Overload Control Technique for MTC Communications in Wireless Cellular Networks

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Abstract

MTC (Machine-Type Communication) applications are known as an indispensable part of the future internet and they have received considerable research attentions. In MTC, a huge amount of MTC devices try to transmit data to eNB within a very short period of time. It brings about RAN (Radio Access Network) overload issue. To tackle the issue, 3GPP specifies ACB (Access Class Barring) as an overload resolution mechanism but it is still open issue to control ACB parameters autonomously. We propose a control mechanism of ACB parameter based on the predicted traffic load. In general, prediction accompanies inevitable approximation error. Our mechanism determines ACB parameter by considering the predicted traffic load and approximation error simultaneously. Simulation results show that the proposed mechanism increases the number of successful devices, and decreases the number of failed devices and access delay.

Keywords: Access class barring, LTE-A networks, Machine-type communication, Random access

1 Introduction

MTC (Machine-Type Communication) applications in 3GPP (3rd Generation Partnership Project) networks are used to provide connectivity between machines or devices with no human intervention [1-3]. MTC applications are one of the most important elements of the future internet. It includes a wide range of applications such as smart metering, intelligent transport system, infrastructure management, consumer electronics, and mobile healthcare. In MTC, generally small amounts of data are infrequently transmitted from a large number of devices towards a system. The growing number of devices brings about new communication and processing challenges. Because a large number of devices try to access the same channel in LTE-A (Long Term Evolution – Advanced) system, devices contend for radio resources and the contention brings about system overload [4].

Overload control is a critical feature to protect the system from excessive connectivities from a large number of devices [5]. When a large number of devices request to access RAN (Random Access Network) at the same time, signaling flows increase tremendously. Particularly, because data transmissions in MTC communications are regulated by duty cycles, the overload problem deteriorates severely. Thus, excessive connectivities from a large number of devices result in packet collision and long access delay, and service quality of an application decreases. Even though many researchers try to solve the problem, it is still open issue for further research [6].

To solve the problem, 3GPP has considered ACB (Access Class Barring) scheme [7]. An eNB (evolved Node-B) periodically broadcasts barring parameters which involve a barring factor ($0 \le p \le 1$) and a barring duration. Based on the broadcasted parameters, a device determines whether it temporarily postpones its random access. When a device starts a random access procedure, the device generates a random number between 0 and 1. If the random number is equal to or greater than p, then the access is postponed for the barring duration. As the value of p decreases, the resource contention decreases but the access delay between the first attempt and the completion of the random access increases. As the value of p increases, packet collision due to high contention increases. In other words, if a severe congestion occurs in a system and p is set to extremely low value, the access delay unacceptably increases.

In 3GPP proposals, when the number of devices which try to access RAN is low, ACB is deactivated by setting p to 1. When the number of devices which try to access RAN is high and the degree of collision increases, ACB is activated by setting p to a specific value (e.g., 0.1) [7]. The ACB leads to unsatisfactory performance because it does not reflect the traffic condition on the value of the barring factor. Therefore, we propose a mechanism to adapt the value of the

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barring factor in ACB based on the traffic estimation. The experimental results show that our mechanism improves system performances including the number of successful devices/colliding devices/failed devices, and access delay.

In this paper, the main contributions are:

(1) Identifying requirements of barring factor control based on traffic condition;

(2) Identifying inevitable error of the prediction of traffic condition;

(3) Providing a control mechanism of the barring factor to compensate the approximation error of traffic prediction;

(4) Performing experiments to investigate the performance of the provided mechanism.

The rest of the paper is organized as follows: In Section 2, we describe a system model and related work. In Section 3, we propose a mechanism to adaptively determine the value of a barring factor in ACB. In Section 4, experimental results are discussed. In Section 5, conclusion and the future research direction are drawn.

2 System Model

In LTE-A, MAC (Medium Access Control) procedures are divided into two categories. The one is contention-based random access procedure for devices in RRC (Radio Resource Control) idle mode. The other is contention-free radio resource allocation for devices in RRC connected mode. For MTC, devices try to send data within a short period of time and they perform the random access procedure to establish network connection for data transmission.

A device attempts to access in a random access opportunity which is predefined time/frequency resource. The eNB broadcasts the periodicity of random access opportunity which is called as time slot in the paper. A device follows a random access procedure to reserve uplink resource in a time slot. First, a device randomly selects a preamble for the first message of random access procedure. There are a predefined set of orthogonal preambles available per cell. A device transmits the selected preamble to allow eNB to estimate the transmission timing of the device. Second, eNB sends RAR (Random Access Response) to adjust the device transmit timing and assigns uplink resources to the device. Then, the device transmits identity information to eNB. If more than two devices choose the same preamble in the first step, a collision occurs in the transmitted message of this step. Finally, eNB transmits a contention-resolution message. If packet collision occurs and eNB decodes one of collided packets, eNB acknowledges the device which sent the decoded packet. Unacknowledged devices fail the random access. The failed devices retransmit a newly chosen preamble in another time slot based on a uniform back-off algorithm. The devices repeat a random access procedure until the maximum number of preamble transmission is reached.

2.1 Related Work

Recently, literature explore the overload problem in few years. Backoff-based mechanisms adjust the random access of devices in time slots by using backoff window [8]. In [9], access attempts are rejected based on the average admission rate. It estimates the reject probability of an access attempt using a proportional integrative derivative controller. In [10], devices transmit one or none of the available preambles in multiple random access sub-frames, and access codewords for contention are created. Thus, the amount of available contention resources is increased. In [11], a self-optimizing overload control mechanism is presented. It enables eNB to automatically add or reduce random access resources when it detects an increase or decrease of traffic load.

Even though several researches are available, ACB is still considered as a simple and effective mechanism to regulate the access opportunities of devices in LTE-A. In ACB-based approach, researches formulate the control of the barring factor as an optimization problem [12-14]. They build analytical models to maximize/minimize the performance metrics such as the number of successful devices, service time for all devices to successful access, or average access delay between the first access attempt of a device and the completion of the random access. To reduce the computational complexity of the optimization approaches, approximation approaches are proposed. In [15], eNB controls the barring factor based on the probability of packet transmission. In [16], congestion control among cells is considered. The eNBs cooperate on global stabilization and access load sharing. In [17], the number of contending devices is estimated with Markov Chain to control the barring factor. Table 1 categorizes the recent studies.

Table 1. Recent studies on overload problem

category	description	recent studies
standardized	optimization approach	[12][13][14]
	approximation approach	[15][16][17]
Non-standardized	resource control approach	[10][11]
	access control approach	[8][9]

The conventional mechanisms control the barring factor based on the current traffic load or predicted traffic load. However, the prediction accompanies inevitable approximation error. Thus, we propose a new mechanism to control the barring factor considering the approximation error of traffic prediction.

3 Proposed Mechanism

In this paper, using the correlation in a traffic load in a short period of time, the autoregressive process of order 1 (AR(1)) is adopted to predict future traffic load. By the predicted traffic load, our mechanism autonomously determines the value of the barring factor in ACB. Because we predict the future traffic load using AR(1), the error occurring in the prediction process needs to be controlled. If the future traffic load is overestimated, the barring factor may be chosen too low to meet the access delay requirement of delay-sensitive applications. If the future traffic load is underestimated, the barring factor may be chosen too high to meet the packet loss requirement of loss-sensitive applications. To compensate the error, we additionally consider the approximation error when the barring factor is chosen.

The operation of our mechanism is composed of two steps. The first step is to predict future traffic load using AR(1). Let z_t denote the measured traffic load at a time slot t. By AR(1) process, current traffic load is expressed as a linear sum of previous traffic load and uncorrelated normal noise e_t with mean zero and variance σ_e^2. The traffic load at $t+1$ is estimated by

$$\tilde{z}_{t+1} = \sigma_1 z_t + e_{t+1.} \quad \textbf{(1)}$$

By Yule-Walker equations [18], ϕ_1 is an autocorrelation of z_t at lag-1 (ρ_1) and σ_e^2 is given by

$$\sigma_e^2 = E[z_t^2](1-\phi_1\rho_1).. \quad \textbf{(2)}$$

The second step is to decide the barring factor with the predicted traffic load and approximation error. Figure 1 shows the approximation error which is given by

$$\iota_{t+1} = \frac{\tilde{z}_{t+1} - \tilde{z}_t}{\tilde{z}_{t+1}}. \quad \textbf{(3)}$$

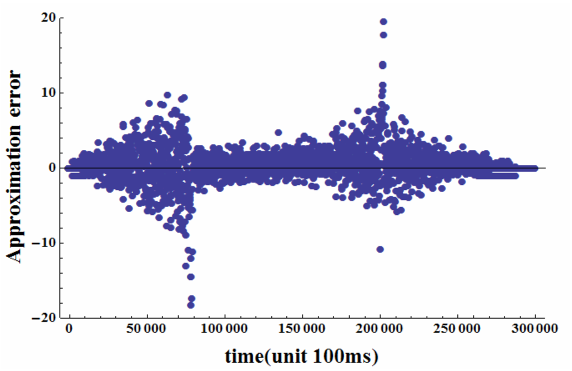


Figure 1. The approximation errors when AR(1) is used to predict future traffic load.

As shown in the figure, errors are different in time slots. In sharply increased / decreased intervals of traffic load, the error is also increased. In relatively stationary intervals of traffic load, the error is decreased. Thus, we adopt the distinct errors in time slots to select the value of the barring factor by

$$p = \frac{CH_M}{\tilde{z}_{t+1} + \eta_{t+1}} \quad \textbf{(4)}$$

where CH_m is the maximum number of frequency resources that system allows.

4 Experimental Results

In the experiments, the traffic model for smart electric metering MTC application is used as an experimental scenario. A smart meter is a new kind of gas and electricity meter that sends meter readings to an energy supplier. Smart meter applications include automatic meter reading, energy demand management, and micro electric generation management. In smart metering applications, devices communicate in highly synchronized manner. In the application, the household density in urban area of London is considered as an example [1]. In the example, the predicted number of households in a cell is 35,670. The frequency of periodical reporting of meter readings ranges from 5 mins to 24 hours. The access intensity generated from smart meters is influenced by the frequency. The access intensity is defined as the number of random access attempts made during a time slot. We set the frequency to 5 mins.

An eNB serves a number of N devices in a cell. Each device generates one access request during a period of time T. That is, all devices are activated to transmit data between $t=0$ and $t=T$. We set T to 5 mins. The access intensity follows the distribution $p(t)$. The access intensity in the i-th access opportunity is given by

$$AccessIntensity(i) = N\int_{t_i}^{t_{i+1}} p(t)dt, \quad \textbf{(5)}$$

where t_i is the i-th access opportunity. The $p(t)$ follows the Beta distribution with the values of $\alpha=3$ and $\beta=4$ as below.

$$p(t) = \frac{t^\alpha (T-t)^{\beta-1}}{T^{\alpha+\beta-1} Beta(\alpha,\beta)} \quad \textbf{(6)}$$

where $Beta(\alpha,\beta)$ is the Beta function.

In [19], eNB activates or deactivates its overload control scheme by using a congestion coefficient. The congestion coefficient is given by

$$\text{Congestion Coefficient} \quad \textbf{(7)}$$

$$= 1 - \frac{Num\ of\ RAR\ sent\ in\ a\ time\ duration}{Num\ of\ preamble\ tranmissions\ in\ a\ time\ duation}.$$

When the congestion coefficient exceeds a specific threshold, e.g., 0.4, an overload control scheme is activated. On the contrary, the control scheme is deactivated when the congestion coefficient goes below the threshold.

Figure 2 shows the variance of barring factor according to the access intensity defined in (5). In sharply increased intervals of access intensity, the barring factor is also sharply decreased in time. When the access intensity decreases sharply, the factor increases accordingly. The figure shows that our mechanism dynamically adjusts the barring factor in response to the variance of the access intensity by using (4). Figure 3 shows the variance of barring factor by varying CH_M. In the figure, M indicates the maximum number of frequency resources and we set it to the number of orthogonal preambles available per cell. In the original ACB [7], once the original ACB is activated, the barring factor is set to 0.1. To evaluate the performance, we compare our mechanism with the original ACB which is a de facto standard for overload control in LTE-A. When CH_M decreases, the interval which the factor is dynamically adopted widens because the barring factor is adjusted more sensitively. In other words, as CH_M decreases, the sensitivity increases and the barring factor is adjusted too early or too late.

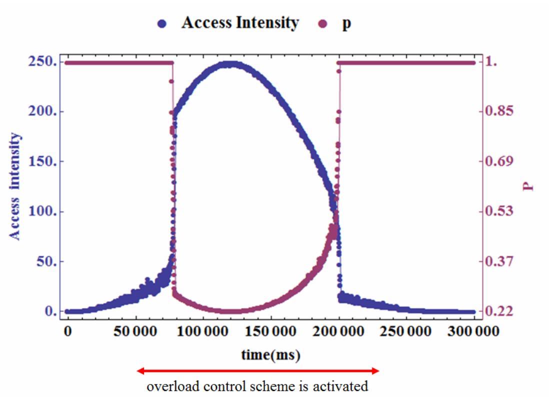


Figure 2. The value of barring factor by varying the access intensity

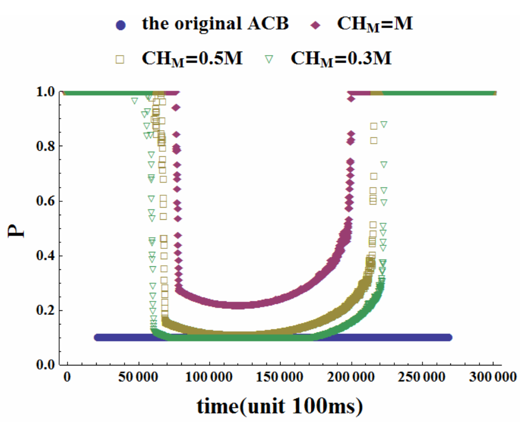
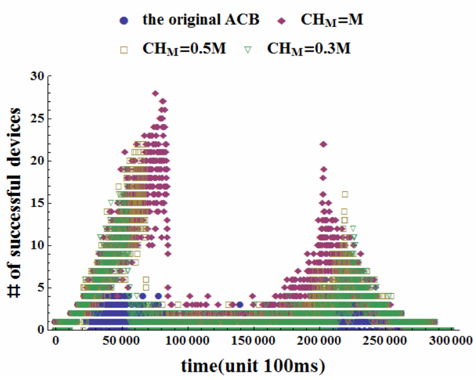


Figure 3. The value of barring factor by varying CH_M

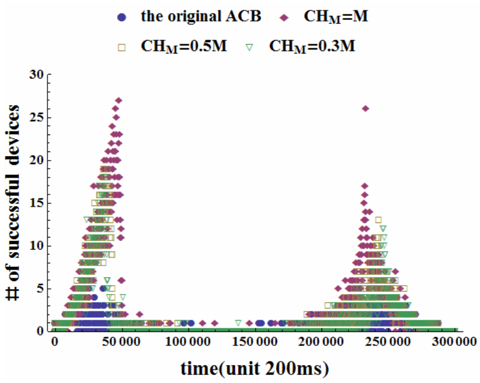
Figure 4 shows the number of devices which successfully access to eNB with varying the time slot. Our mechanism shows about 3 times better than the original ACB, on average. Among the performance with varying CH_M, when $CH_M = M$, the performance is about 50% better than that when $CH_M = 0.5M$ or $CH_M = 0.3M$. When the time slot is set to 200ms, the performance of $CH_M = M$ is about 30% better than other cases. When CH_M increases, the value of p increases and the number of devices which attempt to access the channel increases. Thus the number of successful devices increases accordingly. However, because the number of contending devices increases, the collision also increases, as shown in Figure 5. Figure 5 shows the number of devices which send random access attempts using the same preamble with varying the time slot. When $CH_M = M$, the number of colliding devices is about 30% more than that when $CH_M = 0.5M$ or $CH_M = 0.3M$. When the time slot is set to 200ms, the performance of $CH_M = M$ is about 5% worse than other two cases. When the performance in terms of the numbers of successful devices and colliding devices is analyzed, the gain from the access success is the larger than the loss from the access collision. When the performance is compared with the original ACB, the original ACB has about 20% less collisions than ours, on average. With time slot of 200ms, it has about 5% less collisions than ours. Because the original ACB sets p to 0.1, the number of barred devices increases and the collision among the unbarred devices decreases.

Figure 6 shows the number of devices which finally fail the random access attempts because the maximum number of preamble transmission counter has been reached. Even though the number of colliding devices in the original ACB is less than that of ours, it is because the barred devices increases due to the low value of p. In the figure, the number of failed devices in the original ACB is about 20% more than that of ours, on average. With time slot of 200ms, it is about 5% more than that of ours. With varying time slot size, when $CH_M = M$, the performance is about 13.5% and 4% better than these when $CH_M = 0.5M$ and $CH_M = 0.3M$.

Figure 7 shows the average access delay which is the average of the time for each random access procedure between the first access attempt and the completion of the procedure. The original ACB bars more devices from the random access and the number of colliding devices is relatively low. However, the number of successful devices is low. The number of failed devices and the access delay are high. In other words, the access delay of ours is about 30% and 10% lower than that of the original ACB with the time slot of 100ms and 200ms, respectively. Among the performance with varying CH_M, when CH_M increases,

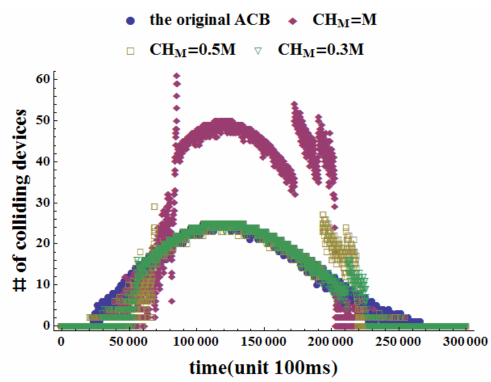


(a) time slot = 100ms

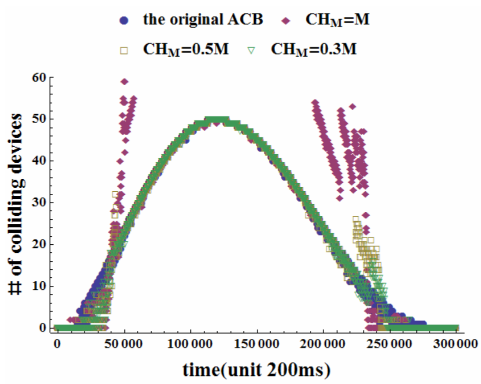


(b) time slot = 200ms

Figure 4. The number of successful devices by varying CH_M

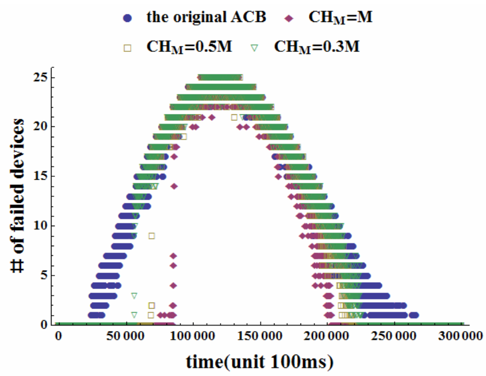


(a) time slot = 100ms

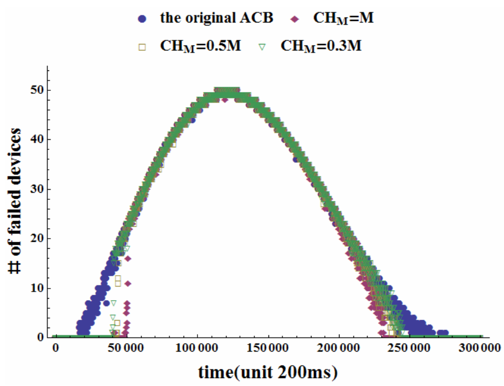


(b) time slot = 200ms

Figure 5. The number of colliding devices by varying CH_M

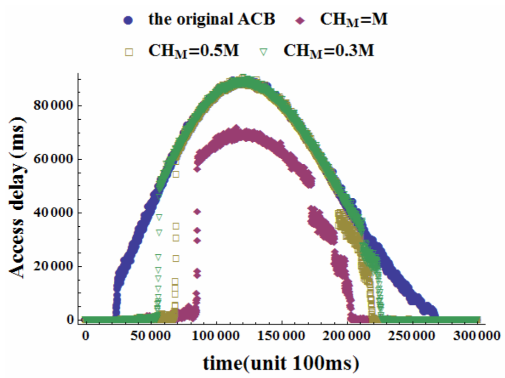


(a) time slot = 100ms

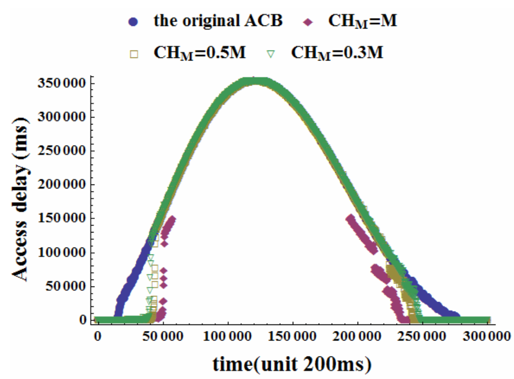


(b) time slot = 200ms

Figure 6. The number of failed devices by varying CH_M



(a) time slot = 100ms



(b) time slot = 200ms

Figure 7. The access delay by varying CH_M

the number of the failed devices decreases and the number of the colliding devices increases. Thus, the access delay also decreases. That is, the delay is about 30% and 10% better than these when $CH_M = 0.5M$ and $CH_M = 0.3M$ with the time slot of 100ms.

5 Conclusion

In order to tackle the overload issue of MTC communications, we present an overload control mechanism to adjust the barring factor in ACB according to the predicted traffic load and approximation error. In the prediction process, the approximation error is inevitable. To compensate the error, we additionally consider the approximation error, as well as the predicted traffic load when the barring factor is chosen. Simulation results show that our mechanism shows the better performance than the original ACB in terms of the number of successful devices/colliding devices/failed devices, and access delay because it predicts the change of traffic intensity and compensates the approximation error.

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References

[1] 3rd Generation Partnership Project, *Technical Specification Group Radio Access Network; Study on RAN Improvements for Machine-type Communications, 3GPP TR 37.868 V11.0.0*, 2011.

[2] 3rd Generation Partnership Project, *Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Resource Control (RRC); Protocol Specification, 3GPP TS 36.331 V12.7.0*, 2015.

[3] C. Pereira, A. Aguiar, Towards Efficient Mobile M2M communications: Survey and Open Challenges, *MDPI Sensors*, Vol. 14, No. 10, pp. 19582-19608, October, 2014.

[4] Y.-W. Chen, Y.-Y. Chu, P.-Y. Hsu, J.-H. Tsai, P.-Y. Liao, A Heuristic Design for the Uplink Scheduling in LTE-A Networks, *Journal of Internet Technology*, Vol. 17, No. 4, pp. 711-717, July, 2016.

[5] P. Jain, P. Hedman, H. Zisimopoulos, Machine Type Communications in 3GPP Systems, *IEEE Communications Magazine*, Vol. 50, No. 11, pp. 28-35, November, 2012.

[6] M.-Y. Cheng, G.-Y. Lin, H.-Y. Wei, A. C.-C. Hsu, Overload Control for Machine-Type-Communications in LTE-Advanced System, *IEEE Communications Magazine*, Vol. 50, No. 6, pp. 38-45, January, 2012.

[7] M. Hasan, E. Hossain, D. Niyato, Random Access for Machine-to-Machine Communication in LTE-Advanced Networks: Issues and Approaches, *IEEE Communications Magazine*, Vol. 51, No. 6, pp. 86-93, June, 2013.

[8] J.-J. Cheng, C.-H. Lee, T.-M. Lin, Prioritized Random Access with Dynamic Access Barring for RAN Overload in 3GPP LTE-A Networks, *The IEEE Global Communications Conference (GLOBECOM) Workshops*, Houston, TX, 2011, pp. 368-372.

[9] A. Ksentini, Y. Hadjadj-Aoul, T. Taleb, Cellular-based Machine-to-Machine: Overload Control, *IEEE Network*, Vol. 26, No. 6, pp. 54-60, November, 2012.

[10] N. K. Pratas, H. Thomsen, C. Stefanovic, P. Popovski, Code-Expanded Random Access for Machine-Type Communications, *The IEEE Global Communications Conference (GLOBECOM) Workshops*, Anaheim, CA, 2012, pp. 1681-1686.

[11] A. Lo, Y. Law, M. Jacobsson, M. Kucharzak, Enhanced LTE-Advanced Random-Access Mechanism for Massive Machine-to-Machine (M2M) Communications, *The 27th World Wireless Research Form* (*WWRF*), Düsseldorf, Germany, 2011, pp. 1-7.

[12] Z. Wang, V. W. S. Wong, Optimal Access Class Barring for Stationary Machine Type Communication Devices with Timing Advance Information, *IEEE Transactions on Wireless communications*, Vol. 14, No. 10, pp. 5374-5387, June, 2015.

[13] S. Duan, V. Shah-Mansouri, V. W. S. Wong, Dynamic Access Class Barring for M2M Communications in LTE Networks, *The IEEE Global Communications Conference* (*GLOBECOM*), Atlanta, GA, 2013, pp. 4747-4752.

[14] S. Duan, V. Shah-Mansouri, Z. Wang, V. Wong, D-ACB: Adaptive Congestion Control Algorithm for Bursty M2M Traffic in LTE Networks, *IEEE Transactions on Vehicular Technology*, Vol. 65, No. 12, pp. 9847-9861, December, 2016.

[15] G. Wang, X. Zhong, S. Mei, J. Wang, An Adaptive Medium Access Control Mechanism for Cellular based Machine to Machine (M2M) Communication, *The IEEE International Conference on Wireless Information Technology and Systems* (*ICWITS*), Honolulu, HI, 2010, pp. 1-4.

[16] S.-Y. Lien, T.-H. Liau, C.-Y. Kao, and K.-C. Chen, Cooperative Access Class Barring for Machine-to-Machine Communications, *IEEE Transactions on Wireless Communications*, Vol. 11, No. 1, pp. 27-32, January, 2012.

[17] H. He, Q. Du, H. Song, W. Li, Y. Wang, P. Ren, Traffic-aware ACB Scheme for Massive Access in Machine-to-Machine Networks, *The IEEE International Conference on Communications* (*ICC*), London, UK, 2015, pp. 617-622.

[18] G. E. P. Box, G. M. Jenkins, and G. C. Reinsel, *Time Series Analysis: Forecasting and Control*, Prentice Hall, 1994.

[19] Intel Corporation, *Further Performance Evaluation of EAB Information Update Mechanisms*, 3GPP R2-120270, 2012.

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