RESEARCH

A Novel Group Paging Control Method for Massive MTC Accesses in LTE Networks

Cong Wang[1*], Chengqiang Wei[2], Ning Li[2], Wenfeng Ma[1] and Hui Tian[1]

Abstract

The fifth-generation (5G) systems have to deal with massive deployment of machine-type-communication (MTC) devices. System overload may occur during a random access (RA) procedure under a limited number of preamble resources and physical uplink shared channel (PUSCH) resources especially when there exist massive MTC devices in a cell. In order to resolve the system overload (caused by the massive MTC deployment), the 3GPP proposed the adopted a group paging (GP)-based uplink access technique. But its performances dramatically decrease as the number of MTC devices increases. In this paper we propose a novel method, named ACB-based group paging overload control method (AGO). To reduce the number of simultaneous access MTC devices, AGO first scatters the MTC devices over a GP interval, and then automatically adjusts ACB parameters according to the load conditions. By doing so, AGO achieves high-channel access probability for MTC devices. Simulation results show that this method is superior to the GP and Pre-backoff (PBO) mechanisms in terms of success and collision probability, average access latency and resource utilization rate.

Keywords: 5G; Group paging; ACB; massive MTC devices (MTC); Machine to machine communication (M2M); overload control; random access

1 Introduction

The main goal of Internet of Things (IoT) is to ensure connection of massive numbers of machine terminals to cellular networks. Machine-type Communication (MTC), also known as machine-to-machine (M2M) communication, is envisioned as a main enabler for the IoT [1]. According to its definition, MTC means the communications between machines (devices) without (or with a little) human intervention [2]. MTC applications have been experiencing rapid growth in various domains, such as intelligent transport systems, smart cities, e-Health, smart grids, industry automation, monitoring and control systems, etc. [3, 4].

With the development of IoT applications, the number of MTC devices is also growing rapidly. Unlike human-to-human (H2H) communications, a severe random access (RA) overload may occur during the RA procedure since a large number of IoT devices attempt RAs at the same time in general cellular systems. Hence, various techniques have been proposed to resolve the RA overload problem of the cellular systems in literature, such as the slotted aloha scheme, the pull-based scheme, the MTC device back-off scheme, the access class barring (ACB) scheme and the group paging (GP) scheme, etc.

GP is an effective solution proposed by the 3GPP group to alleviate the congestion in LTE networks. It is a very effective method to control network overload in the pull-based scheme [5]. In the GP method, the MTC devices are grouped together according to various metrics, such as time-controlled, delay-tolerant, Quality of Service (QoS), etc. Each group is assigned an ID, named Group ID (GID). Therefore, the MTC devices in one group can be paged by only one paging message. After receiving the paging message, all members in the group initiate the random-access process in the upcoming available random-access slot. But its performances dramatically decrease as the number of MTC devices increases.

As a congestion control mechanism, ACB has been studied and used in 2G / 3G networks [6]. In LTE / LTE-A, the ACB mechanism consists of an AC barring factor and an AC barring time parameter. These two parameters are broadcasted by the Evolved Node B (eNB) to the competing devices (including H2H and M2M) through System Information Block (SIB). Before the device initiates the random-access process, it determines whether the group is prohibited according to the system information. Each device in the forbidden group selects a random value between 0 and 1, and

*Correspondence: lgd_dolphin@139.com
[1]College of Field Engineering, Army Engineering University of PLA, 210007 Nanjing, China
Full list of author information is available at the end of the article

then compares it with the AC barring factor. If it is less than the factor, the device initiates the random-access process. Otherwise, the device will be force to enter the back-off process. By doing so, ACB can achieves high-channel access probability for MTC devices. However, it is difficult to set ACB parameters according the load dynamically.

In this paper we propose a novel method, named ACB-based group paging overload control method (AGO). To reduce the number of simultaneous access MTC devices, AGO first scatters the MTC devices over a GP interval, and then automatically adjusts ACB parameters according to the load conditions.

The remainder of the paper is organized as follows: Section 2 gives a brief review of the related works. Section 3 introduces LTE Random Access Procedure. Section 4 elaborates the proposed scheme: ACB based group paging overload control method (AGO). The performance of the AGO scheme is presented using some metrics with the computer simulation in section 5. The paper is concluded in Section 6.

2 Relate Works

With the access of massive MTC devices to the network, the problem of network overload becomes more and more prominent. According to key problems in recent M2M communications, there are many studies being carried out to alleviate RAN overload and network congestion [7]. These studies divide control mechanism into push-based and pull-based methods [5]. In push-based scheme, it mainly includes ACB mechanism, dynamic resource allocation mechanism and random-access resource separation mechanism. In the pull-based scheme, the network (eNB) initiates the RACH procedure. The MTC device can only send data to the eNB after being paged. Group paging mechanism [5] is a very effective method to control network overload in the pull-based scheme. In the GP method, the MTC devices are grouped, and only devices in the same group can be paged in the same paging message. As a pull-based overload control method, the performance of group paging is analyzed by an iterative method. Compared to uniform distributed traffic, the devices in group paging are usually activated simultaneously in the first access slot, which results in an extremely high system load [8]. The authors in [9] propose to control access of M2M devices by strict slot scheduling. In [10], A continuous group paging (CGP) method is proposed to improve the access success probability of devices through repeated paging interval. However, for some configurations, the performance of CGP method is worse than that of classical group paging mechanism. In [11, 12], a mechanism called Pre-backoff (PBO) is proposed. Before the first preamble transmission, the device is forced to some back-off time, which reduces the number of devices connected to the network at the same time, and improves the access success probability compared to the classical group paging. The authors also investigate the impact of backoff window size on the system performance. The authors in [13] adjust the backoff indicator dynamically to ensure the delayed devices would not enter into the next paging cycle. Further in [14], based on the stability analysis, an optimal pre-backoff scheme has been proposed for group paging to reduce energy consumption.

ACB scheme is currently regarded as the major solution in M2M communications. The existing literatures mainly focus on the dynamic adjustment method of ACB parameters [15, 16, 17, 18]. In [15], a dynamic adjustment of ACB parameters with PID is proposed. In order to adjust ACB parameters, random access load needs to be estimated. In reference [16], according to the network collision status, a Markov-Chain-based traffic-load estimation scheme is proposed. Further in [17, 18], two dynamic access class barring (D-ACB) algorithms have been presented. In the paper, these algorithms can determine the ACB factors dynamical, and achieve an effective result of reducing total service time.

Unlike traditional H2H communications, M2M communications service features are different, and the required QoS is also different. To meet different QoS requirements, authors in [19] propose a Multiple Access Class Barring (MACB) mechanism. In MACB, different access priorities are set for different applications. In order to improve access performance, 3GPP has provided the Extended Access Barring (EAB) mechanism. In EAB, the time-delayed MTC devices are divide into 0 to 9 regular access levels. The eNB can enable or restrict the random access process of MTC devices with a certain access level according to the current overload condition [20]. Reference [21] proposed an Extended Access Barring (EAB) mechanism to enhance the performance of ACB scheme. Although the ACB and EAB mechanisms have a certain degree of containment against overload, they still cannot minimize the overload, and EAB mechanisms is mainly for time-tolerant business.

Both ACB and GP mechanism have disadvantages. As a push-based method, ACB is a decentralized approach, so the overall resource utilization of the system is not stable. In addition, how to dynamically adjust ACB parameters according to load changes has always been a major problem. GP mechanism, as a pull-based methods, is a centralized control solutions, so the overall resource utilization is stable. But GP method has some defects in signaling overhead and inflexibility. In

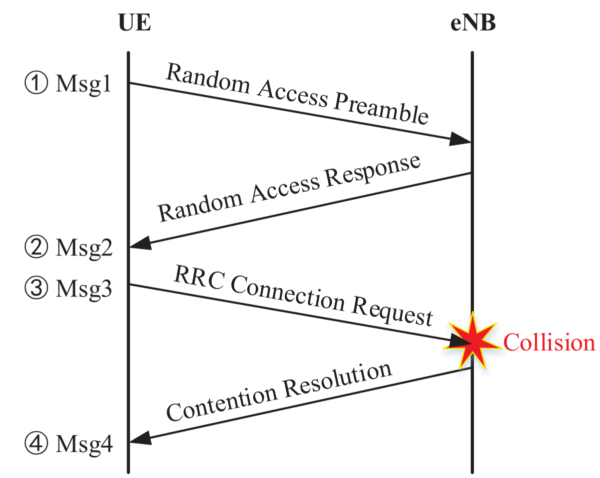

Figure 1 Random access procedure

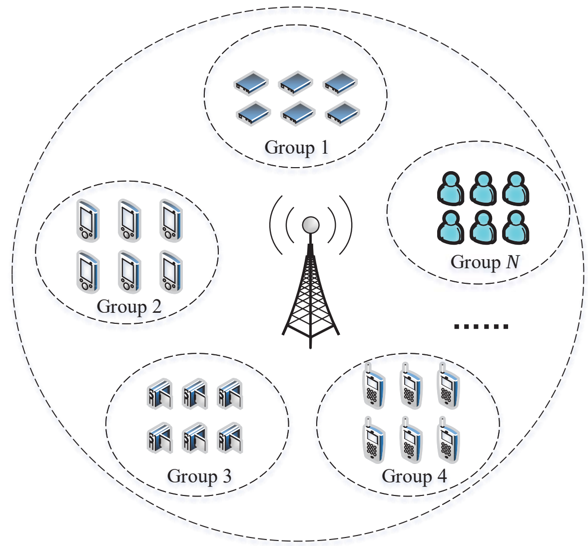

Figure 2 System Model

addition, the ACB and GP mechanisms do not perform well in dealing with massive MTC device access.

3 LTE Random Access Procedure

In this section, we briefly introduce the RA procedure in LTE system. The RA procedure is shown in figure 1.

Random Access Preamble Transmission (Msg1): Once a device launches an access request to the RACH, it will randomly select a preamble, and transmit the preamble to the eNB via PRACH. Since the preamble selection is randomly, if there are two or more devices selecting the same preamble, and transmit them at the same time, then there could be a collision.

Random Access Response (Msg2): After receiving the Msg1, eNB decodes the message, and transmit a random access response (RAR) to the UE devices. The RAR includes a RA preamble identifier (ID), an uplink grant for MSG3, timing alignment (TA) command for corresponding UEs, and assignment of a temporary identifier (the cell radio network temporary identifier, CRNTI). UE is expected to receive RAR within a timing window. If a device dose not receive the RAR, it will perform back-off mechanism in the back-off window (W_{BO}).

RRC Connection Request (Msg3): After receiving the Msg2, the UE will use the dedicated resource block (RB) to send a connection request message on PUSCH to the eNB. The devices, with a preamble conflict in Step 1, are assigned to the same RBs. So the eNB will not be able to decode the Msg3 of these devices. This will cause the random access process to fail.

Contention resolution (Msg4): After receiving RRC connection request message, the eNB transmits a contention resolution message to related devices. If a device receives the contention resolution message, it means that the random-access procedure was successful. Otherwise, it will perform a fallback operation, and launch a new access request later.

4 ACB Based Group Paging Overload Control Method (AGO)

4.1 System Model

We consider a single cell LTE network consisting of a single eNB and a number of MTC devices (M). We assume that these devices are divided into N groups, and are uniformly distributed over the groups. Therefore there are (M/N) MTC devices in a group. The system model is showed in figure 2. The eNB reserved R random access (RA) channels for the random-access process based on competition. The total number of available resources is equal to the number of frequency bands in the RA slot multiplied by the number of RA preambles. In this case, we assume that there is only one frequency band in each access slot, that is, the total number of available resources is equal to the number of preambles. in classical GP method, When the paging message, addressed by the GID, is received, the members of the GID group will start the contention-based RACH procedure at the same time. Different from the classic GP method, AGO combines the ACB mechanism and GP mechanism, and performs ACB mechanism in the paged group. Only devices that pass the ACB mechanism can start the contention-based RACH procedure.

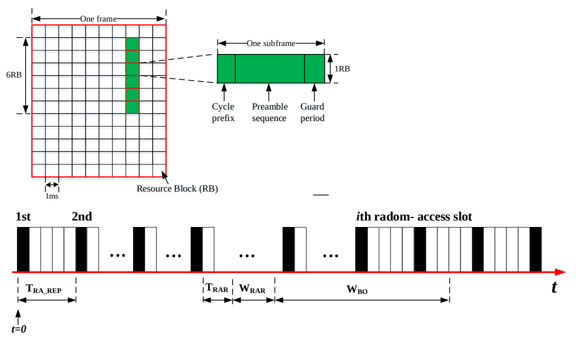

Figure 3 System Model

4.2 Classical Group Paging Method

In LTE network, time is divided into radio frames of fixed length. As shown in Figure 3, each radio frame contains multiple sub-frames. One or more sub-frames in a radio frame used for devices to perform random access process are called RA slots. When the group-paging message is received, all MTC devices in the group should transmit their first preambles at the first random-access slot. If the MTC device competition failed, then the MTC devices should perform back-off and retransmit a new preamble up to $(N_{PT_{\max}}-1)$ times. Where $N_{PT_{\max}}$ represents the maximum number of preamble transmission in paging interval. Let T_{RAR} be the processing delay at the eNB, T_{RA_REP} be the interval between two consecutive RA slots, W_{BO} be the Backoff window, W_{RAR} be the number of random-access response messages (RAR) contained in the random-access response window, and N_{RAR} be the maximum number of RARs per a response message. After sending the preamble, the device waits for $T_{RAR}+W_{RAR}$ sub-frames to receive RAR message in group paging. Therefore the total number of RARs contained in the RA window (N_{ACK}) is:

$$N_{ACK}{=}N_{RAR}\times W_{RAR} \tag{1}$$

For each preamble transmission, each MTC device may spend up to $(T_{RAR}+W_{RAR}+W_{BO})$ subframes before retransmitting a new preamble. Hence, the maximum number of random-access slots for group paging $(I_{\max})$ is [22]:

$$I_{max}=1{+}(N_{PT_{\max}}{-}1)\left\lceil\frac{T_{RAR}+W_{RAR}+W_{BO}}{T_{RA\_REP}}\right\rceil \tag{2}$$

Let R be the number of Access Opportunities (RAOs) reserved by the eNB in each random-access slot. M_i represents the number of M2M device starting the contention-based RACH procedure at i RA slot. $M_i[n]$ represents the number of M2M devices that transmits the preamble for n^{th} times in slot(i). $M_{i,s}[n]$ is the number of devices that successfully transmits the preamble for the n^{th} times in slot(i). $M_{i,c}[n]$ is the number of devices that failed transmits the preamble for the n^{th} times in slot(i). p_1 is the detection probability for the first preamble transmission, and then the detection probability for the n^{th} preamble transmission is p_n, which is equal to:

$$p_n{=}1-e^{-n} \tag{3}$$

The number of successful MTC devices is equal to [22]:

$$M_{i,s}[n]=\begin{cases} M_i[n]e^{-\frac{M_i}{R}}p_n, \text{if } M_{i,s}\le N_{ACK} \\ \frac{M_i[n]e^{-\frac{M_i}{R}}p_n}{M_{i,s}}N_{ACK}, \text{otherwise}\end{cases} \tag{4}$$

$$\begin{aligned} M_{i,c}[\mathrm{n}] &= \mathrm{M}_i[n]-M_{i,s}[\mathrm{n}] \\ &= \begin{cases} \mathrm{M}_i[n](1-e^{-\frac{M_i}{R}}p_n), \text{if} M_{i,s}\le N_{ACK} \\ \mathrm{M}_i[n](1-\frac{p_n}{M_{i,s}})N_{ACK}, \text{otherwise}\end{cases}\end{aligned} \tag{5}$$

Where $M_{i,s}$ represents the number of MTC device finishing the contention-based RACH procedure at i RA slot. It can be defined as follows.

$$M_{i,s}{=}\sum_{n=1}^{N_{PT_{\max}}} M_i[n]e^{-\frac{M_i}{R}}p_n \tag{6}$$

Then, M_i can be derived by the following equation [23]:

$$M_i{=}\sum_{n=1}^{N_{PT_{\max}}} M_i[n] \tag{7}$$

4.3 ACB mechanism

In order to control the number of devices accessing the network at the same time, and then reduce the collision probability, AGO dynamically adjusts the ACB parameters according to the amount of loading in each RA slot.

In LTE network, the eNB divides the devices (including H2H devices and M2M devices) into different groups according to different standard requirements. If ACB is not in effect, then all devices within the

group can initiate the random-access process at the same time. If ACB is in effect, only the allowed groups can directly initiate the random-access process. Devices in the forbidden group need to go through the ACB mechanism to initiate the random-access process. The ACB parameter $ac\_BarringFactor$ is a probability with a possible value of 0.0 to 0.95. the ACB information is broadcasted in system information block (SIB) Type 2 (SIB2).

If an M2M device belongs to a forbidden group, its ability to initiate a random-access process depends on the $ac\_BarringFactor$ parameter. The device randomly selects a value between [0,1] and compares it with the value of $ac\_BarringFactor$. If the value is less than $ac\_BarringFactor$, the M2M device can initiate the random-access process, otherwise it is barred [24].

From literature [25], we can know that the optimal ACB parameter value is:

$$ac\_BarringFactor = \min\left(1, \frac{R}{M_i}\right) \tag{8}$$

When the random-access process occurs, the eNB calculates the optimal ACB parameters according to the loading in the current time slot. Devices attempting to access the eNB randomly select a value between [0,1] and compare it with the ACB parameter. Only devices with random number less than the value of ACB parameter may be allowed to participate in the random-access process. Devices that fail the ACB test will start the back-off mechanism and wait for the next access opportunity.

Finally, the number of competing devices in each random-access slot can be dynamically controlled by equation (15).

$$M_i = \sum_{n=1}^{N_{PT_{\max}}} (M_i[n] \times ac\_BarringFactor) \tag{9}$$

4.4 Analytical Model

In the following, we will use an analytical model to calculate the number of access success and conflict during a paging access interval.

At the first available RA slot, the devices, which are paged, will send the preamble. Due to the limited number of preamble resources and physical uplink shared channel (PUSCH) resources, some device will be collided. Since the number of devices carrying out the first preamble transmission in each time slot is equal to the number of devices newly arrived, i.e. $M_i[1] = M_{arv}$. Then, after the first preamble transmission, the numbers of successful MTC devices and collided devices are [14]:

$$M_{1,s} = \begin{cases} M_i e^{-\frac{M_i}{R}} p_1, \text{if } M_i e^{-\frac{M_i}{R}} p_1 \leq N_{ACK} \\ N_{ACK}, \text{otherwise} \end{cases} \tag{10}$$

$$M_{1,c} = M_1 - M_{1,s} \tag{11}$$

After the RAR window, the device that fails to transmit the preamble at the first time will go back for a certain time and restart the random-access process. Since the back-off time is uniformly distributed, the collided devices are uniformly distributed over the back-off window. The number of devices that transmit the preamble at the second time in a RA slot is equal to the part of slots (named as ∂_a, ∂_{bc} and ∂_d), from the back-off interval, falling before this RA slot multiplied by the number of collided MTC devices. The position of the first RA slot (a) in the back-off window is shown in figure 4. The figure 4 shows the first preamble transmission process and the devices that failed to access the eNB follow the back-off mechanism and wait for the second preamble transmission. From the figure 4, the position of the first RA slot (a) in the back-off window is as follows [14]:

$$x_a(i) = i + \left\lceil \frac{T_{RAR} + W_{RAR}}{T_{RA\_REP}} \right\rceil \tag{12}$$

Where, $x_a(i)$ is the order of the first RA slot in the back-off window. The proportion of the MTC devices for the second preamble transmission in time slot (a) is equal to the time of the slot (a), in a sub-frame unit, minus the duration before the start of the back-off window (normalized by W_{BO}):

$$\partial_a = \frac{\left\lceil \frac{T_{RAR}+W_{RAR}}{T_{RA\_REP}} \right\rceil T_{RA\_REP} - (T_{RAR} + W_{RAR})}{W_{BO}} \tag{13}$$

Regarding the RA slots from (b) to (c), they will be just after the RA slot (a), i.e.:

$$x_{bc}(i) = i + \left\lceil \frac{T_{RAR} + W_{RAR}}{T_{RA\_REP}} \right\rceil + h \qquad h = 1, 2, \ldots, H_{\max} \tag{14}$$

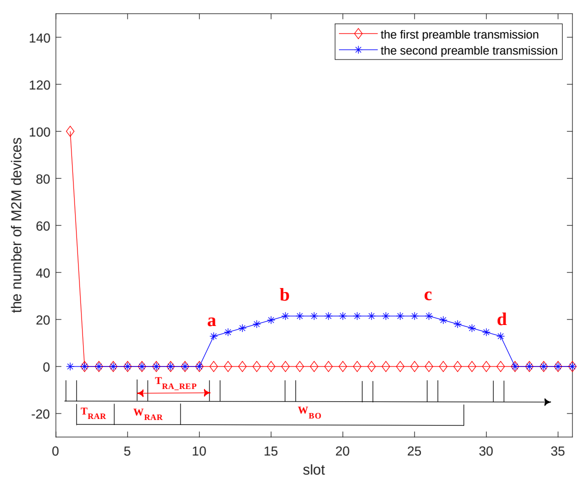

Figure 4 Number of MTC devices at each RA slot for the first and second preamble transmission for $R = 54$ and $M/N = 100$[14]

where, $h = 1, 2, \ldots, H_{\max}$. $H_{\max}$ represents the number of RA slots between the slots (b) and (c). It is equal to $H_{\max} = \lfloor (W_{BO} - \partial_a W_{BO})/T_{RA\_REP} \rfloor$. However, the proportion of MTC devices that retransmit their preambles at these RA slots is equal to:

$$\partial_{bc} = \frac{T_{RA\_REP}}{W_{BO}} \tag{15}$$

The remaining devices will be retransmitted in the RA slot (d), then the position of RA slot (d):

$$x_d(i) = i + \left\lfloor \frac{T_{RAR} + W_{RAR} + W_{BO}}{T_{RA\_REP}} \right\rfloor + 1 \tag{16}$$

The proportion of devices that retransmit in RA slot (d):

$$\begin{aligned} \partial_d &= 1 - \partial_a - \partial_{bc} H_{\max} \\ &= \tfrac{T_{RAR}+W_{RAR}+W_{BO}}{W_{BO}} - \tfrac{T_{RA\_REP}}{W_{BO}} \left\lfloor \tfrac{T_{RAR}+W_{RAR}+W_{BO}}{T_{RA\_REP}} \right\rfloor \end{aligned} \tag{17}$$

Since more than N_{ACK} devices cannot get network services, formula (4) can be rewritten as:

$$M_{i,s}[n] = M_i[n] e^{-\frac{M_i}{R}} p_n \tag{18}$$

Therefore, We can get the following results:

$$M_{i,s}[1] = M_i[1] e^{-\frac{M_i}{R}} p_1 \tag{19}$$

$$M_{i,c}[1] = M_i[1] - M_{i,s}[1] = M_i[1](1 - e^{-\frac{M_i}{R}} p_1) \tag{20}$$

According equation (7), when $t = 1$, we have:

$$M_1 = \sum_{n=1}^{N_{PT_{\max}}} M_1[n] \tag{21}$$

It is easy to get from Figure 4:

$$\begin{aligned} &M_1[1] = M_{arv} \\ &M_1[2] = M_1[3] = \cdots = M_1[N_{PT_{\max}}] = 0 \\ &M_1 = M_{arv} \\ &M_{1,c}[1] = M_1[1](1 - e^{-\frac{M_1}{R}} p_1) \end{aligned} \tag{22}$$

Similarly, we can get M_2, and $M_2 = M_{arv}$. Continually, when $t = 3$, we can get:

$$M_3 = \sum_{n=1}^{N_{PT_{\max}}} M_3[n] \tag{23}$$

$$\begin{aligned} &M_3[1] = M_{arv} \\ &M_3[2] = \partial_a M_{1,c}[1] = \partial_a M_1[1](1 - e^{-\frac{M_i}{R}} p_1) \\ &M_3[3] = M_3[4] = \cdots = M_3[N_{PT_{\max}}] = 0 \\ &M_3 = M_{arv} + \partial_a M_1[1](1 - e^{-\frac{M_1}{R}} p_1) \end{aligned} \tag{24}$$

By induction, we can get M_i, for each time slot(i).

In the previous hypothesis, we considered that the newly arrived device for each time slot is constant, which is M_{arv}. But in practical systems, in general, the device arrival rate obeys a specific distribution. For the burst massive M2M devices access scenario, we adopt the beta distribution as the M2M arrival model, and its distribution period is $I_{\max}$. As in reference [26], the parameters of beta distribution are $\alpha = 3$ and $\beta = 4$.

$$g(t) = \frac{t^{\alpha-1}(I_{\max} - t)^{\beta-1}}{I_{\max}^{\alpha+\beta-1} B(\alpha, \beta)} \tag{25}$$

t represents the sequence number of RA slot. $B(\alpha, \beta)$ is the Beta function, and $g(t)$ is the distribution probability of M2M devices at each random access time. Therefore, the number of new arrivals of M2M devices

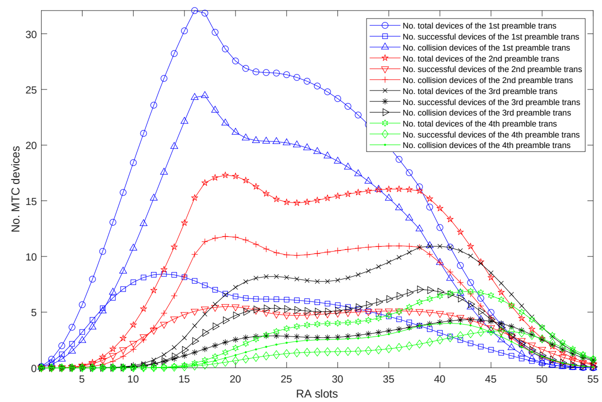

Figure 5 The number of newly arrived devices, the total devices, the successful devices and the collision devices for each preamble transmission in each random-access slot; $M/N = 1000$,$PT_{\max}$=10, $\alpha = 3$, $\beta = 4$.

in each random-access slot, that is, the number of devices that transmitted preamble during each random-access time is $M_{\text{arv}}(t)$:

$$M_{arv}(t) = (M/N) \int_{t}^{t+1} g(t)dt \tag{26}$$

M/N represents the number of devices attempting to access the network. Assuming $M/N = 1000$, The number of newly arrived devices, the total devices, the successful devices and the collision devices for each preamble transmission in each random-access slot are shown in figure 5.

When $M/N = 500$, the number of devices to be connected in each time slot is less than the number of preamble available in this time slot, so the ACB mechanism does not work, and $M_i[1] = M_{arv}(i)$. When the number of devices in each time slot is greater than the number of preamble available in the slot, such as $M/N = 2500$ or $M/N = 4500$, the ACB mechanism begins to control the number of devices that initiate random access process at the same time. As shown in the figure 6, the number of devices that can access the network is greatly reduced.

5 Performance Evaluation

5.1 Performance Metrics

We used the parameters given in table 1 to simulate GP, PBO and the AGO, and evaluate the performance of the above three schemes in term of success and collision probability, average access latency and resource utilization rate.

The Average Delay refers to the average time for the device to successfully complete the random access process, that is, the total time delay of the devices, which completed the random access process divided by the total number of devices, which completed the random access process. T_i represents the delay of the device that initiates the random access process, and completes the preamble and information transmission in time slot i. The definition of T_i is as follows [22]:

$$T_i = (i-1)T_{RA\_REP} + (T_{RAR} + W_{RAR}) + \overline{T_{MSG}} \tag{27}$$

$\overline{T_{MSG}}$ represents the average time for the device to successfully transmit information (including message3 and message4). In this paper, we assume that $\overline{T_{MSG}}$ is 11, so the average access delay is:

$$\overline{D_a} = \frac{\sum_{i=1}^{I_{\max}} \sum_{n=1}^{N_{PT_{\max}}} M_{i,s}[n] T_i}{\sum_{i=1}^{I_{\max}} \sum_{n=1}^{N_{PT_{\max}}} M_{i,s}[n]} \tag{28}$$

The Success Probability P_S refers to the number of devices that complete the entire random access process within the maximum number of preamble transmissions divided by the total number of devices (including devices that are activated or sleep). Its definition is as follows:

$$P_S = \frac{\sum_{i=1}^{I_{\max}} \sum_{n=1}^{N_{PT_{\max}}} M_{i,s}[n]}{M} \tag{29}$$

The Collision Probability (P_C) is the ratio of the number that two or more MTC devices send random access attempts in the same frequency band with the same preamble to the total number of RAOs reserved by the eNB [20]. In other words, P_C is the ratio of the total number of RAOs in conflict to the total number of RAOs retained. In each random access time slot, the conflicting RAOs is equal to the reserved RAOs(R) of the eNB minus the successful RAOs ($M_i e^{-\frac{M_i}{R}}$) and the idle RAOs ($R e^{-\frac{M_i}{R}}$)[27]. Then collision probability P_C is:

$$P_C = \frac{\sum_{i=1}^{I_{\max}} (R - M_i e^{-\frac{M_i}{R}} - R e^{-\frac{M_i}{R}})}{I_{\max} R} \tag{30}$$

The resource utilization (RU) can be defined as the ratio of the total number of successful MTC devices to

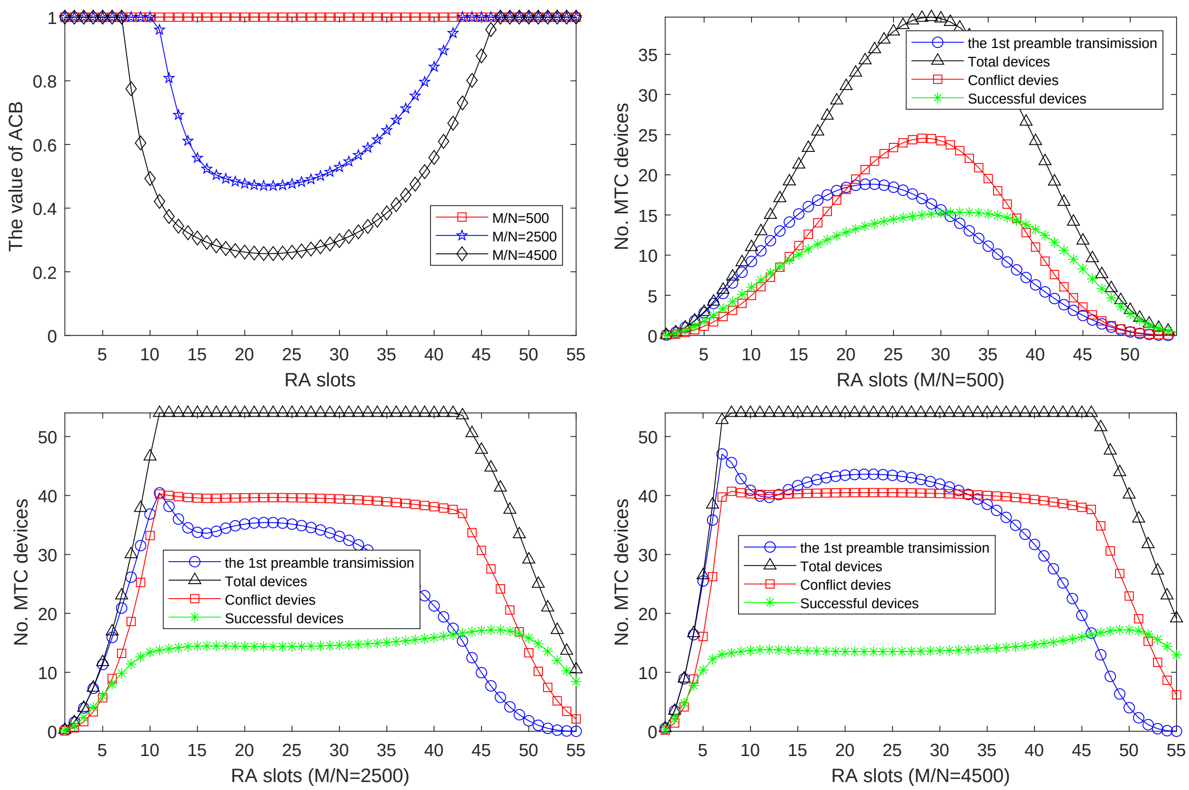

Figure 6 The value of ACB parameter, and the change rule of the NO. MTC devices under different conditions; $\alpha = 3$, $\beta = 4$, $R = 54$, W_{BO}=21, T_{RA_REP}=5 and $N_{PT_{\max}}$=10.

Table 1 Basic Simulation Parameters

Notations	Definitions	Values
M/N	Average number of MTC devices size (unit: sub-frame)	500–4500
R	Total number of preambles in a random-access slot	54
P	The value of ac_BarringFactor	0.1–0.95
$N_{PT_{\max}}$	Maximal number of preamble transmission	10
N_{RAR}	Maximal number of RAR that can be carried in a response message	3
T_{RAR}	Processing time required by a eNB to detect the transmitted preamble (unit: sub-frame)	2
W_{RAR}	Length of the random-access response window (unit: sub-frame)	5
N_{ACK}	Maximal number of MTC devices that can be acknowledged within the random-access response window	$N_{RAR} \times W_{RAR}$
T_{RA_REP}	Interval between two successive random-access slots (unit: sub-frame)	5
W_{BO}	Back-off window size (unit: sub-frame)	$BI + 1$
p_n	Preamble detection probability of the nth preamble transmission	p_n=$1 - e^{-n}$
BI	Back-off indicator (unit: sub-frame)	20
W_{PBO}	Pre-backoff window in s sub-frame unit	30

the total available RAOs, and it can be given by the following equation:

$$RU = \frac{\sum_{i=1}^{I_{\max}} \sum_{n=1}^{N_{PT_{\max}}} M_{i,s}[n]}{I_{\max} R} \tag{31}$$

Let k be the number of preambles sent by an M2M device from the start of random access to completion of the random access process. Cumulative distribution function (CDF), $F(k)$, is the statistical value of the number of preamble transmissions. $F(k)$ is a ratio, which refers to the ratio of the number of devices that complete the random access process to the total number of completed random access processes when the number of preamble transmissions is not greater than k. $F(k)$ ranges from 0-1. Hence, according to the [22], $F(k)$ is expressed as follows:

$$F(k) = \frac{\sum_{i=1}^{I_{\max}} \sum_{m=1}^{k} M_{i,s}[m]}{\sum_{i=1}^{I_{\max}} \sum_{n=1}^{N_{PT_{\max}}} M_{i,s}[n]} \tag{32}$$

5.2 Results

Figure 7 shows the average access delay of the three mechanisms. It can be seen that when there are fewer devices in the group, the access delay of GP mechanism and PBO mechanism is basically the same. As the number of devices increases, GP mechanism is superior to PBO mechanism. Compared with the former two mechanisms, when the number of devices in a group is small, the performance of AGO mechanism is lower than the former two mechanisms. As the number of devices in the group increases (when $M/N > 1000$), the performance is significantly better than the previous two mechanisms. Moreover, the delay is relatively stable and is not affect by the number of devices.

According to the success probability simulation results (figure 8), when massive M2M devices are connected, the access success rate declines, and when $M/N = 1000$, the GP mechanism and PBO mechanism drop significantly. In contrast, the performance degradation of the proposed mechanism is relatively flat. When $M/N = 4500$, the success probability can still be maintained at more than 15%.

As shown in figure 9, the AGO mechanism proposed in this paper has effectively alleviated the network congestion problem. As the number of M2M devices increases, the collision probability of AGO increases slightly, but the increase rate is slower. Finally, the collision probability is controlled at about 20%. For the GP mechanism and the PBO mechanism, as the number of M2M devices increases, the collision probability of the two mechanisms increases rapidly. When $M/N = 500$ to 1000, the collision probability increases rapidly from 20% to about 60%. Then the collision probability tends to be stable. When $M/N = 4000$, the collision probability is over 70%, and close to 80%. in summary, in the steady state, the collision probability of the GP mechanism and the PBO mechanism is close to 80%. Comparing to the two mechanisms, AGO always controls the collision probability below 30% through the ACB mechanism.

Figure 10 shows the CDF of the preamble transmissions. In general, the performance of PBO is better than that of GP, and the performance of the AGO is better than both of them. In GP, in the case of $M/N = 500$, when the number of preamble transmission exceeds 5, the probability of success can reach 50%. And more than 7 times, the probability of success can reach 70%. In PBO, Under the same conditions, when the number of preamble transmission exceeds 5, the probability of success is close to 70%. Therefore, the performance of PBO is better than that of GP. In the case of $M/N = 1000$, with the increase of the number of devices, the performance of PBO and GP decreases dramatically. This means that more retransmissions are required to complete the access process.

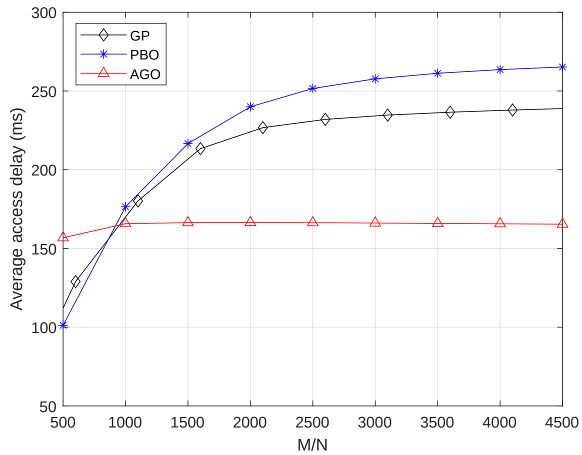

Figure 7 Average access delay for the considered methods.

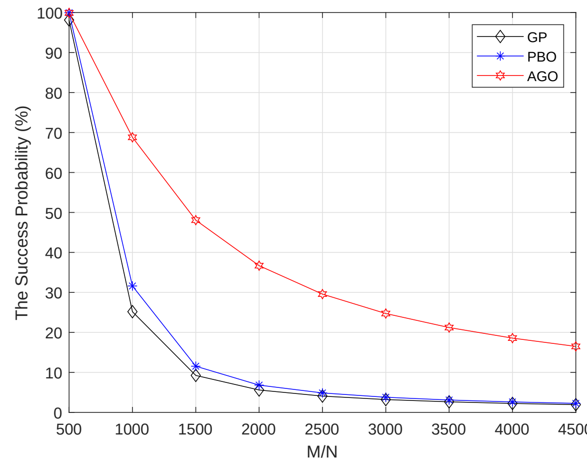

Figure 8 The success probability for the considered methods.

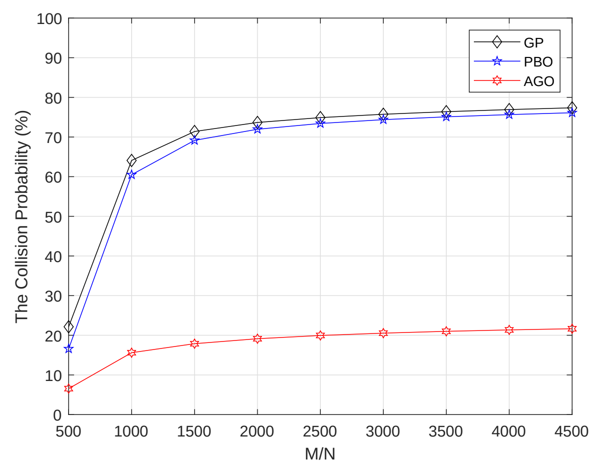

Figure 9 The collision probabilities for the considered methods.

In comparison, AGO has little change in performance when $M/N = 500$ and $M/N = 1000$. When the number of preamble transmissions exceeds 3 times, the success rate of AGO can reach 80%. In summary, when the number of devices in the group is the same, the number of preamble transmissions in the AGO mechanism we mentioned is relatively small. From the perspective of energy consumption, our proposed method reduces the number of retransmissions, thereby reducing energy consumption, so it is more conducive to the communication of MTC devices.

As shown in figure 11, from the perspective of resource utilization, when the number of MTC devices is relatively small ($M/N < 800$), the resource utilization rate of GP mechanism is better than that of PBO mechanism. When the number of MTC devices is large ($M/N > 3000$), the PBO mechanism behaves almost the same as the GP mechanism. Compared with the two mechanisms, the proposed mechanism achieves higher resource utilization (when $M/N = 1000, RU = 23.16\%$). Especially when the number of MTC devices is large, the resource utilization rate of the AGO mechanism remains at about 25%.

6 Conclusions

In this paper, we have proposed an ACB-based group paging overload control method for massive MTC accesses in LTE network. Instead of all MTC devices in the group can access the random-access process, only MTC devices passed the ACB mechanism can access the random-access process. In this paper, we first scatter the MTC devices over a GP interval reduce access conflicts. And then we assume that the newly arrived MTC devices obey the beta distribution, and calculate the number of newly arrived devices. We calculate the number of devices needed to access the network in the current time slot according to the number of newly arrived devices and the devices in the previous time slot that failed to access. Based on this, AGO can adjusted the ACB parameters dynamically. AGO has been evaluated for a relatively large number of MTC devices (4500 MTC devices). Compared with GP and PBO mechanisms, AGO achieves many improvements, in term of success probability, collision probability, resource utilization rate and average access delay, etc. Beside the success probability, average access delay improvements, AGO controls the collision probability very well. When the number of MTC devices is large (4500 MTC devices), the collision probability can also be controlled at about 20%. In addition, AGO also achieved good results in terms of average

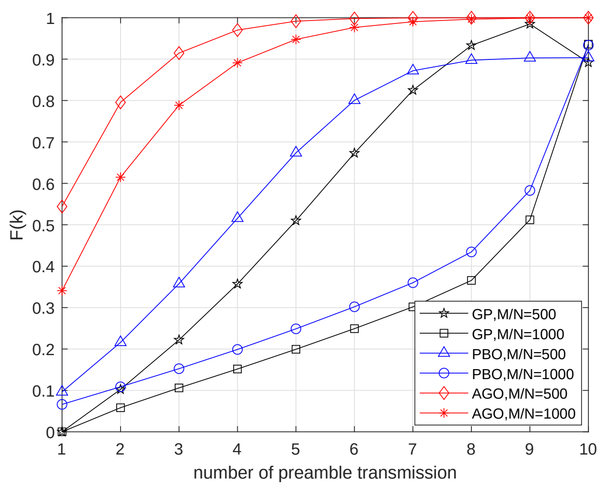

Figure 10 CDF of Preamble transmissions for the considered methods.

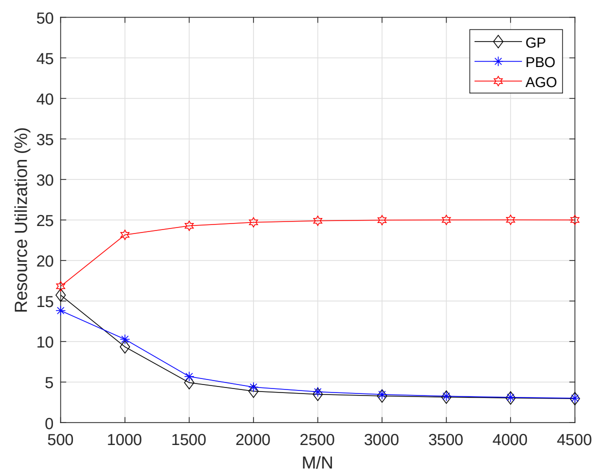

Figure 11 The resource utilization for the considered methods

number of preamble transmissions. Regardless of the number of MTC devices, AGO can achieve a success rate of about 90% under the preamble transmission of about 4 times. This shows that the number of devices in the group has little effect on AGO. Therefore, AGO is more suitable for massive MTC device application scenarios.

Abbreviations
GP: Group Paging; PBO:Pre-BackOff; AGO: ACB-based Group Paging Overload Control Method; MTC: Machine Type Communication; M2M: Machine to Machine Communication; ACB: Access Class Barring; PUSCH: Physical Uplink Shared Channel; GID: Group ID; RAR: Random Access Response; RA: Random Access; RAO: Access Opportunities; RACH: Random Access Channel; SIB: System Information Block; RU: Resource Utilization; CDF: Cumulative Distribution Function.

Acknowledgements
Not applicable.

Author's contributions
Wang Cong and Wei Chengqiang conceived the idea and wrote the paper; Li Ning analyzed the simulation results; Ma Wenfeng and Tian Hui performed the experiments. All of the authors participated in the project, and they read and approved the final manuscript.

Funding
This work was supported by the National Natural Science Foundation of China under grant 61771486.

Competing interests
The authors declare that they have no competing interests.

Author details
[1]College of Field Engineering, Army Engineering University of PLA, 210007 Nanjing, China. [2]College of Communications Engineering, Army Engineering University of PLA, 210007 Nanjing, China.

References
1. Andreev, S., Galinina, O., Pyattaev, A.: Understanding the iot connectivity landscape: A contemporary m2m radio technology roadmap. IEEE Communications Magazine **53**, 32–40 (2015)
2. Lawton, G.: Machine-to-machine technology gears up for growth. Computer **37**, 12–15 (2014)
3. Kartsakli, E., Lalos, A., Antonopoulos, A.: A survey on m2m systems for mhealth: A wireless communications perspective. Sensors **14**, 18009–18052 (2014)
4. Chen, M., Wan, J., Gonzalez, S., Liao, X., Leung, V.C.M.: A survey of recent developments in home m2m networks. IEEE Communications Surveys & Tutorials **16**, 98–114 (2015)
5. 3GPP: 3GPP RAN2 71: Pull Based RAN Overload Control. Madrid, Spain (2010.08). 3GPP
6. 3GPP: 3GPP TR 23.898: Access Class Barring and Overload Protection; (Release 7). (2005.03). 3GPP
7. Hussain, F., Anpalagan, A., Vannithamby, R.: Medium access control techniques in m2m communication: Survey and critical review. Transactions on Emerging Telecommunications Technologies **28** (2014)
8. Sui, N., Xu, Y., Wang, C., Xie, W.: Performance analysis of a novel hybrid s-aloha/tdma protocol for beta distributed massive mtc access. Sensors **17** (2017)
9. Arouk, O., Ksentini, A., Hadjadj, A.Y., Taleb, T.: On improving the group paging method for machine-type-communications. In: IEEE (ed.) In Proceedings of the 2014 IEEE International Conference on Communications, June 2014, pp. 484–489 (2014)
10. Harwahyu, R., Cheng, R., Sari, R.F.: Consecutive group paging for lte networks supporting machine-type communications services. In: IEEE (ed.) In Proceedings of the 2013 IEEE 24th International Symposium on Personal Indoor and Mobile Radio Communications (PIMRC) (2013)
11. Jiang, W., X, W., Deng, T.: Performance analysis of a pre-backoff based random access scheme for machine-type communications. In: In Proceedings of the 2014 International Conference on Intelligent Green Building and Smart Grid (IGBSG 2014), pp. 1–4 (2014). Taipei, Taiwan
12. Harwahyu, R., Wang, X., Sari, R., Cheng, R.G.: Analysis of group paging with pre-backoff. EURASIP Journal on Wireless Communications and Networking **34** (2015)
13. Chen, J., Lin, Y., Cheng, R.: A delayed random access speed-up scheme for group paging in machine-type communications. In: In Proceedings of the 2015 IEEE International Conference on Communications, pp. 623–627 (2015). Taipei, Taiwan
14. Arouk, O., Ksentini, A., Taleb, T.: Group paging-based energy saving for massive mtc accesses in lte and beyond networks. IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS **34**, 1086–1102 (2016)
15. Ksentini, A., Hadjadj-Aou, Y., Taleb, T.: Cellular-based machine-to-machine: Overload control. IEEE Network **26**, 54–60 (2012)

16. He, H., Du, Q., Song, H.: Traffic-aware acb scheme for massive access in machine-to-machine networks. In: In Proceedings of the 2015 IEEE International Conference on Communications (ICC), pp. 617–622 (2015)
17. Duan, S., Shah-Mansouri, V., Wong, V.W.S.: Dynamic access class barring for m2m communications in lte networks. In: In Proceedings of the 2013 IEEE Globecom Workshops (GC Wkshps), pp. 9–13 (2013)
18. Duan, S., Shah-Mansouri, V., Wang, Z.: D-acb: Adaptive congestion control algorithm for bursty m2m traffic in lte networks. IEEE Transactions on Vehicular Technology **65**, 9847–9861 (2016)
19. Zangar, N., Gharbi, S., Abdennebi, M.: Service differentiation strategy based on macb factor for m2m communications in lte-a networks. In: In Proceedings of the 2016 13th IEEE Consumer Communications & Networking Conference, pp. 9–12 (2016)
20. 3GPP: 3GPP TR 37.868: Study on RAN Improvements for Machine-Type Communications. Sophia-Antipolis Cedex, France (2011.08). 3GPP
21. Phuyal, U., Koc, A., Fong, M.H.: Controlling access overload and signaling congestion in m2m networks. In: In Proceedings of the 2012 Conference Record of the Forty Sixth Asilomar Conference on Signals, Systems and Computers (ASILOMAR), pp. 4–7 (2012)
22. Wei, C.H., Cheng, R.G., Tsao, S.L.: Performance analysis of group paging for machine-type communications in lte networks. IEEE Transactions on Vehicular Technology **62**, 3371–3382 (2013)
23. Arouk, O., Ksentini, A., Taleby, T.: Group paging optimization for machine-type communications. In: In Proceedings of the 2015 IEEE International Conference on Communications (2015)
24. Phuyal, U., Koc, A.T., MH, P., Vannithamby, R.: Controlling access overload and signalling congestion in m2m networks. In: In Proceedings of the Forty Sixth Asilomar Conference on Signals, Systems and Computers, pp. 591–595 (2012)
25. Cao, C., Li, N., Wang, C., Xie, W.: Dynamic allocation of rach resource for delay-sensitive devices in m2m communications. In: In Proceedings of the 2016 5th International Conference on Computer Science and Network Technology (2016)
26. Gupta, A.K., Nadarajah, S.: Handbook of Beta Distribution and Its Applications. CRC Press, Boca Raton, Florida, USA (2004)
27. Wei, C.H., Cheng, R.G., Tsao, S.L.: Modeling and estimation of oneshot random access for finite-user multichannel slotted aloha systems. IEEE Communications Letters **16**, 1196–1199 (2012)