Retransmission-Based Access Class Barring for Machine Type Communications

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Abstract. Supporting trillions of devices is the critical challenge in machine type communication (MTC) communications, which results in severe congestions in random access channels of infrastructure-based cellular systems. 3GPP thus developed the access class barring (ACB) to control the expected number of simultaneous access requests in a preamble as one. The assignment of classes with specific access parameters for MTC devices becomes an cirtical issue in ACB since it affects the performance from the perspectives of successful access probability and access delay significantly. This paper proposes a novel classification scheme where we group MTC devices according to their number of transmission trials while without introducing extra overheads. A heuristic algorithm is proposed, where the devices with more number of retransmission failures will have more chance to access the preamble. By adaptively changing the ACB factor, the proposed heuristic algorithm can reduce the access delay effectively while maintaining high access success probability. The simulation results show the improvement of the proposed scheme from the existing ACB schemes.

Keywords: Access class barring (ACB)
Machine type communication (MTC) · RAN overloading
Retransmission

1 Introduction

Infrastructure-based Machine to machine (M2M) communications, also known as machine type communication (MTC) in 3GPP terminology, is an emerging concept that allow MTC devices to communicate with each other via the assistance of base station (known as evolved NodeB; eNB in 3GPP terminology) without or with minimal human interaction [1]. By leveraging the short-distance transmissions, MTC enables faster and more reliable communications than traditional human initiated communications [2], and is regarded as an attractive solutions for future Internet of Things (IoT) applications. With the concern of numerous number of MTC devices, how to efficiently manage massive access from MTC

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devices to prevent radio access network (RAN) overloading and subsequent congestion is the most critical challenge [3–6]. The congestion due to significant number of simultaneous access incurs heavy delay, the waste of resources, and low access success rate.

Recently, many schemes are proposed to alleviate the RAN overloading problem, such as specific backoff [7], slotted access [8], pull-based [9], dynamic PRACH resource allocation [10], and access class barring (ACB) [11,12] schemes. Among them, ACB scheme receives a lot of attentions since the access of MTC devices are separated by using different classes in a more flexible and efficient way [13]. In particular, eNB broadcasts all MTC devices an ACB factor (i.e., access probability) p and the backoff time corresponding to different access classes. With such information, MTC device will draw a value q, where $0 \leq q \leq 1$, and if $q \leq p$, the MTC device is allowed to perform random access procedure. On the other hand, if the MTC device is barred, it can only make a new attempt after the backoff timer is expired. When RAN overloading or congestion happens, the access probability p can be set extremely small by eNB in order to avoid frequent random access attempts. However, it causes serious delay, and such tradeoff should be carefully considered when applying ACB.

In order to increase access success probability as much as possible while maintaining an acceptable access delay, ACB should be designed to be more "adaptive" to the environment. However, the original ACB scheme is hard to achieve that due to reason that the access probability p is fixed. In other words, eNB cannot adjust the ACB factor according to the current RAN loading level in a realtime fashion. This paper therefore proposes a heuristic algorithm where eNB regards the number of MTC devices who perform the preamble transmissions as the current loading level and adjust p accordingly. In particular, we consider the number of preamble retransmissions send by MTC devices who successfully perform random access. The devices with more number of retransmission trials (i.e., failures) will have more chance to access the preamble so that the fairness among MTC devices is achieved. We conduct simulation experiments, and the results show that the proposed retransmission-based ACB scheme can reduce the access delay effectively and while maintaining high access success probability comparing with the existing ACB schemes.

The rest of this work is organized as follows. The related work and background is described in Sect. 2. In Sect. 3, we present the system model. Section 4 describes the idea that how we let each MTC device know which groups it belongs in every random access occasion. Section 4.1 describes the method that eNB dynamically resets the barring factor. In Sect. 5, simulation results are presented to compare our proposed scheme with the traditional scheme. The work is concluded in Sect. 6.

2 Background and Related Work

After knowing the parameter of random access, each MTC device will randomly choose a preamble from the preamble pool, and the MTC device will increase the number of preamble transmissions by one and wait for RAR (i.e., `Msg 2`). Upon receiving the `Msg 2` in the RAR window, the MTC device processes UL grant and Timing Alignment and prepare for sending the connection request (`Msg 3`). If the MTC device fails to receive `Msg 2` in the RAR window due to the reason that eNB fails to detect the preamble from the device, it checks whether its number of preamble transmission is smaller or equal to the maximum number of preamble transmission. If it is, the MTC device retries to perform preamble transmission after waiting a uniform backoff time. If not, the MTC device is informed of random access procedure failure and it is not allowed to perform the procedure. Moreover, if the MTC device fails to receive contention resolution after sending connection request due to the collision of `Msg 3`, it performs the same behavior of failing to receive RAR. We assume that once an UE successfully transmits the preamble chosen only by itself to eNB, and it will finish the RA procedure.

When massive devices try to access the network simultaneously, it will cause RACH congestion because of the limited preamble in a PRACH slot and those devices who choose the same preamble will lead to collision in `Msg 3`. The congestion problem may rise intolerable delay and low access success probability so it has been considered as an essential issue in MTC.

It was shown that [14] proposed QoS guaranteed prioritized random access scheme with a dynamic access barring scheme. Different virtual resource has been allocated for different classes in order to reduce the collision probability. It was shown that [13] introduced the QoS-Aware Self-Adaptive RAN Overload Control (QoS-Dracon) mechanism to reduce the RAN overload problem, taking into account users' QoS requirements. The QoS-Dracon scheme prioritizes delay-sensitive devices over delay-tolerant ones when performing Random Access procedure. It proposed a simple function based on the number of preamble transmissions of delay-sensitive devices to estimate the RAN load.

It was shown that [15] developed a Markov-Chain based traffic-load estimation scheme according to the preamble collision status. With the estimation scheme, the eNB can adjust p (ACB factor or Access probability) adaptively based on the overload situation. There are different simulation results compared with traditional ACB mechanism when setting different parameters used to update p. The results suggested the effectiveness of the traffic-aware ACB on the control of p to balance the loads.

It was shown that [16,17] proposed a mechanism to update ACB factor adaptively. The work in [16] evaluate a congestion coefficient based on successful devices and contending device within each time region. And the ACB factor can be derived dynamically by the congestion coefficient. The work in [17] proposed an algorithm, which by using available information such as number of available preambles and number of successful preamble transmissions to dynamically update ACB factor.

3 System Model

Consider that when an extreme scenario (e.g., power outage, earthquake) happens, MTC devices will try to reestablish synchronization with eNB in a short time period. In order to simulate the extreme scenario in which a large amount of MTC devices access network in a highly synchronized manner, we adopt traffic model 2 (Beta distribution) mentioned in [4] as arrival distribution and set the PRACH configuration to 6, which means RACH will occur every 5 ms within 180 kHz. In our system model, we consider that there are total N_{sys} MTC devices and then we define a time slot as an RACH slot so that the arrival period will be 2000 time slots indexed by an nonnegative integer j ($j = 0, 1, 2, \ldots, 2000$) by reason of the 10 s distribution period according to traffic model 2.

$$p(t) = \frac{t^{\alpha-1}(T-t)^{\beta-1}}{T^{\alpha+\beta-1}Beta(\alpha,\beta)}, \tag{1}$$

where $Beta(\alpha, \beta)$ is the Beta function and $\alpha = 3, \beta = 4$.

With the knowledge of above, Eq. (1) is the probability that each MTC device will perform preamble transmissions at t^{th} RACH slot during T limited distribution of access attempts. As a result, the number of MTC devices N^j that perform preamble transmissions at the j^{th} RACH slot is shown in the following equation

$$N^j = N_{sys}\int_{t_{j-1}}^{t_j} p(t)dt, \quad j = 1, 2, \ldots, 2000, \tag{2}$$

where t_j is the j^{th} RACH slot.

Two performance metrics are considered as follows.

- successful access probability: the probability of the successful completion of the random access procedure under the constraint of maximum number of retransmissions.
- access delay: given a successful completion of MTC transmission, the number of RACH slots spend in an access procedure i.e., from the beginning of random access attempt to the completion of the random access procedure.

4 Retransmission Based ACB Scheme

In ACB, eNB typically broadcasts information about random access before MTC devices perform the random access procedure. In the proposed scheme, we leverage this broadcasting message to enforce the grouping process of MTC devices. In particular, we include "the range of preamble" in the message so that MTC devices could identify their own group by checking the allocated preamble currently. As shown in Fig. 1, if the number of preamble transmissions is within the range of 1 to 5, the MTC devices will be classified into group 1.

Obviously, eNB cannot get the precise number of MTC devices who tried to perform preamble transmission since the failed trials cannot reach the eNB and

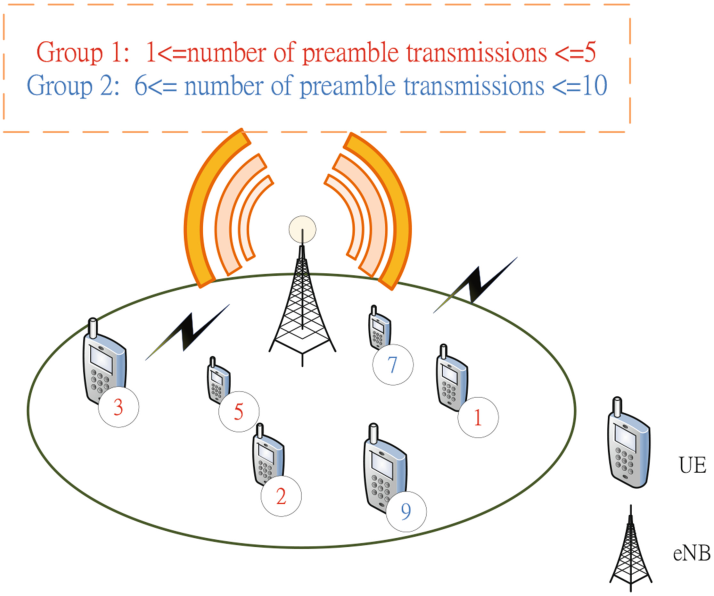

Fig. 1. Group model of proposed method

thus cannot provide any useful information. In this case, we can only estimation N' according to the existing information (e.g., the number of success preambles and the number of collision preambles). The main idea of retransmission-based ACB is that we leverage the MTC device who successfully performs preamble transmissions since they can provide additional information to the eNB. In particular, the MTC device includes "the number of preamble (re)transmissions it has ever tried" in `Msg 3`. With the retransmission information, the eNB is able to calculate $G^m_{\alpha,\beta}$, which is the number of MTC devices who belong to m^{th} group and who perform αth to βth preamble transmissions in an RACH slot. We can make use of $G^m_{\alpha,\beta}$ to observe RAN loading and further change the ACB factor p to cope with different loading condition. That is, our scheme could adaptively adjust the ACB factor p. The detailed message flow of the proposed scheme is illustrated in Fig. 2.

4.1 Problem Formulation

In order to get N', we consider $P_{s,i|N}$, which is the probability that an UE successfully performs its i^{th} transmissions given N users attempting to perform preamble transmissions, and the access success probability can be derived as

$$P_{s,i|N} = p_{d,i} \left(\frac{R-1}{R}\right)^{N-1}, \tag{3}$$

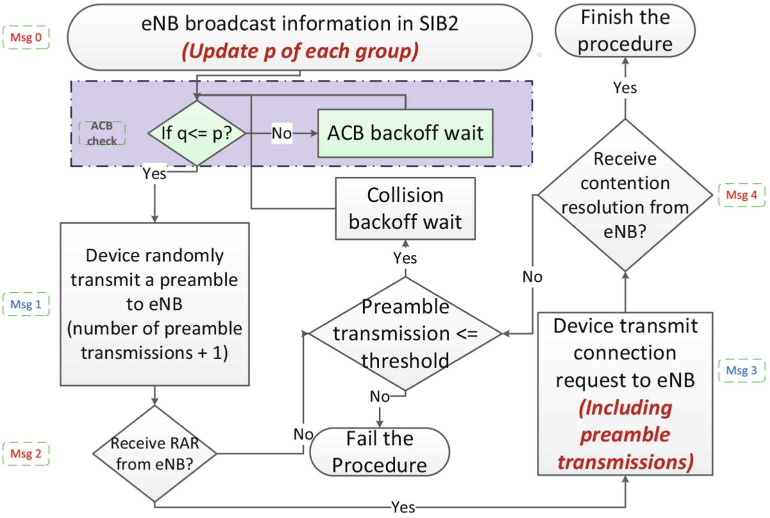

Fig. 2. Message flow of retransmission-based ACB

where $p_{d,i} = 1 - \left(\frac{1}{e}\right)^i$ is the preamble detection probability applied to model the effect of path loss and power ramping. Moreover, Eq. (3) means that an UE succeeds in the i^{th} preamble transmission if all the other $N-1$ UEs select the other $R-1$ preambles, and the non-collided preamble is detected by the eNB.

Let N_s be the number of UEs who successfully perform preamble transmissions. As a result, we consider $E(N_s|N)$ as the expected number of UEs who successfully perform preamble transmission given N users attempting to perform preamble transmissions, and the $E(N_s|N)$ is given by

$$\begin{aligned} E(N_s|N) &= \sum_{i=1}^{\theta} N_i P_{s,i|N} = \sum_{i=1}^{\theta} N_i p_{d,i} \left(\frac{R-1}{R}\right)^{N-1} \\ &= \frac{\sum_{i=1}^{\theta} N_i p_{d,i}}{N} N \left(\frac{R-1}{R}\right)^{N-1} = \bar{p_d} N \left(\frac{R-1}{R}\right)^{N-1}, \end{aligned} \quad (4)$$

where θ is the maximum number of preamble transmissions and $\bar{p_d}$ is the expected preamble detection probability (e.g., $\bar{p_d} = \frac{\sum_{i=1}^{\theta} N_i^j p_{d,i}}{\sum_{i=1}^{\theta} N_i^j}$, where $\sum_{i=1}^{\theta} N_i^j = N^j$). This equation is also mentioned in [18]. We can get the expectation of UEs who successfully perform preamble transmissions given $\bar{p_d} = 1$ (ideal condition) according to the variation of N.

4.2 ACB Factor Update

Each group, whose threshold (number of preamble transmissions) is larger than other groups, has higher priority and index. Therefore, we assign each group to a different weight, and the groups with higher priority are assigned to a larger weight. The weight of group m, w_m, can be considered as the proportion of the allocation of RACH resources, so it should be defined as $\sum_{m=1} w_m = 1$. We divide MTC devices into two groups, and the weight of group 2 is higher than group 1 (e.g., $w_2 > w_1$) due to we hope the groups whose number of preamble transmissions close to maximum preamble transmissions; So that group 2 can own more RACH resources to promote the access success probability.

Algorithm 1. ACB Factor Update in Retransmission-Based ACB

```
Input: $R$, number of success preambles and collision preambles, design parameters
    $w_m$
 1: set $time\ slot = 0$; $p_m = 1$, for all $m$
 2: while do $N_s + N_f < N$
 3:     $time\ slot = time\ slot + 1$;
 4:     if (activate preamble $\geq$ 50 percent ) then
 5:         check the table and then set max($N'$)
 6:     else
 7:         check the table and then set min($N'$)
 8:         $W = \{w_1, w_2, .., w_m\}$, sort $W$ to an descending order
 9:         set $w' = m^{th}$ weight in set $W$
10:         $p_m = \frac{w'R}{N'}$;
11:     end if
12: end while
```

We aim at distributing MTC devices over several RACH slots when congestion happens. The maximal $E(N_s|N)$ is achieved by setting N equal to R or $R-1$. In other words, we hope that there are only $N \approx R$ MTC devices who attempt to perform preamble transmission in an RACH slot, so it can be derived as

$$\sum_{m=1}^{n} N' p_m = \sum_{m=1}^{n} w_m R = R, \tag{5}$$

where the p_m is the ACB factor of group m and the R_m is the number of MTC devices who belong to group m and pass the ACB scheme. Thus, the p_m which is the ACB factor of group m is able to be obtained from Eq. (5) shown in the following.

$$p_m = \frac{W_m R}{N'} \tag{6}$$

Our proposed algorithm is given in Algorithm 1. First, we set the default value, slot to 0 and p_m to 1 for each group (line 1). The loop (lines 2–12) run until all device finishes the RA procedure. In each time slot (line 3), we check if the activated preamble is more than the half of available preamble, if it is, we will set the N' to the bigger one (line 5). Otherwise, the N' will be set to the smaller one and the weight list will be sort in descending order and set to each group, then the factor of each group p_m will be calculated (lines 7–10).

Our algorithm to adjust ACB parameter p is shown in Algorithms 1 and 2. In these two algorithms, we take the preamble utility into account because it can reflect the number of MTC devices who attempt to perform preamble transmissions indirectly. When there are two possible N', it is determined by the preamble utility. If the preamble utility is low, we set the smaller one of the N'. Otherwise, if the preamble utility is high, we choose the larger N' to be the estimation of N.

5 Simulation Results

This subsection conducts extensively simulation experiments under the Matlab platform. We consider 20000 to 30000 MTC devices, where arrival period of those MTC devices is 10 s. The number of preambles is 54, PRACH Configuration Index is 6, sand the maximum allowable transmissions is 10. Two groups are assigned in the simulation and ACB backoff time is 320 ms while ACB factors for both group are 1. In this case, all the access requests pass the limitation of access probabiltiy of ACB scheme, which implies a huge number of MTC devices will perform random access procedure. In such an extreme case, we can evaluate the performance of adaptiveness in the proposed retransmission-based scheme. The ratio of resource (i.e., preamble) allocated for group 1 and group 2 is 3 : 7. Please note that those parameter setups follow the suggestions from [4]. We consider the typical ACB schemes with factors $0.2, 0.3$, and 0.4.

Effects of the number of devices on successful access probability. Figure 3 shows effects of number of devices on successful access probability. It is observed that when the number of devices increases, the successful access probability decreases. It is due to the simple reason that a larger number of devices access the media, a higher probability that collisions will happen. Moreover, as the ACB factor becomes larger, the successful access probability becomes smaller. It is due to the reason that the ACB factor is higher, the devices have more change to access, and the successful access probability becomes smaller. The proposed retransmission-based scheme with ACB factor 1 shall have a significant low successful access probability. However, due to the feature of adaptiveness, the proposed scheme has excellent performance result which is similar to that of ACB scheme with factor 0.2.

Effects of the number of devices on access delay. Figure 4 shows effects of number of devices on access delay. Obviously, as the number of devices who request to access becomes larger, the number of collision becomes higher, and the access delay becomes longer. Moreover, as the ACB factor becomes lower, the occurrence probability of collision becomes higher, and the access delay becomes longer. Surprisingly, the proposed scheme could have a similar performance to the typical ACB scheme with factor 0.4. From the two figures, we can observe a result that the proposed retransmission-based ACB scheme could can reduce the access delay effectively while maintaining high access success probability.

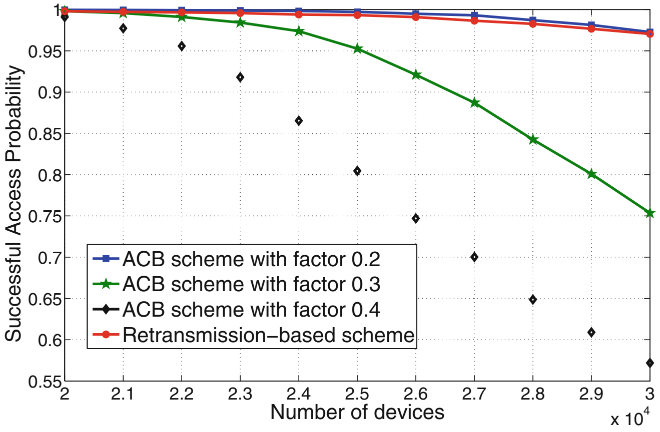

Fig. 3. Effects of congestion controls on access success probability

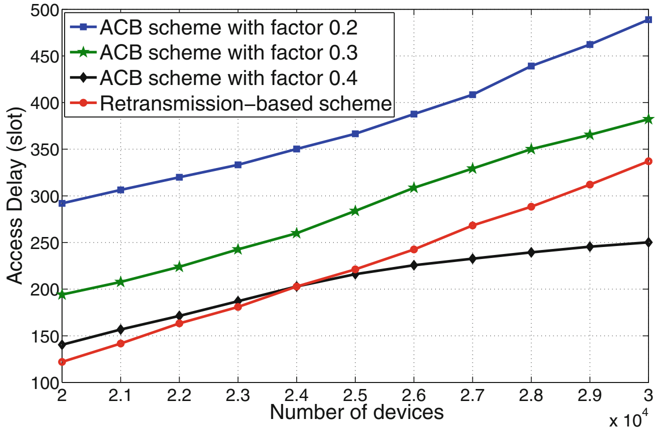

Fig. 4. Effects of congestion controls on access success delay

6 Conclusion

To resolve the challenge of RAN overloading in LTE due to the numerous access requests from MTC devices, this paper proposed a retransmission-based ACB scheme where the current loading level of RAN is leveraged to adjust the ACB factor. In this case, the MTC devices reach to the preamble access are controlled and phenomenon of RAN overloading is alleviated. In particular, we leverage the number of preamble retransmissions send by MTC devices who successfully perform random access to estimate the loading of RAN. From the simulation results, we can observe a surprising result that the proposed retransmission-based ACB scheme could can reduce the access delay effectively while maintaining high access success probability comparing with the typical ACB scheme.

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