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Preamble Reservation based Access for Grouped mMTC Devices with URLLC Requirements

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***Abstract*—Ultra-reliable low latency communication (URLLC) and massive machine type communications (mMTC) are two of the three major technological pillars in 5G. For medium access in mMTC scenarios, e.g., smart cities, a major bottleneck for achieving reliable access is channel congestion due to LTE-A based random access. Hence, priority-based access schemes are preferred in order to provide reliable and low latency access for mMTC devices in 5G networks. In this paper, we categorize the devices covered inside a cell into grouped and non-grouped sets and propose a preamble reservation based 2-step access scheme where grouped devices gain network access via a designated group leader using reserved preambles. Through analysis and simulations, we demonstrate that the proposed scheme enables ultra-reliable and low latency access for grouped devices while improving the performance of non-grouped devices through proper configuration of parameters.**

I. Introduction

Emerging 5G networks focus mainly on supporting enhanced mobile broadband, ultra-reliable low latency communication (URLLC) and massive machine type communications (mMTC). In futuristic 5G scenarios, up to 1 million devices per square kilometer are envisaged to be deployed in smart cities with a large number of them connected to the network to provide various types of services, known as mMTC or massive Internet of things (mIoT). Accordingly, such scenarios require massive network access connections [1]. One of the main bottlenecks to facilitate a massive number of connections is caused by the existing long term evolution-advanced (LTE-A) random access (RA) procedure [2]. In LTE-A, a limited number of preambles are available for the RA process, causing a high preamble collision probability, long latency, and low access success probability for competing devices. This problem is severe in mMTC, especially when a higher number of competing devices arrive as bursty traffic [1]-[3].

There has been a plethora of research on improving the LTE/LTE-A RA for MTC devices. In [3], 3GPP specifies several possible solutions to address LTE RA congestion. One popular approach is access class barring (ACB) based solutions where devices are classified into access categories with different access probabilities and barring times. In enhanced ACB, low priority devices are dynamically barred/unbarred depending on traffic arrival rate. Moreover, approaches like dynamic resource allocation, MTC specific backoff approaches, slotted RA and pull based (eNB initiated) access procedures were also considered [3]. In addition to 3GPP based solutions, there are several other approaches proposed to reduce RA congestion as presented in [1] and the references therein. Moreover, group based access schemes are also proposed to reduce collision probabilities [9]. However, most of these existing approaches were developed targeting at MTC scenarios but *not designed for accommodating mMTC traffic especially when bursty traffic is considered*. Although most solutions provide reliable communication, there is no guaranteed access for higher priority devices. Moreover, the reliability improvements are often achieved without addressing the reliability versus latency tradeoff adequately.

For 5G new radio (NR), the RA process is proposed to be assisted with beam steering techniques in order to reduce preamble collision probability [5]. Alternatively, non-orthogonal RA based schemes [6] and grant free access schemes [8] have been proposed to solve the existing RA congestion problems in 5G networks. Although these techniques would be useful in NR systems, the RA congestion problems with co-located LTE-A/NR deployments remain as unsolved for mMTC scenarios.

Triggered by the limitations in existing access schemes and an observation that only a fraction of devices needs URLLC access, we propose in this paper a group based preamble reservation access scheme for reliability and latency critical mMTC devices. The proposed scheme enables group based access for a set of mMTC devices through a designated group leader with reserved preambles. Different from existing schemes, our scheme focuses on providing both high reliability and low latency access for grouped devices. Furthermore, it enables a *2-step access process* instead of following the standard 4-step RA procedure in LTE-A, leading to lower latency and less energy consumption for mMTC devices. Additionally, we investigate the impact of the proposed solution on the non-grouped devices and evaluate the performance of both sets of devices using three 3GPP specified performance metrics [3].

The rest of the paper is organized as follows. Sec. II presents the considered network scenario and assumptions. Thereafter, Sec. III provides details about the proposed scheme and Sec. IV presents the analytical model for performance evaluation. The analytical and simulation results are provided in Sec. V. Finally, the paper is concluded in Sec. VI.

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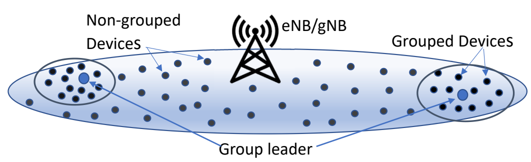

Fig. 1: Grouped and non-grouped devices.

II. Network Scenario and Assumptions

The envisaged network scenario considers a futuristic smart city that contains a massive number of devices performing various tasks, from environmental and critical infrastructure monitoring to smart grids and industrial automation. As one of the several possible deployment scenarios in 5G NR [5], these IoT devices are covered by LTE-A eNBs that co-exist with 5G gNBs. In such scenarios, when a triggering event occurs, a large number of sensor devices require instant communication with the eNB/gNB. The observations from each sensor are important to measure the urgency level of the triggering event and for data collection. Hence, they require very high level of reliability as well as low latency.

Consider M number of MTC/mMTC devices inside the coverage area of a given cell. These devices are capable of direct communication with the eNB and device-to-device (D2D) communication in an ad-hoc manner. A certain fraction of these devices, i.e., γM, where $0 \leq \gamma < 1$, are sensing devices that observe critical triggering information and require low latency and ultra reliability. The proposed group based access scheme is targeted at this set of devices, referred to as grouped devices (GDs) which are assumed to be static. There are N_G number of groups each containing a certain number of devices. As shown in Fig. 1, the remaining $(1-\gamma)M$ devices are referred to as non-grouped devices (NGDs).

Device grouping could be based on specific scenarios, for instance, considering the functionality and geographic locations of the devices. Furthermore, we assume that device grouping is pre-configured, e.g., upon device deployment. The devices in the same group are assumed to have synchronous communication requirements, i.e., in case of a triggering event, all devices in the same group attempt to transmit their observations to the eNB. Each group has a group leader. The group leader is assumed to be a more powerful device in terms of processing capability and battery lifetime compared with other member devices and the members in a particular group are aware of their group leader. Furthermore, device grouping and group leader selection are reconfigurable. We further assume that a triggering event would be detected by all the group devices including the group leader.

The NGDs follow the traditional LTE-A RA scheme [2]. Accordingly, two or more NGDs selecting the same preamble would lead to a collision and consequently all involved devices have to retransmit up to a maximum transmission limit, N_{PT}. To represent the MTC/mMTC access characteristic, the traffic arrival is considered to be a bursty type and represented by a time limited Beta distribution function, $p(t)$, as recommended by 3GPP [3]. Additionally, a single frequency band is considered and it is assumed that if a preamble is received, the eNB has enough radio resources to allocate to all these devices. Some of the main notations, their meanings and the respective numerical values used in this study are listed in Table. I.

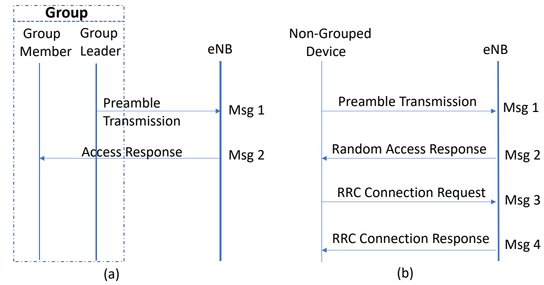

Fig. 2: (a) 2-step access for grouped devices, (b) 4-step LTE-A random access for non-grouped devices.

III. The Proposed Access Scheme

As illustrated in Fig. 2(a), GDs will access the network following the proposed contention-free 2-step access scheme to be explained in the following subsections whereas the NGDs will adopt the legacy LTE-A 4-step contention based RA scheme shown in Fig. 2(b).

A. Access Scheme for Grouped Devices

1) Initial network attach: At the initial deployment, devices communicate with the eNB based on the existing LTE-A RA scheme and register themselves with their associated eNB. During the registration process, the eNB collects location information and infers the required timing advance details related to the set of connected devices and then stores them for later usage. Through the initial attach process, the eNB allocates an address to each group member and reserves a preamble for each group. The group leader and its members are informed about these allocations.

2) Access on triggering event: In an event where the observed measurements of sensors exceed a pre-defined threshold, a triggering event will be initiated. We assume that the group leader can also sense this triggering event considering its more powerful capabilities. In this case, the group leader will immediately transmit its allocated preamble in the next available RA slot. In another case where the group leader does not sense the triggering event, D2D communication between nodes can be utilized to inform the group leader about the event. In this paper, we focus on a scenario where the group leader observes the event at the same time as the other group members.

3) Access response from the eNB: When the eNB receives a preamble that is reserved for a specific group, it identifies the group from the preamble. Since each group leader in different groups has its own reserved preamble, this access process is collision-free. Once the eNB identifies the corresponding group which the received preamble belongs to, it retrieves the information about the registered group members. The eNB is aware of the immediate access requirement of these GDs. It then allocates resource blocks for individual group members based on the addresses assigned during the initial attach process. The eNB transmits the relevant timing advance information for each group member based on the calculations from the registration process so that each member can adjust their transmission time accordingly for radio frame synchronization. Since devices are static, the timing advance values would remain the same unless modified by a separate update.

B. Access for Non-grouped Devices

The NGDs will follow the legacy LTE-A RA scheme [2] for network access. Since N_G preambles are reserved for N_G group leaders, the number of available preambles for NGDs is reduced by $N_G(< R)$, i.e., it becomes $R - N_G$, where R is the total number of preambles available in an RA slot. Concurrently, the number of NGDs competing for the $R-N_G$ preambles also decreases to $(1-\gamma)M$. In an event of collision, the collided devices will retransmit after waiting for a backoff interval based on a random number selected from a uniformly distributed range $[0 \sim W_{BO}-1]$. For successfully transmitted preambles, Msg 3 and Msg 4 will be transmitted subsequently in order to complete the RA process as shown in Fig. 2(b).

C. Selection of Number of Groups and Devices

As mentioned earlier, the grouping of devices in the proposed scheme is pre-defined but the parameters are reconfigurable. While having a higher N_G would enable access for a larger number of latency critical devices, the selection of N_G and γ needs to be performed carefully to avoid performance degradation of NGDs. Generally, the number of devices per preamble gives an indication about the possibility of different users selecting the same preamble and thereby causing collisions. In LTE-A without grouping, this ratio is M/R. For a grouped scenario with N_G number of groups and γM grouped devices, this ratio is given by $(1-\gamma)M/(R-N_G)$ for NGDs. In order to improve the performance level that will be achieved by NGDs without grouping, the following condition should stand

$$\frac{(1-\gamma)M}{(R-N_G)} < \frac{M}{R}. \quad (1)$$

The inequality in (1) can be further simplified into $N_G < \gamma R$. This relationship can be utilized when deciding N_G and γ so that the performance of NGDs is not compromised.

IV. Performance Analysis

The performance analysis of the proposed scheme is twofold. First, the GDs' performance is presented. Next, the impact of grouping on NGDs is evaluated. Three evaluation metrics which were recommended by 3GPP [3], i.e., preamble collision probability, access success probability and average delay for sucessful transmissions are selected.

A. Performance of the Grouped Devices

Since each group has a reserved preamble, the access process for GDs is contention-free. Hence, the probability of preamble collision at the eNB is 0. Accordingly, the access success probability for GDs is 1.

TABLE I: Notations, explanations, and values [3] [7]

Notation	Explanation	Value
T_P	The duration of arrival period (in terms of subframes).	10000
M	Total number of devices which request service during T_P	10000-120000
W_{BO}	Backoff window size (subframes)	20
T_{RA_REP}	Interval between two successive RA slots (in terms of subframes)	5
R	Total number of preambles in an RA slot	54
N_{PT}	Maximum number of preambles transmissions	10
N_{RAR}	Maximum number of RA responses (RARs) that can be carried in a response message	3
W_{RAR}	Length of the RA response window (in terms of subframes)	5
p_n	Preamble detection probability of the n^{th} preamble transmission	$p_n = 1 - \frac{1}{e^n}$
T_{RAR}	Processing time required by the eNB to detect transmitted preambles (subframes)	2
N_G	Number of groups	5, 10, 15
γ	Fraction of devices from M that are grouped	0.2, 0.4
N_{UL}	Maximum number of devices acknowledged within an RA response window	$W_{RAR} \times N_{RAR}$
T_D	Delay from a preamble transmission to the reception of the RAR response	$W_{RAR} + T_{RAR}$

Several factors could contribute to the latency of GD communications. Denote by P_n the probability that eNB can detect group leaders' n^{th} preamble transmission. For a successful detection, at least one transmission is required from the group leader. Whether a retransmission is needed or not depends on the detection status of the previous transmission, up to $N_{PT}-1$. Accordingly, the number of preamble transmission attempts required for a successful detection can be expressed as $(1+\sum_{n=1}^{N_{PT}-1}(1-P_n))$. In this expression, 1, which appears out of the summation, indicates the first preamble transmission. Once the preamble is transmitted, group members need to wait for T_D duration until they receive Msg 2 with access grant and resource allocations from the eNB as shown in Fig. 2(a). Hence, considering the number of required retransmissions, the average delay for successfully transmitting a preamble, D_a, can be calculated as follows

$$D_a = \left(1 + \sum_{n=1}^{N_{PT}-1} (1-P_n)\right)T_D = \left(1 + \sum_{n=1}^{N_{PT}-1} (e^{-n})\right)T_D. \quad (2)$$

B. Performance of the Non-grouped Devices

Since NGDs follow the legacy LTE-A RA procedure, we adopt an analytical model similar to the one proposed in [7] with further improvements in order to calculate the impact of the proposed scheme on NGDs' performance in the *presence of device grouping*. Fig. 3 illustrates the timing diagram with RA slots and arrivals. An RA slot refers to the subframe where competing NGDs would transmit their preambles following the LTE-A RA procedure. The same as in [7], we configure the interval between two successive RA slots T_{RA_REP} as 5.

The number of initial arrivals of devices at the i^{th} RA slot is given by the following equation

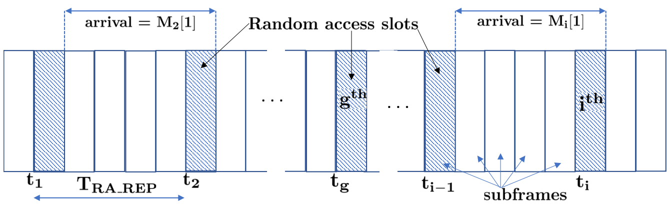

Fig. 3: Random access slots and arrivals: timing diagram inside T_P.

$$M_i[1] = M(1-\gamma)\int_{t_{i-1}+1}^{t_i+1} p(t)\,dt, \tag{3}$$

where $p(t)$ is based on the Beta distribution defined in [2] and t_i is the starting time of the i^{th} RA slot. For a given RA slot i, in addition to the initial arrivals, $M_i[1]$, there could be devices attempting their n^{th} preamble transmission ($1 < n \leq N_{PT}$) due to previously failed $(n-1)^{th}$ preamble transmission at the g^{th} RA slot. The positions of the g^{th} and i^{th} RA slots are demonstrated in Fig. 3. Here, $M_i[n]$ denotes the number of devices performing their n^{th} preamble transmission on the i^{th} RA slot, calculated as follows

$$M_i[n] = \sum\nolimits_{g=G_{\min}}^{G_{\max}} \alpha_{g,i} M_{g,F}[n-1], \tag{4}$$

where G_{min} and G_{max} denote the lower and upper limits of the window of the RA slot values that g could take. That is, in order to transmit the n^{th} transmission on the i^{th} RA slot, the $(n-1)^{th}$ transmission failure should occur between G_{min} and G_{max} time before t_i. $\alpha_{g,i}$ denotes the percentage of the backoff interval of the g^{th} RA slot that overlaps with the transmission interval of the i^{th} RA slot. G_{min}, G_{max} and $\alpha_{g,i}$ values are calculated as follows [7]

$$G_{\min} = (i-1) - \tfrac{T_D+W_{BO}-1}{T_{RA\_REP}},\ G_{\max} = i - \tfrac{T_D+1}{T_{RA\_REP}}.$$

$$\alpha_{g,i} = \begin{cases} \frac{t_g+T_D+W_{BO}-t_{i-1}}{W_{BO}}, \text{if} \quad G_{min} \leq g \leq i - \frac{T_D+W_{BO}}{T_{RA\_REP}}; \\ \frac{T_{RA\_REP}}{W_{BO}}, \text{if } i - \frac{T_D+W_{BO}}{T_{RA\_REP}} < g < (i-1) - \frac{T_D}{T_{RA\_REP}}; \\ \frac{t_i-(t_g+T_D)}{W_{BO}}, \text{if } (i-1) - \frac{T_D}{T_{RA\_REP}} \leq g \leq G_{max}; \\ 0,\ \text{otherwise}. \end{cases}$$

Furthermore, $M_{g,F}[n-1]$ in (4) denotes the number of devices that failed their $(n-1)^{th}$ preamble transmission at the g^{th} RA slot. This can be calculated by the relationship $M_i[n] = M_{i,S}[n] + M_{i,F}[n]$ where $M_{i,S}[n]$ is the number of successful n^{th} preamble transmissions at the i^{th} RA slot and it is obtained as follows

$$M_{i,S}[n] = \begin{cases} M_i[n]e^{-\frac{M_i}{R-N_G}}p_n, \ \text{if} \sum\limits_{n=1}^{N_{PT}} M_i[n]e^{-\frac{M_i}{R-N_G}}p_n \leq N_{UL}; \\ \frac{M_i[n]e^{-\frac{M_i}{R-N_G}}p_n N_{UL}}{\sum\limits_{n=1}^{N_{PT}} M_i[n]e^{-\frac{M_i}{R-N_G}}p_n}, \quad \text{otherwise}. \end{cases} \tag{5}$$

Here, $M_i = \sum_{n=1}^{N_{PT}} M_i[n]$. Note that, even when the preamble transmission is performed without collision, there is no guarantee on the successful reception of the RA response due to detection errors at the eNB caused by channel impairments and the constraint on the maximum number of devices acknowledged within an RA response window, denoted by N_{UL}.

1) Collision probability: is defined as the collision probability, denoted as P_c, and it is obtained as follows

$$P_c = \frac{\sum\limits_{i=1}^{I_R}\left(R - N_G - e^{-\frac{M_i}{(R-N_G)}}\left(M_i + (R-N_G)\right)\right)}{I_R(R-N_G)}. \tag{6}$$

In (6), term I_R denotes the number of RA slots inside the considered time duration.

2) Access success probability: The access success probability, P_s given in (7) below, is the probability that a device successfully completes the RA procedure within N_{PT} transmissions. Note that an access success means not only a sucessful preamble transmission but also the completion of all 4 steps in the LTE-A RA process.

$$P_s = \frac{\sum\limits_{i=1}^{I_R}\sum\limits_{n=1}^{N_{PT}} M_{i,S}[n]}{M(1-\gamma)}. \tag{7}$$

3) Average delay for successful devices: The average access delay for the successfully accessed devices is the ratio between the accumulated access delay experienced by those devices with successful access and the total number of the successfully accessed devices, expressed as

$$D'_a = \frac{\sum\limits_{i=1}^{I_R}\sum\limits_{n=1}^{N_{PT}} M_{i,S}[n]T_n}{\sum\limits_{i=1}^{I_R}\sum\limits_{n=1}^{N_{PT}} M_{i,S}[n]}, \tag{8}$$

where T_n is the average access delay of a successfully accessed device that performs exactly n preamble transmissions.

V. Numerical Results

This section presents the numerical results obtained from both the analytical model and simulations based on the parameter configurations mentioned in Table I and the recommendations given in [3]. Different network scenarios are analyzed by reconfiguring M, γ and N_G parameter values. The performance of the proposed scheme is compared with the legacy LTE-A scheme without grouping, i.e., $N_G = 0$. Different from the existing LTE-A RA analysis that considers up to 30k devices, our evaluation includes up to 120k devices in order to reflect an mMTC scenario.

A. Collision Probability and Access Success Probability

As mentioned in Subsec. IV-A, the collision probability for GDs equals to 0 whereas the access success probability equals to 1 thanks to the contention-free access. This ensures guaranteed reliable communication for GDs. For NGDs, Fig. 4 illustrates the variation of collision probability P_c as a function of M and γ. For a given N_G, P_c increases monotonically with an increasing M. Conversely, Fig. 5 presents the access success probability of NGDs and it exhibits an inverse relationship with P_c, owing to the monotonically decreased values for an increasing number of devices. This is a result of the increased competition that occurs with an increased number of devices. When M is very large, i.e., for mMTC, the collision probability is very high, resulting in a very low access

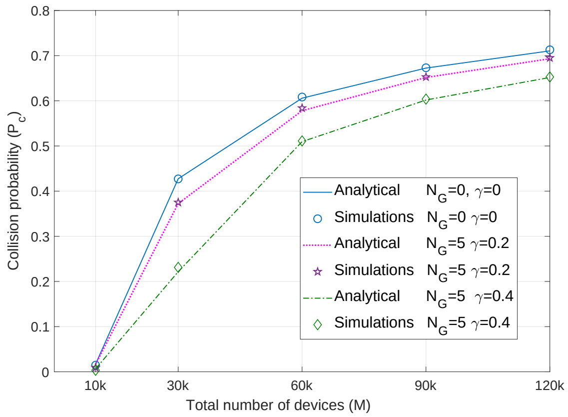

Fig. 4: Collision probability of NGDs for different γ.

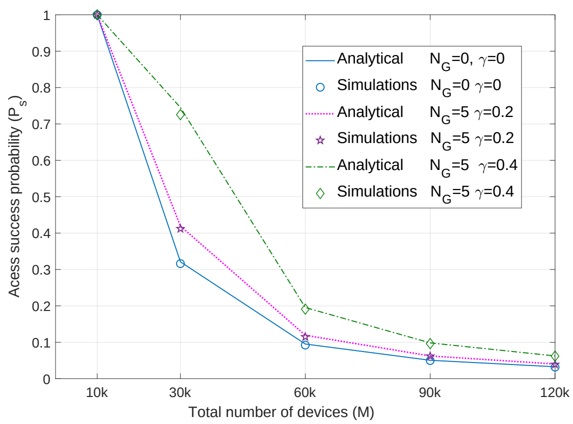

Fig. 5: Access success probability of NGDs for different γ.

probability. For the considered scenarios, when grouping is enabled, i.e., $N_G > 0$, NGDs have a higher access probability and lower P_c compared with the legacy LTE-A scheme without grouping. Although grouping reduces the number of available preambles for NGDs by N_G, the amount of devices competing for RA also reduces due to device grouping. Hence, by properly selecting γ and N_G, the performance of NGDs could be improved while ensuring ultra-reliable and low latency access for GDs.

B. Average Access Delay for Successfully Accessed Devices

The average delay for the successfully accessed GDs obtained from (2) equals approximately to 11 subframes based on our parameter configuration. This is significantly lower in comparison with the delay that a successful device would experience without grouping, for different M as presented in Fig. 6. The behavior of the delay of the GDs is governed by (2) and it is independent of the number of devices in the group. For NGDs, the average delay of the successfully accessed devices increases up to a certain value and thereafter it shows a stable behavior. When M becomes higher, the percentage of successfully accessed devices reduces dramatically as observed in Fig. 5. Therefore, the number of devices included for the calculation of average delay is a low ratio in comparison with the total number of devices competing for access. Among these successful devices, most of the successful attempts occur in the initial and final stages of bursty arrivals, resulting in a lower

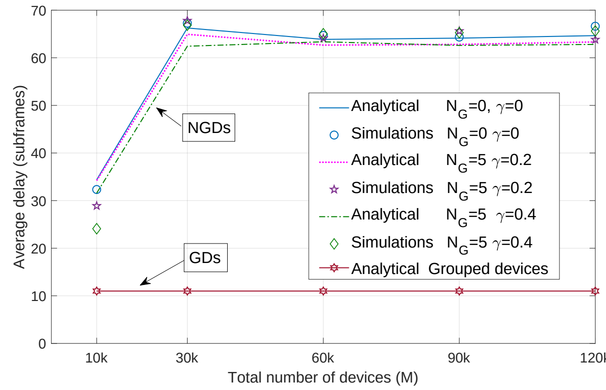

Fig. 6: Average delay for successful preamble transmissions.

number of retransmissions and lower average delay. Hence, when $M > 30k$ the obtained average delay tends to be stable.

C. Impact and Selection of N_G and γ

The impact of N_G is further investigated in Fig. 7 and Fig. 8. Here we keep $\gamma = 0.2$ constant and change the number of groups, N_G. Hence, the number of preambles available for NGDs is varying. It is evident that a higher number of groups degrade the NGDs' performance in terms of P_c and P_s. Therefore, a fine-tuned balance between N_G and γ is required for improving the performance of NGDs. As mentioned in Subsec. III-C, grouping can be done with a proper selection of N_G and γ without degrading the performance of NGDs. This can be further observed in Fig. 7 and Fig. 8. With grouping enabled access, where $N_G < \gamma R$, the NGDs have better performance compared to leagacy LTE-A with $N_G = 0$. To illustrate the consequence of violating the condition in (1), a scenario with $N_G = 15$ and $N_G > \gamma R$ has been considered. The obtained results show that the NGDs' performance is worse than what is experienced with the legacy LTE-A scheme. Hence, the importance of following the condition given in (1) is further emphasized. While the proposed scheme ensures ultra-reliable and low latency communications for GDs, the proper selection of γ and N_G values according to the above criteria ensures that NGDs also have better performance compared with LTE-A RA scheme without grouping. In other words, with proper parameter configuration, the proposed scheme guarantees the performance of GDs while also improving the performance of NGDs.

D. Success Percentage for Transmission Attempts

Fig. 9 demonstrates the percentage of successful preamble transmissions at each transmission attempt when the device population is 30k. With a higher collision probability associated with 30k devices, the number of successful preamble transmissions in each attempt is comparatively low. However, the success percentage at each transmission attempt is higher in the grouping enabled scheme compared with the legacy scheme. In both cases, the success percentage decreases with each transmission attempt. This is due to the bursty nature of the arrivals. At the peak of bursty arrivals, lots of devices compete for preamble transmissions, resulting in a high number of collisions in a given RA slot. Furthermore, this

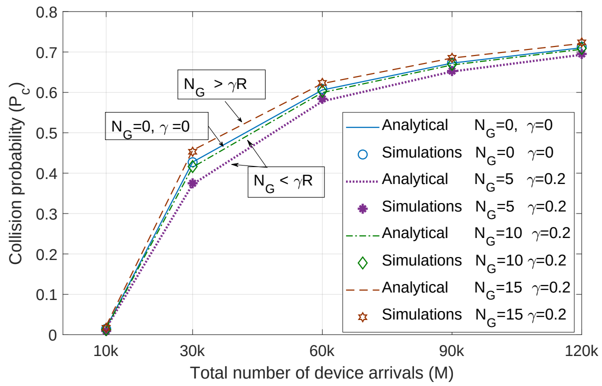

Fig. 7: Collision probability for different number of groups.

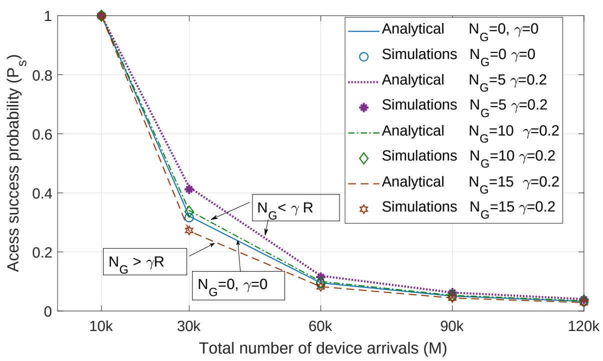

Fig. 8: Access success probability for different number of groups.

causes retransmissions in the subsequent RA slots and thereby reduces the successful preamble transmission probability. The considered maximum value for the backoff period, $W_{BO} = 20$, recommended by [3], is a comparatively low value with respect to the high traffic intensity at the peak of bursty arrivals. Therefore, retransmissions occur in close by RA slots following the failed RA slot(s). This causes further congestion and thereby increases the collision probability of retransmission attempts. During the initial and final phases of bursty arrivals, the traffic intensity is comparatively light leading to a higher number of successful first transmission attempts. However, since the preamble detection probability is at its lowest value for the first transmission, the success percentage still exhibits a lower value.

Additionally even if the device is successful in its preamble transmission, it may not receive the RA response due to limited number of devices acknowledged by eNB in a given RA response window represented by N_{UL}. This is especially observable in mMTC scenarios. Hence, in case of mMTC with bursty arrivals, it is important to consider possible approaches to increase the N_{UL} value to acknowledge a higher number of devices from eNB within one RA response window.

E. Further Discussions

As demonstrated above, the proposed scheme enables ultra-reliable access to GDs. Concurrently, the access latency has been greatly reduced compared with the LTE-A RA scheme. Access latency can also be further reduced by utilizing the enhancements proposed to the NR frame structure [5]. Moreover, the preamble utilization efficiency could be further improved

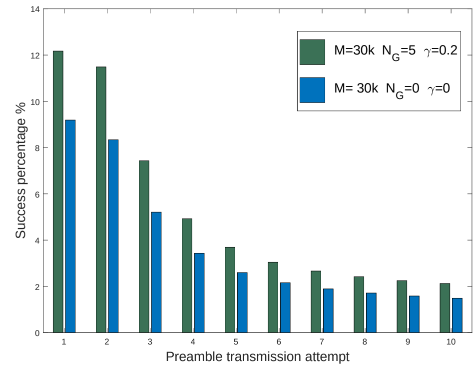

Fig. 9: Success percentage of preamble transmission when $M = 30k$ for both the legacy RA and proposed schemes.

by applying a slotted access based enhancement proposed in [3] to our scheme. Additionally, thanks to the group based 2-step access process, the proposed scheme reduces the number of messages transmitted and received by GDs. This will influence in a greater reduction of energy consumption in GDs and correspondingly increase the lifetime of the networks.

VI. Conclusions

In this paper we have proposed a group based access scheme for mMTC devices that require URLLC access to instantaneously transmit their observations. The proposed group based access scheme considers preamble reservations for GDs that are used by group leaders to communicate with the eNB. The contention-free based access provides guaranteed access for GDs with lower latency values compared with the legacy LTE-A scheme. Additionally, the impact of the proposed scheme on NGDs is also evaluated based on both analysis and simulations. The results indicate that with a proper configuration the proposed scheme guarantees the performance of GDs while also improving the performance of NGDs.

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