On Improving the Group Paging Method For Machine-type-Communications

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***Abstract*—Machine-type-Communication (MTC) is seen as a major service in next generation cellular mobile networks. However, the forecasted very large number of MTC devices may overload the RAN (Radio Access Network) part of the network, which may impact Non-MTC communications. Group paging is considered as one of the most efficient mechanisms proposed to alleviate the problem of the RAN overload. In this paper, we introduce a new solution to improve the performance of the current group paging method and overcome its disadvantages. The proposed solution is intended for MTC devices in the RRC_CONNECTED_OUT_OF_SYNC state, in which MTC devices have an RRC context without being synchronized with the network. Numerical results demonstrate that the proposed solution highly improves the performance of existing group paging mechanisms.**

I. INTRODUCTION

Machine-Type-Communication (MTC), also known as Machine-to-Machine (M2M) communication, refers to a new type of service facilitating the communication between machines or devices without requiring human intervention. M2M devices support a broad variety of applications (e.g. eHealth, surveillance, and Intelligent Transport System (ITS)), in a wide range of domains impacting different markets and environments [8]. This type of communications is expected to connect an enormous number of MTC devices, which will certainly offer many revenue opportunities. M2M is becoming a promising technology attracting the attention of many operators and vendors.

Although considered as the best candidate to deploy M2M ecosystems, cellular mobile networks were optimized for services like voice calls and simple messaging from Human-to-Human (H2H), Human-to-Machine (H2M), and Machine-to-Human (M2H) applications [8]. In order to enable M2M market over mobile cellular networks, the SA2 group of the Third Generation Partnership Project (3GPP) is currently proposing system improvements in order to support efficiently MTC devices in Universal Mobile Telecommunications System (UMTS), Long Term Evolution (LTE), and LTE-Advanced networks (LTE-A) [6]. However, there are still many challenges that need to be solved to deploy M2M ecosystems. In fact, as mentioned in [12], the huge number of MTC devices will generate a very large amount of signaling/data traffic and may overload both the Radio Access Network (RAN) and the Core Network (CN), which may impact both MTC and Non-MTC connections. This congestion may cause intolerable delays, packet loss, or service unavailability to current Human-to-Human (H2H) communications. Tackling this problem necessarily passes by designing Mobile Network Operators (MNOs)-friendly MTC applications. However, MNOs can not leave the control of the signaling to MTC application's developers. Otherwise the networks of the operators and their provided quality of service will be at risk. Therefore, mechanisms guaranteeing the required quality of service and the network availability while alleviating the system's congestion and overload are needed.

Many methods were proposed in the literature in order to address the problem of system's congestion and overload. One of the 3GPP solutions is the paging method. In this method, the MTC devices will start the RACH (Random Access Channel) procedure just after receiving a paging message. However, this method is not practical in the presence of a high number of MTC devices as it will take a long period to page all the devices, e.g. paging 36000 MTC devices will take $11.25\,s$. Existing solution of this problem in the literature consists in organizing the MTC devices in groups, where each one is represented by a group ID (GID). Therefore, the MTC devices in one group can be paged by only one paging message. Upon receiving a paging message that includes their GID, the MTC devices start the RACH procedure. Again, this group paging method still has many disadvantages, such as the low value of resources' utilization as the optimal value is about 20% [9]. Another disadvantage is the access success probability that rapidly decreases when the size of the group exceeds a certain threshold. In this paper, a novel method is proposed to overcome these disadvantages while improving the performance of group paging. The main idea of this method is to attribute the reserved resources to the MTC devices instead of leaving them to randomly choose an access resource, leading to ensure a contention-free RACH access for MTC devices.

The remainder of this article is organized as follows. Related works are presented in the section II. Background on the UE (User Equipment) state machine in LTE and the RACH procedure are presented in section III. Section IV presents system model and our proposed solution CDR (the Controlled Distribution of Resources) in details. Numerical results are introduced in section V. Finally, conclusion is introduced in section VI.

II. RELATED WORK

RAN overload control approaches can be classified into push-based and pull-based approaches [11]. In the former approaches, the MTC devices push their traffic to the network

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until a RAN overload is detected. From the network viewpoint, these approaches are considered as decentralized control models. In the latter approaches, the network pulls the MTC devices traffic to control the load. From the network viewpoint, these approaches are considered as centralized control models [3].

A. Push-based overload control schemes

Different push-based RAN overload control schemes were proposed in the literature. Generally, these approaches are based on one or a combination of the following mechanisms:

1) Separate RACH resources for MTC and Non-MTC devices: When sharing the same resources, the MTC and Non-MTC devices experience the same collision probability in case of congestion. Resources' separation limits the number of MTC devices accessing the network, while maintaining a normal network access for Non-MTC traffic. This separation in LTE can be achieved either by splitting the preambles into MTC group(s) and Non-MTC group(s) or by allocating (in time or frequency) PRACH (Physical RACH) occasions either to MTC devices or to Non-MTC devices.

2) Dynamic allocation of RACH resources: This method can be used if the network has the capability to foresee the periods when the access load will surge with MTC devices' traffic. To handle this load, additional RACH resources can be allocated for the MTC devices.

3) MTC specific Backoff scheme: As the priority of Non-MTC traffic is higher than MTC traffic, spreading out the MTC traffic in a large time interval allows increasing the access probability of Non-MTC traffic. This can be achieved by assigning a larger backoff window for MTC devices. Therefore, this kind of solutions can guarantee network availability for Non-MTC devices.

4) Access Class Barring (ACB): In this scheme, a separate Access Class could be assigned for each class (QoS requirement) of MTC devices. This will allow the network to subtly control their access while controlling the access of the other devices. Depending on parameters transmitted by the network, the UE (User Equipment) can determine its permission to access the network. This permission is determined by the access probability p, which is also known as the ACB factor. The access is barred for a mean time duration if the number (n), randomly generated by the UE, is equal or greater than the access probability.

The main advantage of this type of methods is that there is no extra signaling. It is also suitable for timely handling unscheduled events [3], e.g. smart meters reporting timely urgent readings or timely deal with other time-critical events. However, there are many disadvantages of this type of methods, such as the variation of resource utilization, the difficulty of regulating the network load, and the high variation in RACH intensity.

B. Pull-based overload control schemes

Two main approaches exist in this class: Contention-free RACH procedure and Paging method. In the contention-free RACH procedure, the eNB utilizes reserved resources in order to initialize the RACH procedure. First, the eNB sends a message to the UE, informing it about the preamble to be used. Once the message is received, the UE initializes the RACH procedure using the indicated preamble. In LTE, the downlink paging channel is intended for sending the paging information to the UEs, informing them about the changes in the system information. The network may transmit a paging message in a way to trigger the RACH procedure. Therefore, the MTC devices in the paging method start their RACH procedure only when they receive a paging message containing their IDs. However, in the presence of a very large number of MTC devices, the one-by-one paging will lead to both high paging load and long paging delay. In the current paging mechanism, which was originally designed for H2H services, there are two paging occasions in one radio frame ($10\,ms$). At most, 16 MTC devices can be paged by one paging message. Therefore, if the network has to page 36000 MTC devices, it needs 2250 paging messages to page all the MTC devices, which will take $11.25\,s$. To overcome this problem, it was proposed in [2] to organize the MTC devices into groups, where each group is represented by a group ID (GID). Then, the MTC devices in one group can be paged by one paging message.

In general, there are many advantages of pull-based methods. The resources' utilization in these methods is more stable and predictable than that in push-based methods.The regulation of network load is also flexible and easier in the pull-based methods. The signaling load is, however, slightly higher due to the paging messages load.
For the rest of the paper and for the sake of convenience, we name the group paging as the ordinary group paging and the proposed method as the proposed solution or CDR (The Controlled Distribution of Resources).

III. BACKGROUND

A. UE State Machine in LTE:

A machine or a terminal in LTE can be in one of the two states (as illustrated in the figure 1): RRC_CONNECTED and RRC_IDLE [13]. In the RRC_CONNECTED state, a RRC (Radio Resource Control) context is established between the terminal and the network. This allows the terminal to transmit/receive data to/from the network. In this state,

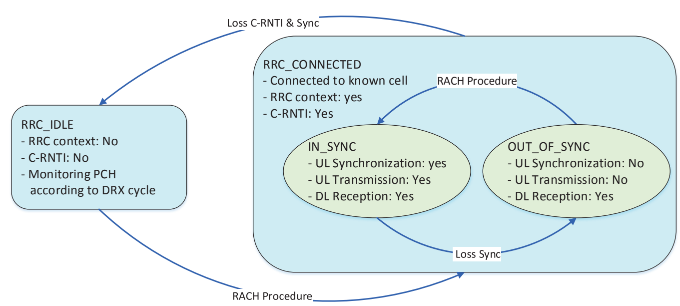

Fig. 1: UE State Machine in LTE

the terminal has, among other things, a temporal identity, named as C-RNTI (Cell-Radio Network Temporary Identifier), assigned by the cell to which the terminal is attached. Depending on whether there is uplink synchronization, the RRC_CONNECTED state can be divided into two substates: IN_SYNC and OUT_OF_SYNC. In this paper, these substates are named RRC_CONNECTED_IN_SYNC and RRC_CONNECTED_OUT_OF_SYNC, respectively. As long as the uplink is synchronized, the uplink transmission is possible. Otherwise, the terminal must perform the random access procedure in order to restore the uplink synchronization. In the RRC_IDLE state, no RRC context is established. Thus, the terminal, in this state, does not belong to a specific cell. In order to move to the RRC_CONNECTED state, the terminal must perform the RACH (Random Access Channel) procedure.

B. RACH Procedure:

When a UE in the RRC_IDLE state or in the RRC_CONNECTED_OUT_OF_SYNC state tries to connect to the LTE network, the first thing that the UE must do is to perform the RACH procedure whose signaling flow is illustrated in the figure 2. There are two forms of random access procedures: contention-based and contention-free random access procedures. As an example, the first one is

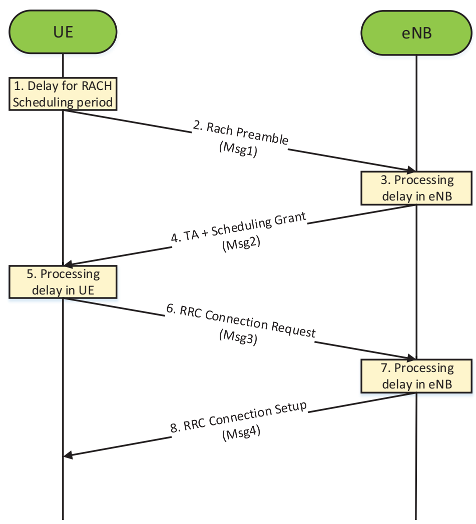

Fig. 2: Random Access Procedure

used for initial access in order to establish a radio link, i.e. moving from RRC_IDLE to RRC_CONNECTED_IN_SYNC. It is also used to establish uplink synchronization if uplink or downlink data arrives and the UE is in the RRC_CONNECTED state without being synchronized, i.e. moving from RRC_CONNECTED_OUT_OF_SYNC to RRC_CONNECTED_IN_SYNC. The second one can be used, for example, for handover or DL (DownLink) data arrival. The steps of the RACH procedure are as follow:

1) Random-Access Preamble Transmission (Msg1): The first step consists in transmitting a randomly chosen preamble. This step allows the eNB to estimate the transmission timing of the terminal, which is used later for adjusting the uplink synchronization.

2) Random-Access Response (Msg2): Once the random access preamble is transmitted, the UE monitors the PDCCH (Physical Downlink Control Channel) to receive the random access response (RAR) message during the RAR window. The RAR message consists of the TA (Timing Advance) command, which is used to adjust the uplink synchronization, and the TC-RNTI (Temporary C-RNTI). The TC-RNTI is the temporary identity of the UE in the cell and it is promoted to C-RNTI if the UE has no yet a C-RNTI. The RAR message also assigns to the terminal uplink resources to be used in the next step. For contention-free RACH procedure, the UE supposes that the RACH procedure has been successfully finished, while the UE with contention-based RACH procedure continues to the third step.

3) RRC Connection Request (Msg3): After successfully receiving Msg2 and adjusting the uplink synchronization, the UE sends the Msg3 containing its ID and the RRC connection request using the UL-SCH (UpLink-Shared Channel) assigned to the UE in the step 2.

4) RRC Connection Setup (Msg4): This step helps in solving access problems when more than one terminal use the same resources (the same preamble and the same PRACH) while successfully receiving the second message (Msg2). Indeed, the terminals, in this case, share the same temporary identifier (TC-RNTI). Each terminal receiving the downlink message compares the identity in the message with the one transmitted in the third step. Only the terminal that observes a match between the two identities will declare that the random access procedure has been successfully finished. The other terminals restart the RACH procedure.

IV. Controlled Distribution of Resources (CDR) For MTC devices

A. System Model

We consider in this paper that each group contains M MTC devices in a paging area comprising N cells, as in [1]. These devices are uniformly distributed over the cells, thus each cell contains M/N MTC devices. In the proposed solution, it is assumed that all MTC devices are in the RRC_CONNECTED_OUT_OF_SYNC state and, therefore, all the MTC devices have C-RNTI. In other words, the MTC devices have RRC context, but there is no synchronization between the devices and the network (i.e. there is no Uplink transmission). When there is data to be sent or a request from the network to get information, the MTC devices must first proceed with the random access procedure. At this point, it is assumed that the M MTC devices are assigned by a group Identity (GID). The network reserves R dedicated random access resources and utilizes the GID in order to page the M MTC devices to access the network simultaneously. In LTE, the transmission is organized in radio frames of ten milliseconds in the time domain. Each radio frame is divided into multiple sub-frames of one millisecond and the random access transmission is determined in specific sub-frame [10], which is named as a random access slot in this paper. The random access resources in LTE are determined in terms of random access opportunities (RAOs) that are equal to the number of frequency bands in each random access slot multiplied by the number of reserved random access preambles [4]. Upon receiving a paging message containing the GID, the MTC device in the proposed solution shall start the random access procedure by sending certain preamble in certain random access slot determined using the C-RNTI of this MTC device.

B. Proposed Mechanism CDR:

The idea behind the CDR mechanism is that instead of leaving each MTC device choosing randomly an access resource, we can attribute the available resources as follows[1]:

- Assign dedicated random access resources to the group during a certain interval (group access interval). In CDR, this interval depends on the number of MTC devices and the number of reserved preambles. However, as mentioned in [9], this interval in the ordinary group paging depends on the maximum number of preamble transmission.
- Assign a pair of values (a, b) to each MTC device, where "a" is the number of the random access slot during the group access interval and "b" is the ID of the preamble in this random access slot.

Thereby, the number of required random access slots in CDR is obtained as follows:

$$N_{slots} = \left\lceil \frac{M/N}{R} \right\rceil \quad (1)$$

where, R is the number of reserved preambles and $\lceil x \rceil$ denotes the upper integer value of x.

Because of the limitation of the number of RARs in each RAR message, the number of preambles reserved for the group in the CDR should be inferior or equal to the maximal number of MTC devices N_{ACK} that can be acknowledged within the random access response window (W_{RAR}). Where N_{ACK} is:

$$N_{ACK} = N_{RAR} \times W_{RAR} \quad (2)$$

N_{RAR} is the maximum number of RARs that can be carried in a response message.

For instance, if we consider the following parameters: $W_{RAR} = 4$, $N_{RAR} = 1$, $R = 4$, and $M/N = 12$; we obtain $N_{ACK} = 4$. In this case, the number of required slots is $N_{slots} = 3$. Table I depicts the attribution of MTC devices in the reserved slots. From this table, we clearly remark that in an optimal situation no resource is wasted. However, the worst case takes place when there is only one MTC device in the last slot (see table II).

RA Slot 1		RA Slot 2		RA Slot 3	
MTC devices	The pair of values (a, b)	MTC devices	The pair of values (a, b)	MTC devices	The pair of values (a, b)
MTC 1	(1, 1)	MTC 5	(2, 1)	MTC 9	(3, 1)
MTC 2	(1, 2)	MTC 6	(2, 2)	MTC 10	(3, 2)
MTC 3	(1, 3)	MTC 7	(2, 3)	MTC 11	(3, 3)
MTC 4	(1, 4)	MTC 8	(2, 4)	MTC 12	(3, 4)

TABLE I: The attribution of MTC devices in the reserved slots in the optimal case

RA Slot 1		RA Slot 2		RA Slot 3	
MTC devices	The pair of values (a, b)	MTC devices	The pair of values (a, b)	MTC devices	The pair of values (a, b)
MTC 1	(1, 1)	MTC 5	(2, 1)	MTC 9	(3, 1)
MTC 2	(1, 2)	MTC 6	(2, 2)		
MTC 3	(1, 3)	MTC 7	(2, 3)		
MTC 4	(1, 4)	MTC 8	(2, 4)		

TABLE II: The attribution of MTC devices in the reserved slots in the worst case

Now, we will detail the procedure to attribute the values of "a" and "b" to each MTC device. It is important to recall that the proposed solution is dedicated to the case where the MTC devices are in the RRC_CONNECTED_OUT_OF_SYNC state and, thus, the MTC devices have, among other things, the group ID (GID) and C-RNTI. In order to attribute the pair of values (a, b), we avoided directly assigning the pair of values once the MTC device joins the group. Indeed, this requires additional signaling overhead to be exchanged with each MTC device. The CDR mechanism depends on the C-RNTI, which can take values comprised in the interval $(003D - FFF3)_{hex} = (0000\ 0000\ 0011\ 1101 - 1111\ 1111\ 1111\ 0011)_{bin}$, as mentioned in [4]. We propose allocating a subinterval of values to the group. As an example, we can reserve the values $V_I = (0000\ 1111\ \mathrm{xxxx\ xxxx})$, which corresponds to the interval $(0000\ 1111\ 0000\ 0000 - 0000\ 1111\ 1111\ 1111)_{bin}$, where x is either "0" or "1". This interval can contain $2^8 = 256$ MTC devices. This means that a particular group can comprise at most 256 MTC devices. If we take the parameters in the table III, the number of MTC devices ($M/N = 256$) and the number of reserved preambles ($R = N_{ACK} = 15$), then the number of required slots is $N_{slots} = 18$ slots.

The pair of values (a, b) can be obtained directly from the C-RNTI of each MTC device using the following steps:

- Sending the mask MSK to all MTC devices. This mask can be sent through the paging message used to inform the MTC devices to start the RACH procedure. In our example, the mask MSK is equal to $(0000\ 1111\ 0000\ 0000)_{\mathrm{bin}}$.
- Each MTC device performs the logical operation XOR between the mask and its C-RNTI as follows:

$$PID = MSK \oplus V_I \quad (3)$$

- The pair of values (a, b) can be obtained using the following equations:
  - $a = 1 + \lfloor PID/R \rfloor$, which represents the number of the random access slot and takes values in $[1, N_{slots}]$. Here, $\lfloor x \rfloor$ represents the lower integer value of x.
  - $b = 1 + (PID\ mod\ R)$, which denotes the identity of the preamble in the random access slot specified by "a", and it takes values in $[1, R]$.

  As an example, for a MTC device whose PID is equal to 129, the pair of its (a, b) values is equal to $(9, 10)$. Thus, the MTC device whose PID is equal to 129 will transmit the 10^{th} preamble in the 9^{th} slot.

At the network side, the eNB can determine the C-RNTI for each MTC device as follows:

- The eNB can know the pair of values (a, b) based on which preamble is used and in which random access slot the preamble was transmitted. Following a general form notation, we know that $PID/R = y + z/R$, where $y = \lfloor PID/R \rfloor$, which is an integer value, and $z = (PID\ mod\ R)$. By using the equations of "a" and "b", we can obtain that $y = (a - 1)$ and $z = (b - 1)$. Hence, $PID = (a - 1) \times R + (b - 1)$, which can be used at the network side to obtain the PID of the corresponding MTC device.
- In order to obtain the C-RNTI of the MTC devices, an

[1]For simplicity, we assume that there is only one frequency band in each random access slot

XOR is performed between the mask and the PID.
$\mathrm{C\_RNTI} = \mathrm{PID} \oplus \mathrm{MSK}$

If we return to our example, we have $a = 9$ and $b = 10$. Using the precedent equations, the PID of the corresponding MTC device is: $PID = 129$ and the C-RNTI of this MTC device is: $\mathrm{C\_RNTI} = (0000\ 1111\ 1000\ 0001)_{\mathrm{bin}}$

V. PERFORMANCE EVALUATION

We implemented our proposed solution CDR using Matlab. The RACH parameters specified in the Table 6.2.2.1.1 in [5] and the control-plane latency analysis determined in the Table B.1.1.1-1 in [7] are used in the simulation. The parameters used in the simulation are summarized in the table III. For the sake of comparison, the simulation and numerical results in [1] and [9] are used.

Notations	Definitions	Values
M/N	Average number of MTC devices in each cell	10 ~ 1000
R	The total number of preambles in a random access slot	15
N_{RAR}	Maximum number of RARs that can be carried in one response message	3
W_{RAR}	Size of random access response window in sub-frame unit	5
N_{ACK}	Maximum number of MTC devices that can be acknowledged within the RAR window	$N_{ACK} = N_{RAR} \times W_{RAR}$
N_{RA_SLOT}	Interval between two successive random access slots in sub-frame unit	$N_{RA\_SLOT} = 5$ if PRACH configuration Index = 6
N_{PR_D}	Processing time required by an eNB in order to detect the transmitted preamble in sub-frame unit	2

TABLE III: Basic simulation parameters

A. Performance Metrics

The collision probability, the access success probability, the average access delay, statistics of access delay, and the resource utilization are used as the performance metrics in this paper in order to evaluate the CDR mechanism. The definitions of these metrics are given in [5]. The collision probability is defined as the ratio between the number of collided RAOs (two or more MTC devices use the same preamble and the random access slot) and the total number of reserved RAOs (with or without random access attempts). Note that, in CDR there is no collision as each MTC device chooses a different preamble and random access slot than all other MTC devices. Therefore, the collision probability is always equal to zero. The access success probability is the probability to successfully complete the RACH procedure within the maximal number of preamble transmission. In the proposed solution, the access success probability is 100% as there is no collisions during the transmission of the preamble. Furthermore, there is no need of the messages Msg3 and Msg4 (used for the random access procedure) as the eNB can know exactly which MTC device transmits which preamble and in which random access slot. Therefore, the random access procedure in the proposed solution becomes like contention-free random access procedure. Let D_k be the access delay for the k^{th} MTC device, where $k \in [1, M/N]$. This delay consists of the time required to transmit the preamble $(1+(a_k-1)\times T_{RA\_SLOT})$ and the time required to receive the RAR message $(T_{PR\_D} + \lceil \frac{b_k}{N_{RAR}} \rceil)$. The access delay D_k can be expressed, then, as follows:

$$D_k = 1 + (a_k - 1) \times T_{RA\_SLOT} + T_{PR\_D} + \lceil \frac{b_k}{N_{RAR}} \rceil \quad (4)$$

where a_k and b_k are the pair of values (a, b) of the k^{th} MTC device. Let d be the delay for the RACH procedure between the first random access slot in the paging access interval and the completion of the RACH procedure. The statistics of access delay is defined as the CDF (cumulative distribution function) of the delay for each RACH procedure between the first random access slot and the completion of the RACH procedure for the successfully accessed MTC devices. The CDF of access delay, denoted by $C(d)$, can be expressed as $C(d) = \frac{\sum_{n=1}^{d} MTC_n}{M/N}$, where MTC_n is the MTC device whose access delay is no more than n. The average access delay $\overline{D}$ is the total access delay for all successfully accessed MTC devices divided by the total number of successfully accessed MTC devices, and it can be expressed as $\overline{D} = \frac{\sum_{i=1}^{M/N} T_i}{M/N}$. The utilization of RAOs, denoted by U, is the ratio between the number of successfully accessed MTC devices and the number of reserved RAOs, i.e. $U = \frac{M/N}{N_{slots} \times R}$.

B. Results

Figure 3 illustrates the collision probability and access success probability as function of the number of MTC devices in each cell. We see that the collision probability of the CDR is always 0%, while it increases from 0.18% to 72.8% in the ordinary group paging. Indeed, in this last method, the number of MTC devices (M/N) (in each cell) changes from 10 to 1000. The access success probability of the CDR is always 100%, while it decreases from 100% to 21.3% for the ordinary group paging. This can be explained by the fact

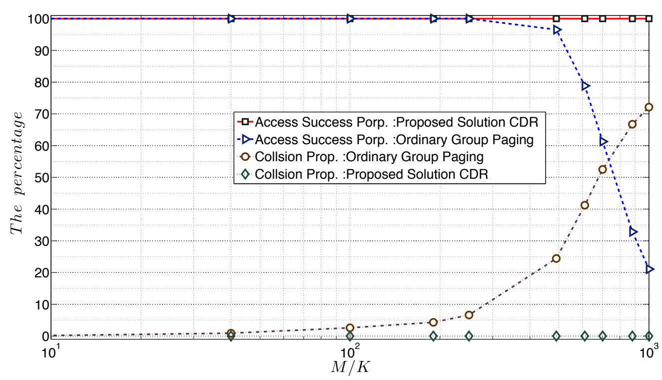

Fig. 3: The percentage of Collision and Access Success Probabilities

that each MTC device in the CDR chooses a unique preamble and a random access slot than the other devices, while the MTC device in the ordinary group paging randomly chooses a preamble that can create collision, which leads to degrade access success probability when there is a large number of MTC devices, i.e. a high contention on the RACH resources. Figure 4 shows the average value of access delay for both the ordinary group paging and the CDR. The figure clearly demonstrates that the delay in the CDR is less than in the ordinary group paging. However, this delay increases as the number of MTC devices increases and becomes greater than the delay for the ordinary group paging when $M/N = 1000$. The average delay for the ordinary group paging is $168.16\,ms$ while it is $170.2\,ms$ for the CDR. To better interpret results of figure 4, we divide this figure into two regions: the first region where the delay of the CDR is less than that for the ordinary group paging and the second one on the contrary. The results of

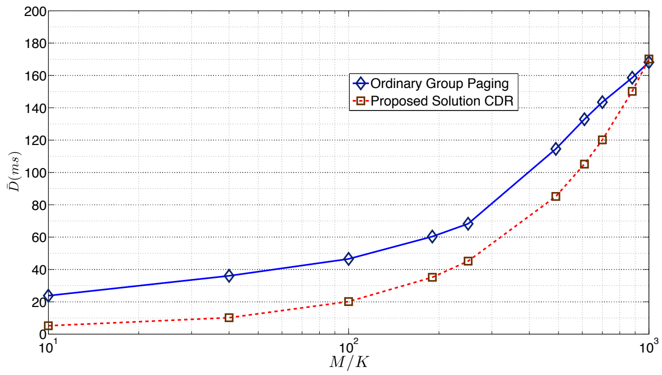

Fig. 4: Average Value of Access Delay

the first region of the figure can be explained by two factors: (i) no need for preamble retransmission in the CDR a; (ii) the absence of the messages Msg3 and Msg4 in the RACH procedure (i.e. the RACH procedure in the CDR became like contention-free RACH procedure). Therefore, the delay in the proposed solution depends only on the time required to transmit the preamble and to receive the message Msg2. In addition, as there is no need to preamble retransmission, the power consumption is reduced, which is a very important issue for the MTC devices with limited power resources. The results of the second region is explained by the access success probability for the CDR, which is always equal to 100%. Therefore, the average access delay of the CDR increases as

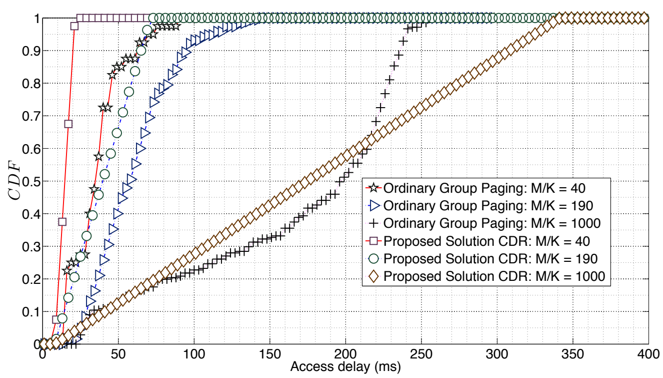

Fig. 5: CDF of Access Delay

the number of MTC devices increases. However, the access success probability decreases as the number of MTC devices increases in the ordinary group paging. Regarding the CDF

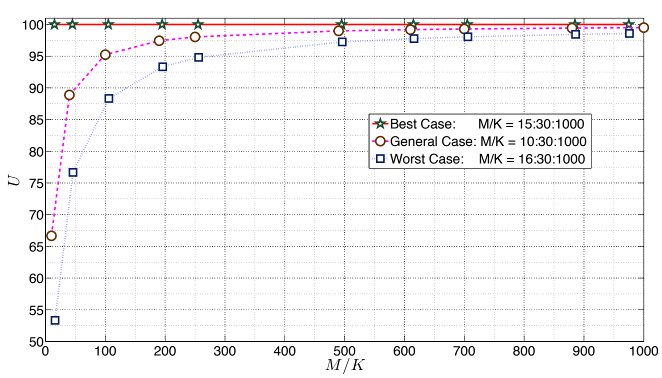

Fig. 6: Resource Utilization of the CDR

of access delay, the figure 5 shows clearly that the CDF of the CDR is always linear. The figure also illustrates that the maximum delay of the CDR when $M/N = 1000$ is larger than that for the ordinary group paging. We argue this by the fact that the paging access interval, in the ordinary group paging, depends on the maximal number of preamble transmission and not on the number of MTC devices. In contrast, the paging access interval in the CDR depends on the number of MTC devices and, thus, the maximum delay increases by increasing the number of devices. The figure 6 illustrates the resource utilization for the CDR. We see clearly that the resource utilization increases as the number of MTC devices increases and it is always larger than 50%, whereas it is mentioned in [9] that the optimal value of resource utilization for the ordinary group paging is approximately 20%.

VI. Conclusion

In this paper we presented the CDR mechanism to improve the performance of the ordinary group paging for MTC devices. CDR is dedicated to the case where the MTC devices are in the RRC_CONNECTED_OUT_OF_SYNC state, and ensures that the RACH procedure is a contention-free procedure. Numerical results have confirmed the superiority of the CDR mechanism compared to the ordinary group paging method. Besides reducing collisions and increasing channel access probabilities, CDR allows to reduce power consumption, which is a very important issue for MTC devices with limited power resources. Future works will consist in extending the CDR mechanism to be applicable not only in the RRC_CONNECTED_OUT_OF_SYNC state, but also for other RRC states.

References

[1] 3GPP R2-113198, "Further Analysis of group paging for MTC" ITRI, RAN2#74, May 2011.

[2] 3GPP R2-104870, "Pull Based RAN overload control" Huawi, China Unicom, RAN2#71, August 2010.

[3] 3GPP R2-104873, "Comparing Push and Pull based approaches for MTC" Institute for Information Industry (III), Coiler Corporation, RAN2#71, August 2010.

[4] 3GPP TS 36.321, "Medium Access Control (MAC) protocol specification", v11.3.0, June 2013.

[5] 3GPP TR 37.868, "Study on RAN improvements for Machine-type-Communications" V11.0.0, September 2011.

[6] 3GPP TR 23.888, "System Improvements for Machine-Type-Communication (MTC)" V11.0.0, September 2012.

[7] 3GPP TR 36.912, "Feasibility study for further Advancements for E-UTRA (LTE-Advanced)" V11.0.0, September 2012.

[8] ETSI TS 122 368, "Service Rquierements for Machine-Type-Communication (MTC)" V10.4.0, May 2011.

[9] C. H. Wei, R. G. Cheng, and S. L. Tsao, "Performance Analysis of Group Paging for Machine-type-Communication in LTE Networks" *IEEE Transaction on vehicular thechnology*, vol. 62, no 7, p. 3371 - 3382, September 2013.

[10] R. G. Cheng, C. H. Wei, S. L. Tsao, and F. C. Ren, "RACH Collision Probability for Machine-type-Communications", *Vehicular Technology Conference (VTC Spring)*, 2012 IEEE 75th. IEEE, 2012. p. 1-5.

[11] M. Y. Cheng, G. Y. Lin, and H. Y. Wei,"Overload control for machine-type-communications in lte-advanced system ", *IEEE Communications Magazine*, vol. 50, no 6, p. 38-45, June 2012.

[12] M. Y. Cheng, G. Y. Lin, and H. Y. Wei,"Toward Ubiquitous Massive Accesses in 3GPP Machine-to-Machine Communications", *IEEE Communications Magazine*, vol. 49, no 4, p. 66 - 74, April 2011.

[13] E. DAHLMAN, S. PARKVALL, and J. SKOLD, "4G: LTE/LTE-Advanced for Mobile Broadband", ISBN: 978-0-12-385489-6, Academic Press, Elsevier, 2011.