Service Differentiation Strategy Based on MACB Factor for M2M Communications in LTE-A Networks

Nawel Zangar [1,2]
nawel.zangar@insat.rnu.tn

Sami Gharbi [2]
sami.gharbi.88@gmail.com

Marwen Abdennebi [3]
marwen.abdennebi@univ-paris13.fr

[1] Mediatron Laboratory Higher School of Communications, Sup'Com Tunis Tunisia

[2] Faculty of Science of Tunis, FST Department of Computer Sciences Tunisia

[3] Laboratoire de Traitement et de Transport de l'Information, Université de Paris Nord, Sorbonne Paris Cité, France

Abstract – **One of the promising technologies which is being regarded in the future 5G standard long Term Evolution (LTE) Release 13 is Machine-to-Machine or M2M communications. It represents a key component of Internet of Things (IoT) and smart spaces. One of the most difficult challenges to support M2M communications is their huge number compared to available radio resources. Hence, to deal with random access channel (RACH) overload and to better control the access in LTE-A Networks, the 3GPP proposed the Access Class Barring (ACB) factor concept. In this paper, we proposed an algorithm to improve this method based on adaptive multiple ACB factors, according to M2M traffic category with respect to their access delay budget and drop rate (QoS parameters). Simulations were done for testing the effectiveness of our MACB scheme and show that using multiples ACB factors and dynamically adjusting them to the congestion level in addition to traffic type category increases the access probability and reduces overload. The obtained results were then compared to the basic ACB method and show that the access probability increases especially for high priority traffic.**

Keywords – **M2M, MACB, LTE-A, RAN Overload, QoS**

I. INTRODUCTION

Internet of Things is a large concept, which will evolve from M2M in addition to many other technologies. The main objective of IoT is to define the interaction of smart object with the environment. M2M communication is a key component of IoT and smart spaces since it defines the underlying technologies for an end to end communication between different connected devices in various environments, wireless or wired, and for various applications and services [1][2].

M2M devices use mobile network resources to communicate with remote application infrastructure for the purposes of monitoring and control, without or with limited human intervention. Supporting M2M communications in mobile network and especially in LTE-A network is a big challenge to deal with. Indeed, M2M applications are very different from classical mobile uses, since they present a high signalling traffic causing a potential network congestion and overload.

To overcome congestion caused by M2M devices in LTE-A networks, many control mechanisms were proposed [3][4][5]. In [6] 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 [7].

A Backoff Time was imposed to M2M equipments in order to stop their transmission during a certain period of time. In [8] Access Class Baring (ACB) procedure based on an access probability factor was detailed. The value of ACB factor will be adjusted depending on M2M traffic load. When congestion level is very high, ACB factor will be set to a low value, hence a few number of M2M devices will access channel, so congestion will be reduced significantly. However, ACB factors method neglect M2M traffic type category and consider that all messages have the same priority even if it is emergency alerting and high priority traffic.

In this paper, we proposed adaptive solution to differentiate three traffic priorities and improve the previous ACB method. We proposed Multiple ACB (MACB) algorithm which defines multiple ACB factors according to M2M traffic priority (high, medium and low). These barring factors are generated by a single eNodeB or by multiple ones that cooperate to jointly decide on the barring factors values [9][10]. Our goal is to decrease congestion level without affecting the access delay especially for high priority traffic.

The remainder of this paper is organized as follows. In section II, we give an overview of RAN overload control mechanism, focusing on ACB approach as it is our main concern. In section III we define our adaptive MACB algorithm. In section IV we detailed the simulations test along with the performances analysis. Finally, Section V concludes our work and gives a description of perspectives.

II. BACKGROUND

A. Random Access Procedure in LTE-A

In LTE-A networks, the Random Access procedure can be either contention based or contention free. To get access to the network, this procedure is mandatory whether for UE equipment or MTC devices [11] [3GPPTS-36.211]. M2M devices commonly operate in contention manner to access channel.

The contention-based Access is a four step procedure, where messages are exchanged between M2M devices and eNodeB.

1. **Random Access Preamble Transmission (msg1)**: it consists in choosing randomly a preamble (sequence of code) by MTC equipment, then transmitting this preamble through the Physical Random Access Channel (PRACH) [12] as a request to get time-frequency resource block. When two or more M2M devices send the same preamble a collision occurs.
2. **Random Access Response (RAR) (msg2)**: in this step the eNodeB allocates a time alignment instruction according to the preamble sequence then acknowledges all the preambles that have been received and assigns uplink resources to the M2M equipment to be used in the third step of the random access procedure. So, if two or more M2M equipment choose the same preamble sequence in the first step they will be instructed to transmit their IDs in the same time-frequency resource block in Step 3 and then a collision will happen.
3. **RRC (Radio Resource Control) Connection Request, (msg3)**: the M2M equipments will use uplink resources UL-SCH (Up Link Shared Channel) to transmit their IDs after receiving the acknowledgement and by using the time-frequency resource block designed by the eNodeB.
4. **Contention Resolution, (msg4)**: a contention resolution message will be sent from the eNodeB to MTCs using the DL-SCH (Down Link Shared Channel) with the IDs of MTCs successfully decoded. This step also resolves contentions provoked by multiple terminals using the same preamble in the first step to access the system. Meanwhile, if a collision occurs, the eNodeB will inform the MTCs which Step 3 message are successfully decoded and this MTCs equipment will send an acknowledgement. If the MTC ID is not included in the contention resolution message, then a collision has occurred.

The RACH procedure is considered finished only when both msg3 and msg4 are successfully received.

B. *RAN Overload Control Mechanism*

The 3GPP, proposed many solutions to overcome congestion in LTE-A network due to massive access of M2M devices [13][14][15].

A Separation of RACH resources between MTC devices and Human to Human (H2H) devices was proposed in [16]. In [17], a dynamic allocation of RACH resources was proposed, where eNB may allocate additional resources for MTC devices in case of a huge load. Another proposition is to delay the RA re- trials by setting the backoff time to a large value. Authors in [2] proposed to group the MTC devices to reduce redundant signaling and hence congestion. Another approach based on Access Class Barring scheme (ACB) is used for barring or not the access to MTC devices. In the next, we will explain ACB method in detail, as our solution is based on.

C. *ACB procedure*

The ACB procedure is considered to be one of the most efficient method to prevent congestion and RAN overload.

The ACB principle consists in sending a barring probability p in [0, 1] by the eNodeB to all M2M devices who want to access channel.

The M2M device proceeds to the random access procedure by choosing randomly a number q in [0, 1]. It can access the network if q is less than the Barring factor p else the device is barred for a barring time duration [8].

In [18], ACB factor was adjusted dynamically based on traffic load, they adopt an adaptive scheme, rather than using fixed ACB factor.

A lot of research has been proposed to adapt ACB factor, but so far no research has been done to adapt ACB factor to the category of network traffic. The latter is the subject of our proposition called "Multiple ACB factors" MACB.

III. MULTIPLE ACCESS CLASS BARRING FACTORS ALGORITHM

The MACB algorithm consists of two parts, the first one is to change equipment's behavior to allow them sending an indicator of congestion for each type of traffic according to its priority; hence we define a "Smart M2M" device; The second part is to generate several ACB factors each related to a different category. Three priority level was fixed (high, medium, low) according to access delay sensitivity and hence to the carried application type.

In order to choose those factors (or the appropriate factors), the eNodeB can individually decide of the appropriate ACB factors or consults several eNodeBs to generate ACB factors in a cooperative way [9][10], hence achieving more stabilization.

A. *Equipment's behavior*

A congestion indicator can be included in msg3 of RACH procedure which helps eNodeB to define the congestion level in the network, this has been proposed in [5]. Our idea, however, is suggesting an indicator to each traffic category. Hence equipment's behavior can be adapted to three types of categories which are:

- High priority traffic (HP): This category is dedicated to the emergency alerting.
- Medium priority traffic (MP): This category is dedicated to different H2H and MTC like conversational voice, mobile streaming, video, browsing, and file transfer.
- Low priority traffic (LP): This category is dedicated to regular monitoring.

In fact the equipment can identify the category of traffic before getting access to the network. If this category is a HP type then it will follow a behavior dedicated to this category which starts by setting a counter named $\alpha 1$ which is the number of repetition time by the equipment to transmit the preamble in the first step of procedure RACH, so after sending the preamble, the UE increases the number of transmission times α1 by one and waits for random access response (msg2) from the eNodeB.

Once the random access response in the RAR window is received, the MTC is ready for sending RRC Connection Request (msg3). If the MTC fails to receive random access response in the RAR window (that means that the eNodeB fails to find the preamble from the UE), then the UE randomly chooses a time slot for preamble retransmission based on the value of Backoff Indicator. Otherwise, the UE will be informed of RACH procedure failure and should report the random access failure to the higher layer. If the category is MP or LP type then before transmitting the preamble an ACB verification should be done, in fact the preamble of MP type will be compared with a factor named P1 dedicated from the eNodeB before starting the RACH procedure and the preamble of LP type will be compared with another factor also dedicated from the eNodeB named P2.

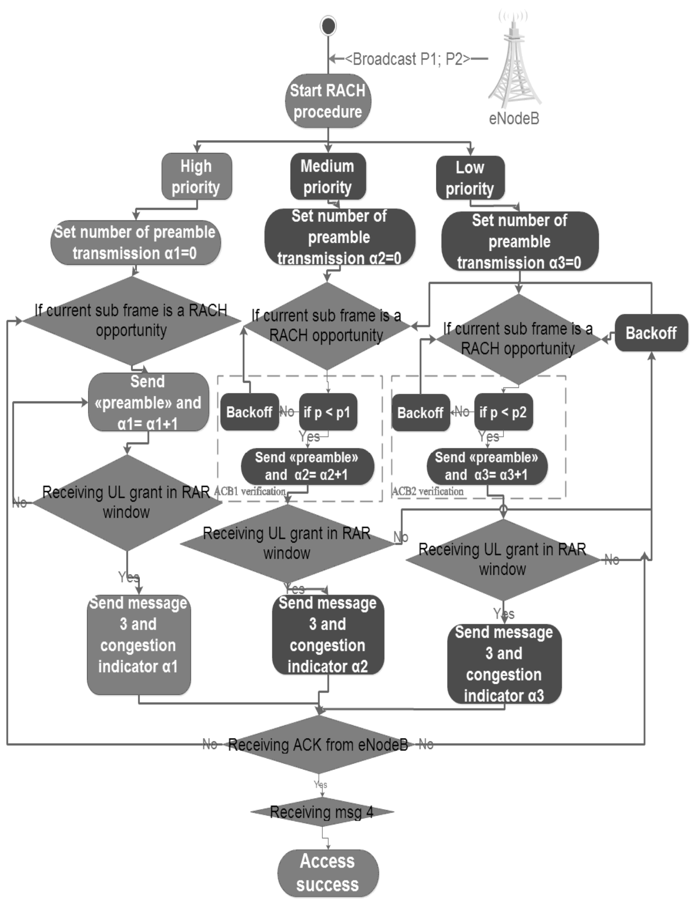

Figure1. Equipments Behavior

Then two counters named α2 and α3 are assigned respectively to MP and LP traffic type. Those counters are the number of repetition time by the equipment to transmit the preamble in the first step of procedure RACH, so after sending the preamble, the UE increases the number of transmission times, α2 or α3, and after this verification the same patterns will be repeated as for the HP type. All this procedure is explained in the figure 1.

B. MACB factors Algorithm

After receiving the previous indicators (α1, α2, α3), eNodeB can estimate the level of congestion and adapt ACB factor for each category and finally broadcast those new ACB factors to prevent congestion in the next PRACH slot. We propose to generate two ACB factors named P1 and P2, the first one is dedicated to medium priority traffic (P1, MP), and the second one is dedicated to low priority traffic (P2, LP). No verification needed for high priority traffic. Our algorithm is described below.

```
BEGIN
    S1=0, S2=0, S3=0
    WHILE PRACH THEN
        Receiving overload indicator
        IF α1 THEN
            S1=S1 + α1
        ELSE IF α2 THEN
            S2=S2 + α2
        ELSE
            S3=S3 + α3;
        END IF
    END WHILE;
    IF S1 > Th1 THEN
        ACB1 ← minimum value
        ACB2 ← minimum value
    ELSE IF S2 > Th2 THEN
        ACB1 ← minimum value
        ACB2 ← average value
    ELSE IF S3 > Th3 THEN
        ACB1 ← average value
        ACB2 ← average value
    ELSE ACB1 ← 1 and ACB2 ← 1;
    END IF
    Broadcast P1 and P2;
END
```

In first step, the eNodeB sets three counters (S1; S2; S3) to zero, in fact S1 is a counter that gathers all the factors α1, that are received from different MTCs equipments with HP traffic category, into each PRACH slot. S2 gathers α2 and S3 gathers α3. When PRACH starts after receiving those overload indicators (in Msg3), if the indicator is HP then S1=S1+α1 (α1 is the indicator for HP type), if it is MP then S2=S2+α2 (α2 is the indicator for MP type), and if it is LP then S3=S3+α3 (α3 is the indicator for LP type). If the process is not finished, the same patterns will be repeated.

Once the process is finished, S1 value will be compared with threshold, named th1. If the S1 value exceeds th1, that means that the level of congestion in HP category is very high, thus the P1 and P2 factors must be decreased to a minimum value to prevent heavier traffic load of MP and LP traffic type in the next PRACH slots, when trying to access the network. Hence, the decrease of P1 and P2 will then increase the probability of success of the HP type.

In the other hand, if the value of S1 is less than th1, then the value of S2 will be compared with th2 (threshold 2). If the value of S2 exceeds th2, this means that the level of congestion in MP category is very high and then P2 will be in a minimum value to prevent LP traffic type equipments from accessing the network and P1 will be of a maximum value. So equipments with MP traffic type have the maximum probability of success in the next PRACH slot.

If the value of S2 is less than th2, the value of S3 will be compared with th3 (thershold3). If it exceeds th3 then the factors P1 and P2 should be fixed to allow some of the LP traffic type accessing the network with the HP and MP traffic type thus guarantee some fairness

Otherwise, this means there is no congestion in the network, hence factors P1 and P2 values will be fixed to one, so no verification needed for MP and LP traffic type. The final step will be the broadcast of P1 and P2 values by the eNodeB.

IV. PERFORMANCES ANALYSIS AND NUMERICAL RESULTS

A. *System Analysis*

In this sub-section we evaluate the performance of the proposed adaptive MACB algorithm. The first step is to determine the appropriate parameters P1 and P2 from which will depend all the access process, the collision probability, this for all the considered traffic classes, HP, MP or LP. Hence the determination of these parameters should be done according to the QoS requirements for each class, i.e., for each application belonging to this traffic class.

The access probability P_{acc} increases proportionally to the ACB factor so if P is set to a lower value, the access probability will decrease and a limited number of MTC devices can pass the ACB check, hence the access delay will increase. However, if P is set to a high value this leads to congestion and overload. Thus it is very important to adapt ACB factors value to traffic load in addition to their QoS requirements.

In this section we will give a general methodology to explain how this process should be undertaken. We will consider only the HP class as this is the most important in term of QoS requirements, for example drop rate and of course delay. We will then compute the average packet drop rate P_d and the mean delay T_m according to P1 and P2 parameters and also according to the traffic load.

It is simple to guess that those values depends on the number of collisions in the PRACH, the more collision we have, the higher will be the number of transmission attempts and hence the access delay. The same for the drop probability as a drop will happen once the number of transmission attempt reach the maximum limitation N_{max} as given in [2]. The collision probability itself depends on the total number of flows competing in the PRACH, and on the PRACH itself, i.e., the number of preambles $N_{preambles}$ given in [9].

It is then clear that the first value to compute is the collision probability P_{coll} for HP traffic. If we consider a full buffer for the equipment and depending on the number of active traffic flow in each category, N_{HP}, N_{MP}, N_{LP}, respectively for HP, MP and LP categories, this probability becomes:

$$P_{coll} = 1 - P_{acc}$$

$$P_{coll} = 1 - \left(1 - \frac{1}{N_{preambles}}\right)^{Neq-1} \qquad (1)$$

Where Neq is the average equivalent number of flows in the system:

$$N_{eq} = \lceil N_{HP} + p1 N_{MP} + p2 N_{LP} \rceil$$

The average delay T_m depends also directly on the duration *T1* of the *PRACH* procedure as well as from the duration *T2* of reattempt in case of collision. This mean value T_m is computed through the expected value.

$$T_m = E[T] = \sum_{k=1}^{N\max} (T_1 + k.T_2).(1 - P_{coll}).P_{coll}^k \qquad (2)$$

Finally, the packet drop rate depends only on N_{max} and the collision probability P_{coll}.

$$P_d = (P_{coll})^{N_{\max}+1} \qquad (3)$$

We give an example below for the strategy to adopt for the parameters adjustments. We choose a number of flows equal to 100, with 10 HP, 40 MP, and 50 LP flows. The value for T1 and T2 are taken from [2] and [9] and are approximated to about 17 and 9 ms respectively. Actually they are computed through the complete PRACH procedure, including the RAR, contention resolution process and of course the mean backoff time in case of collision for T2 computation. Then, the obtained results for the mean access delay and the drop rate are given in figure 2 and figure 3 respectively.

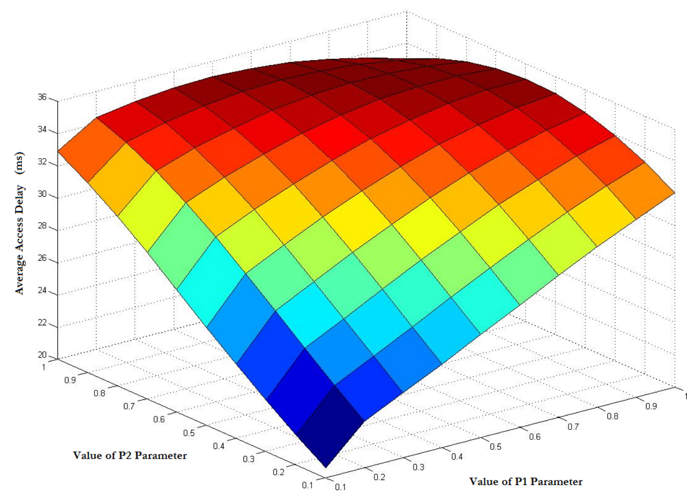

Figure 2. Average access delay according to P1 and P2 parameters

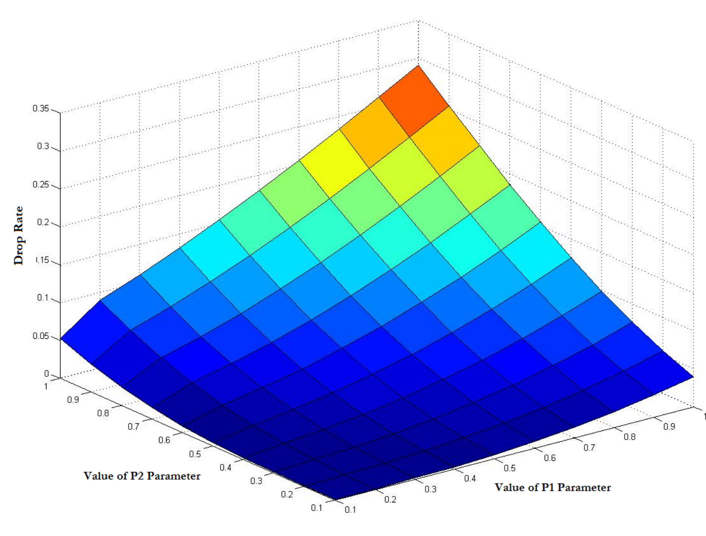

Figure 3. Packet Drop Rate according to P1 and P2 parameters

From the figure 2 and figure 3 above, we can easily see that drop rate and mean access delay values increase with the probabilities parameters p1 and p2. This is obvious as from these values the MP and LP traffic in the air interface is adjusted and hence the contention and collision rates for HP.

The most important information from those two figures is that we are able to determine the appropriate value of P1 and P2 parameters for a considered QoS threshold. For example, if the QoS threshold is 25 ms for average access delay and 1% for the drop rate, the appropriate configuration in our case for the MACB parameters will be:

$$\textit{QoS Threshold}\begin{cases} T_m = 25\text{ms} \\ P_d = 1\% \end{cases} \Rightarrow \begin{cases} P1 = 0.3 \\ P2 = 0.5 \end{cases}$$

Once we can dynamically adjust MACB parameters according to the QoS requirements (drop and delay), we propose to validate our proposal through simulation in the sub-section below.

B. Simulation Results

Simulation tests were done using Network Simulator NS3 [19]. The impact of the number of M2M devices on access probability for every PRACH must be tested and we will illustrate the importance of traffic differentiation and its impact on access probability.

In order to evaluate our proposal, we defined three scenarios. In the first one, the congestion was considered on "HP" traffic category, in the second one the congestion was considered on "MP" traffic category and finally we simulate congestion on LP traffic category. The three thresholds th1, th2, and th3 were obtained using experimental tests, so the tune of the optimal threshold was empirically. This gave the following results: th1 = 30, th2 =70 and th3 =100.

We consider the following parameters:

- S1=Access attempts for « HP » traffic.
- S2=Access attempts for « MP » traffic.
- S3 = Access attempts for « LP » traffic.

Figure 4 shows the access percentage (or rate) of M2M traffic (first scenario); where congestion is happen on HP traffic category. For HP traffic, the access percentage without MACB is equal to 13.33% and increase to 73% when applying our method. However, no improvement is possible for MP (from 10% to 11%) and LP (from10% to 7%) traffics.

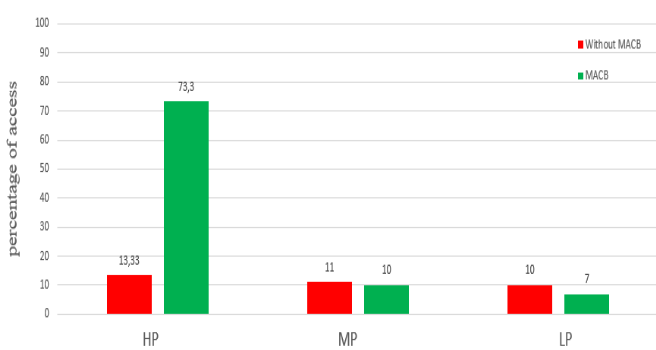

Figure 4: ACB vs MACB Algorithm «HP congestion»

Figure 5 shows the access percentage for the second scenario; where congestion is happen on MP traffic category. For HP traffic, the access percentage without MACB is equal to 35% and increase to 65% when applying our method. For MP traffic, the access percentage without MACB is equal to 22% and increase to 37% when applying our proposition. However, congestion increases and access percentage decrease from 17% to 6% for LP traffic, this is due to the low value of P2 factor, in order to reserve more resources for MP Traffic.

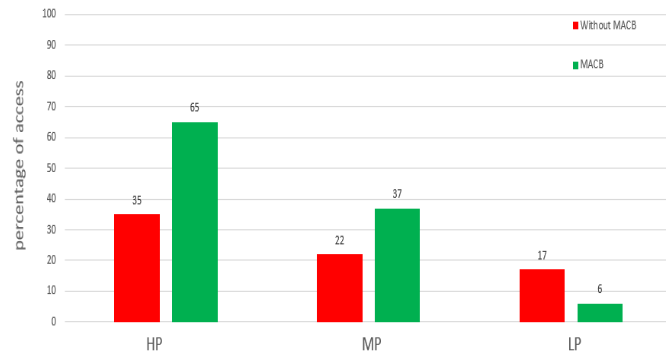

Figure 5: ACB vs MACB Algorithm «MP congestion»

In the last scenario (Figure 6), Congestion is considered on LP traffic category. For HP traffic, the access percentage without MACB is equal to 25% and increase to 55% when applying our method. For MP traffic, the access percentage without MACB is equal to 23.33 % and increase to 25% when applying our proposition. Congestion decreases for LP traffic and access percentage increases from 22.72 % to 27.7 %.

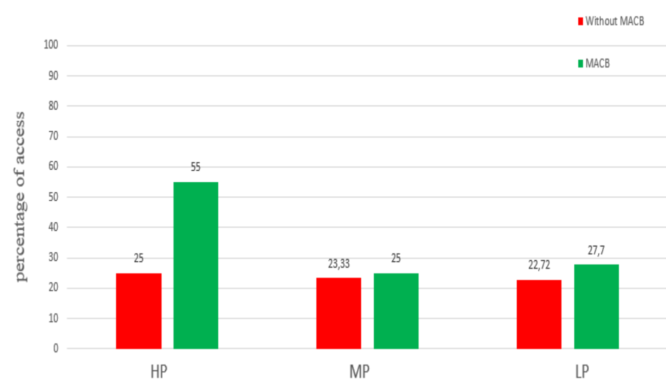

Figure 6: ACB vs MACB Algorithm «LP congestion»

We can observe that our proposed adaptive MACB algorithm makes possible to dynamically control the channel access probability (or percentage) for each considered traffic category. This means that according to *p1* and *p2* parameters and according to the traffic demand in the air interface (number of applications/flows and their bitrates), we are able to guarantee the QoS requirements for HP flows, and to a lesser degree for MP category. The adjustment of parameters *p1* and *p2* according to these QoS requirements is done through the calculation of packet drop rate and access delay (as explained in sub-section *A.*).

V. CONCLUSION AND OUTLOOK

In this paper, we present an adaptive multiple access class barring factor algorithm, according to M2M traffic type category. The defined barring factors, P1 and P2, were adjusted according to influent performance parameters: the access delay budget and the drop rate, with respect to QoS requirement. Simulations test were done in order to show the effectiveness of our approach. We conclude that, using multiples ACB factors, and dynamically adapt them to the congestion level and traffic type category increases the access probability especially for HP traffic and reduces overload.

In future work, we propose to apply analytical fluid-based random access model for MTC devices [20] to find an optimal value of MACB factors, thus guaranteeing an optimal number of M2M devices contending through Random Access.

REFERENCES

[1] ETSI TS 102 689 V1.1.1, “Machine-to-Machine communications; M2M service requirements”, Aug.2010.

[2] 3GPP TR 23.888 V1.6.0, “3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; System Improvements for Machine-Type Communications;” (Release 11) (2011-11).

[3] Overload Control for Machine-Type-Communications in LTE-Advanced. M-Y Cheng, G-Yu Lin, and Hung-Yu Wei, A-Chun Hsu, IEEE Communications Magazine • June 2012.

[4] Geng Wu, Shilpa Talwar, Kerstin Johnsson, Nageen Himayat, and Kevin D. Johnson, “M2M: From Mobile to Embedded Internet”, IEEE Communications Magazine, April 2011.

[5] A. Ksentini, Y. Hadjadj-Aoul, T. Taleb, “Cellular-based Machine Type Communication: Overload control”, In IEEE Network, Vol. 26, Issue 6, Pages: 54 – 60, November 2012.

[6] K.-D. Lee, S. Kim, and B. Yi, “Throughput comparison of Random Access Methods for M2M Service over LTE Networks,” Proc. 2011 IEEE GLOBECOM Workshop, Dec. 2011, pp. 373-377.

[7] A. Lo, Y. W. Law, and M. Jacobsson, “Enhanced Random-Access Mechanism for Massive Machine-to-Machine (M2M) Communications,” Proc. 27th Meeting of Wireless World Research Forum, Oct. 2011.

[8] D. Suyang, S.-M. Vahid, W. Vincent W.S., “Dynamic Access Class Barring for M2M Communications in LTE Networks”, submitted to IEEE Global Communications Conference (GLOBECOM), Atlanta, GA, Dec. 2013.

[9] Shao-Yu Lien, Tzu-Huan Liau, Ching-Yueh Kao, and Kwang-Cheng Chen, "Cooperative access class barring for machine-to-machine communications," *IEEE Trans. Wireless Communications*, vol. 11, no. 1, pp. 27-32, Jan. 2012.

[10] Lien SY, Liau TH, Kao CY, Chen KC, Cooperative Access Class Barring for Machine-to-Machine Communications, IEEE Transactions on Wireless Communications, vol. 11, no. 1, pp. 27-32, January 2012.

[11] Yu Chen and Wei Wang, "Machine-to-Machine Communication in LTE-A," in IEEE 72nd Vehicular Technology Conference, 6-9 Sept. 2010, pp. 1 - 4.

[12] 3GPP TS 36.321 V10.2.0 (2011-06): Medium Access Control (MAC) protocol specification. June 2011.

[13] 3GPP TR 37.868 V11.2.0 (2011-09): Study on RAN Improvements for Machine-type Communications. Sept. 2011.

[14] L. Shao-Yu, C. Kwang-Cheng, L. Yonghua, “Toward Ubiquitous Massive Accesses in 3GPP Machine-to-Machine Communications”, IEEE Communications Magazine, Apr. 2011.

[15] 3GPP TS 22.011, V8.6.0, “Service Accessibility”, (2008-12).

[16] K.-D. Lee, S. Kim, and B. Yi, “Throughput comparison of Random Access Methods for M2M Service over LTE Networks,” Proc. 2011 IEEE GLOBECOM Workshop, Dec. 2011, pp. 373-377.

[17] A. Lo, Y. W. Law, and M. Jacobsson, “Enhanced Random-Access Mechanism for Massive Machine-to-Machine (M2M) Communications,” Proc. 27th Meeting of Wireless World Research Forum, Oct. 2011.

[18] CMCC TSG R2-113197, Performance Comparison of Access Class Barring and MTC Specific Backoff Schemes for MTC, 3GPP Meeting, 2327 Aug. 2010.

[19] http://www.nsnam.org/ns-3-19/download/

[20] Bouzouita M, Hadjadj-Aoul Y, Zangar N, Tabbane S and Viho C, A, "Random access model for M2M communications in LTE-advanced mobile networks", Modeling and Simulation of Computer Networks and Systems, Elsevier, 2015.