Collision-Aware Resource Access scheme for LTE-based Machine-to-Machine communications

Zahra Alavikia and Abdorasoul Ghasemi

***Abstract*—Long-Term Evolution (LTE) network is considered as the most promising infrastructure to provide efficient connectivity for a large number of autonomous Machine-Type Communications Devices (MTCDs). In order to improve the Random Access (RA) throughput of massive access Machine-to-Machine (M2M) communications over LTE networks, we propose a Collision-Aware Resource Access (CARA) scheme to reduce the collisions on the granted Physical Resource Blocks (PRBs). In CARA, the evolved Node B (eNB) exploits early collision detection of preambles at the first message and informs the MTCDs in the corresponding random access response (RAR) message if it can detect the collision successfully. The collided MTCDs then contend for PRBs access using an appropriate probability for efficient use of granted PRBs. Analytical and numerical performance evaluations of the CARA show that the RA throughput can be improved in comparison with the traditional RA procedure.**

***Index Terms*—Machine-Type Communications (MTC), Long-Term Evolution (LTE), Random access procedure.**

I. INTRODUCTION

Machine-to-Machine (M2M) communications which is defined as Machine-Type Communications (MTC) in the context of 3rd Generation Partnership Project (3GPP), is a new autonomous communication paradigm between MTC devices (MTCDs) and remote servers. To provide the wide area coverage for MTCDs, the use of cellular networks, and more particularly, Long-Term Evolution (LTE) /LTE-Advanced (LTE-A) network, attracted significant attention during recent years [1]. In the LTE/LTE-A, each MTCD applies the Random Access (RA) procedure to gain access to the evolved-Node B (eNB) and obtain required Physical Resource Blocks (PRBs) for data transmission. In this regard, the MTCD randomly draws a preamble from the dedicated preambles for the MTC and sends it in message 1, Msg1, to the eNB. If the eNB successfully detects the transmitted preamble, it grants some PRBs for the detected preamble in message 2, Msg2. In message 3, Msg3, the MTCDs with the same transmitted preamble uses the granted PRBs to send their scheduling requests to the eNB. In the RA procedure, if multiple MTCDs send the same preamble in Msg1, the collision may occur. Hence, the collided MTCDs which select the same preamble, cannot gain access to the eNB [1], [2].

The collision problem of MTCDs in the RA procedure of massive access scenarios in the LTE/LTE-A has been addressed in several works. A classification of these solutions is provided in [1]. Among them, Access Class Barring (ACB) is introduced by 3GPP as an effective way to bar each specific MTC class under excessive load condition [3]. In the ACB, the eNB broadcasts the barring factor in each Physical Random Access Channel (PRACH) opportunity. An MTCD which has data for the transmission starts the RA procedure if its selected normalized uniform random number is less than the barring factor. The eNB should estimate the active load in each PRACH opportunity to compute the appropriate ACB factor [4]. To enhance the performance of RA procedure using the ACB scheme, the authors in [5] employed the Timing Advance Command (TAC) of Msg2 to decrease the collision on granted PRBs by assuming identical TACs in multiple PRACH opportunities. In [6] a resource allocation scheme based on the preamble collision detection is introduced where the preamble collision is detected by attaching the MTCDs' identifier in PRACH.

In these works similar to the traditional RA procedure, the eNB does not assign PRBs to the collided preambles which are detected in the first step of RA procedure. Notice that the eNB can detect the RA collision in message 1, Msg1, of the RA procedure if the delay spreads of the received preambles have enough disparities [7]. In this regard, in [8], a method based on the delay spread of received signals at PRACH receivers has been developed to detect a preamble collision at the first step of RA procedure. In this paper, we use the information of the collided preambles at the eNB to probabilistically control the MTCDs' access to the granted PRBs in Msg2. That is, by exploiting the early collision detection using the delay spread of the received signals, another access control stage is added to the third step of the ACB based RA procedure. Simulation results show that this access control stage can improve the performance of ACB-based scheme in terms of RA throughput and average access delay. The RA throughput refers to the expected number of successful access attempts in each PRACH opportunity.

In the rest of this paper, the backgrounds on the traditional RA procedure is presented in Section II. System model is presented in Section III. Section IV is dedicated to the proposed Collision-Aware Resource Access (CARA) scheme. Performance evaluation results are demonstrated in Section V before concluding in Section VI.

II. BACKGROUNDS ON RA PROCEDURE

The RA procedure in the LTE technology consists of four Medium Access Control (MAC) messages. Msg1 is a randomly drawn preamble from dedicated preambles for the MTCDs and transmitted through the PRACH. Preamble detection is then performed by the eNB to detect the transmitted

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preambles through computing the Power Delay Profiles (PDP) of the received signals. The peaks of the PDP which are greater than a detection threshold are used to find the transmitted preambles by the MTCDs. Note that, by considering the cell size and maximum delay spread, the eNB may be able to detect which preambles have been transmitted by two or more MTCDs. Hence, the eNB can detect the collision of Msg1 if the PDP of the received preambles are distinctly far apart from each other in time, i.e., almost be greater than the maximum delay spread which is probable in medium/large cells. The eNB does not transmit Msg2, if the collision is detected [3], [7]. In the case that the eNB cannot detect the collision of Msg1, it transmits the Random Access Response (RAR) message to grant some PRBs for the detected preambles. The main fields of the MAC RAR are as follows: the Random Access Preamble Identifier (RAPID), TAC, and Uplink Grant (UL-G) field. The contending MTCD sends its connection request through the UL-G if the RAPID of the received RAR has the same value as the transmitted preamble in Msg1. When two or more MTCDs receive the same RAPID, they will use the same UL-G to send the corresponding Msg3, and will collide. Finally, the eNB replies to the successfully received Msg3s by sending the contention resolution message in message 4, Msg4 [2].

III. SYSTEM MODEL

We consider a single cell with radius R in which N_T MTCDs are randomly and uniformly distributed [5]. According to the developed traffic model for coordinated MTCDs by 3GPP [3], we use the Beta distribution with parameters $\alpha = 3$, $\beta = 4$, and activation time $T_a = 10s$ as $g(t) = \frac{t^{\alpha-1}(T_a-t)^{\beta-1}}{T_a^{\alpha+\beta-1}Beta(\alpha,\beta)}$, to model the huge arrivals of the requests at the eNB where $Beta(\alpha,\beta)$ denotes the Beta function.

Let μ denote the number of MTCDs which are allowed to initiate the RA procedure. Each active MTCD begins the ACB procedure using the current broadcasted μ and the barring factor by the eNB, p_{ACB}. The eNB then updates p_{ACB} by dividing the value of μ by the number of active MTCDs, n_{act}, using $p_{ACB} = min\left\{1, \frac{\mu}{n_{act}}\right\}$ [3], [4]. We assume that the eNB can perfectly estimate the number of active MTCDs in each RA procedure. The active MTCD which successfully passes the ACB procedure is named contending MTCD and starts the CARA procedure. Otherwise, it retries for the next PRACH opportunity. It is assumed that the preamble transmission power is high enough that the eNB can detect the preambles and proceeds to the collision detection stage. In this paper, we consider the expected delay of the received signatures to decide about the state of the preamble collision [7]. In this regard, we consider a simple scenario in which the collision can be detected by the eNB if (1) is satisfied [9].

$$\frac{R_{max} - R_{min}}{c} > \frac{1}{2b} \tag{1}$$

where R_{min} and R_{max} denote the closest and farthest colliding MTCDs' distances to the eNB, respectively. c and b in (1) are the speed of light and the bandwidth of the PRACH, respectively. We notice that the eNB can determine the propagation delay of each received signal through computing the position of maximum discrete correlation between cyclic shifted received preamble sequence and each of 64 predefined preambles codes [5].

IV. PROPOSED SCHEME

A. CARA Scheme

CARA is an improved version of the traditional ACB enabled RA procedure where a collision avoidance scheme is used at the third step of the procedure to enhance the number of successful access attempts in the massive access scenario of the MTC. In fact, in CARA, the second and third steps of the traditional RA procedure have been modified. The flow-chart for each step of the CARA scheme is shown in Fig. 1. In the first step, the contending MTCDs transmit their randomly selected preambles from M available preambles. Next, at the second step, the eNB decides about the state of preamble collision. In the CARA scheme, when eNB detects the preamble collision in Msg1, it sets the collision flag bit F by which the MTCDs can be made aware of the preamble collision. See Fig. 1. The reserved flag bit in the MAC payload of the RAR can be used as the collision flag bit to indicate the state of the collision. In the third step of RA procedure, each contending MTCD checks the collision flag bit and sends Msg3 through UL-G provided that it receives Msg2 with $F = 0$. However, in the case of $F = 1$, the MTCD inferred that the preamble has been chosen by multiple MTCDs and hence contends to access for PRBs with an appropriate probability which is shown by q. It should be noted that in the traditional RA procedure, if the eNB detects the preamble collision at the first step, it will not grant the PRBs for that preamble, and thus, the corresponding MTCDs will not transmit their requests at the third step of the RA procedure. In what follows, we describe how each collided MTCD can compute the value of q.

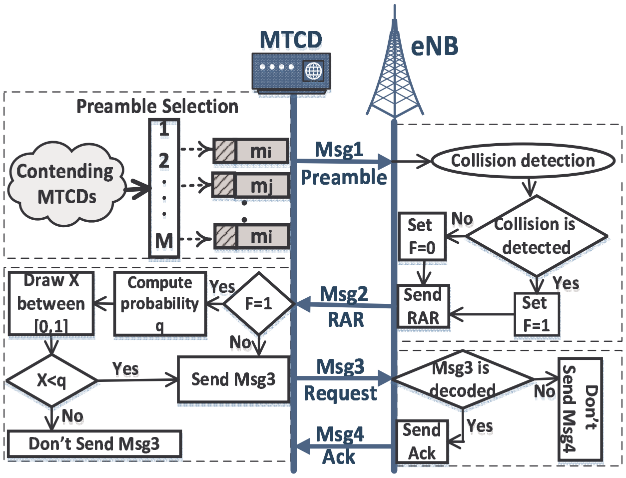

Fig. 1. Steps of CARA procedure.

Let $MTCD_m$ denote a specific collided MTCD which has selected preamble m in Msg1. Also, assume N_c and N be the random variables denoting the number of contending MTCDs

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and the number of contending MTCDs that have selected preamble m except $MTCD_m$, respectively. In what follows, we show that q could be computed using M and N_c. In a real massive access scenario of M2M communications, however, each MTCD can approximate the expected value of N_c by μ because the number of contending MTCDs is regulated around μ applying the barring mechanism.

Given that $N_c = n_c$ and $N = n$, to ensure one access attempt in average by the contending MTCDs for preamble m, each of these MTCDs should schedule its access attempt to the granted PRBs according to (2).

$$\Pr(access|N=n) = \frac{1}{n+1} \tag{2}$$

Let m_n be the event that n out of $n_c - 1$ MTCDs select preamble m. Then, the occurrence probability of m_n is given by the binomial probability mass function (pmf) as $B(n; n_c - 1, \frac{1}{M}) = \binom{n_c-1}{n}\left(\frac{1}{M}\right)^n\left(1-\frac{1}{M}\right)^{n_c-1-n}$. In the case that $F = 1$, $MTCD_m$ finds that preamble m is at least selected by one other MTCD. Thus, the occurrence probability of m_n can be obtained from (3).

$$\Pr(m_n|n>0) = \frac{B(n;\, n_c-1, \frac{1}{M})}{\sum_{i=1}^{n_c-1} B(i;\, n_c-1, \frac{1}{M})}, \tag{3}$$

Using (3), each MTCD is able to estimate the probability that preamble m is selected by n other MTCDs at the first step of RA procedure for $n > 0$. Finally, using (2) and (3), $MTCD_m$ is able to find the probability of access attempt, q, as:

$$\begin{aligned} q &= \sum_{n=1}^{n_c-1} \Pr(access|N=n)\Pr(m_n) \\ &= \frac{\frac{M}{n_c}\sum_{n=0}^{n_c-1}\binom{n_c}{n+1}(\frac{1}{M})^{n+1}(1-\frac{1}{M})^{n_c-1-n} - (1-\frac{1}{M})^{n_c-1}}{1-(1-\frac{1}{M})^{n_c-1}} \\ &= \frac{M}{n_c} - \frac{(1-\frac{1}{M})^{n_c-1}(1-\frac{1}{n_c})}{1-(1-\frac{1}{M})^{n_c-1}} \end{aligned} \tag{4}$$

where n_c could be replaced with μ by the collided $MTCD_m$.

B. Analysis of CARA

In order to compute the achievable RA throughput of the CARA, at first, we need to find the probability of collision detection failure at the eNB. According to (1), this probability is given by $\Pr(R_{max} - R_{min} < Z_0)$ where $Z_0 = \frac{c}{2b}$. Assume that $N = n$ MTCDs select preamble m at the first step of RA procedure, and their distances to the eNB are shown by $R_1, ..., R_n$. Since MTCDs are distributed randomly and uniformly in the cell, the probability density function (pdf) of the i^{th} MTCD's distance to the eNB, r_i, is given by $f_{R_i}(r_i) = \frac{2r_i}{R^2}, 0 \leqslant r_i \leqslant R$. Let R_{max} and R_{min} be the random variables denoting the maximum and minimum of $\{R_1, ..., R_n\}$. Noting that $R_1, ..., R_n$ are independent and identically distributed random variables, the pdf of R_{min} can be computed as:

$$f_{R_{min}}(r) = \frac{d}{dr}\Big(1 - \prod_{i=1}^{n}\Pr(R_i \geqslant r)\Big) = \frac{2nr}{R^2}\Big(1-\frac{r^2}{R^2}\Big)^{n-1} \tag{5}$$

using $\Pr(R_i \geqslant r) = \int_{r_i=r}^{R}\frac{2r_i}{R^2}dr_i = 1 - \frac{r^2}{R^2}$.

Then, the conditional distribution function of $\Pr(R_{max} - R_{min} < Z_0|R_{min} = r)$ can be obtained from (6).

$$\begin{aligned} \Pr(R_{max} \leq R_{min} + Z_0|R_{min} = r) &= \prod_{i=1, R_i \neq R_{min}}^{n} \frac{\Pr(r < R_i \leq r + Z_0)}{\Pr(r < R_i \leq R)} \\ &= \begin{cases} \left(\frac{Z_0^2 + 2rZ_0}{R^2 - r^2}\right)^{n-1} & if \;\; 0 < r \leq R - Z_0 \\ 1 & if \;\; R - Z_0 < r \leq R \end{cases} \end{aligned} \tag{6}$$

By conditioning on R_{min} and using the theorem of total probability we can have:

$$\begin{aligned} &\Pr(R_{max} - R_{min} < Z_0|N=n) = \\ &\qquad \int_0^R \Pr(R_{max} \leq R_{min} + Z_0|R_{min} = r)\, f_{R_{min}}(r)dr \end{aligned} \tag{7}$$

By substituting (5-6) in (7) and after simplifying, we have:

$$\begin{aligned} \Pr(R_{max} - R_{min} < Z_0|N=n) &= \frac{1}{R^{2n}}\Big(Z_0^{n-1}(2R - Z_0)^n(\frac{2nR + Z_0}{2(n+1)}) \\ &+ \frac{Z_0^{2n}}{2(n+1)}\Big), \quad R \geq Z_0 \end{aligned} \tag{8}$$

Note that for the case of $R < Z_0$, the condition in (1) can not be satisfied and hence the throughput of CARA reaches to the throughput of the traditional RA procedure.

After we have computed the probability of collision detection failure as (8), we need to compute the expected number of active MTCDs in the k^{th} PRACH opportunity, $\mathbb{E}[N_{act}(k)]$. $\mathbb{E}[N_{act}(k)]$ is the sum of the expected number of backlogged MTCDs, MTCDs which cannot succeed in the previous PRACH opportunity, and the expected number of new arrivals. Let $A(k)$ be the random variable denoting the number of new arrivals during $[t_{k-1}, t_k]$. The expected value of $A(k)$ can be calculated according to the Beta distribution as $\mathbb{E}[A(k)] = N_T \int_{t_{k-1}}^{t_k} g(t)dt$. Therefore, the value of $\mathbb{E}[N_{act}(k)]$ can be computed as given in (9).

$$\mathbb{E}[N_{act}(k)] = \mathbb{E}[N_{act}(k-1)] - \mathbb{E}[N_{sc}(k-1)] + \mathbb{E}[A(k)], \tag{9}$$

where $\mathbb{E}[N_{sc}(k-1)]$ denotes the expected number of successful access attempts at the $(k-1)$ opportunity and is computed as follows. For simplicity of the presentation, we omit the PRACH index in what follows.

The value of $\mathbb{E}[N_{sc}]$, i.e., CARA's achievable throughput, is computed as the sum of the expected number of preambles which are selected by exactly one MTCD and those which are selected by multiple MTCDs and leads to successful resource access at the third step of RA procedure. Therefore, the achievable RA throughput of the CARA can be computed using (8) for all possible values of n as given in (10).

$$\begin{aligned} \mathbb{E}[N_{sc}] = \Big[MB\big(1; E[N_c], \frac{1}{M}\big)\Big] + \Big[M\sum_{n=2}^{E[N_c]} \\ \Big(1 - \Pr(R_{max} - R_{min} < Z_0|N=n)\Big)B(1;n,q)B(n; E[N_c], \frac{1}{M})\Big] \end{aligned} \tag{10}$$

where $\mathbb{E}[N_c]$ is the expected number of contending MTCDs and is equal to $\min\{\mathbb{E}[N_{act}], \mu\}$; $B(1;n,q)$ is the probability that only one out of n MTCDs transmits Msg3 with probability

q. We compute the value of q by replacing n_c in (4) with $\mathbb{E}[N_c]$. It is noted that in an excessive load condition where $\mathbb{E}[N_{act}] > \mu$, $\mathbb{E}[N_c]$ in (10) can be substituted by μ. The first term of (10), $MB(1; E[N_c], \frac{1}{M})$, denotes the achievable RA throughput of those preambles which are transmitted by exactly one MTCD; that is the throughput of the traditional RA procedure with the ACB scheme. The second term of (10) is the achievable RA throughput from successfully transmitted requests by the MTCDs which select the same preambles at the first step of RA procedure. Let μ^* denote the optimal value of μ in which $\mathbb{E}[N_{sc}]$ in (10) is maximized in an overload conditioin. Recall that the maximum achievable throughput of the traditional RA procedure happens at $\mu^* = \left(\ln(\frac{M}{M-1})\right)^{-1}$; where μ^* is obtained by taking the derivative of $MB(1; E[N_c], \frac{1}{M})$ with respect to μ.

As a special case of $R \gg Z_0$, $\Pr(R_{max} - R_{min} < Z_0 | N = n)$ in (8) would be equal to zero, which means that the eNB can detect all preamble collisions successfully. Hence, the CARA's throughput in (10) can be simplified as:

$$\mathbb{E}[N_{sc}] = \left[\mathbb{E}[N_c](1 - \frac{1}{M})^{E[N_c]-1}\right] + \left[q\mathbb{E}[N_c]\left((1 - \frac{q}{M})^{E[N_c]-1} - (1 - \frac{1}{M})^{E[N_c]-1}\right)\right] \tag{11}$$

where, as in (10), $\mathbb{E}[N_c]$ can be replaced with μ in an overload condition. For large values of μ, the value of $(1 - \frac{1}{M})^{\mu-1}$ in (4) reaches to zeros, so we have $q \longrightarrow \frac{M}{\mu}$. By replacing the values of $\mathbb{E}[N_c]$ and q in (11) with μ and $\frac{M}{\mu}$ respectively, the value of the first term of (11) which is the throughput of the traditional RA procedure, i.e., $\mu(1 - \frac{1}{M})^{\mu-1}$, reaches to zero for $\mu \gg 1$. In this case, the value of the second term of (11) is decreased to Me^{-1}. Hence, the throughput of the CARA in (11) will be Me^{-1} for $\mu \gg 1$.

Having the value of $\mathbb{E}[N_{sc}]$, we can compute the average access delay which is denoted by $\mathbb{E}[D]$. Let $p_{sc}(k)$ be the probability that the access attempt in the k^{th} PRACH opportunity is successful. $p_{sc}(k)$ can be obtained by dividing $\mathbb{E}[N_{sc}]$ by the expected number of active MTCDs at the k^{th} opportunity, that is $p_{sc}(k) = \frac{\mathbb{E}[N_{sc}](k)}{\mathbb{E}[N_{act}](k)}$. Also, the probability of new arrival in the k^{th} PRACH opportunity denoted by $p_a(k)$ is given by $p_a(k) = \int_{t_{k-1}}^{t_k} g(t)$. Let T be the time duration between two consecutive PRACH opportunities. Assume that the number of retransmission attempts for each MTCD is unlimited. The average RA delay of the MTCDs is computed by multiplying T and the expected number of RA opportunities between new arriving request and its successful transmission to the eNB as given in (12).

$$\mathbb{E}[D] = T \sum_{i=1}^{C} \sum_{k=i}^{I} (k - i + 1) p_a(i) p_{sc}(k) \prod_{j=i}^{k-1} (1 - p_{sc}(j)) \tag{12}$$

where C is the number of PRACH opportunity during the MTCDs' activation time and is obtained using $\frac{T_a}{T}$; I denotes the expected number of PRACH opportunity during the MTCDs' total service time and is estimated by $C + \frac{\mathbb{E}[N_{act}(c)]}{\mathbb{E}[N_{sc}(c)]}$.

V. PERFORMANCE EVALUATION

In the simulation setup we consider the LTE PRACH configuration with index 6 in which the period of PRACH opportunity is $5ms$, i.e., $T = 5ms$ [3]. The power ramping factor is nullified by setting the power ramping step to $0dB$ [10]. The duration of PRACH opportunity is considered to be 1ms with bandwidth of 6 PRBs where each PRB is $180kHz$ [7]. The backoff parameter with index 0 is used in this paper [2]. We assume that each MTCD retries the RA procedure until it successfully gains access to the eNB. Other simulation parameters are as follows: $N_T = 40000$, $M = 54$, and $b = 1.08MHz$. The simulation results are the average of 20 independent runs.

Fig. 2 shows the RA throughput of both CARA and the traditional RA schemes over the time for $R = 0.6km$ and $R = 4km$ according to the simulation results and analysis in (10). Using (10) and performing an exhaustive search, the optimum number of contending MTCDs for $R = 0.6km$ and $R = 4km$ in CARA happens at $\mu^* = 76$ and $\mu^* = 86$ respectively. Also, as expected in the traditional RA procedure the optimum value of μ is M. We find from Fig. 2 that the RA throughput of the CARA for both scenarios of $R = 0.6km$ and $R = 4km$ are greater than the traditional RA procedure. In the CARA scheme, by increasing the radius of the cell, the probability of collision detection at Msg1 of RA procedure is increased which leads to the increase in RA throughput of the system. Furthermore, the total service time of the synchronized MTCDs is decreased using the CARA scheme as it is expected in Fig. 2.

In addition, as it is shown in Fig. 2, the throughput of the proposed scheme and the traditional RA have the same trend up to about $1.8s$. To illustrate the reason of this behavior, the expected number of active MTCDs in this interval is drawn in Fig. 2 as an inset. Due to the Beta distribution of the requests arrivals, for $t < 1.8s$ the expected number of active MTCDs is much less than the number of preambles. Hence, the probability that an arbitrary preamble is chosen by more than one MTCDs is negligible and the throughput of the proposed scheme and the traditional RA have the same trend in this interval. It is noted that the advantages of the proposed scheme against traditional RA procedure is significant in massive access scenario in which multiple MTCDs select the same preamble.

The next simulation results in Fig. 3, Fig. 4, and Fig. 5 are provided for the excessive load scenario and the corresponding average RA throughput between $3s$ and $7s$ are depicted.

In Fig. 3, the throughput and average access delay of the CARA for $R = 4km$ are compared with the traditional RA procedure against different values of μ. According to Fig. 3, the throughput and average access delay of the CARA are, respectively, greater and less than the traditional scheme for all values of μ. As it is expected, the maximum value of CARA's throughput for $R = 4km$ happens at $\mu = 86$. Also, for a high enough value of μ, the throughput of traditional RA procedure reaches to zero while the throughput of the CARA scheme decreases to Me^{-1}. In this case, the average RA delay of the CARA is sustained around a certain threshold and the

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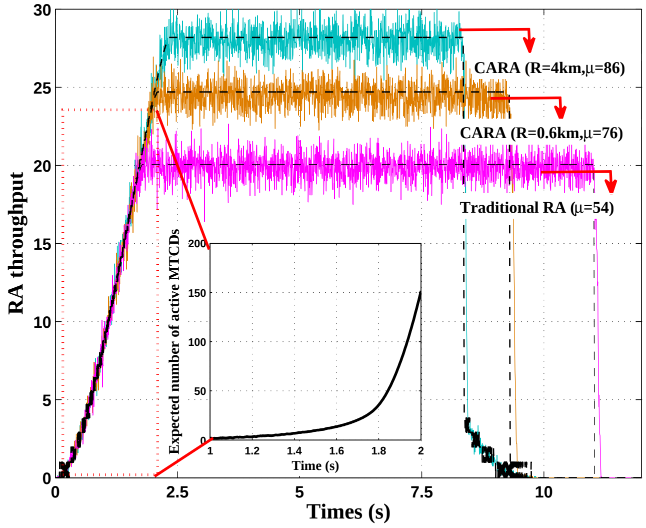

Fig. 2. The throughput of CARA and traditional RA schemes over the time (dashed lines:analysis; solid lines:simulation). The inset shows the expected number of active MTCDs for $t < 2s$.

traditional RA's delay is increased by increasing the values of μ.

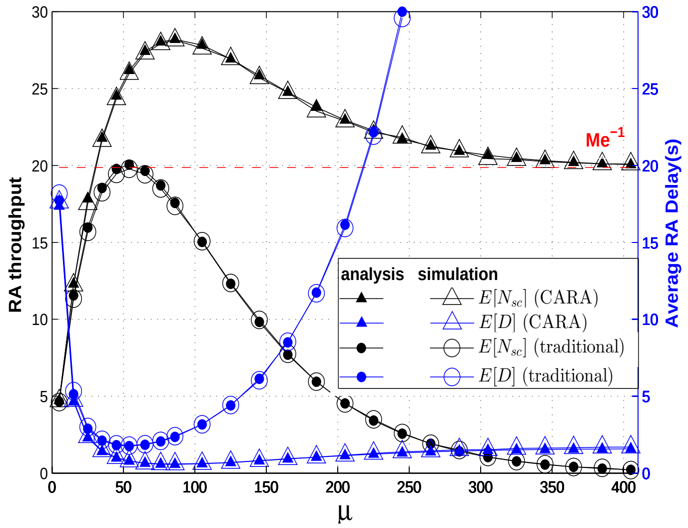

Fig. 3. Average values of throughput and access delay of CARA and traditional RA schemes against different values of μ .

In Fig. 4, the RA throughput of the proposed scheme and the traditional RA procedure for $\mu = 45, 54, 86$ against different values of cell size is shown. As it is shown in Fig. 4, the throughput of CARA is greater than the traditional RA procedure for all considered values of μ and R. Also, by increasing R, the probability of preamble collision detection at the eNB is increased which increases the throughput in the CARA scheme up to its maximum value. In Fig. 4, the upper bounds of CARA's throughput for $\mu = 45, 54, 86$ and $R \gg Z_0$ are shown using (11). The least throughput of CARA scheme happens at $R = Z_0$; which is equal to the throughput of the traditional RA procedure.

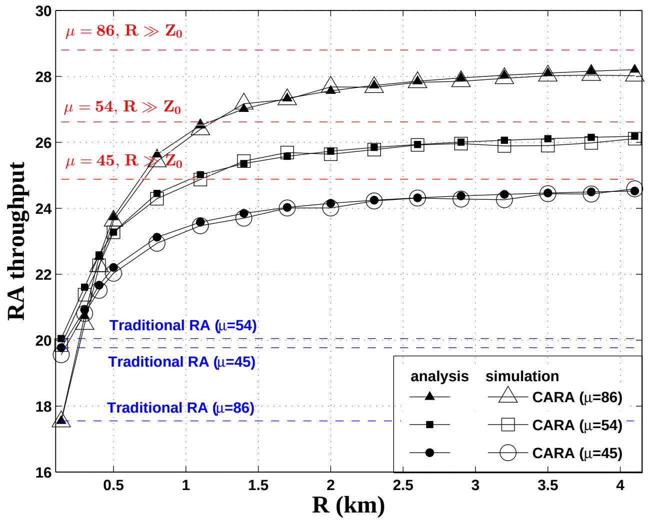

Fig. 4. Average throughput of CARA and traditional RA procedure against different values of R.

In Fig. 5 we investigate the effect of the possible estimation errors of n_{act} on the throughput of the CARA. To this end, the actual value of n_{act} in each PRACH opportunity is multiplied by $(1+\theta)$, where θ denotes the percentage of estimation error, and $\theta < 0$ and $\theta > 0$ indicate the under and over estimation of the number of active MTCDs, respectively. The analysis results are obtained by dividing $\mathbb{E}[N_c]$ in (10) by $(1+\theta)$. From Fig. 5, even with the estimation error, the proposed scheme outperforms the traditional ACB based RA procedure for a given value of the estimation error. The reason is that in CARA scheme, multiple channel accesses by the extra MTCDs can be reduced by applying further collision avoidance scheme after the first stage. Also, for a specific value of estimation error, the degradation of the RA throughput is more sensitive to under-estimation for both schemes. The reason is that when the eNB estimation of the number of active MTCDs is less than actual active MTCDs, the value of the ACB factor is adjusted to a greater value compared to the optimal one; which leads to the increase in the number of contending MTCDs and causes more collisions. In the over-estimation case, however, the value of p_{ACB} is set more conservative, which results in under-utilization of RA resources.

VI. CONCLUSION

We propose a collision avoidance scheme for multiple resource access in the third step of RA procedure to enhance the RA throughput of massive M2M communications over the LTE networks. Adopting a simple model for early collision detection of preambles using the power delay profile, we discuss how the contending MTCDs which are collided in the first step of RA should adjust their access probability to exploit the granted PRBs in an efficient manner. Results show that using this scheme the RA throughput could be improved

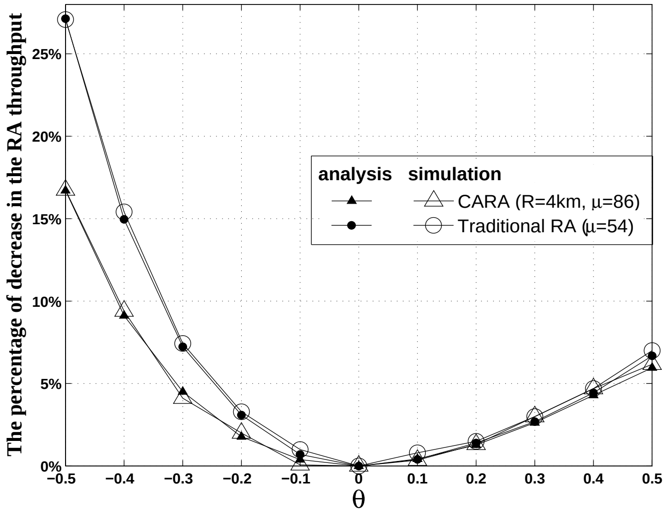

Fig. 5. The percentage of throughput degradation of CARA and traditional RA procedure against different values of θ.

compared with the traditional RA procedure specially for the massive access scenarios and when the cell size is large. In future works we consider the effects of wireless channel and the structure of the receiver on the success probability of early preamble collision detection and the performance of the proposed scheme.

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