Impact of M2M Traffic in Random Access Channel over LTE Networks

Mariyam Ouaissa, M. Benmoussa, A. Rhattoy, M. Lahmer and I. Chana

Abstract Nowadays, humanity is surrounded by many technological devices that are connected to the Internet (sensors, smart meters, etc.). These devices can transmit and receive data automatically via interfaces for wireless transmission of data, thus generating Machine-to-Machine (M2M) traffic. This massive connectivity provides attractive new services, usually transmitting fragments of small data. This is especially true for Long-Term Evolution (LTE), which was originally optimized for users Human-to-Human (H2H). The main problem caused by the introduction of M2M applications is the congestion that occurs at the access network because of the tremendous number of devices that attempt to simultaneously access the network. This article provides M2M communication methods based on the 3GPP standard. In this paper we consider concurrent access to radio resources in a M2M/H2H coexistence scenario based on a dynamic random access algorithm for LTE network. This work studies the impact of M2M terminals massively and simultaneously attempting to have a random access to LTE. First, we emphasize the problem of resources sharing by MTC devices. Then we assess the impact of the introduction of M2M services on the performance of applications H2H according to throughput metric.

Keywords M2M · MTC · H2H · RACH · Internet of Things · LTE

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1 Introduction

Machine-to-Machine (M2M) is a trending concept that allows a huge number of machines to communicate independently via a network without human intervention. M2M allows the emergence of new services from different application areas such as transport, health, monitoring, and improving the human life. M2M was normalized in cellular networks Long-Term Evolution Advanced (LTE-A) by Machine-Type Communication (MTC) [1], their massive connectivity and ability to offer new interactive services, also raised significant challenges for managing a large number of devices, usually transmitting small fragments of data through wide range of emerging applications for the current cellular technology such as 3rd Generation Partnership Project (3GPP) LTE, which has been improved for the Human to Human (H2H) traffic. The community of 3GPP has been interested by various topics of study related to M2M communication.

LTE is the latest evolution of mobile telephony standards defined by the 3GPP. The network includes two parts: the radio access network Evolved UMTS Terrestrial Radio Access Network (EUTRAN) and the core network Evolved Packet Core (EPC). The base network EPC uses all Internet Protocol (IP) (Fig. 1) [2, 3].

Many challenges will face the operators of current mobile networks during the introduction of M2M applications for heterogeneous communication scenarios. The main problem caused by the introduction of these applications is the congestion that occurs at the access network because of the large number of devices that try to simultaneously access the network. The remainder of this paper is organized as follows. Section 2 introduces an overview of MTC in LTE Network. Section 3 explains the LTE random access procedure. Section 4 presents the impact of M2M in Random Access Channel (RACH) according to different metrics. In Sect. 5 we compare the throughput and collision probability of H2H and M2M Random Access. Finally, conclusions are retained for Sect. 6.

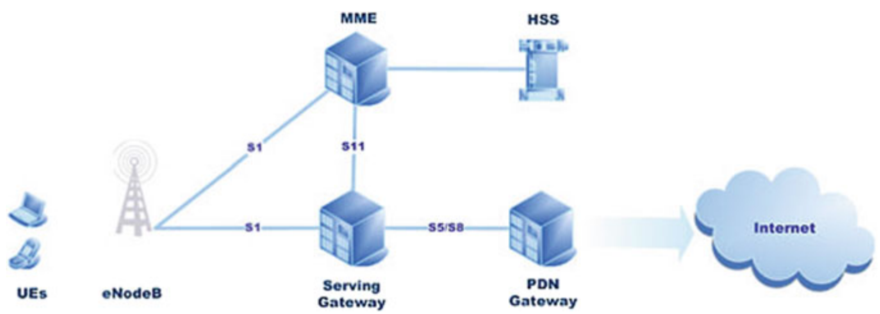

Fig. 1 LTE network architecture

2 Machine Type Communication in LTE Networks

Machine-Type Communication (MTC) is the communication between machines without human intervention. This occurred because of the remarkable increase in the number of devices that require a connection wireless network, giving a large difference in the ratio of number devices to that of humans. This means that devices will communicate autonomously, complicating the direct control of devices by humans. MTC devices can communicate through a wired or wireless network [4, 5]. Existing cellular networks are supposed to support a wide range of MTC communications. This is due to their existing architecture and support roaming provided by cellular networks and next-generation LTE, the most suitable networks for cellular MTC. However, cellular networks are mainly intended for the Human–Human communication (H2H), on the other side, the MTC communication has various features such as the huge number of devices, small data loads and the way traffic (principally uplink). These previous characteristics of MTC communications can cause an immense problem of congestion in the radio access of a cellular network.

3 LTE Random Access Procedure

A crucial requirement for any cellular system is the ability for the device to request the establishment of connection. This is known by the "Random Access Procedure." Random access (RA) is made not only during the initial access, but during the transition from inactive to active state and also after periods of inactivity in the uplink direction. The random access procedure is made of the following four steps (Fig. 2) [6, 7]:

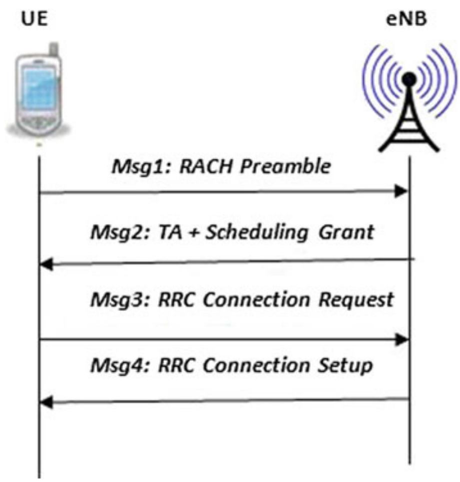

Fig. 2 EPS security architecture

- Step 1: "Random access preamble transmission" (Msg1): The first step is based on the transmission of a random access preamble, allowing the Evolved Node B (eNodeB) of the cell to estimate the transmission time of the terminal. Synchronization is necessary as otherwise the device cannot transmit data in the uplink direction. Therefore, the terminal selects a preamble and outputs it on the Physical Random Access Channel (PRACH).
- Step 2: "Random access response" (Msg2): In the second step, the eNodeB sends a synchronization message to adjust the terminal emission timing, depending on the measurement performed in the first step. In addition to synchronizing the uplink, the eNodeB also allocates resources to the terminal for use in the third step of the procedure.
- Step 3: "RRC Connection Request (Msg3)" during this third step, the terminal transmits its identity to the network using the UL-SCH (Uplink Signaling Channel). The exact content of this signal depends on the state of the terminal, in particular if the terminal is already known by the network or not.
- Step 4: "RRC Connection Setup (Msg4)" The fourth and final step is based on the transmission of the network's contention resolution message to the terminal on the DL-SCH (Downlink Signaling Channel). This step also resolves any contention caused by multiple devices trying to access the system using the same random access resource.

4 Impact of MTC on Random Access Channel

The RACH procedure was proposed long ago. We can find this procedure in the UMTS cellular technology, as in LTE. The paper [8] of 3GPP explains the approximation of collision probability of the RACH procedure. From this probability, the probability of transmission success and the probability of failure can be deduced. The RACH procedure approached the mechanism "Slotted ALOHA" because it is carried out within well-defined time slots: If a device tries to access the network in a slot time not specified for the RACH procedure, it will be prevented. Therefore, the calculation of the collision probability is similar to that of Slotted ALOHA mechanism. According to [9], the probability of collision is:

$$P_c = 1 - \exp\left(\frac{-\gamma}{L}\right) \quad (1)$$

With:

γ random access intensity (number of random access test/s/cell)
L Total number of RACH opportunities/s.

In [9], the author presents an analytical model to derive the probability of collision, the probability of success and the idle probability. In [10] the author analyzes the mathematical period of the RACH procedure, the probability of success, failure, all based on the definition of the collision probability given by 3GPP, also this article summarizes an analysis of average delay.

MTC is characterized by a massive number of MTC devices in a cell. Therefore, some or all of these MTC terminals may attempt to access the base station simultaneously using an uncoordinated random access. In order to evaluate the impact of MTC in RACH, we choose three metrics already defined in 3GPP standards [11]: the probability of collision, the probability of success, and the access delay:

- Collision probability: the probability that two or more MTC devices realize a random access test using exactly the same preamble for the set period of time.
- Success Probability: the probability of successfully completing the RACH procedure respecting the maximum number of retransmissions.
- Access Delay: the average delay for each RACH procedure between the first access trial and the end of the RACH procedure for MTC devices that have successfully accessed the network.

Figure 3 illustrates respectively the collision probability (a) and the success probability (b) for different number of preamble sequences available according to the number of competing devices trying to access the same resources.

We observed in the two figures that the increase in MTC devices competing for access to the same resources in a cell causes an increase of packet collision rate in Fig. 3a, resulting a decrease in the probability of success (Fig. 3b). The increasing of the number of preambles translated better performance of the collision probability and success probability.

Figure 4 represents respectively the throughput (a) and the average delay (b) for a mobile terminal, according to the number of MTC devices competing for different numbers of preamble sequences available.

In Fig. 4a, when the number of MTC devices competing in a cell increases, the throughput increases, but from a certain number of terminals, the throughput decreases, this is due to the fact that when the number of MTC increases the collision rate increases as well (Fig. 3a). If the random access fails after a collision, the MTC terminal must wait for some time before starting a new random access,

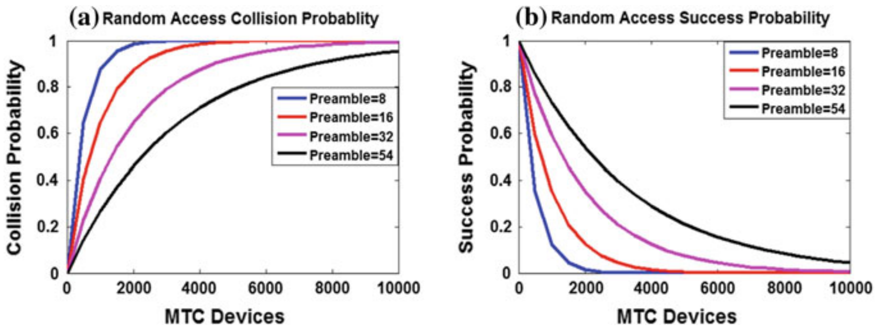

Fig. 3 Random access (RA) collision probability (**a**) and success probability (**b**)

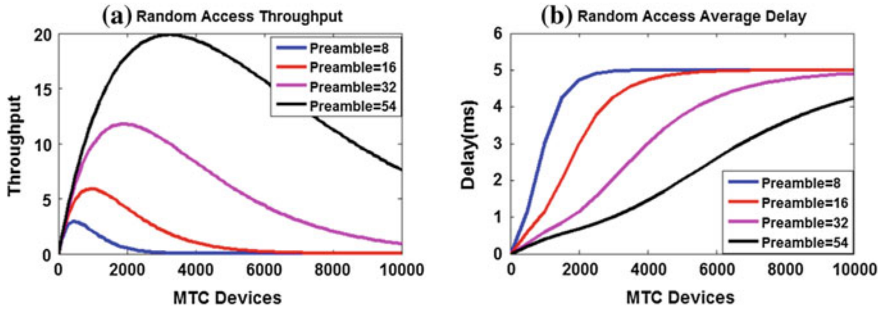

Fig. 4 Random access (RA) throughput (**a**) and average delay (**b**)

which introduces a latency of access to the channel and increases the size of the MTC queue requesting the channel and even causes an increase of the collision rate and the number of retransmission frames leading to a decrease in throughput.

In Fig. 4b, when the number of MTC devices in a cell increases, the access delay increases, when increasing the number of MTC rate of collisions increases, if the random access fails after collision, MTC terminal must wait for some time before starting a new random access, which introduces a large channel access latency (may be unacceptable for some real-time MTC) and increases the size of the MTC queue requesting the channel and causes the increase of the collision rate and the number of retransmission frames causing increasingly high-latency channel access. It is noted that increasing the number of preambles reflects the best performance of the access period.

5 Comparison Between M2M and H2H Traffics

The RACH throughput T, expressed by the arrival rate of RA attempts γ and the number of RACH opportunities S, is written as follows [12]:

$$T = \gamma . \exp\left(\frac{-\gamma}{S}\right). \tag{2}$$

The RACH throughputs for H2H and M2M, using Poisson [13] as an arrival process, are expressed by the following equations:

$$T_{\mathrm{H2H}} = \lambda_{\mathrm{H2H}} . \exp\left(-\frac{\lambda_{\mathrm{H2H}}}{(N-m)}\right) \tag{3}$$

$$T_{\mathrm{M2M}} = \lambda_{\mathrm{M2M}} . \exp\left(-\frac{\lambda_{\mathrm{M2M}}}{m}\right) \tag{4}$$

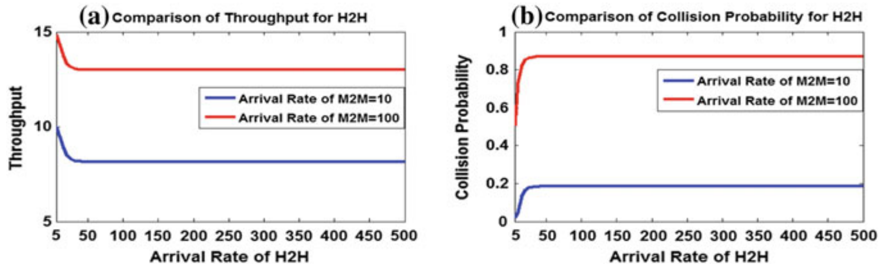

Fig. 5 Comparison of throughput (**a**) and collision probability (**b**) for H2H when λ_{M2M} = 10,100

Therefore, the RACH throughput is given by:

$$T = \lambda_{\text{H2H}} \cdot \exp\left(-\frac{\lambda_{\text{H2H}}}{(N-m)}\right) + \lambda_{\text{M2M}} \cdot \exp\left(-\frac{\lambda_{\text{M2M}}}{m}\right). \tag{5}$$

In this section, the throughput and collision probability of M2M and H2H communication are compared for different parameters values. We consider that the eNB affects 54 preambles for User Equipment (UE), to use H2H traffics can use one of 5 preambles, whereas M2M traffics can use one of the other 49 preambles.

Figure 5 presents RACH throughput (a) and collision probability (b) for H2H UEs according to the variation of the arrival rate of RA attempts of H2H (λ_{H2H}) with the arrival rate of RA attempts of M2M UE's (λ_{M2M}) is fixed to 10 and 100.

It is shown in Fig. 5a that we have a better throughput when the arrival rate λ_{M2M} is 100 compared to 10. In Fig. 5b it can be seen that we have a high-collision probability with M2M arrival rate λ_{M2M} = 100.

Figure 6a illustrates the variation of the collision rate based on the number of M2M devices competing in a cell for a number of devices H2H set, the collision rate increases. As it is shown in this figure, the M2M users experience less number of RACH procedure in collision with λ_{H2H} = 10 compared to 100.

Figure 6b presents the RACH throughput for M2M according to the variation of RACH arrival rate λ_{M2M} with arrival rate λ_{H2H} = 10,100. By increasing the arrival rate λ_{M2M} the throughput increases until 19 when λ_{M2M} = 80 in the case of arrival rate λ_{H2H} is 10.

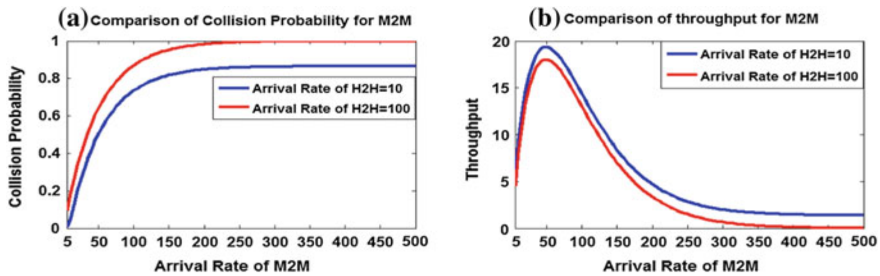

Fig. 6 Comparison of collision probability (**a**) and throughput (**b**) for M2M when λ_{H2H} = 10,100

In Fig. 6b, when the number of M2M devices competing in a cell increases for a fixed number of H2H devices, the throughput increases, but from a given number of terminals, the throughput decreases, this is due to the fact that, when the number of M2M increases, the collision rate increases as in Fig. 6a. If the random access fails after collision M2M devices must wait for a certain period of time before starting a new random access, which introduces latency access to the additional channel.

6 Conclusion

M2M communications are characterized by high density of the machine by cell unlike H2H communications. In this article, we considered simultaneous access to the radio resources in a coexistence scenario M2M/H2H. First, we have formulated the resource sharing problem by MTC. Then we evaluated the impact of the introduction of M2M services on the performance of H2H applications in terms of collision and throughput. We can conclude that the system performance degrades when the number of M2M devices increases, and these performances depend on the resource allocation between M2M and H2H.

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