $N_{sc,i}$ the number of subcarriers (preamble indexes), 180 the width of the PRB (kHz), $period_i$ the period of the i^{th} CE, and δ_i its extension due to differential delay as computed in Eq. 3.

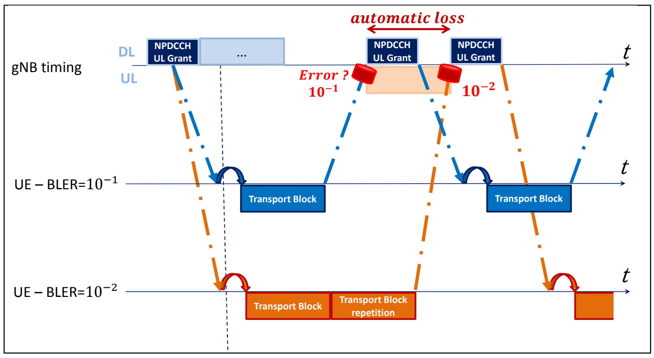

Fig. 5: Error free HARQ process for 2 differents BLER selections.

In Section IV, we observe the variation of the cell capacity in terms of number of UEs as function of beam/cell size, i.e., δ.

The other solution considered in TR.38.821 to solve the differential delay issue in satellite is to use the GPS of UEs. However, there are two issues. First, the base station does not know the TA of the UE until it is able to send data to it, and it is unable to provide it with a relevant resource allocation. And second, GPS is very energy consuming on the UE side. Thus, while it is reasonable to assume that 5G smartphones will have a GPS with sufficient battery size, for IoT terminals this seems less likely.

C. *Propagation delay effect on BLER selection*

Once the TA has been established, the delay should not cause any more concern since the protocol timers have been adapted to the satellite case. The base station allocates the resources in the NPUSCH according to the UE specific TA and shifts its reception window.

Nevertheless, an interesting trade-off between repetitions and re-transmissions in the HARQ process emerges. In NB-IoT, only one or two HARQ process at a time can be allocated (depending on device class). The base station waits until it has received Transport Block N before allocating Transport Block N+1 or N+2. Therefore, the total delay of the communication will be extended with the use of the satellite. However, when the base station is unable to decode Block N, the entire communication is delayed by 500ms (see Figure 6). Generally in GEO satellite context, the link is made more robust (lower probability to loss a Transport Block) in order to avoid such significant delay in the communication. The two solutions to make the communication more robust are a) to choose a lower Modulation and Coding Scheme (MSC) index - I_{MCS} or b) to repeat the TB.

IV. Results

The objective of this section is to evaluate the impact of both guard times § III.B and BLER selection § III.C mechanisms on the performance of an NB-IoT cell in a satellite context. For this purpose we have implemented an event driven simulator in python that includes random access, frame mechanics, sub-frame (DL) and Resource Unit (UL) allocation, and taking into

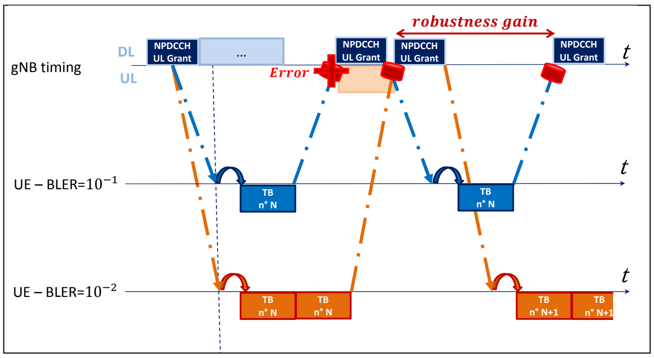

Fig. 6: BLER impact on the HARQ process in the case of an error on the UE with the least robust communication.

TABLE I: Common Settings

Parameter	Setting
Backoff value	1024 ms
UE Power Class	23 dBm
Max number of attempts	8
User-Plane Optimization	Activate

Channels		CE 0	CE 1	CE 2
	UL SNR Thresholds (dB)	7.4 5.6		
NPRACH	Number of repetitions - N_{rep}	1	2	4
	Number of subcarriers - N_{sc}	12	12	12
	Periodicity (ms)	320	160	320
	DL SNR Thresholds (dB)	3.0 1.6		
NPDCCH	N_{rep}	1	2	4
	Ratio in Downlink (1/G)	25%		

account transmission times, propagation times and transition times between UE states. We used this simulator to determine a) the communication delays (defined as the duration between the first preamble transmission by the UE and the correct reception of the data by the gNodeB) and b) the impact of the mechanisms described in Section III on the aggregated throughput of an NB-IoT cell.

A. Scenario configuration

Within the considered beam we used the SNR distributions defined in the technical report [5]. Our work is aimed at *Subcase n°5* of this report:

- GEO satellite
- 45°for central beam elevation
- Handheld UEs (Omnidirectional antenna)
- Band S
- Frequency re-use

To study the effect of different target BLERs on the performance of the cell we need their values as a function of the SNR. They can be found in the literature and are quite similar to the LTE values for the QPSK modulation [9, 10]. We obtained the curves for the downlink signal by our own Matlab simulations. The BLER curves for uplink are summarized in Figure 7. In order to take into account the effect of repetition, we consider that each time the number of repetitions doubles, the received SNR also doubles, i.e. a 3dB gain for a small number of repetitions [11, 12].

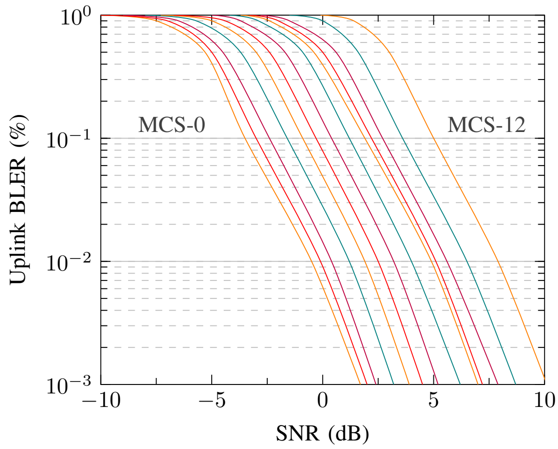

Fig. 7: Uplink BLock Error Rate curves depending on Signal to Noise Ratio. Modulation and Coding Scheme (MCS) is varying from index 0 to index 12 (multi-tone transmission).

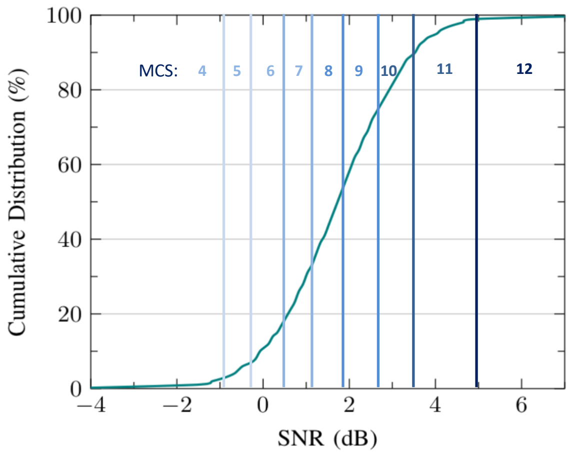

Fig. 8: SNR distribution for uplink in GEO case (3GPP assumptions). Modulation and Coding Scheme (MCS) indexes are shown for a BLER target of 10^{-1} and multi-tone 45 kHz modulation. Thresholds have been derived from Figure 7.

We combined SNR distributions and BLER curves (Fig. 7) to adapt the MCS to the target BLER. Figure 8 corresponds to a targeted BLER of 10^{-1}. Unlike for terrestrial links, SNRs have a much more homogeneous distribution in satellite links, which has the effect of attenuating the differences between the modulation and coding scheme of the different coverage classes. It is worth noticing that single-tone transmission and a targeted BLER of 10^{-1} no repetitions are needed. We have also defined coverage areas based on the distribution of the SNR by choosing to assign 25% of the UEs to the best coverage, CE 0; 50% to the medium coverage, CE 1; and 25% to the worst coverage, CE 2 (Table I). UL thresholds are deduced from Figure 8.

B. Differential Delay Analysis

In this section, we study the impact of the guard times, introduced to deal with intra-cellular delay (§ III.B), from two

TABLE II: Differential Delay impact on Cell Performance

Beam Size in km	< 100	500	1000	3500
Differential Delay - δ	$< 267\mu s$	$4ms$	$7ms$	$10ms$
Throughput in NPUSCH from simu. ($kbits.s^{-1}$)	177.6	154.3	138.6	114.0
Relative Loss	ø	12.9%	22.3%	33.8%
Theoritical Loss	ø	12.5%	21.8%	31.2%

perspectives:

Communication Delay - Because every RAO is longer in case of differential delay, resource allocation is delayed. Simulations show that on a single communication, the impact on the duration of the communication is negligible - of the range of the differential delay. On the other hand, it is interesting to look at the impact of the differential delay when the cell load is increased.

Aggregated Cell Throughput - The additional resources taken by the NPRACH reduce the capacity of the cell according to Table II. Indeed, as explained in Section. II, it is expected to observe a degradation of performance due to guard times and the increase of the CP size. From Eq. 4, we obtain a linear loss with respect to guard times. However our results reveal that the relative throughput loss is higher than expected. This is due to a snowball effect: resource allocation is optimized for a segmentation of power of 2, resulting from a) the grant allocation in NPDCCH period[2] and b) delay parameter in grant for NPUSCH can only take a value in $\{8,16,32,64\}$ ms. These findings are crucial for dimensioning the size of the satellite beams.

C. Propagation Delay Analysis

In this section, we consider the trade-off between the delay and the spectral efficiency as function of the target BLER.

1) Delay depending on cell type: Figure 9 shows the delay of the communication according to the cell type. GEO cells add the effects of transmission delay with each new message exchange and poor coverage conditions. Steps appear when a longer Transport Block is allocated without increasing the average number of messages. The slope at these steps reflects coverage conditions alone.

2) BLER Selection: **Impact on the communication delay:** Figure 10 points to an interesting finding. For several decades, cellular standards have used a Block Error Rate of 10^{-1} which optimizes the delay in a terrestrial setting. However, the balance between repetition and re-transmission is quite different in a geostationary satellite environment. Extreme propagation times encourage the reduction of re-transmissions (NACK) in favour of repetitions (MCS). So we found a path towards reducing the communication delay by 10% with a BLER configuration of 10^{-2}. We can observe steeper slopes for strong BLERs (proof of the robustness of the communication), but fewer messages are sent on average.

[2]The period of NPDCCH, T, is calculated such that $T = G \cdot max(N_{rep})$ in ms according to [7]- Table I presents the settings for our simulations.

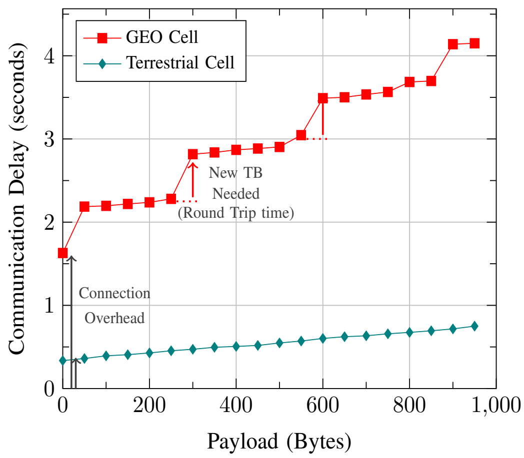

Fig. 9: Delay of communications from first connection attempt to last payload bytes sent, depending on payload and cell type. The differences are due to coverage and round trip delay. Data plotted for BLER = 10^{-1}.

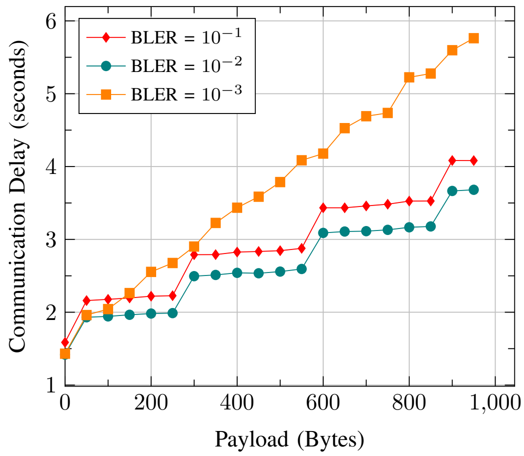

Fig. 10: Delay of communications depending on robustness (BLER) and payload. The optimum configuration for latency is found around a BLER of 10^{-2}. A value all the more interesting knowing that the targeted BLER in terrestrial deployment is 10^{-1} .

An interesting question is whether the results of Figure 10 are still valid when increasing the cell load. To find out if a 10^{-2} is always preferable, we have increased the number of new communications per second, which leads to two types of message failure:

- Collision: when choosing random preambles during the Access Phase.
- Congestion: resources starvation on allocated channels during the Data Phase.

We can see the load is significantly increasing the communication time in Figure 11. Interestingly, we notice that the conclusions drawn from Figure 10 still hold with higher loads – the use of a 10^{-2} BLER always leads to lower communication delays.

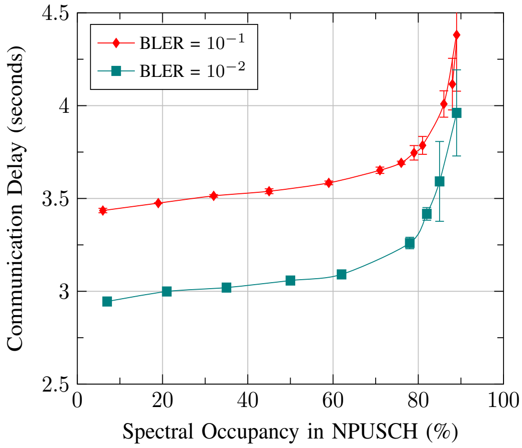

Fig. 11: Delay of communications from first connection attempt to last payload bytes sent, depending on spectral occupancy and BLER.

Note that the data is traced with a minimum success rate of 99% hence the absence of values for high loads.

Impact on the cell capacity: Surprisingly, Figure 12 shows a higher system capacity in terms of aggregated useful bits (in uplink) for a BLER of 10^{-2}. In the terrestrial case, a targeted BLER of 10^{-1} is considered to be the most efficient. Our result is explained by a) an excellent distribution of SNR considered in 3GPP (Figure 8 from [5]) and b) the fact that we used a $15kHz$ transmission bandwidth. We therefore recommend to favour small bandwidth transmissions if a configuration with a 10^{-2} BLER is targeted.

In order to understand truly Figure 12, it is worth remembering that a communication fails for two reasons. Either it collides during the Access Phase in the NPRACH or it lacks resources (congestion) during the Data Phase. This is why we have plotted Figure 13, it shows that the channel limiting the capacity of the cell is not the same depending on the size of the payload. Three different situations can be noticed:

- Large Payloads: above 3000 Bytes. NPUSCH limits the cell capacity. This is the channel impacted the most when payload increases.
- Medium Payloads: around 1000 Bytes. For every communication, we assumed a connection setup. This connection setup induces traffic on the different channels and especially on the control channel. This is the resource starvation in the NPDCCH which is the cause of the capacity reduction.
- Small Payloads: under 100 Bytes. To evaluate the use of the NPRACH, the random access theory must be used. NPRACH is a Slotted Aloha process and therefore the channel is at its maximum potential when it is used at 36.7% [13] , above this value, the collisions are counterproductive. So on Figure 13, we see that 100 Bytes payload per communication is the balance point where collisions on the NPRACH become more prevalent than the lack of resources in the NDPCCH.

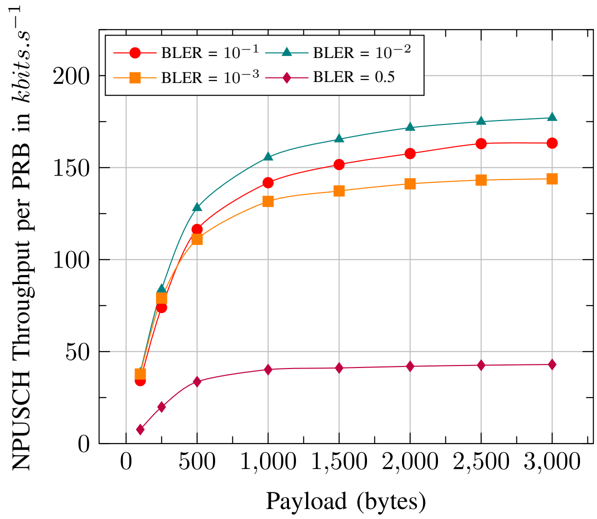

Fig. 12: The impact of the chosen BLER on the capacity of the cell in terms of communication per second and total cell throughput. Settings in Table I.

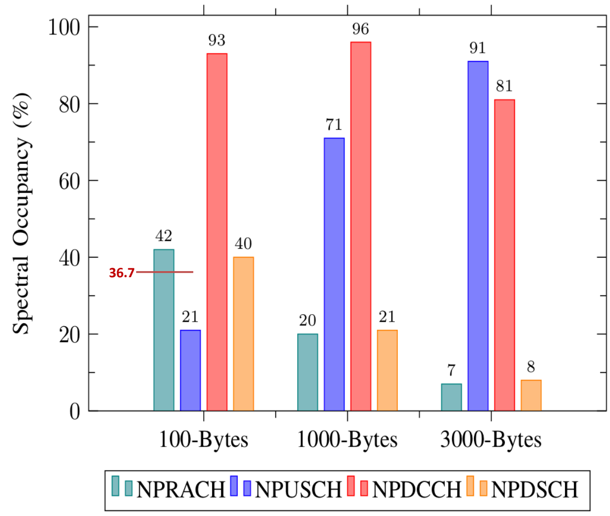

Fig. 13: Occupancy of the spectral resources when the cell reaches its maximum utilization. Depending on the payload size the resource starvation does not occur on the same channel.

In the light of these results, it seems necessary to configure the different channels according to the type of service needed. For instance, the ratio of NPDCCH in the downlink could be increased in the case of mainly UL traffic: a) it will increase the number of possible connection setups and b) NPDSCH performance will not be impacted as we show the margin in its spectral occupancy.

V. Related Work

The Narrowband IoT has already been the subject of satellite studies. In a LEO context, the authors of [14] propose a technique to solve the problem raised by the differential Doppler shift between users of the same cell. Their solution is to divide the cell into sub-parts with comparable Doppler effects in order to cluster resource allocation. On the other hand, in [15], the authors studied the performance of NB-IoT when considering only random access slots. NPRACH and NPUSCH are mixed up and therefore there is no resource allocation. The interest is that the effects of Doppler (non-GEO cases) are not to be taken into account. On the downside, it is necessary to deal the the possibility of collisions between data packets. The authors therefore studied the performance of Coherent Combining on the NB-IoT waveform in a LEO satellite context.

In this work we considered 3 coverage classes with each one a modulation and a number of repetitions applied for all the devices of the class. In reality, however, the MODCODs allocations are fine tuned according to the SNR of the UEs and the load of the cell. This work is being undertaken by the authors of [16] for LTE communications, i.e., 4G. Furthermore, we have considered the backoff and the number of connection attempts constant throughout a scenario, but [17] shows that, in a satellite scenario, a real-time adjustment of these parameters is required to optimize the cell throughput. The authors use the information available at the base station (current load and number of random access collisions) to predict the number of connections and the future load in order to optimize the cell configuration.

VI. Conclusion

Using terrestrial cellular technologies for satellite systems is traditionally considered as very challenging. However, the particularities of NB-IoT – repetitions, narrow band signal, low latency and throughput sensitivity – make it uniquely positioned to break the mold. Furthermore, 5G promises to implement software separation of network equipment in order to enable the co-existence of the different services on the same infrastructure. In this context, NB-IoT by satellite fits perfectly as one of the RANs meeting IoT-5G requirements that the terrestrial technologies will have difficulty fulfilling: global coverage and no roaming. As a result, there is a significant momentum around the specification of the "Non Terrestrial Network" at 3GPP, as illustrated by the technical reports TR.38811 and TR.38821 [18, 5].

After introducing the challenges arising from the use of 5G cellular technology on a geostationary satellite, we studied the mechanisms to address those related to delay. Our evaluation quantified the relative loss incurred by the use of the geostationary satellite for an NB-IoT cell. The results show how much the delay spread inside a beam is bringing down the performance, the advantage of using the narrowest possible beams is quite clear. The study of the impact of the target Block Error Rate selection on cell performance is also very interesting. In particular, the data revealed a different optimum for the trade-off between re-transmission and repetition concerning GEO satellite. In order to optimize the communication delay and the spectral efficiency, a target BLER of 10^{-2} is preferable to a target BLER of 10^{-1}. This is an especially interesting discovery as it results from both the use of NB-IoT-specific single-tone transmission and homogeneous SNR distribution of GEO satellite.

We believe that our findings could be a useful input to the work on the specification of the NB-IoT deployment on satellite, which is expected to start in the first quarter of 2021.

References

[1] GSMA, "Gsma iot report iot in the 5g era," November 2019.

[2] Statistica. Report : Iot number of connected devices worldwide. [Online]. Available: https://www.statista.com/statistics/471264/iot-number-of-connected-devices-worldwide/

[3] Ligado. Satellite-adapted 5g iot. [Online]. Available: https://ligado.com/solutions/standards-based-satellite-iot/

[4] S. E. Group. Esa and gatehouse telecom sign contract to develop space-based nb-iot network. [Online]. Available: https://www.satellite-evolution.com/single-post/2020/03/17/ESA-and-GateHouse-Telecom-sign-contract-to-develop-space-based-NB-IoT-network

[5] 3GPP, "Technical specification group radio access network; solutions for new radio (nr) to support non-terrestrial networks (ntn) (release 16)," vol. 3GPP TR 38.821, January 2020.

[6] ——, "Technical specification group radio access network; evolved universal terrestrial radio access (e-utra); physical layer procedures (release 15)," vol. 3GPP TS 36.213, no. V15.5.0, March 2019.

[7] ——, "Technical specification group radio access network; evolved universal terrestrial radio access (e-utra); physical channels and modulation (release 15)," vol. 3GPP TS 36.211, no. V15.6.0, June 2019.

[8] X. Lin, A. Adhikary, and Y. . Eric Wang, "Random access preamble design and detection for 3gpp narrowband iot systems," *IEEE Wireless Communications Letters*, vol. 5, no. 6, pp. 640–643, Dec 2016.

[9] M. Soussi, P. Zand, W. Pasveer, and G. Dolmans, "Evaluating the performance of emtc and nb-iot for smart city applications," 08 2018.

[10] L. Ding, F. Tong, Z. Chen, and Z. Liu, "A novel mcs selection criterion for voip in lte," in *2011 7th International Conference on Wireless Communications, Networking and Mobile Computing*, Sep. 2011, pp. 1–4.

[11] P. Andres-Maldonado, P. Ameigeiras, J. Prados-Garzon, J. Navarro-Ortiz, and J. M. Lopez-Soler, "An analytical performance evaluation framework for nb-iot," *IEEE Internet of Things Journal*, vol. 6, no. 4, pp. 7232–7240, Aug 2019.

[12] ——, "Analytic analysis of narrowband iot coverage enhancement approaches," in *2018 Global Internet of Things Summit (GIoTS), Bilbao, Spain*, June 2018.

[13] A. Tanenbaum, *Computer Networks*. Prentice Hall, 1989.

[14] O. Kodheli, S. Andrenacci, N. Maturo, S. Chatzinotas, and F. Zimmer, "Resource allocation approach for differential doppler reduction in nb-iot over leo satellite," in *2018 9th Advanced Satellite Multimedia Systems Conference and the 15th Signal Processing for Space Communications Workshop (ASMS/SPSC)*, Sep. 2018, pp. 1–8.

[15] S. Cluzel, L. Franck, J. Radzik, S. Cazalens, M. Dervin, C. Baudoin, and D. Dragomirescu, "3gpp nb-iot coverage extension using leo satellites," in *2018 IEEE 87th Vehicular Technology Conference (VTC Spring)*, June 2018, pp. 1–5.

[16] H. Mousavi, I. S. Amiri, M. Mostafavi, and C. Choon, "Lte physical layer: Performance analysis and evaluation," *Applied Computing and Informatics*, vol. 15, no. 1, pp. 34 – 44, 2019. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S2210832717301990

[17] H. Chelle, M. Crosnier, R. Dhaou, and A. Beylot, "Adaptive load control for iot based on satellite communications," in *2018 IEEE International Conference on Communications (ICC)*, May 2018, pp. 1–7.

[18] 3GPP, "Technical specification group radio access network; study on new radio (nr) to support non-terrestrial networks(release 15)," vol. 3GPP TR 38.811, September 2019.