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Abstract

Machine to Machine, (M2M) is an emerging technology in communication system and networking research area. It is also referred to as Machine Type Communication (MTC). The M2M communication is considered as an indispensable part of Internet of Thing (IoT). One of the major challenge of incorporating MTC devices into 5G Heterogeneous Network (HetNets) is to overcome the overload problem caused by the huge number of concurrent and ubiquitous access attempts of MTC devices. When differentiated M2M services coexist, such as emerging alerting and regular monitoring services, the problem becomes more and more complicated and challenging. This is because emerging alerting services are High – Priority (HP) services, they need to access to the Base Station within a short stipulated time frame Whereas regular monitoring services are Low-Priority (LP) services, they get much fewer chance to access the network. To conquer the problem, we propose an efficient Random Access Channel (RACH) mechanism for massive access of differentiated M2M services. Our solution aims at balancing the random access intensity among cells according to M2M traffic category. Simulation results were done for testing the effectiveness of our proposed mechanism and show that using a base station (BS) selection method and tacking into account differentiated M2M services can increase the access success probability and reduce overload as well as improve throughput while satisfying the load balancing between BSs.

1 Introduction

M2M communication is an emerging technology to provide ubiquitous connectivity among devices without human intervention [1]. MTC devices are increasingly becoming an integral part of our lives. Such devices are being used in varied applications such as smart cities, smart grids, energy monitoring, and health care [1]. M2M communications are expected to grow more and more during the next coming years, reaching 10.5 billion connections by 2019 [2]. Supporting efficiently such huge number of devices within current and future mobile networks (i.e. 5G Heterogeneous Network) is of a paramount concern for mobile network operators. Indeed, enabling full-automated devices comes including an increased number of devices requiring simultaneously establishing a connection to the access network (i.e. eNodB and small cell). This may result in severe overload and congestion problems between the different terminals attempting to access the network.

According to the comprehensive research [3], the MTC devices can be categorized into two types of traffic: Devices generated High-priority (HP) traffic, which can be dedicated to emergency alerting like health monitoring, fire monitoring. Devices generated Low-priority (LP) traffic, which can be dedicated to regular, monitoring like pollution monitoring, temperature monitoring. The HP devices are delay sensitive services, they need access to BS within a short stipulated time frame whereas the LP devices are delay tolerant services, they can tolerate several seconds or even minutes.

In 5G HetNets, available RACH preamble are limited and if billions of devices contend then they all stay in contention phase by colliding among themselves in every radio frame [4]. This becomes a challenge for an operator to enable more MTC devices under a single base station. To alleviate this problem, several schemes were proposed and studied. In [5] authors propose to separate RACH resources between Human-to- Human (H2H) and Machine Type Communication (MTC) devices, dynamic allocation of RACH resources according to channel load was defined in [6]. A Backoff Time was imposed to M2M equipment's in order to stop their transmission during a certain period of time. However, all of these solutions neglect M2M traffic type category and consider all MTC devices have the same priority even if it is emergency alerting and High- priority traffic.

To address the aforementioned problem, this paper proposes an efficient RACH mechanism. Our proposed mechanism is especially based on a method of Base Station selection, according to M2M traffic category. Simulation results show significant improvement in access success probability and achieves performance improvement in reducing delay especially for High-priority traffic.

The remainder of this paper is outlined as follows, in the next section; we will discuss some related works. Section III describes the traditional random access procedure in LTE- Advanced. In section IV, we will explain the proposed approach with details. Section V, a simulation framework is introduced and related results are analyzed. Section VI closes the paper with a conclusion and some perspectives.

2 Related Work

In this section, we discuss the existing RACH solutions for MTC devices. In [7] authors have proposed a special group based random access scheme. This solution is based on clustering of devices and each cluster has a cluster head. Instead of all devices contending with a macro BS for RACH, they contend only with other devices in the same special group. Special group resolves contention for devices under a group domain. There can still be preamble collisions among intra cluster and inter cluster devices.

In [8] authors investigate the use of small cells to support Random Access (RA) and the allocation of Zadoff-Chu sequences to small cells, which is used to generate preambles for RA procedure. Small cells can be deployed on demand to handle mainly RA loads from MTC devices. However, this mechanism use additional infrastructure to solve the problem and it increases the capital expenditure of the operator.

In [9] authors have proposed a q-array splitting algorithm to resolve collision among MTC devices. Their proposal includes new fields in MSG4, which instructs the colliding User Equipment (UE) to choose a preamble within a new confined set of preambles; also, it suggests a radio frame for UE to transmit the next RACH. The q-array tree grows until each UE gets a unique radio frame and preamble to transmit excluding the contention resolved UEs. In this mechanism, the BS assists UEs in resolving the contention.

In [10] authors have proposed a Fast RACH mechanism (FRM) that enables densely deployed MTC devices connect to BS in less time and with least power consumption. The devices are categorized into devices generated frequent data (DFD) and devices generated non-frequent data

(DNFD). In order to support the above two categories the authors came up with a few guidelines while selecting the parameters for RACH mechanisms.

Although aforementioned studies can reduce collision probability, they have mostly focused on limiting the number of MTC devices accessing to the BS simultaneously. Such approaches may inhibit large number of MTC devices from connecting to the network and cause long access delay and high-energy consumption. Furthermore, these approaches do not take the access intensity among base stations into consideration in order to guaranty Quality of Service and balance the network load.

Therefore, we propose a new efficient RACH mechanism for massive access of differentiated M2M services. We adopt an efficient Base station selection mechanism according to MTC traffic category based on delay requirement. Our solution obtains significant improvement in access success probability and achieves performance improvement in reducing access delay especially for high priority traffic.

3 Overview: RACH mechanism

RACH is used for associating a user to the BS. In LTE, each UE picks a preamble out of available preamble and transmit in the RACH slot of a radio frame. Say there is only one RACH slot per radio frame, in such a case collisions will happen if two devices pick the same preamble. The number of available preambles are limited and if multiple UEs contend, they will collide. If such a system has to be used for MTC devices deployed in millions under a single base station then the network will fail to associate the users. Therefore, there is a need for a procedure, which orthogonalizes the RACH transmission so that all the million devices can connect to BS.

Depending on the purpose, Random Access procedure can be either contention- free or contention-based. The first one is used especially in case of Handover in order to manage delayed-constrained access requests with high success requirements. This type of Random Access procedure is not much impacted by M2M traffic. Conversely, the contention- based random access procedure is much more sensitive to M2M traffic. In this paper, we focus only on the contention- based manner.

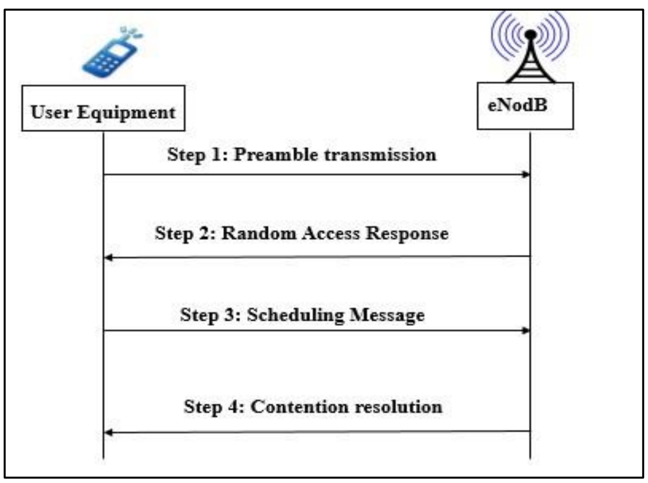

Figure 1: Contention-based RA Procedure

As illustrated in Fig.1 the contention-based RA procedure is composed of four signaling steps, which are more described in the following:

- Step 1 [Preamble Transmission]: The UE randomly chooses one of the preambles reserved for contention-based and transmits its request in the first available RA slot. In this case if two or more UEs select the same preamble in the same RA slot, a collision occurs and the corresponding requests will not be detected by the eNodB.
- Step 2 [Random Access Response (RAR) Transmission]: The UE waits to receive the RAR, which contains information such as a time alignment (TA) command to adjust the terminal transmit timing, and the resources on the Uplink Shared Channel (PUSCH resources) that have been assigned to UEs for the third step on the RA procedure.
- Step 3 [Scheduling message]: After receiving the corresponding RAR, the UE adjusts uplink transmission time according to the received TA and transmits a scheduled message on PUSCH. In this case, if more than one UE selects the same preamble in step 1, they will receive the same RAR and send their scheduled message on the same PUSCH. Therefore, multiple scheduled message are collided on PUSCH.
- Step 4 [Contention Resolution]: If the eNodB correctly decodes scheduled message from step 3, it transmits the contention resolution to the corresponding UE. In this case, if UE cannot receive the RAR message or contention resolution within corresponding timing window, it regards preamble transmission as a collision and reattempts RA procedure after a random back off.

4 Proposed Approach

This section firstly describes the system model. Then it presents the problem formulation. At last, the proposed algorithm is specially addressed.

4.1 System Model

The network architecture of M2M communications is depicted in Figure 2. We consider a 5G/HetNets, which is consist of a single Macro Cell (eNodB) with a number of Small Cells (HeNodB) inside its coverage area. We assume that these small cells are operating in out band configuration; they are independent from the macro cell and have their own radio resources. The MTC devices are densely deployed over the network.

As shown in Figure 2 the Device deployed in 5G/HetNets may be located in the overlapped area overlapped area and therefore send Random Access (RA) requests to more than one Base Station (BS). In our case a BS can either be a Macro Cell or a Small Cell. Clearly, the massive access of MTC devices to the BS forms the major bottleneck and overload in M2M network, which therefore, are the focus of the work. Meanwhile, the appropriate BS selection method to help reducing congestion probability, access delay as well as improve throughput becomes very important, which is the work conducted in this work.

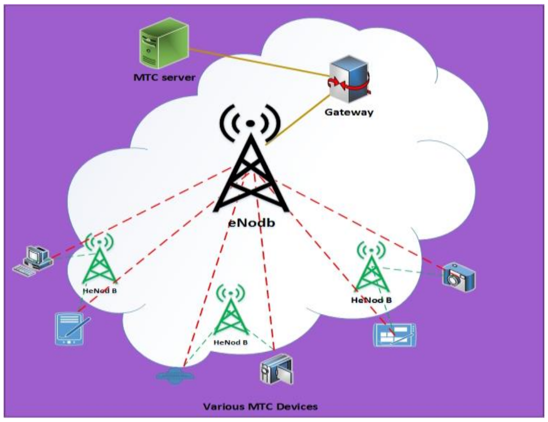

Figure 2: System Model

- Problem Formulation

Our proposed scheme solves the RAN overload problem in the scenarios of the co-existence of High-Priority (HP) and Low- Priority (LP) traffics. Generally, in a 5G Ultra Dense Network each UE sends RA request to its neighbor BS in order to synchronize with the network. The BS validates this request and if successful, it grants some uplink channel to the UE. The MTC device employs similar procedure.

MTC devices are deployed all over the network. In Fact, they can send RA requests to more than one BS. Figure 3depicts a network model in which overlapping areas exist. This environment is the focus of this work to develop an analytical model.

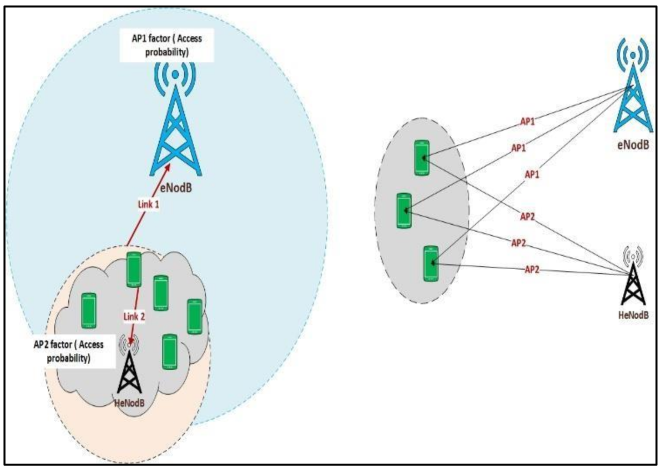

Figure 3: Network Model

Thus in order to guaranty QoS and balance the network load, it is necessary to adopt an efficient base station selection method when a large number of MTC devices initiate RA procedure. The success probability of preamble transmission of a device is defined as:

$$\mathrm{P(D)} = e^{-\gamma/N} \qquad (1)$$

Which γ represents the arrival rate and N represents the number of devices accessing to the network. This probability of success is equivalent to P (D|BS). This means this means the probability of MTC given a particular base station, here; D represents the vector of MTC devices.

The device can choose any surrounding BS. We consider that all the prior probability of all base station will be the same. If there are ϕ base stations covering the area, the prior probability will be:

$$P(BS1) = P(BS2 = \cdots P(BS\varphi) = 1/\varphi \ (2)$$

The objective function of selecting an appropriate BS is to increase the throughput of the base station. To achieve this objective, the BS selection probability will be maximum as the success probability, which can be estimated as:

$$P(D|BS) = \frac{P(D|BSi) * P(BSi)}{P(D)} \qquad (3)$$

Where P (D) is formulated as:

$$P(D) = \sum_{i=1}^{\varphi} \sum_{j=1}^{N} P(Dj|BSi) * P(BSi) \qquad (4)$$

4.3 Proposed Algorithm: Novel RACH mechanism

Our proposed RACH mechanism integrates the BS selection method and takes into consideration tow type of traffics. Figure 4. Shows the flow diagram of RACH mechanism. This method works as follow:

- Each BS estimates the access probability (D|BSi) based on the packets arrival rate and its transmission rate.
- Step 2: Every BS periodically broadcasts the access probability
- Step 3: Each MTC device or group of MTC device selects the BS based on the maximum as posterior probability (BSi|D). In Fact, the equipment can identify the category of traffic before getting access to the network; if this category is High priority type with delay sensitive then it has a priority to select the appropriate base station. Else if the this category is Low priority type with delay tolerant then before selecting the appropriate base station it can waits for T radio frame. Where T= 10ms which represents the duration of each RACH slot.

After selecting the appropriate base station, the MTC device is ready for sending the preamble and waiting for the random access response from the base station.

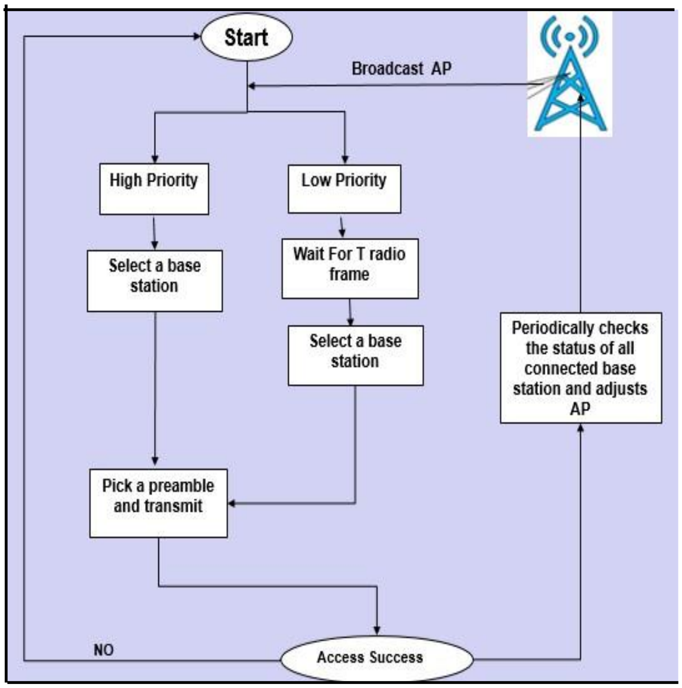

Figure 4: Proposed Algorithm

5 Performance Evaluation

In this section, we firstly describe the key performance metrics in order to evaluate the effectiveness of our proposed approach then we give the simulation results and interpretations.

5.1 Performance and evaluation metrics

In this sub-section, we evaluate the performance of the proposed scheme. The first step is to determine the appropriate base station selection from which will depend all the access process, the access success probability, this for all the considered traffic classes high priority and low priority. Hence, the determination of these parameters should be done according to the QoS requirements of each class. In fact the evaluation metrics used in this work are:

Access success probability: is the ratio between the numbers of devices successfully completing RA procedure and the total number of available devices.

Collision probability: The collision probability is defined as the ratio of collided preambles to the total number of available ones.

Average Access delay: is the ratio between the total access delay time of devices (the time of the first access attempts of RA procedure until the successful completion of RA procedure) and the total number of devices successfully completing the RA procedure.

Throughput: It is the number of RA attempts that can be served by the system per second. For a Poisson arrival process, the RACH throughput is depended of the arrival rate and the number of RACH opportunity. We assume that the number of opportunities is equivalent to the number of preambles.

5.2 Results and interpretation

In order to verify the performance of the proposed approach, we consider a 5G/HetNets that is served by a macro cell and a number of small cells surrounding and there is distribution of network load between these cells. Then, only MTC devices are considered in the serving cell and the arrival random access attempts follow a beta distribution.

We assume that all preambles are available for use by the MTC devices except the dedicated preambles. The macro cell will always have enough resources to deal with requests for devices that successfully passed through the first three steps of the random access procedure. The different simulation parameters are grouped in the table I [6], [7], and [8].

Parameter	**Value**
MTC traffic model	Beta (3,4)
Maximum number of Devices	10000
RA slot per frame	2
Arrival rate attempts ( )	20
Number of Small cell per Macro cell	15
Total number of preambles	64
Bandwidth	20Mhz
Radio Frame duration	10 ms

Table 1: Simulation parameters

We evaluate the performance of the proposed approach with regard to Access success probability, Average access delay and throughput compared to the conventional RACH procedure. We have used MATLAB environment to implement the simulation and evaluate it.

Figure 5 shows the probability of success access in which the devices are able to make successful connection verses the total number of contending devices. Both the schemes have similar performance when the number of MTC devices are few but performance of the conventional

RACH is observed to deteriorate so fast as the number of devices increases. In the case of our proposed approach, the performance is observed to be invariant after some threshold (increase in number of MTC devices) which is higher than that of the conventional RACH. This enables our proposed approach to guarantee better performance even during massive access requests, thus ensuring that all devices get a connection at a bearable cost of delay (as shown in the case of Figure 4). The exhibited low performance in the conventional RACH is due to inability of RACH to support massive concurrent requests leading to many backlogged machines, which either back-off completely or keep retrying to establish a connection.

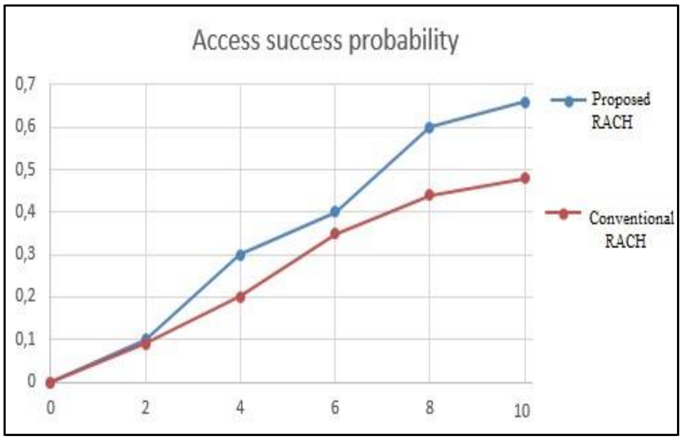

Figure 5: Access success probability

The results in Figure 6 shows the total number of contending devices verses the Throughput. As expected, the average access delay decrease with the number of simulations contending devices.

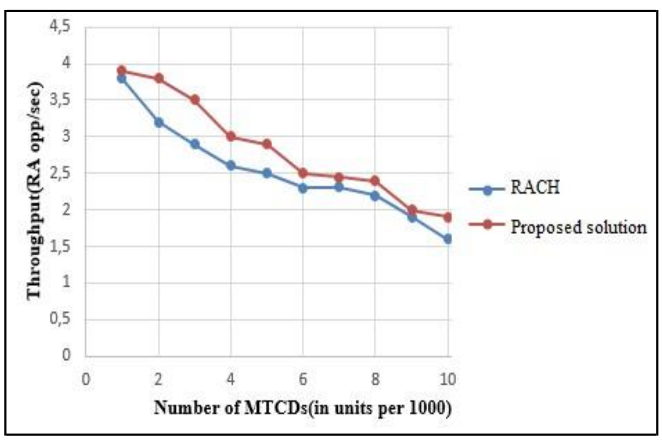

Figure 6: Throughput

Using the access delay as a metric in taking measurements. Figure 7 shows the performance of the RACH Procedure and the proposed solution. Expectedly, there is a marked improvement in access delays with MTC devices being able to access the network as fast as using the proposed solution based on load balancing.

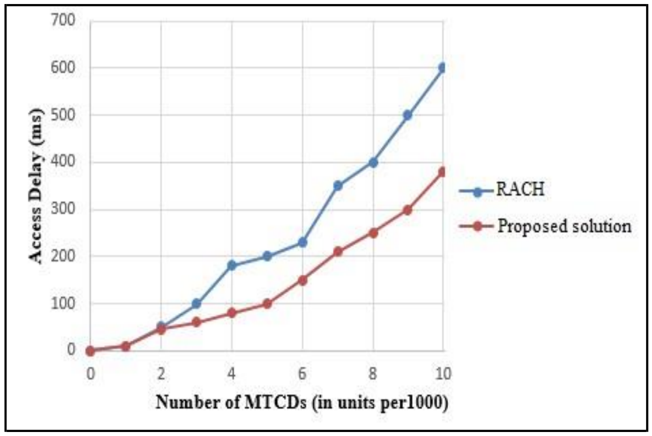

Figure 7: Access Delay

6 Conclusion and Perspective

In this paper, we firstly presented the RAN overload issue caused by massive MTC devices attempting to access the Base Station in 5G/HetNets. As for the scenario where High-priority and Low-priority traffics coexist. We then point out the asymmetric random access intensity problem in a heterogeneous network. We finally proposed a novel RACH mechanism to jointly guarantee the RAN overload requesting from differentiated services. Simulations tests were done in order to show the effectiveness of our approach. We conclude that using a method of base station selection and take into consideration differentiated M2M services with respect to delay requirement increases the access probability especially for HP traffic and reduce overload as well as improve throughput while satisfying the load balancing between BSs.

In future work, we propose to apply an access control method in order to reduce Radio Access Network congestion, thus guaranteeing an optimal number of MTC devices contending through Random Access.

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