Performance Analysis of a Machine-to-Machine Friendly MAC Algorithm in LTE-Advanced

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***Abstract*— One of the main challenges in Machine Type Communication (MTC) services in the 3GPP LTE networks is to improve device power efficiency for Machine to Machine (M2M) communication. We consider MTC application scenarios which consist of a number of devices connecting to the network concurrently. The methods considered in TR 37.868 involve Disjoint Allocation (DA) and Joint Allocation (JA). The DA scheme is based on separating the available RACH (random access channel) preambles into two disjoint sets for Human-to-Human (H2H) and M2M calls. In the joint allocation scheme the H2H calls have access to the preamble set of M2M consumers. Performance analyses of the schemes assume that both H2H and M2M calls follow Poisson traffic models. In this paper we consider the joint allocation scheme in which M2M calls have access to H2H preambles as we expect more M2M calls in the future. We derive and present analytical expressions for the throughput, the collision probability, the success probability, and the idle probability for DA and JA methods based on the assumption that RA (random access) arrivals of M2M and H2H devices follow Beta and Poisson distributions respectively. The energy consumption performances of the two methods are compared. Results show that with the new JA method we can reduce the number of collisions and save the power consumption of M2M devices up to 4%.**

Keywords—machine-to-machine; random access process; MAC layer; power save; preamble; Beta distribution

I. INTRODUCTION

M2M service is expected to be a major aspect of the next generation mobile communications. Since LTE networks are basically generated and optimized for H2H communications, the existing protocols are not designed to support MTC[1] devices efficiently. Several modifications are needed to improve the performance requirements of M2M communications in this network. Due to the stringent battery power constraints of M2M devices, there is a demand to focus on solutions to decrease the power consumption of M2M devices over 4G networks [1]. It is necessary to design protocols which can reduce power consumption of M2M communication and minimize machine dependency on any external energy resources.

TR 37.868 [2] is a 3GPP technical report which summarizes the improvements on the radio access network (RAN) to avoid high RA collision probabilities when the number of devices goes up to tens of thousands per cell. The reason behind is that, when a User Equipment (UE) in LTE is in an idle state, it is essentially unknown to the network [3]. To establish a connection to the network, the device has to go through the RA procedure. The challenge here is to reduce the number of collisions due to the competition between devices, so that we can save energy by reducing the number of retransmissions. The basic principle of the power saving procedure is that a user (we use UE, user and device interchangeably) starts sending its preambles with lower power and in case a transmission fails in the previous attempt, then gradually increases its transmit power. As a result, more power is consumed by a UE with re-transmission of the preamble request.

Following one of the RAN overload control mechanisms in TR 37.868, RACH preamble resources can be split into two groups for H2H and M2M separately. This is called the disjoint allocation (DA) method. Based on the DA method, [4] gives an adaptive preamble split scheme which ensures minimum call setup delay for H2H users. The subsets of preambles will be calculated by estimating the ratio of UEs in CBRA (Contention Based Random Access) and Non-CBRA. [5] simulates the effect of group based preambles using the received path loss by UE. This could reduce the probability of collision for H2H without considering the M2M devices which are mostly fixed in location. [6] defines a new MAC algorithm, namely, JA method for H2H users by sharing the set of M2M access preambles between H2H and M2M. It compares the effects of the JA mechanism on the throughput of the H2H users with the 3GPP DA approach. Performance analyses of these schemes are made for M2M communications with Poisson traffic which is not suitable for event-based M2M applications [2].

In this paper we investigate the effect of sharing H2H preamble set with M2M devices as one of the possible solutions in reducing the RACH collisions for MTC service in LTE-A networking systems. We compare the performance of the DA and JA methods on power consumption of M2M users in RA procedure, in which the JA method shares the preamble

[1] MTC and M2M refer to the same service in LTE system.

set of H2H users with M2M devices. In particular, we analyze the throughput, collision and successful performance of the two approaches and validate them using our simulation results. We assume that the RACH arrival models for M2M and H2H users follow Beta and Poisson distributions respectively. We also study the impact of the JA technique on reduction in the number of collisions for M2M devices in RA procedure which helps in saving energy. As our method is similar to the methods studied in [6] the method of analysis is similar.

The remainder of this paper is organized as follows. Section II gives a brief description of random access process in LTE networks. In Section III, we describe our proposal and give analytical expressions for the throughput and the probability of success/collision of the M2M and H2H transmission over RACH channel. We also obtain performance metrics for the M2M and H2H users with the proposed DA and JA methods. Power consumption model is given in Section IV. The numerical results are presented in Section V. Finally we conclude the work in Section VI.

II. RACH PROCEDURE IN LTE NETWORKS

In LTE networks, any asynchronous user must perform RA process to connect an eNB (evolved node B). In LTE the process of synchronization happens in RACH channel. After synchronization with eNB and reserving an uplink channel, the UE can transmit data through Physical Uplink Shared Channel (PUSCH). The RA request consists of preamble, which is a digital signature that a UE transmits in the RACH time-slot (TS). The information about available preamble sets with time and frequency of RACH-TSs (RA-TS) are provided continuously by eNB through System Information Broadcast (SIB #) messages. There are 64 orthogonal pseudo-random preambles available for each RA-TS [2], in which about 10 preambles will be reserved for high priority cases. If two or more devices transmit the same preamble in the same RA-TS, a collision occurs. Otherwise, due to the orthogonality of the preambles, the different preambles can be detected by the eNB. The information of RACH arrival time, *ConfigurationIndex* is periodically broadcasted through SIB2 message by the eNB. In this work, following TR 37.868, we also consider the RACH *ConfigurationIndex*= 6, in which any new RA-TS happens every 5 sub-frames and in a pre-defined frequency (each sub-frame in LTE lasts for 1ms, and a RA-TS lasts for 0.5 ms). If I, m, M denote the number of RA-TSs in one second, the number of frequency bands in each RA-TS, and the number of preambles per RA-TS respectively, then the total number of random access opportunities (RAOs) per second can be calculated as $L = I \times m \times M$. E.g., for duration of 10 sec and available 54 preambles in each RA-TS, there will be $(1000/5)\times 1 \times 54 = 10800$ total available RAOs.

III. SYSTEM MODEL

In TR 37.868 two types of RACH arrivals for MTC devices has been suggested, namely traffic Type1 and traffic Type2. The first one is realistic, i.e. users access the network uniformly, and the second one is an extreme scenario which means a large number of M2M devices access the network in a bursty manner, e.g. after a power outage over a distribution time T. In this work we assume that RACH arrival requests of H2H and M2M users follow a Poisson distribution (Type1), and a Beta distribution (Type2) respectively. Users are distributed uniformly within the eNB cellular area, in which we have assumed that users stay in their position during the RACH procedure until their RA request is received successfully by the eNB.

With each RA-TS we can associate two measures called probability of success and probability of collision. We will calculate these quantities in the following sections. The parameter of real interest in any random access scheme is the throughput. Throughput is the product of the number of RAOs per second and the number of successful transmissions per RA-TS.

In the case of Poisson arrivals we can find probability of success or probability of collision by using parameters of the Poisson distribution. Moreover, superposition of two Poisson processes with rates L1 and L2 is a Poisson process with rate L1+L2. These properties help in expressing the throughput as a function of intensity or arrival rate. However, in the case of Beta arrivals we don't have such properties which can be used. We just know that arrivals follow a time limited Beta distribution in the interval $(0, T)$ with parameters α, β as given by (4) and number of new arrivals in one RA-TS is given by (5).

A. Metrics for H2H users in RACH procedure

Under the assumption that RA arrivals of H2H users follows a Poisson distribution, the random access intensity for a specific TS is λ / M, where λ is the overall RACH intensity of H2H users per second [6]. From slotted ALOHA, the RACH throughput for H2H, T^{H2H}, is given by product of No. of RACH opportunities and probability of success per RACH opportunity [8], as

$$T^{H2H} = \lambda \exp(-\frac{\lambda}{M}). \tag{1}$$

The success probability for H2H users per RA-TS, is given by $P_s^{H2H} = \frac{No.of\ successfull\ random\ access\ in\ one\ RA-TS}{No.of\ available\ RAOs\ in\ one\ RA-TS}$ which can be written as

$$P_s^{H2H} = \frac{T^{H2H}}{M} = \frac{\lambda}{M}\exp(-\frac{\lambda}{M}). \tag{2}$$

The idle probability for H2H users, P_i^{H2H}, is the probability that no one arrives in a TS. Similar to [8], $P_i^{H2H} = \exp(-\frac{\lambda}{M})$. Therefore, the collision probability for H2H users, P_c^{H2H}, can be derived as

$$P_c^{H2H} = 1 - P_i^{H2H} - P_s^{H2H} = 1 - \exp(-\frac{\lambda}{M}) - \frac{\lambda}{M}\exp(-\frac{\lambda}{M}). \tag{3}$$

B. Metrics for M2M users in RACH procedure

Assume N number of MTC devices activate between $0 \le t \le T$ with the time limited Beta density function $f(t)$ with parameters α and β as

$$f(t) = \frac{1}{\mathrm{B}(\alpha,\beta)} t^{(\alpha-1)}(1-t)^{\beta-1} I_{(0,1)}(t), \tag{4}$$

in which $\mathrm{B}(\alpha,\beta)$ is the Beta distribution function, and $I(t)$ is the regularized function such that $\int_0^T f(t)\,dt = 1$. Then the number of M2M RACH arrivals in the i^{th} RA-TS is given by [2], [7]

$$n_i = N \int^{t_i} f(t)\,dt, \tag{5}$$

where t_i is the time interval between i^{th} RA-TS and the next access opportunity, and the distribution function $f(t)$ is normalized as

$$f(t) = \frac{t^{(\alpha-1)}(T-t)^{\beta-1}}{T^{(\alpha+\beta-1)}\,\mathrm{B}(\alpha,\beta)}, \quad \alpha = 3, \beta = 4. \tag{6}$$

We wish to compute the throughput under Beta arrivals. Towards that end, we would like to calculate probability of successful preamble transmissions by n users (includes new arrivals and backlogged users). Suppose there are M available preambles in each RA-TS and users are allowed to choose preambles with equal probability given by $1/M$. Successful transmission takes place when exactly one user (device) chooses a given preamble. Given any preamble, it is easy to see that the probability that one out of n choose that preamble is given by,

$$\binom{n}{1}\frac{1}{M}(1-\frac{1}{M})^{(n-1)}. \tag{7}$$

Therefore, the throughput for M2M devices in time slot i, is given by

$$\binom{n}{1}(1-\frac{1}{M})^{(n-1)}. \tag{8}$$

Note that value of n depends on Beta distribution parameters and N. Though we can plot the throughput as a function of n, its dependency on Beta distribution can be determined only through simulation. Whereas, in the Poisson arrivals we can express throughput as a function of arrival rate.

Eqn. (8) is the throughput for M2M devices in time slot i, we denote by T^{M2M}, which can be rewritten as

$$T^{M2M} = n(1-\frac{1}{M})^{(n-1)}. \tag{9}$$

From (7), the success probability for M2M devices can be written as $\mathrm{P}_s^{M2M} = \frac{n}{M}(1-\frac{1}{M})^{(n-1)}$.

Using (7) the idle probability for M2M devices which means there is no device to choose a preamble m ($m \in \{1,2,...,M\}$), can be written as

$$\mathrm{P}_i^{M2M} = \binom{n}{0}(1-\frac{1}{M})^{n}. \tag{10}$$

Therefore, the collision probability for M2M devices can be derived as

$$\mathrm{P}_c^{M2M} = 1 - \mathrm{P}_s^{M2M} - \mathrm{P}_i^{M2M} = 1 - \frac{n}{M}(1-\frac{1}{M})^{(n-1)} - (1-\frac{1}{M})^{n}. \tag{11}$$

We present the simulation results of probabilities for M2M devices with number of MTCs $N = 30k$ and $M = 54$ preambles against their theoretical models without contributing H2H users in Fig. 1. It can be seen that simulation results match the theoretical values.

C. Proposed approach

In 3GPP, disjoint allocation (DA) method (see Fig. 2(a)) is used in which the available preambles are split into two groups. One group is used for H2H devices and the other for M2M devices. In [6], the authors have studied a joint allocation method in which H2H devices are allowed to access all the preambles and M2M devices can access a fraction of the preambles. Moreover, Poisson arrival process is assumed for both H2H and M2M devices. In the future we anticipate more M2M users than H2H users to use the network. In addition M2M user arrival process is found to follow a Beta distribution [2]. To manage more number of M2M devices effectively and reduce their number of collisions we study the scheme in which M2M devices access all the preambles and H2H devices access only a fraction of available preambles (see Fig 2(b)).

D. Metrics for DA preamble method in RACH procedure

In following we define four metrics for each of the methods.

Using the derived probabilities in previous subsection, the probability of success $P_{S,DA}$, collision $P_{C,DA}$ and idle $P_{I,DA}$ for H2H and M2M users in DA method can be derived as

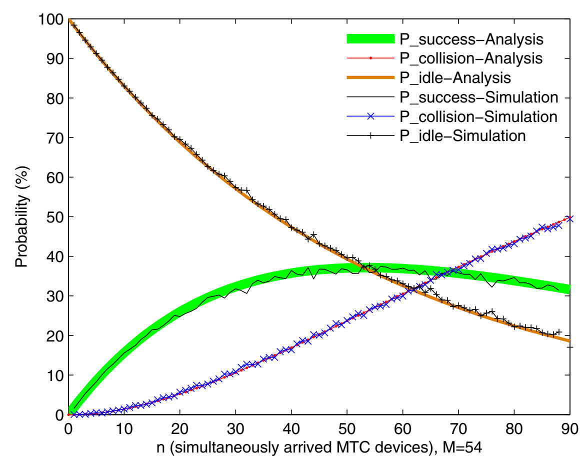

Fig. 1. Simulation and theoretical values of M2M probabilities, N = 30k.

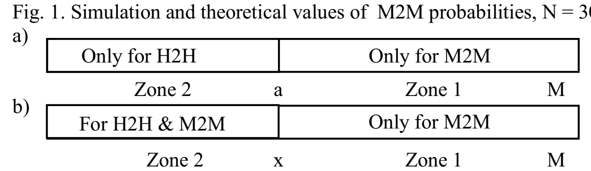

Fig. 2 (a). Subsets of preambles for H2H and M2M users in DA method [TR 37.868]. (b) Splitting the number of preambles in JA method. x: the number of preambles shared by both H2H and M2M (x is a variable). M-x: the number of preambles allocated for only M2M devices (using a scheme from [6]).

preambles to H2H and M2M users respectively (please see Fig. 2. (a)).

$$P_{S,DA}^{H2H} = \frac{\lambda}{a}\exp(-\frac{\lambda}{a}); \quad P_{S,DA}^{M2M} = \frac{n}{(M-a)}(1-\frac{1}{(M-a)})^{n-1} \quad (12)$$

$$P_{I,DA}^{H2H} = \exp(-\frac{\lambda}{a}); \quad P_{I,DA}^{M2M} = (1-\frac{1}{(M-a)})^{n} \quad (13)$$

$$P_{C,DA}^{H2H} = 1-\frac{\lambda}{a}\exp(-\frac{\lambda}{a}) - \exp(-\frac{\lambda}{a});$$
$$P_{C,DA}^{M2M} = 1-\frac{n}{(M-a)}(1-\frac{1}{(M-a)})^{n-1} - (1-\frac{1}{(M-a)})^{n}. \quad (14)$$

And therefore, the RACH throughput for H2H and M2M users can be modeled as

$$T_{DA}^{H2H} = \lambda\exp(-\frac{\lambda}{a}); \quad T_{DA}^{M2M} = n(1-\frac{1}{M-a})^{(n-1)}. \quad (15)$$

Where n is the arrival number of M2M devices in a RA-TS defined by (5) and a, $M-a$ are the subsets of allocated preambles to H2H and M2M users respectively.

E. *Derivation of metrics for JA preamble method in RACH procedure*

In this approach, M2M devices have access to all preambles in zone 1&2. So that, a portion of the M2M RACH request uses the preamble set of H2H in zone2. We can divide the RACH attempts arrival of M2M into two portions, zone1 and zone2 as: $n\frac{M-x}{M}$ and $n\frac{x}{M}$ respectively. Hence, the arrival of RA attempts in zone2 is a summation of H2H and M2M arrivals, as

$$\alpha = \lambda + n\frac{x}{M}, \quad (16)$$

and the arrival of RA attempts in zone1 can be written as

$$\gamma = n\frac{M-x}{M}. \quad (17)$$

Thus, we can write the throughput of RA attempts for H2H and M2M devices in JA method as

$$T_{JA}^{H2H} = \lambda\exp(-\frac{\alpha}{x}); \quad (18)$$

$$T_{JA}^{M2M} = n\frac{x}{M}(1-\frac{1}{x})^{(\alpha-1)} + \gamma(1-\frac{1}{M-x})^{(\gamma-1)}. \quad (19)$$

Similarly, the probability of success, idle and collision for M2M devices can be written as

$$P_{S,JA}^{M2M} = n\frac{x}{M^2}(1-\frac{1}{x})^{\alpha-1} + \frac{\gamma}{M}(1-\frac{1}{(M-x)})^{\gamma-1}, \quad (20)$$

$$P_{I,JA}^{M2M} = (1-\frac{1}{M})^{n}, \quad (21)$$

$$P_{C,JA}^{M2M} = 1-n\frac{x}{M^2}(1-\frac{1}{x})^{\alpha-1} - \frac{\gamma}{M}(1-\frac{1}{(M-x)})^{\gamma-1} - (1-\frac{1}{M})^{n}. \quad (22)$$

Note that equations (18) to (20) are modeled based on simulation results.

As it is shown in Fig. 2, by comparing (14) and (22), in which the arrival rate of the M2M devices, n varies per TS, with constant H2H arrival rate $\lambda = 1$, M2M users experience less number of collision in RACH process with JA method rather in DA method. This results in reduction of energy consumption for M2M users during the RACH procedure, which we will discuss further in the numerical results.

Following [6], for taking care of the RACH throughput of H2H users in JA we have to check how many preambles x are required to provide the same RACH throughput for H2H as in DA. We can define x as $x := T_{DA}^{H2H} = T_{JA}^{H2H}(x)$, so we can obtain x as

$$\lambda\exp(-\frac{\lambda}{a}) = \lambda\exp(-\frac{\lambda}{x})$$
$$\Rightarrow x = \frac{\lambda}{\frac{\lambda}{a}-\frac{n}{M}} = \frac{a}{1-\frac{na}{M\lambda}} \quad such\, that\ x \geq a. \quad (23)$$

As it comes from (23), value of x depends on n and λ. By increasing n feasible x appears in greater λ. This boundary will affect the performance of JA method, which we elaborate this more in the numerical results.

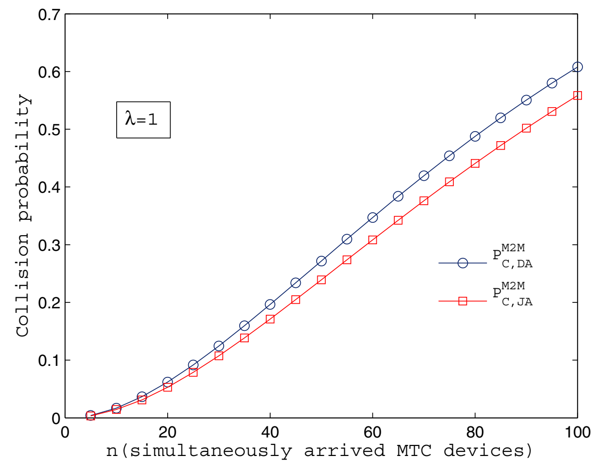

Fig. 2. Comparison of collision probability for M2M devices using DA and JA Methods.

TABLE I. SIMULATION PARAMETERS

Parameters	Assumptions
UE distribution	Uniform within the eNB cell area
Path loss model	PL(dB) = 128.1 +37.6 log(R), R in Km [10]
Maximum BS TX power	46dBm
Number of transmitter antenna	N=1
ENodeB coordination	[x,y]=0
P_{CMAX}	23dBm
P_{IRTP}	-104 dBm
Preamble format	1
$\Delta_P(dB)$	0 dB
Δ_{Ramp}	2 dB
Max No. of preamble retransmission	10
Preamble configuration index	6
Total number of preambles (M)	54
Subset of preambles for H2H in DA method	m = 5
Number of MTC devices (nMTC)	5K to 40 K
T (distribution period)	Traffic Type1: 60 Sec Traffic Type2: 10 Sec

IV. POWER CONSUMPTION CALCULATION IN RACH PROCESS

Once a user requires uplink synchronization, by turning on the device starts to change its receiver frequency till it can receive and decode MIB (Message Information Broadcast) message. Then, the device can get the LTE downlink synchronization and figures out the System Frame Number (SFN) configuration. Just after downlink synchronization, the user is able to decode the SIB messages. In which, the required information about following is broadcasted

- *PreambleInitialReceivedTargetPower* $(P_{IRTP}(dBm))$: Is the expected power level of the RA request in PRACH when it reaches the eNB. Value varies from -120dBm to -90 dBm.
- *PowerRampingStep* $(\Delta_{Ramp}(dB))$: This is mainly used when an eNB is not able to detect the RA request then UE will retransmit the RACH request by increasing the power to the Δ_{Ramp} factor.
- *DeltaPreamble* $(\Delta_P(dB))$: This is preamble format based delta offset. There are four formats available for preambles which are called as preamble formats. Most of the time 0dB is used.
- *PreambleTransmissionMax*: Is the maximum allowed transmission power.
- *ReferenceSignalPower* (P_{RF}): Is the transmitter power of eNB which depends on N number of antennas ($\leq 20\,dBm - 10\log_{10} N$).

Having the above information, UE will calculate and set its PRACH power transmission, P_{PRACH}, as

$$P_{PRACH}(dBm) = \min(P_{CMAX}, PRTP + PL), \tag{24}$$

where, P_{CMAX}, is the maximum UE transmitter power specified in 3GPP TS 36.101 [9], and PL is the calculated received pathloss by UE. Preamble_Received_Target_Power ($PRTP$) at UE is calculated as

$$PRTP(dBm) = P_{IRTP} + \Delta_p + (k-1)\times\Delta_{Ramp}. \tag{25}$$

In which, k is the number of RA request retransmission tries by UE. In TS 36.300 [10], the PL model for a macro eNB is given as

$$PL(dB) = 128.1 + 37.6\log_{10}(R), \tag{26}$$

where R is the transmitter-receiver separation in kilometers.

V. SIMULATION AND NUMERICAL RESULTS

In this section, we present the throughput, the collision probability and power consumption performance of method JA in comparison to DA. To validate our simulation results vs. the reliable 3GPP test cases, we have shown the results of collision probability for M2M devices without using any RAN overload control method in Table II. Where, we have compared the results from TR 37.868 [2] (Sec. 6.3) and our simulation results, for traffic Type1 and Type2 respectively. The basic simulation parameters are given in Table I. The values for traffic Type1 in Table II are achieved in $\lambda = \text{nMTC}/T$, for example the arrival rate of MTC devices for nMTC=5k is 5000/60 = 83 per second. Results are showing reasonably match with the reference values with less than 20% difference.

We have assumed that there are totally M=54 preambles available for devices to use. The subsets of available preambles for H2H and M2M users in DA is $a = 5$ and $M - a = 49$, which are constant. That means H2H and M2M users can choose one of 5 and 49 preambles respectively. Whereas, in JA the subset of the preambles for H2H users is computed by (23) and M2M users can choose one from 54 preambles. Fig. 3 presents the analysis results of RACH throughput for M2M devices with constant M2M arrivals $n = 50, 100$. In which H2H and M2M RACH requests follow the traffic Type1 and traffic Type2 respectively. It is shown that when $n \geq 100$, the throughput in JA is always better than DA for any H2H RACH arrival rate (λ). Whereas, for $n < 50$ only when λ is lesser than 10, the throughput with JA method is greater than DA. This is because of this fact that the throughput of M2M users in JA consists of the throughput in two preamble subsets (please see (19)). The preamble subset in zone2 is shared between H2H and M2M users. With smaller x, M2M devices can access more preambles in zone1 without competing with H2H RA arrivals. Therefore, the M2M throughput has better performance when a smaller subset of preambles is dedicated to H2H users. However, since the arrival rate of M2M devices is following a Beta distribution, n is not a constant in practical scenarios.

Figure. 4 to Fig. 9 are the simulation results. The maximum number of retransmission for each user is assumed 10. Once a

TABLE II. SIMULATION RESULTS OF COLLISION PROBABILITY VS. 3GPP (TR37.868, TABLE 6.4.1.1.1)

Traffic Model	Number of MTC devices (nMTC)	Simulation	3GPP [2]	Variance
Type 1	5K	0.009%	0.01%	0.1
	10K	0.036%	0.03%	0.2
	30K	0.26%	0.22%	0.18
Type 2	5K	0.55%	0.45%	0.2
	10K	2.19%	1.98%	0.1
	30K	45.23%	47.76%	0.05

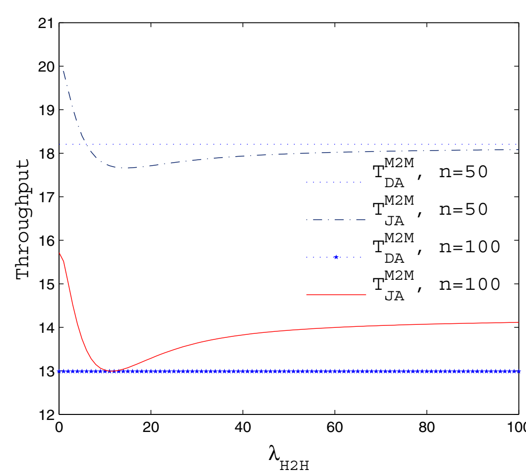

Fig. 3. Throughput comparison for MTC devices with constant n = 50, 100 and M=54.

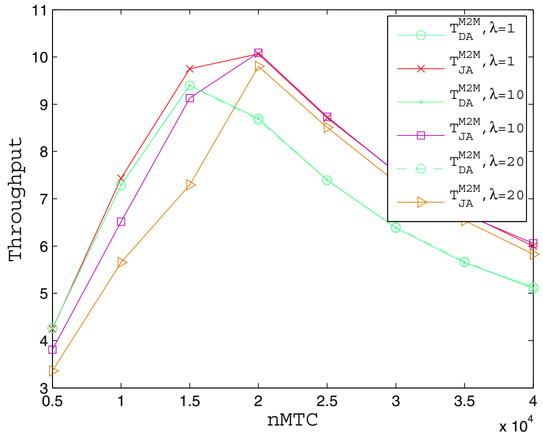

Fig. 4. Comparison of throughput performance for M2M devices in JA vs. DA method, $\lambda = 1, 10, 20$.

UE's No. of retransmission exceeds 10, the UE is not allowed for further RA request. We have assumed a macro eNB is located at a center of a circular shaped cell with radius 500m, in which users are distributed uniformly in the cell area. Assuming they are fixed in position, using (26), the path loss (in dB) for UEs is calculated.

We first present the average of RACH throughput for M2M devices per TS with different number of nMTCs according to the RACH arrival rate of H2H users $\lambda = 1, 10, 20$ in Fig. 4. When the RA arrival rate of H2H users' is 1 the JA method has better performance than DA method for nMTC $\geq$ 10k. Whereas by increasing λ , the performance of JA method decreases. However this method has a slightly better throughput than DA when a greater number of MTC devices arrive to RACH procedure. We then increased the H2H RA arrival rate to an unpractical case as $\lambda = 50$. As we can see in Fig. 5, JA method suffers from the huge number of H2H arrivals and it's even worse than DA with a smaller number of MTC devices. This is because with a smaller number of nMTC, the average number of RA attempts of M2M users per TS, n , with a Beta distribution normally does not exceed 30. So that as described earlier, with behavior of x , the throughput of M2M devices will decrease accordingly. Next three figures, Figs. 6-8, present the collision probability for M2M devices with RA arrival rates of H2H UEs, $\lambda = 5, 10, 100$. With $\lambda < 10$ and nMTC $\geq$ 20k, the JA method has approximately 12.5% better performance in reduction of collision for M2M devices in RACH procedure. Whereas, as expected in JA method, the probability of collision increases in comparison in DA method when RA arrival rates of H2H users is greater than 10. After distributing the users in the cell, using (24), we first determine the initial power consumption of each UE. In case the UE's RACH request in each TS collides, UE increments the No. of the retransmission counter k by one and selects the next two available RACH-TS to retry. Adding these kinds of backlogged users to the new arrived users in each RA-TS, the RACH procedure will continue. The power consumption of each user is a summation of its consumed power at first time and its any retries RA attempts. Fig. 9, shows the average of power consumption for MTC devices with JA method vs. DA method where $\lambda = 1$. To evaluate the results for different arrival rates of H2H RACH requests, we examined the performance of the JA method vs. DA method with λ lesser than 1 to 10. The details of saving energy for M2M RACH requests with the JA method in comparison with DA method are given in Table III. As it comes from the results, on an average JA method saves approximately 4% in energy consumption for the M2M devices in RACH process when $\lambda \leq 10$. That means in practical scenarios, in which the arrival rates of H2H RACH requests are below 10, JA method can perform better than the proposed method in 3GPP in terms of energy saving for M2M devices.

VI. CONCLUSION

In this work, we have analyzed and simulated a new scenario for preamble allocation in RACH procedure in LTE networks and compared its performance with known techniques disjoint allocation (DA) and joint allocation (JA) of splitting preamble strategies. We analyze and simulate the probability of collision, success and throughput performances of two approaches. Simulation and analysis show that our new JA scheme can achieve a better performance in saving energy for M2M devices in comparison to the proposed methods in 3GPP TR37.868. Our simulation results show that with the new scheme of JA method, under a specific RACH load of H2H and M2M connecting users, we can reduce the

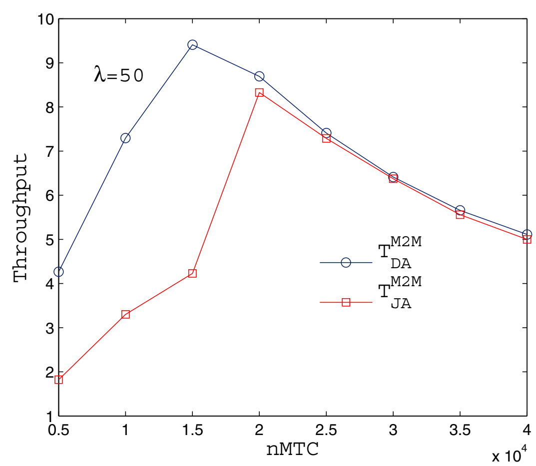

Fig. 5. Comparison of throughput performance for M2M devices in JA vs. DA

TABLE III. AVERAGE OF POWER CONSUMPTION REDUCTION PER MTC DEVICE (PERCENTAGE %) WITH JA- METHOD VS. DA- METHOD

nMTC / λ_{H2H}	5K	10K	20K	25K	30K	35K	40K
0.8	-0.06	0.41	0.08	7.07	3.9	2.9	2.2
1	0.76	0.002	6.57	4.4	3.2	2.36	1.39
10	0.68	-0.12	5.77	3.77	2.22	1.85	1.35

number of collisions and save the power consumption of M2M devices in the RACH procedure. This will help in saving power under bursty behavior of MTC devices and could be used as one of the MAC algorithm candidates for the future of cellular 4G networks.

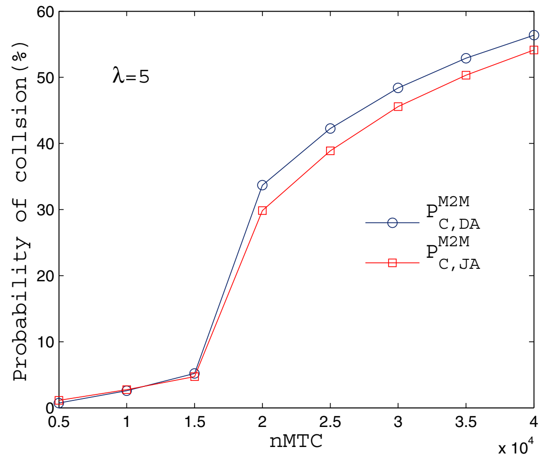

Fig. 6. Comparison of probability of collision for M2M devices in JA vs. DA.

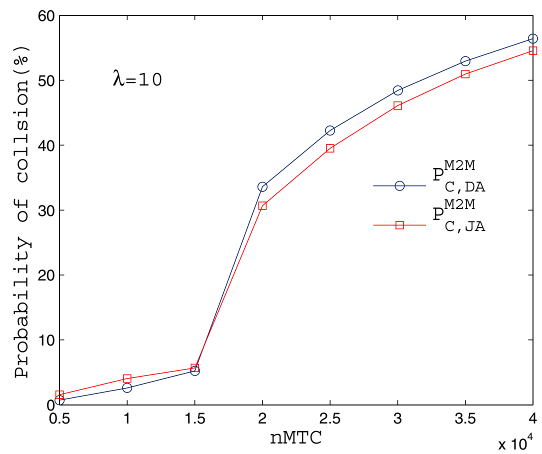

Fig. 7. Comparison of probability of collision for M2M devices in JA vs. DA.

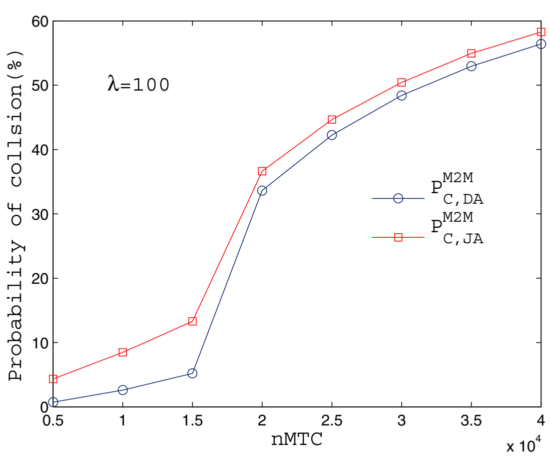

Fig. 8. Comparison of probability of collision for M2M devices in JA vs. DA.

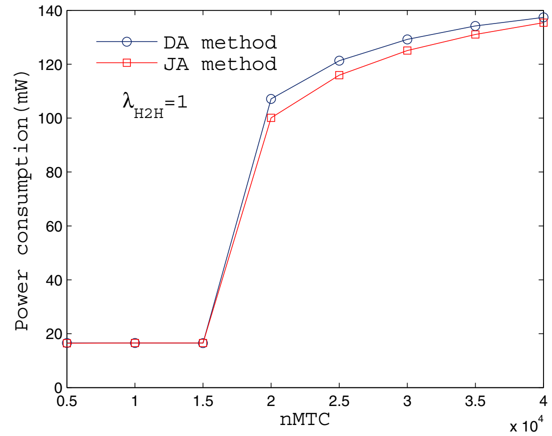

Fig. 9. Comparison of power consumption for M2M devices in RACH process with JA vs. DA method, $\lambda = 1$.

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