Contention-Based Early Data Transmission for 3GPP IoT over Non-Terrestrial Networks

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***Abstract*—3GPP Release-19 is introducing an interesting new feature for narrowband Internet of things (NB-IoT) and enhanced machine type communications (eMTC). The solution, currently enabled only for IoT over non-terrestrial networks, consists in the use of contention-based early data transmission (CB-EDT) procedures to allow a UE send data over shared uplink resources following a random access approach. In contrast to the existing EDT solution, the new feature does not rely on the exchange of a random access preamble and random access response, but rather foresees the UE directly transmitting its message, thus saving overhead and reducing delay. Moreover, CB-EDT implements diversity slotted ALOHA (DSA), so that a UE transmits multiple replicas of its packet over the available uplink resources, aiming to enhance the probability of having at least one of its messages not colllided. Further improvements are attained by using a multicast acknowledgment (message 4), addressing multiple UEs and saving downlink capacity. This article provides a description of the new feature, starting from its basic working principles and adding up details that cover the current 3GPP implementation status. The potential of the solution is demonstrated and discussed by means of numerical results, also identifying potential developments in future releases.**

I. INTRODUCTION

Internet of things (IoT) connectivity represents a fundamental component of the 3GPP ecosystem since Release 13 (Rel-13). By supporting terminals with reduced complexity, possibly working with lower power and on narrow bands, eMTC and NB-IoT [1] enable a broad range of applications for different verticals, ranging from smart manufacturing to home automation. A further, fundamental, impulse to IoT development was triggered as 3GPP embraced non-terrestrial networks (NTN). The ability to collect machine-type data via satellites indeed paves the way to serve devices deployed in remote or otherwise uncovered areas, allowing key use-cases such as environmental monitoring and asset tracking.

In turn, IoT-NTN poses a number of technical challenges to provide connectivity between a user equipment (UE) and a satellite. On the one hand, this called for new solutions to support synchronization and to cope with large Doppler shifts and long round-trip times, mainly addressed in Rel-17 (NB-IoT) and Rel-18 (eMTC) [2], [3]. On the other hand, access and communication protocols have to be adapted to handle a massive number of devices with sporadic small packet transmissions. In this perspective, IoT-NTN is uplink-driven, making legacy LTE-based procedures inefficient. Currently, a UE must trigger a 4-step random access (RA) procedure involving two uplink (UL) and two downlink (DL) messages before sending data. Although early data transmission (EDT) introduced in Rel-15 simplifies this, signaling overhead remains high, impacting the system capacity.

These remarks have led to the definition in the upcoming Rel-19 of a different approach, with the introduction of *contention-based EDT (CB-EDT)* for IoT-NTN [4]. This solution brings two key elements of novelty. In the first place, a UE is able to send a short data message in a contention-based fashion, using non-exclusive UL resources allocated by the network. The transmission can take place without entering a connected mode, and without exchanging negotiation messages, providing an efficient solution to reduce overhead and to accommodate sporadic channel access from IoT devices. To further improve performance, CB-EDT implements diversity slotted ALOHA (DSA). The protocol, originally proposed in the 1980s for satellite communications [5], is based on the principles of slotted ALOHA [6], yet foresees devices to proactively transmit multiple replicas of their messages. This results in additional diversity, at the cost of increased UL traffic from each single device, eventually leading to an enhanced reliability and increased system capacity. Furthermore, DSA has been recently shown to be a core ingredient for more advanced RA schemes [7], [8].

This article describes the new CB-EDT feature, highlighting its elements of novelty and its potential. To this aim, we provide some technical background on EDT and DSA, illustrating at a high level their key elements and working principles. We then delve into the technical details of the medium access procedures being standardized within 3GPP. After presenting numerical results to showcase the potential of CB-EDT, we conclude by highlighting further enhancements that could be targeted in upcoming releases.

II. TECHNICAL BACKGROUND: EARLY DATA TRANSMISSION AND A PRIMER ON CB-EDT

A. Early Data Transmission

The EDT solution was introduced by 3GPP in Rel-15 to allow a UE transmit a short data packet during the RA negotiation. A high-level description of the corresponding medium access (MAC) procedures is sketched in Fig. 1a, reporting the steps relevant for our discussion (we refer the reader to, e.g., [9] for further details). In the considered

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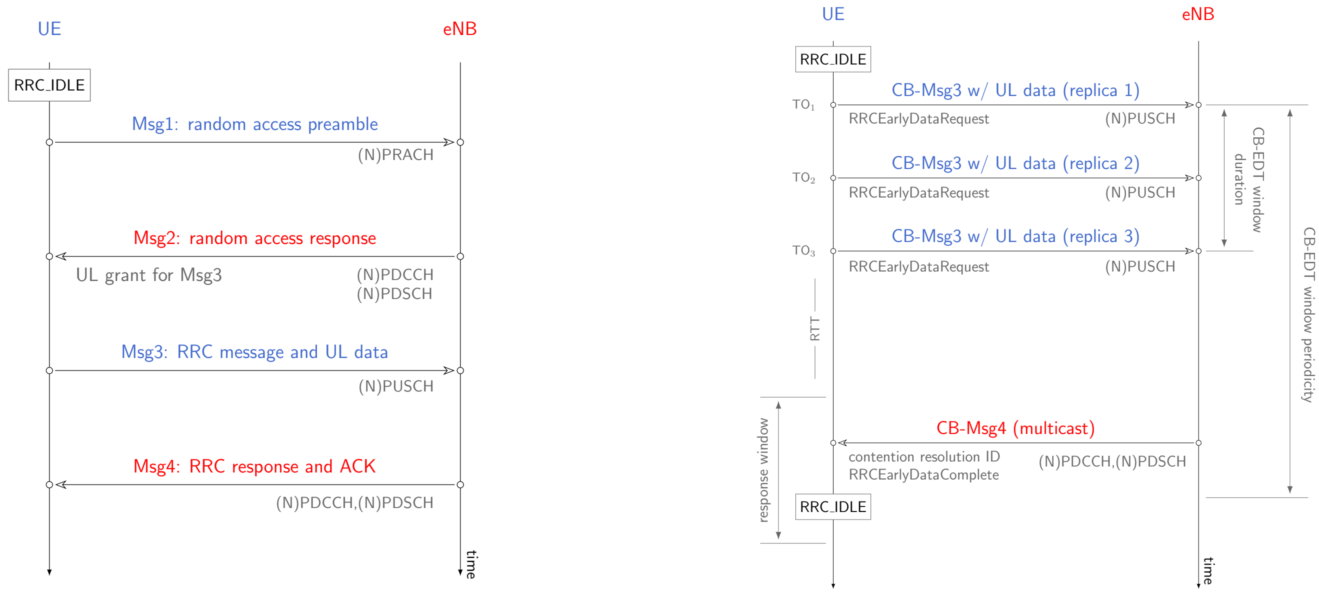

(a) early data transmission (EDT) simplified timeline

(b) CB-EDT simplified timeline

Fig. 1. High-level timelines summarizing the main steps for the EDT and CB-EDT procedures.

case, a UE which does not have scheduled uplink grants, e.g., it is idle for the radio resource control (RRC) layer (RRC_IDLE mode), wants to send data. To this aim, the MAC initiates the establishment of a connection following the 4-step RA process. Accordingly, it transmits a preamble over the resources available in the physical random access channel (PRACH) (or the narrowband PRACH (NPRACH) in the case of NB-IoT). This instantiates a slotted ALOHA contention, as multiple UEs may use the same resources, resulting in a collision, i.e., interfering at the receiver. We remark that the preamble (Msg1) does not contain data, but is simply a message randomly selected by the UE from a pool of predefined groups of single tones (NB-IoT) or Zadoff-Chou sequences (eMTC). If the E-UTRAN Node B (eNB) detects a preamble, a RA response (Msg2) is sent over the physical downlink shared channel (PDSCH). The message, among other things, provides a grant associated with the retrieved preamble, allocating UL resources for a subsequent transmission. In case the UE receives the Msg2, it proceeds with the transmission of a Msg3 over the resources granted in the physical uplink shared channel (PUSCH). If, instead, no response from the eNB is obtained within a predetermined time, the UE will re-initiate the procedure after a random backoff. When resorting to EDT, a small data payload (up to a few hundred bits) can be piggybacked to the RRC message that the MAC has to deliver with the Msg3. The procedure is completed with the transmission of a Msg4 by the eNB, possibly acknowledging reception of the data as well as providing additional commands to the UE.

EDT allows a UE to attempt delivery of data before completing the 4-step RA negotiation, and without establishing a complete RRC connection. However, the protocol entails two negotiation messages, one in UL and one in DL, before the data/acknowledgment exchange takes place. This results in overhead, and, for IoT-NTN, a longer delay due to the large round trip time (RTT).

B. Contention-Based EDT

To overcome these limitations, 3GPP introduced in Rel-19 a purely contention-based approach as part of the work item IoT-NTN phase 3 [10]. To illustrate at a high level the MAC procedures of CB-EDT, we refer to Fig. 1b, whereas more details are provided in the next section. Following a trigger from the RRC layer requesting the delivery of a small payload, the UE does not access the (N)PRACH to send a preamble, and directly attempts data transmission. This is performed over a set of resources which are periodically allocated by the eNB over the (N)PUSCH, referred to as a *CB-EDT transmission window*, shared among devices according to a RA policy. As will be described shortly, the UE follows DSA over the CB-EDT transmission window, selecting at random some of the available UL grants to send its CB-Msg3, containing both an RRC message and data. If the eNB decodes the message, the UE is addressed by a CB-Msg4 sent in the downlink, acknowledging reception and terminating the data exchange. In contrast to EDT, the new feature leans on the use of RA for data delivery, and does not require any preliminary overhead, as Msg1 and Msg2 are not transmitted.

Diversity Slotted ALOHA: With CB-EDT, UEs transmit their data over the (N)PUSCH implementing the DSA protocol. To elaborate on this, we refer to Fig. 2, and discuss here the key working principles of the protocol. The diagram reports a simple example considering five UEs which attempt delivery of their CB-Msg3 over the same CB-EDT transmission window. The latter is instantiated by the eNB as a group of consecutive time occasions (TOs). For each TO, a set of frequency resources is reserved, and the network parameters are configured such that one CB-Msg3 can be transmitted within one UL grant, i.e., within a (TO, frequency resource) pair. When a UE accesses the CB-EDT window, it selects k UL grants where to send copies (*replicas*) of its message. More precisely, the UE picks at random k TOs among the available ones, and, for each of them, independently chooses at random one frequency resource. In the considered example, for instance, the CB-EDT window has been configured by the eNB with four TOs and ten frequency resources, to be used via DSA with $k = 2$. Accordingly, UE$_1$ decides to transmit the two replicas of its CB-Msg3 over the (TO, frequency resource) pairs $(1, 2)$ and $(4, 10)$. The other UEs apply the same procedure, leading to the pattern of Fig. 2. Note that, due to the uncoordinated selection of the UL grants, some of the messages are sent over the same resources. Such collisions result in interference, which may prevent the eNB from decoding. However, by having devices send multiple copies of their packets, DSA can reduce the impact of this by leaning on diversity. In the reported example, for instance, UEs 1, 2, 3, and 5 are likely to be decoded, as one of their replicas is sent over an interference-free UL grant. The benefits of this approach over slotted ALOHA ($k = 1$) have been extensively studied, e.g., [5], [7], and will be discussed in a later section.

Two concluding remarks are in order. First, CB-EDT's multiple-replica principle mitigates collisions among uncoordinated UEs, unlike the PHY-layer repetition in NB-IoT and eMTC [11], which boosts decoding probability of a single interference-free Msg3 by combining repetitions to counter low signal-to-noise ratio (SNR). In other words, a single (N)PUSCH UL grant in Fig. 2 corresponds to the transmission of a CB-Msg3 replica from a MAC perspective, and may embed multiple repetitions of the physical layer (PHY) codeword as prescribed by the eNB. The two approaches shall thus not be confused but rather be seen as complementary, targeting different problems at different layers. Second, RA protocols are inherently prone to collisions, which may not always be resolved. As shown in Fig. 2, both replicas of UE$_4$ undergo a collision, making decoding unlikely. To cope with this, CB-EDT will foresee the possibility to either attempt again the procedure after a random backoff, or to revert to the 4-step approach.

III. A DETAILED LOOK AT RELEASE-19 CB-EDT PROCEDURES

We provide in this section a more in-depth description of CB-EDT, tackling details of the 3GPP specifications in [4]. Within Rel-19, the feature is solely supported in IoT-NTN for UEs operating in coveage enhancement (CE) mode A or NB-IoT UEs operating with 3.75 kHz subcarrier spacing. In such cases, a UE can initiate a CB-Msg3 transmission when it is in RRC_IDLE state and has UL data to transmit, provided that: i) the total UL data size is less than or equal to the maximum transport block size (TBS) configured by the network, and ii) the signal quality for the UE meets a network-defined threshold. It should be noted that, when transmitting without transitioning to RRC_CONNECTED, the UE cannot rely on timing advance commands; instead, it compensates timing and frequency errors autonomously, leveraging its GNSS position and knowledge of the satellite ephemeris. Should transmissions fail due to residual timing or frequency errors, the UE may revert to the 4-step RA procedure, as discussed at the end of this section.

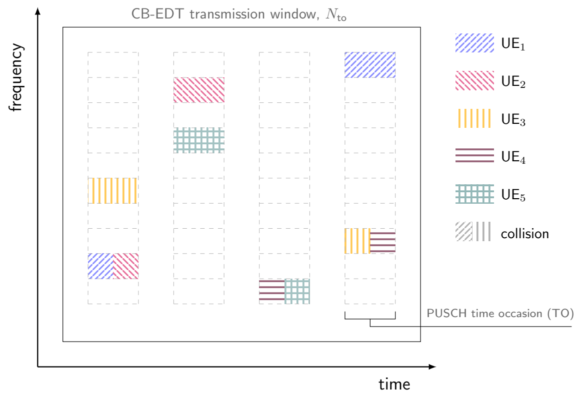

Fig. 2. Example of CB-EDT transmission: five UEs access a CB-EDT transmission window over the PUSCH. DSA is used, with each UEs sending two replicas of its message over randomly selected UL grants.

When ready to initiate the transmission procedure, the UE determines the next start time of a CB-EDT window. The set of (N)PUSCH resources is configured by the eNB, e.g., optimizing for latency and success probability based on the current load. In particular, for UEs in CE mode, the eNB can setup windows per CE level, and similarly, for NB-IoT UEs windows can be per coverage level. The window configuration includes the following parameters:

- transmission window start time
- number of (N)PUSCH TOs within the window, N_{to}
- number of frequency domain (N)PUSCH resources associated with a TO
- (N)PUSCH TO periodicity within transmission window; or (N)PUSCH TO offsets from the start of the window; or (N)PUSCH TO offsets from end of the previous (N)PUSCH TO within the window
- number of replicas to be sent by the UE within the transmission window, k
- transmission window periodicity
- length of the monitoring window for the response message.

Based on this information, the UE transmits k replicas of its CB-Msg3, randomly selecting k TOs among the available ones, and, for each selected TO, picking at random one of the allocated frequency resources. HARQ process 0 and redundant variable (RV) 0 are used to transmit all the replicas. In Rel-19, CB-EDT is supported for both control plane and user plane solutions. In the former case, the UE includes a RRCEARLYDATAREQUEST message in the CB-Msg3 transmission, whereas, in the latter, the UE activates the access stratum security and includes a RRCRESUMEREQUEST message multiplexed with the logical channel UL data in the CB-Msg3.

After the Msg3 transmission, the UE starts the CB-Msg4

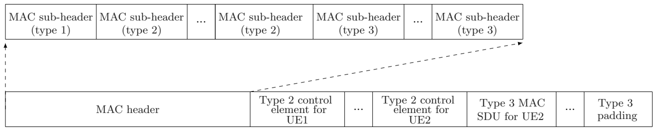

Fig. 3. Multiplexing response types for one or more UEs

TABLE I
MAIN SYSTEM ASSUMPTIONS FOR THE PERFORMANCE EVALUATION

NTN scenario	GEO Set-1 [12]
Channel	AWGN
Subcarrier spacing	3.75 [kHz]
Available subcarriers	48
Uplink SNR	2.2 [dB]
Msg3-EDT size	328 [bit]
Modulation	QPSK
EDT TO duration	128 [ms]
Number of replicas, k	1 or 2 or 3
TOs per CB-EDT window, N_{to}	equal to k

monitoring window, waiting for a network response to determine whether the attempt was successful or not. As illustrated in Fig. 1b, the monitoring initiates after the end of the CB-Msg3 EDT window plus a UE-eNB RTT. The UE can be configured to derive the Radio Network Temporary Identifier (RNTI) used to monitor for the CB-Msg4 based on some parameters that are specific to the transmission window used to send its replicas. This implies that all UEs accessing the same CB-Msg3 EDT window will use the same RNTI and can be addressed by the same CB-Msg4, i.e., the network can send a response that includes the contention resolution ID of multiple UEs whose CB-Msg3 was retrieved. More precisely, the CB-Msg4 response can include any of the following response types:

- Type 1: backoff indicator
- Type 2: success response
- Type 3: logical channel data.

The multiplexing of these response types in a single MAC PDU is shown in Fig. 3. Each response type is identified by a specific MAC subheader. For type 1, the sole subheader is present, whereas a success response (type 2) also includes one MAC control element containing the contention resolution ID for the targeted UE and optionally a new RNTI, timing advance command, and HARQ feedback resource. Finally, for a type 3 response, a MAC SDU is present, carrying logical channel DL data and possibly padding bits. The type 3 response is always preceded by a type 2 response, except when the former indicates padding bits.

If a UE decodes a type 1 response, it updates the backoff parameter value as indicated in the backoff indicator. When reattempting the CB-Msg3 transmission procedure, the UE will then draw a random backoff accordingly, and delay the CB-Msg3 transmission to the next possible CB-EDT window after the backoff expiry. In case of a type 2 response, the UE infers a success if the included contention resolution ID matches the first 48 bits of its CB-Msg3. If the success response does not follow logical channel data, the UE stops monitoring for downlink messages and moves back to RRC_IDLE state without any further action. If, instead, the response message includes both contention resolution ID and a new RNTI assigned to it, the UE monitors for further downlink messages. The network can also indicate to the UE whether it needs to transmit HARQ feedback by providing UL resource in the response message, and include the timing advance command for the next transmission. Finally, if the UE is addressed by a type 3 response followed by a type 2 response, it takes further action depending on the type of the DL message multiplexed together with the success response. Specifically, besides embedding DL data for the UE, the message may either include the RRCEarlyDataComplete message (or RRCRelease message) to move the UE to RRC_IDLE properly (e.g., with additional RRC_IDLE configurations), or it may include the RRCSetup message (or RRCResume message) to move the UE to the RRC_CONNECTED state.

If the UE does not receive any response or receives a response but the included contention resolution ID does not match, it keeps monitoring for downlink messages until the response window expires. At this point, the UE can report to the higher layers a failure of the CB-Msg3 EDT attempt. In this case, the UE may attempt the new CB-Msg3 EDT procedure, may fall back to normal EDT procedure or 4-step random access procedure. To this aim, the network can configure the maximum number of attempts the UE can make before exiting the CB-Msg3 EDT procedure.

IV. NUMERICAL RESULTS

To illustrate the performance of the new CB-EDT feature, we focus on an NB-IoT via NTN setting, and assume that the entire carrier of 180 kHz is reserved for EDT. These operating conditions are reasonable when the deployment is mainly used to support sporadic UL transmissions from IoT devices (e.g., small messages once every few hours). For reference, we use the parameters in Table I, corresponding to 3GPP Set-1 for a geostationary (GEO) satellite [12]. In particular, we focus on a subcarrier spacing of 3.75 kHz, with an UL SNR of 2.2 dB and a Msg3 size of 328 bits. An NPUSCH duration of 128 ms is required in the SNR conditions of interest to achieve a 10^{-2} packet loss rate (PLR) for a Msg3 in the absence of interference.

As the focus of the present discussion is on MAC performance, we abstract in the remainder many PHY aspects, and resort to well-known collision-channel model. Accordingly, if two or more UEs transmit a Msg3 over the same resource (collision), the eNB cannot decode any of them, whereas a Msg3 that does not collide with any other message is successfully retrieved.[1] Finally, we assume that the traffic generation, i.e., the number of new UEs that have data to send, follows a Poisson distribution, and consider a setting without retransmissions.

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[1] This is is a worst-case assumption, as in certain conditions (e.g., large SNR, different FEC rates) a packet may be decoded even in presence of collisions [13], [14]. In particular, the received power imbalance, which is a relevant working assumption due to different UE locations within the satellite coverage, will improve the overall system throughput.

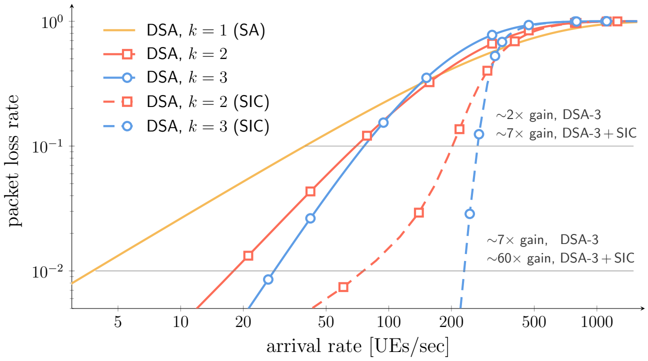

Fig. 4. Packet loss rate vs arrival rate of new UEs for CB-EDT. Solid lines report the behavior of DSA with $k = 1$ (i.e., slotted ALOHA), and $k = 2$, $k = 3$ replicas. Dashed lines denote performance of DSA with $k = 2$ and $k = 3$ when combined with successive interference cancellation.

A. *Uplink performance of CB-EDT: the role of DSA*

To highlight the role of DSA, we report in Fig. 4 the PLR achieved when resorting to a baseline slotted ALOHA scheme (i.e., $k = 1$) and when using $k = 2$ or $k = 3$ replicas (solid lines, square and circle markers). The benefits of diversity are apparent for operating conditions of interest for IoT-NTN. For example, if a PLR of 10^{-2} is targeted, a CB-EDT solution without additional replicas can support at most 4 new UEs per second, whereas the number increases to 18 and 28 with DSA-2 and DSA-3, with a 4.5- and 7-fold gain, respectively. The improvements are confirmed also when a larger PLR can be tolerated: for a loss probability of 0.1, DSA-2 and DSA-3 can support up to 70 and 76 new UE/sec in comparison to the 39 UE/s of slotted ALOHA, almost doubling the uplink capacity. These results motivate the use of DSA when aiming to use UL NPUSCH resources for RA data transmission, and were a key driver for its introduction in Rel-19.

Additionally, we report in Fig. 4 the performance that can be obtained when combining DSA with successive interference cancellation (SIC) (dashed lines). The idea, also known as contention resolution diversity slotted ALOHA (CRDSA) [7], [8] allows the eNB to remove the interference contribution of a decoded Msg3, enabling retrieval of previously collided packets. This principle can be illustrated resorting to Fig. 2. In this case, UE_4 has both its messages interfered. The eNB, however, may proceed as follows: after decoding the first replica of UE_3 (sent in the first TO, fourth frequency resource), the corresponding signal can be regenerated and subtracted from the incoming waveform in the fourth TO, third frequency resource, where UE_3 was colliding with UE_4. After this operation is performed (interference cancellation), the eNB can attempt again to decode the latter time-frequency resource, which sees now only the signal of UE_4, and retrieve the data content. In the simple example, a single step leads to resolving all the users that transmitted over the CB-EDT window, going beyond the capabilities of DSA. The procedure can be applied recursively in case of more complex collision patterns involving multiple UEs [8]. We will elaborate more on this approach – not explicitly standardized in Rel-19 – later in this paper. For the moment, it is relevant to observe how combining DSA and SIC can unleash fundamental improvements, with capacity gains up to 60-fold over slotted ALOHA and 8-fold over DSA when $k = 3$ is used and a PLR of 10^{-2} is targeted.

B. *Downlink overhead: legacy EDT and CB-EDT*

As a further step, we compare the performance of legacy EDT and the newly introduced CB-EDT, taking a holistic view of the system, and considering DL overhead (in this section) and a delay-throughput analysis (in the next subsection).

In the case of legacy EDT, for every successfully detected preamble for which the eNB provides Msg3 NPUSCH resources, at least 56 bits are needed in the DL (Msg2). This comprises 8 bits for the MAC subheader and 48 bits for the payload. The additional contributions for the backoff indicator, CRC bits and padding bits are assumed to be amortized over all the preambles multiplexed in the Msg2. Though the number of bits required are per detected preamble, this can be approximated to be per successful UE as the collision and packet error rate regime we are operating at are small.

A successful unicast Msg4 transmitted by the eNB (in legacy EDT) must include a UE contention resolution ID of 48 bits and 8 bits for the corresponding subheader. The total overhead typically required for the unicast Msg4 is around 120 bits per successful UE, due to the unicast PDCCH scheduling for each Msg4, transmission of other unicast RRC messages associated with the Msg4, CRC and padding bits, etc. Overall, ≈ 176 bits are required in the DL for handling a successful legacy EDT transmission.

In the case of CB-EDT, the only DL transmission is the multicast Msg4 presented earlier. This requires a subheader (8 bits) and the contention resolution identity for every decoded Msg3 (48 bits). The timing advance command, HARQ feedback resource, C-RNTI are optional. Hence ≈ 56 bits per successful UE can be used (much of the other overhead, such as PDCCH, CRC, or padding, is amortized).

Using the 3GPP Set-1 parameters for GEO, we obtain a DL SNR of -3.3 dB, which leads to a maximum supportable DL data rate of 32 kbps (from link-level simulations). Accounting for the 30% additional DL overhead in NB-IoT due to the sync signals in the anchor carrier, the different overheads required to instantiate the solutions lead to a maximum number of UE/s that can be supported in the DL to be 126 UE/s for the 4-step EDT and 399 UE/s for the CB-EDT, with a 3.16-fold improvement enabled by the new feature. As will be shown in the next section, DL can become the bottleneck in terms of the number of UEs/s that are supportable for legacy EDT, while this will not be the case for CB-EDT.

C. *Capacity-vs-delay analysis*

The UL capacity of CB-EDT has already been discussed earlier (see Fig. 4). To determine the UL capacity of legacy EDT, we note that this requires two types of UL messages: Msg1 (NPRACH)[2] and Msg3. As a result, there is a fundamental trade-off in how to split the UL resources between these.

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[2] A preamble transmission time of 12.8 ms is needed to achieve a 0.01 probability of misdetection for NPRACH.

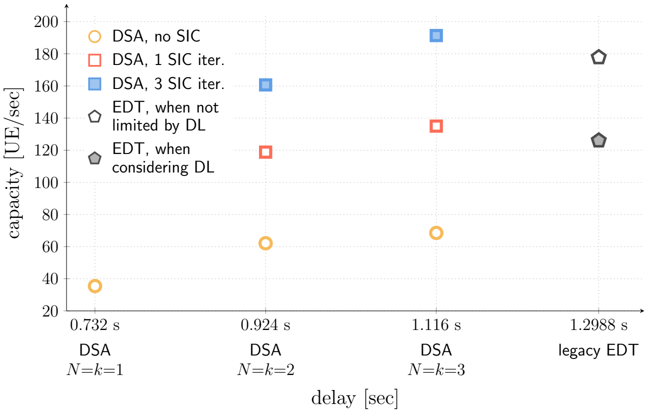

Fig. 5. Capacity, in terms of supported UE/s, vs delay for different schemes: DSA with $k = 1$, $k = 2$ or $k = 3$ replicas, and legacy EDT. For DSA, we also consider the case of using SIC, with only 1 or three interference cancellation iterations. For the legact EDT, the two markers denote the capacity that would be obtained ignoring the DL bottleneck (empty marker), and the one that considers also the DL limitations (filled marker).

Omitting the detailed derivations, for a collision probability of 0.1, the optimal number of preambles/s turns out to be 1875 with 187.5 EDT resources/s available. The maximum arrival rate supported is 197 UEs/s which leads to an average of 187.5 preamble/s detected and 177 successful UEs/s.

Turning our attention now to delays incurred till successful Msg4 reception, for legacy EDT, the contributing components are as follows (we assume that the NPRACH periodicity is equal to the Msg3 duration of 128 ms)

- Average waiting time: NPRACH periodicity/2 = 64 ms
- NPRACH transmission duration: 12.8 ms
- RTT to receive Msg3: 540 ms
- Msg2 duration: 2 ms
- Msg2-to-Msg3 scheduling delay: 12 ms
- Msg3 transmission duration: 128 ms
- RTT to receive Msg4: 540 ms

This results in a total delay of 1298.8 ms.

For CB-EDT, assuming the TOs are back-to-back, the components comprising the delay incurred are:

- Average waiting time: $k \times 64$ ms
- Msg3 transmission duration: $k \times 128$ ms
- RTT to receive Msg4: 540 ms

This results in a total delay of 732 ms for 1 TO, 924 ms for 2 TOs and 1116 ms for 3 TOs.

Using the delay values determined above, along with the prior analysis of maximum supportable UEs/s, we can obtain a capacity-vs-delay snapshot, comparing the various schemes (legacy EDT, CB-EDT with DSA, with and without SIC). This is depicted in Fig. 5. The capacity (in terms of supportable UEs/s) is the minimum across both the uplink and downlink, for the respective schemes. We can thus make the following observations:

- Legacy EDT capacity is limited by the downlink. The standalone uplink capacity of 177 UEs/s cannot be achieved, and is capped by the downlink capacity of 126 UEs/s
- CB-EDT with DSA facilitates lower delay with minimal degradation in capacity with respect to legacy EDT
- CB-EDT with DSA and even a single iteration of SIC (i.e., the most basic variant of CRDSA) provides *higher capacity and lower delay* than legacy EDT.

V. CONCLUSION AND DISCUSSION

The newly introduced CB-EDT feature brings important elements of novelty for IoT-NTN in Rel-19. By allowing UEs to directly send data over the uplink shared channel in a RA fashion, the solution avoids the Msg1-Msg2 exchange required by EDT, reducing the number of transmitted messages as well as latency. Moreover, the use of DSA trigger benefits in terms of diversity, substantially increasing the number of devices that can be supported for packet loss rates of interest with respect to a basic slotted ALOHA approach. Finally, by introducing the possibility of addressing multiple UEs within the same CB-Msg4, the feature leads to further substantial improvements in terms of DL overhead, thereby removing bottlenecks that exist in legacy EDT, in terms of facilitating high UL capacities.

The strong potential of CB-EDT is also confirmed when considering the combination of DSA with interference cancellation techniques, as highlighted by the numerical results reported in this paper. With the current specifications, replicas can be located at the expense of an increased (but potentially feasible, especially for narrowband systems) computational complexity, e.g., having the eNB correlating samples in collided resources with those of the decoded Msg3, to identify where replicas are likely to be present–an approach that can be termed *blind* interference cancellation. Another approach, inspired by the CRDSA protocol [7] consists of using *pointers*. By doing so, the eNB gets to know the locations of all the replicas of a UE as soon as any of the Msg3s is decodedPointers could be implemented by adding a few bits in the CB-Msg3, which identify the resources selected by the UE. Other approaches can achieve the same result without the introduction of any additional overhead (e.g., implicit pointers). The idea consists of seeding a pseudo-random number generator with an UE identifier to output the positions of the replicas. At the receiver side, the decoding of one of the replicas allows to infer the seed, and thus the locations. In the absence of an explicit specification in the standards, an implicit pointer logic may be agreed upon by UE and eNB implementations from respective vendors, thereby facilitating CRDSA. The explicit specification of pointers may be of interest for upcoming releases, in view of the potential gains triggered by DSA and SIC.

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