Overload Control for Machine Type Communications with Femtocells

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***Abstract*—In this paper, we propose the group-based time control mechanism to improve the network overload and delay performance in the femtocell-based machine type communications (MTC) networks. The MTC network may be congested if numerous MTC devices concurrently deliver messages to the MTC server. Femtocells can solve the radio access network (RAN) congestion, however the core network (CN) congestion becomes more difficult to handle. The proposed group-based time control method can spread the traffic load of MTC devices over the time, and thereby mitigate the RAN overload and CN overload simultaneously. Numerical results show that the proposed approach can significantly improve the network congestion and message delay compared to the existing methods.**

***Index Terms*—Femtocell, machine type communications (MTC), machine-to-machine (M2M), group, time control, core network (CN) congestion, radio access network (RAN) congestion.**

I. INTRODUCTION

Machine-type communications (MTC), or machine-to-machine (M2M) communications, is an emerging technology that permits devices to communicate with MTC servers or with each other without human intervention or interaction [1]. It was said that over 50 billion machines are expected to communicate at the year 2020 while there are total 6 billion people in the world [2]. Some use cases such as metering, road security, and consumer electronic and devices are considered in the Third Generation Partnership Project (3GPP) [3]. In addition, some features of MTC are categorized by 3GPP [1], including low mobility, time controlled, small data transmissions, group based MTC features, etc. In the future, the MTC devices will be more and more popular and be installed extensively.

The network congestion may take place because of mass concurrent data transmission from MTC devices. Generally, there are radio access network (RAN) and core network (CN) congestions [1], [4] in the MTC network. The RAN congestion usually occurs in a specific cell coverage when a lot of MTC devices concurrently access the same base station. When a huge number of MTC devices transmit the message from a mass of base stations to a single MTC server, the CN congestion may happen. Nevertheless, the serious CN congestion may result in intolerable delays, packet loss, and service unavailability.

In the literature, most papers investigated the overload probability and delay in the RAN congestion. In [5], the authors proposed an media access mechanism with the access class barring (ACB) method to improve the RAN throughput and average access delay. In [2], a concentrator-based congestion avoidance algorithm is proposed to reduce RAN traffic. Furthermore, a cluster formation algorithm to minimize the installation of concentrator and communications costs in [6]. The studies in [7], [8] handled massive QoS access issue with a call admission control mechanism. However, the proposed methods are too complicated to solve the RAN congestion problem from system perspective.

Femtocell is a key to the success of the MTC network. Femtocells can improve system capacity and indoor coverage with low power and low cost, and will be deployed extensively in the future [9], [10]. Unlike base stations in conventional cellular systems, femtocells connect to the network center through the broadband wire-lines inside the customers' homes. Due to short transmission distance, femtocells require very low transmission power, and it can extend battery life of MTC devices. In addition, femtocells can off-load traffic from macrocell and ease the RAN congestion problem if MTC traffics are shared among the femtocell base stations. Nevertheless, there will be CN overload problems even if RAN congestion situation is eased. The CN congestion will get more serious because huge MTC messages pass radio access and are pumped into the core network for numbers of base stations.

In this paper, we suggest a group-based time control mechanism to solve the CN congestion problem in the femtocell-based MTC network. We divide the MTC devices into several groups, and dedicate each group with a granted time interval. In a granted time interval, only MTC devices in the corresponding group can access the network. Therefore, the group-based time control method can spread the traffic load of MTC devices over the time to reduce the traffic peak, and mitigate both CN and RAN overload. However, if the number of group is large (i.e., smaller group size), the overall message delay may increase due to the longer cycle time. Therefore, we investigate the impacts of arrival rate and group size (group number) on the RAN overload probability, the CN overload probability and the message delay in the femtocell-based MTC network. Numerical results show that the proposed group-based time control mechanism can control both CN and RAN overload, and improve the message delay of MTC devices.

The remainder of this paper is organized as follows. Section II describes the system architecture, the cause of the network congestion, and the random access procedure. Section III details the group-based time control mechanism in the femtocell-based MTC networks, and the performance metrics are described in Section IV. The numerical results are shown in Section V. Finally, concluding remarks are given in Section VI.

II. SYSTEM MODEL

A. System Architecture

The femtocell-based machine type communications (MTC) network is considered as shown in Fig. 1. We assume that $N_{MTC,tot}$ MTC devices are distributed over the N_{Macro} macrocell coverages and served by the same MTC server. For each macrocell coverage, there are N_{Femto} houses, that is, $N_{Macro} \times N_{Femto}$ femtocell base

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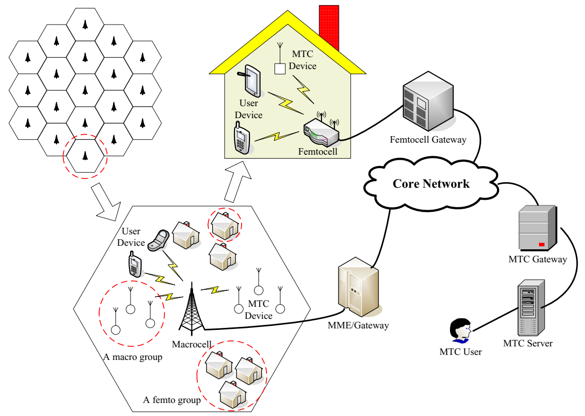

Fig. 1. Femtocell-based machine type communications (MTC) network architecture.

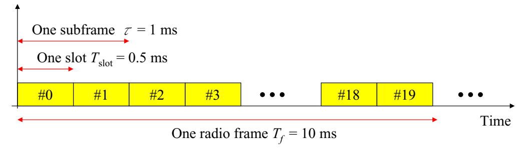

Fig. 2. Radio Frame Structure.

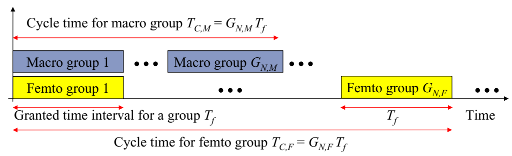

Fig. 3. Group-based Time Control Mechanism in Femtocell-based MTC Network.

stations are overlaid with the macrocell. Besides, $N_{MD,M}$ outdoor MTC devices are deployed in each macrocell coverage, and $N_{MD,F}$ indoor MTC devices are deployed in each house.

Both the outdoor and indoor MTC devices collect the information and send to the MTC server cyclically. For the outdoor environment, the MTC devices can access to the serving macrocell base station and connect to the core network so that the desired information can arrival in the MTC server. Similarly, the indoor MTC devices can connect to the core network by the access to the femtocell base station. Therefore, all the information from indoor and outdoor MTC devices can be reliably transferred to the MTC server except for the network congestion.

B. *Random Access Resource*

We consider the radio frame structure provided by 3GPP [11] as shown in Fig. 2. Each radio frame has the duration of 10 ms, and consists of 20 time slots of length $T_{slot} = 0.5$ ms. Two consecutive time slots comprise a subframe.

The random access procedure consists of two parts: preamble and message parts [12]. In the preamble part, the device transmits a preamble in the random-access window (i.e., the first subframe of the radio frame). Then, if the preamble can be detected, the base station transmits a respond to indicate the uplink resource allocation used for the transmission in the message part. If the preamble can not be detected by the base station, the device will not receive any respond for a period, and need to transmit a new preamble in the next random-access window. In the message part, the device builds the RRC connection setup according to the assigned resource, and transmits the message.

III. Overload Control in Femtocell-based MTC Networks

A. *Grouping*

In the femtocell-based MTC network, we assume that all the MTC devices can be categorized into two groups: macro groups and femto groups, as shown in Fig. 1. All MTC devices served by macrocells are partitioned into macro groups, and all MTC devices served by femtocells are partitioned into femto groups. Moreover, MTC devices in a femtocell are grouped into the same femto group, to reduce total signaling overhead. In each macrocell coverage, each macro group consists of $G_{S,M}$ MTC devices, and each femto group comprises $G_{S,F}$ femtocell base stations. Correspondingly, there are total $G_{N,M}$ macro groups and $G_{N,F}$ femto groups in the femtocell-based MTC network.

B. *Group-based Time Control Mechanism*

Figure 3 shows the conception of the group-based time control mechanism in the femtocell-based MTC network. As shown in Fig. 3, all the MTC devices are divided into $G_{N,M}$ macro groups and $G_{N,F}$ femto groups, respectively. The CN only allows the accesses of a group of MTC devices within an allocated time period (i.e., granted time interval). For the convenience, we assume that all groups have the same granted time interval T_f, and we align the granted interval for the groups. Let all the macro/femto groups have their granted time interval in sequence. Therefore, in the specified granted time interval, the active MTC device can select a random-access preamble to send the connection request.

The granted time interval of each macro/femto group is repeatedly allocated in every cycle time. The cycle time of macro groups and femto groups are defined as $T_{C,M} = G_{N,M} \times T_f$ and $T_{C,F} = G_{N,F} \times T_f$, respectively. Thus, the MTC device can cyclically send the connection request if the MTC device has the message to transmit. However, the transmission may be failure when RAN or CN congestion occurs. If the transmission is failure, the MTC device needs to wait at least a cycle time for it's granted time interval, and sends the connection request again. The MTC device sends the connection request *repeatedly* and *cyclically* until the transmission is successful. If new message generates, the MTC device only transmits the last message to the MTC server.

IV. Performance Metrics

Network congestion occurs because a large number of MTC devices generate the information and forward to the MTC server simultaneously. In general, there are radio access network (RAN) congestion and core network (CN) congestion for the femtocell-based MTC network. The RAN congestion usually happens in a specific cell coverage as a large number of outdoor/indoor MTC devices access the same macrocell/femtocell base station. However, the CN congestion may occur in the core network or on the link between the core network and the MTC server when a high number of outdoor/indoor MTC devices transfer information from the numerous cell coverage to the single MTC server. The serious CN congection may cause the intolerable delays, packet loss, or even service unavailability. In this paper, we consider two performance metrics, including the overload probability and the message delay.

A. Overload Probability

Assume that the message generation for a MTC device is Poisson arrival, and the interarrival time of the message generation is exponential distribution with mean $1/\lambda$. For small λ, assume that at most one message is generated in a cycle time, and only one message is transmitted in each granted time interval T_f. Due to the "small data transmissions feature" of MTC, we assume that a message can be transmitted completely in a granted time interval T_f, and each connection period is T_f. Let $p_{t,M}$ and $p_{t,F}$ be the transmission probability of each MTC device for the macro group and for the femto group, respectively. Then, $p_{t,M}$ and $p_{t,F}$ can be expressed as

$$p_{t,M} = 1 - p_{0,M}(T_{C,M} = G_{N,M}T_f) = 1 - e^{-\lambda G_{N,M} T_f} \quad (1)$$

$$p_{t,F} = 1 - p_{0,F}(T_{C,F} = G_{N,F}T_f) = 1 - e^{-\lambda G_{N,F} T_f} \quad (2)$$

where $p_{0,M}$ and $p_{0,F}$ are the probability that there are no message generated in the period of the cycle time for the MTC device in the macro group and femto group, respectively.

The probability that x MTC devices connect to the macrocell base station in one macro group can be expressed as

$$p_X(x) = \begin{pmatrix} G_{S,M} \\ x \end{pmatrix} p_{t,M}^x (1 - p_{t,M})^{G_{S,M} - x} \quad (3)$$

where $x = 0, \ldots, G_{S,M}$.

For a macrocell base station, as the RAN overload occurs, only $C_{RAN,M}$ MTC devices can send their messages. Therefore, macrocell base station can handle at most $C_{RAN,M}$ connection requests in the RAN overload situation, or at most $G_{S,M}$ connection requests if the RAN is not overloaded. For each macrocell base station, the probability set that there are x MTC devices connect to the CN can be express as

$$P_{M,\alpha} = \begin{cases} [p_X(0), \ldots, p_X(C_{eNB} - 1), \sum\limits_{x=C_{eNB}}^{G_{S,M}} p_X(x)], \\ \qquad\qquad\qquad \text{if} \quad \mathrm{G_{S,M} > C_{eNB}} \\ [p_X(0), \ldots, p_X(G_{S,M} - 1), p_X(G_{S,M})], \\ \qquad\qquad\qquad \text{if} \quad \mathrm{G_{S,M} \leq C_{eNB}} \end{cases} \quad (4)$$

where $\alpha = 1, \ldots, N_{Macro}$.

In the CN, there are at most $N_{Macro} \times C_{RAN,M}$ connection requests from the macrocell base stations. Therefore, the probability that there are 1 to $N_{Macro} \times C_{RAN,M}$ MTC devices connect to the CN in the macro group can be expressed as

$$P_M = P_{M,1} * P_{M,2} * \cdots * P_{M,N_{Macro}} \quad (5)$$

where $*$ is the convolution operator.

It is assumed that the RAN overload does not occur in the femtocell because the number of MTC devices in each house is limited. Therefore, there are at most $N_{Macro} \times G_{S,F} \times N_{MD,F}$ connection requests come to the CN from all the femtocell base stations. The probability that y MTC devices send connect requests to the CN in one femto group can be expressed as

$$p_Y(y) = \begin{pmatrix} \beta \\ y \end{pmatrix} p_{t,F}^y (1 - p_{t,F})^{\beta - y} \quad (6)$$

where $\beta = N_{Macro} \times G_{S,F} \times N_{MD,F}$, and $y = 0, \ldots, \beta$.

Similarly, the probability set that there are 1 to β MTC devices connect to the CN in the femto group can be expressed as

$$p_F = [p_Y(0), \ldots, p_Y(\beta - 1), p_Y(\beta)] \quad (7)$$

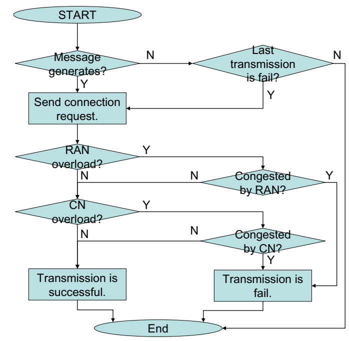

Fig. 4. Transmission flow chart: the procedure for a single MTC device to transmit the message to the MTC server in the granted time interval.

For the CN, all the connection requests come from all the macrocell and femtocell base stations. Therefore, the probability set that each number of connection requests from all the macrocell and femtocell base stations can be express as

$$p_Z = p_M * p_F \quad (8)$$

Let the capacity of one macrocell base station, that of one femtocell base station, and that of the MTC server be C_{eNB}, C_{HeNB}, and C_{MTC}, respectively. To minimize the impact on human-to-human (H2H) communications, assume that only $\mu\%$ of C_{eNB}, $\nu\%$ of C_{HeNB}, and $\eta\%$ of C_{MTC} can be used in the MTC network. Then, we define the RAN overload and CN overload as follows.

Definition 1. *RAN overload: if number of random-access requests received by the macrocell/femtocell base station in a granted time interval is more than the capacity threshold of macro-cell/femtocell base station for the MTC network. In this situation, only ($C_{RAN,M} = C_{eNB} \times \mu\%$) and ($C_{RAN,F} = C_{HeNB} \times \nu\%$) MTC devices can send their messages through the macrocell and femtocell base stations, respectively.*

Definition 2. *CN overload: if total number of connection requests from all MTC devices to the MTC server in a granted time interval is more than the capacity threshold of the MTC server. Meanwhile, only ($C_{CN} = C_{MTC} \times \eta\%$) MTC connections can be handled by the MTC server.*

According to the Definitions 1 and 2, the macrocell RAN overload probability $P_{RAN,M}$ and the CN overload probability P_{CN} are given as

$$P_{RAN,M} = 1 - \sum_{x=0}^{C_{RAN,M}} p_X(x) \quad (9)$$

$$P_{CN,M} = 1 - \sum_{z=0}^{C_{CN}} p_Z(z) \quad (10)$$

B. Message Delay

The message delay is defined as the elapsed time from the instant of the message generation to that of the message reception at the MTC server. Therefore, the delay includes the time of waiting for the granted time interval and the access delay. Moreover, the average waiting time for the granted time interval are $T_{C,M}/2$ and $T_{C,F}/2$ for the macro groups and for the femto groups, respectively.

TABLE I
THE FEMTOCELL SYSTEM PARAMETERS

Parameters	Values
Number of macrocell coverages, N_{Macro}	19
Number of total MTC devices, $N_{MD,tot}$	570000
Number of femtocell in each macrocell coverage, N_{Femto}	5,000
Number of outdoor MTC devices in each macrocell coverage, $N_{MD,M}$	5,000
Number of indoor MTC devices in each house, $N_{MD,F}$	5
Capacity of one macrocell base station, C_{eNB}	800
Capacity of one femtocell base station, C_{HeNB}	200
Capacity of the MTC server, C_{MTC}	15200
$\mu/\nu/\eta$	0.25
Overload probability threshold	0.1

Figure 4 shows the procedure that a MTC device in the granted time interval accesses the network and transmits the message to the MTC server. If a message is generated, the MTC device will send the connection request in the granted time interval of it's group. If the RAN overload or CN overload occurs, the access may be failure. For macrocell RAN overload, only $C_{RAN,M}$ MTC devices can send their messages, while only C_{CN} MTC devices' messages can be handled by the MTC server for CN overload. Then, the redundant connection requests are dropped by the RAN or CN, and the transmission is failure. If the transmission is failure, the MTC device must wait a cycle time period ($T_{C,M}$ or $T_{C,F}$) for sending the request again.

For the convenience to determine the access delay, we define some parameters as follows.

- $P_{CFP,RAN}$: The connection failure probability on the condition of RAN overload.
- $P_{CFP,CN}$: The connection failure probability on the condition of CN overload.
- $\gamma_{RAN,M}$: The average number of failure connections in a macrocell base station because of macro RAN congestion.
- $\gamma_{CN,M}$: The average number of failure connections in a macrocell base station because of CN congestion.
- $\gamma_{CN,F}$: The average number of failure connections in a femtocell base station because of CN congestion

According the above definitions, we have the following three equations.

$$\gamma_{RAN,M} = \max\{0, (G_{S,M} - \gamma_{RAN,M} - \gamma_{CN,M})p_{t,M} + \gamma_{RAN,M} + \gamma_{CN,M} - C_{CN}\} \quad (11)$$

$$N_{Macro}\gamma_{CN,M} + N_{Macro}G_{S,F}\gamma_{CN,F} = \max\{0, N_{Macro}X + N_{Macro}G_{S,F}Y - C_{CN}\} \quad (12)$$

$$N_{Macro}\gamma_{CN,M} : N_{Macro}G_{S,F}\gamma_{CN,F} = N_{Macro}X : N_{Macro}G_{S,F}Y \quad (13)$$

where

$$\begin{cases} X = (G_{S,M} - \gamma_{RAN,M} - \gamma_{CN,M})p_{t,M} + \gamma_{CN,M} \\ Y = (N_{MD,F} - \gamma_{RAN,F} - \gamma_{CN,F})p_{t,F} + \gamma_{CN,F} \end{cases} \quad (14)$$

By iterative operation, we can obtain $\gamma_{RAN,M}$, $\gamma_{CN,M}$, and $\gamma_{CN,F}$. Therefore, the connection failure probability $P_{CFP,RAN}$ and $P_{CFP,CN}$ can be given by

$$P_{CFP,RAN} = \frac{\max\{0, X + \gamma_{RAN,M} - C_{CN}\}}{X + \gamma_{RAN,M}} \quad (15)$$

$$P_{CFP,CN} = \frac{\max\{0, N_{Macro}X + N_{Macro}G_{S,F}Y - C_{CN}\}}{N_{Macro}X + N_{Macro}G_{S,F}Y} \quad (16)$$

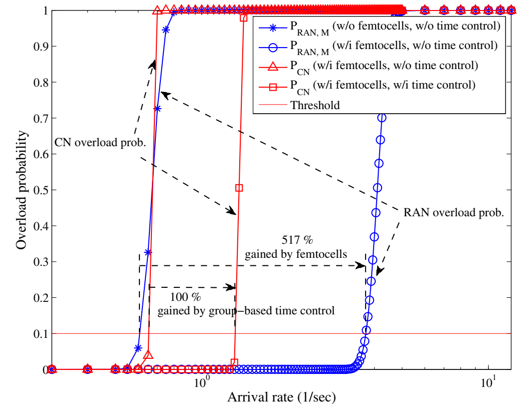

Fig. 5. Overload probability versus arrival rate, where 950 MTC device in each macro group and 760 femtocell base stations in each femto group are considered for the femtocell-based MTC network.

Let $T_{A,M}$ and $T_{A,F}$ be the access time for the MTC device of the macro group and that of the femto group, respectively. Therefore, we can determine the the access time $T_{A,M}$ and $T_{A,F}$ according to the connection failure probability $P_{CFP,RAN}$ and $P_{CFP,CN}$.

$$T_{A,M} = \frac{1 - P_{S,M}}{P_{S,M}} T_{C,M} + T_f \quad (17)$$

$$T_{A,F} = \frac{1 - P_{S,F}}{P_{S,F}} T_{C,F} + T_f \quad (18)$$

where

$$P_{S,M} = 1 - (P_{RAN,M}P_{CFP,RAN} + P_{CN}P_{CFP,CN} - P_{RAN,M}P_{CFP,RAN}P_{CN}P_{CFP,CN}) \quad (19)$$

$$P_{S,F} = 1 - (P_{CN}P_{CFP,CN}) \quad (20)$$

Finally, the average message delay of the macro group D_M and that of the femto group D_F are given by

$$D_M = \frac{T_{C,M}}{2} + T_{A,M} \quad (21)$$

$$D_F = \frac{T_{C,F}}{2} + T_{A,F} \quad (22)$$

V. NUMERICAL RESULTS

In this section, we investigate the impacts of arrival rate and group size on the RAN overload probability, the CN overload probability and the message delay in the femtocell-based MTC network. We consider the femtocell-based MTC network as shown in Fig. 1. We assume that there are total $N_{MTC,tot} = 30000 \times 19 = 570000$ MTC devices distributed over the $N_{Macro} = 19$ macrocell coverages and served by the same MTC server. For each macrocell coverage, there are $N_{Femto} = 5000$ femtocell base stations overlaid with the macrocell. Besides, there are $N_{MD,M} = 5000$ outdoor MTC devices in each macrocell coverage, and $N_{MD,F} = 5$ indoor MTC devices deployed in each house, respectively. The nominal system parameters for the considered femtocell-based MTC network are listed in Table I.

A. Impacts of Arrival Rate and Group Size on Overload Probability

Figure 5 shows the overload probability against the arrival rate λ. In this case, we assume that each macro group consists of $G_{S,M} = 50$ MTC devices, and each femto group comprises $G_{S,F} = 40$

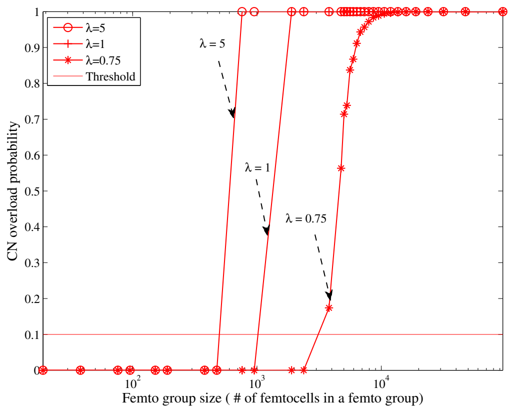

Fig. 6. CN overload probability versus femto group size, where 950 MTC device in each macro group is considered for the femtocell-based MTC network.

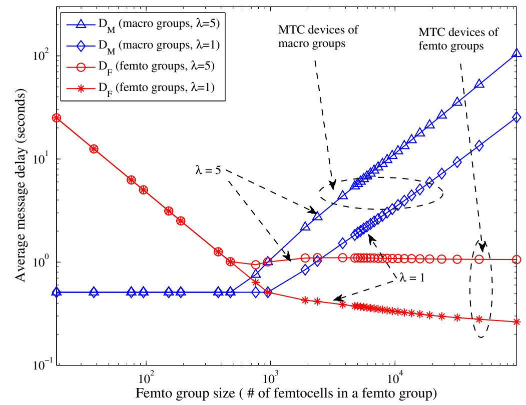

Fig. 7. Average message delay versus femto group size, where 950 MTC device in each macro group is considered for the femtocell-based MTC network.

femtocell base stations in each macrocell coverage. Namely, for the femtocell-based MTC network, each macro group has $G_{S,M} \times N_{Macro} = 950$ MTC devices, and each femto group has $G_{S,F} \times N_{Macro} = 760$ femtocell base stations. Therefore, there are total $G_{N,M} = 100$ macro groups and $G_{N,F} = 125$ femto groups in the femtocell-based MTC network. From the figure, we have the following observations.

1. Femtocells are helpful to solve the RAN congestion in the macrocell base station. Under the overload probability threshold requirement, the macrocell with femtocells can support 517% higher arrival rate, compared to the macrocell without femtocells.
2. The group-based time control mechanism can mitigate the CN congestion in the femtocell-based MTC network. Under the overload probability threshold requirement, the femtocell-based MTC network with group-based time control mechanism can support 100% higher arrival rate, compared to the femtocell-based MTC network without group-based time control mechanism.

Figure 6 shows the CN overload probability against the femto group size, where there are 950 MTC device in each macro group. It is shown that the CN overload probability increases as the femto group size increases. Under the overload probability threshold requirement, the largest permissible femto group size is about 500 femtocells, 1050 femtocells, and 3000 femtocells for $\lambda = 5$ (1/sec), $\lambda = 1$ (1/sec), and $\lambda = 0.75$ (1/sec), respectively.

B. Impacts of Arrival Rate and Group Size on Average Message Delay

Figure 7 shows the average message delay against the femto group size. From the figure, we have the following observations.

1. The femto group size significantly affects the average message delay. When the femto group size increases from 1 femtocell to about 1000 femtocells, the average message delay of the femto group decreases from about 25 seconds to about 1 second and 0.5 second for $\lambda = 5$ (1/sec) and $\lambda = 1$ (1/sec), respectively. As the femto group size keeps increasing to 95000 femtocells, the average message delay of the macro group increases to about 105 second and 25 second for $\lambda = 5$ (1/sec) and $\lambda = 1$ (1/sec), respectively.
2. Properly design the group size can achieve the tradeoff between the delay of the macro groups and that of the femto groups. As $\lambda = 1$ (1/s), for example, the optimal femto group size is about 1000 femtocells in the femtocell-based MTC network.

VI. CONCLUSIONS

In this paper, we proposed the group-based time control method to improve the RAN overload, CN overload, and message delay in the femtocell-based MTC network. We investigated the impacts of arrival rate and group size on the RAN overload probability, CN overload probability, and the message delay in the femtocell-based MTC network. Numerical results showed that the proposed approach can improve 100% higher arrival rate as compared to the conventional cellular systems. Besides, the message delay can be optimized by properly designing the group size.

REFERENCES

[1] 3GPP, "Service requirements for machine-type communications (MTC); stage 1," 3GPP, Tech. Rep. TS 22.368 V10.2.0, Sep. 2010.
[2] K.-R. Jung, A. Park, and S. Lee, "Machine-type-communication (MTC) device grouping algorithm for congestion avoidance of MTC oriented LTE network," in *Security-Enriched Urban Computing and Smart Grid*, ser. Communications in Computer and Information Science, T.-h. Kim, A. Stoica, and R.-S. Chang, Eds. Springer Berlin Heidelberg, 2010, vol. 78, pp. 167–178.
[3] 3GPP, "Study on RAN improvements for machine-type communications," 3GPP, Tech. Rep. TR 37.868 V0.6.3, Oct. 2010.
[4] ——, "System improvements for machine-type communications," 3GPP, Tech. Rep. TR 23.888 V1.0.0, Jul. 2010.
[5] G. Wang, X. Zhong, S. Mei, and J. Wang, "An adaptive medium access control mechanism for cellular based machine to machine (M2M) communication," in *Proc. 2010 IEEE International Conference on Wireless Information Technology and Systems (ICWITS)*, Sep. 2010, pp. 1 –4.
[6] D. Niyato, L. Xiao, and P. Wang, "Machine-to-machine communications for home energy management system in smart grid," *IEEE Communications Magazine*, vol. 49, no. 4, pp. 53–59, Apr. 2011.
[7] S.-Y. Lien and K.-C. Chen, "Massive access management for QoS guarantees in 3GPP machine-to-machine communications," *IEEE Communications Letters*, vol. 15, no. 3, pp. 311–313, Mar. 2011.
[8] S.-Y. Lien, K.-C. Chen, and Y. Lin, "Toward ubiquitous massive accesses in 3GPP machine-to-machine communications," *IEEE Communications Magazine*, vol. 49, no. 4, pp. 66–74, Apr. 2011.
[9] V. Chandrasekhar and J. G. Andrews, "Femtocell networks: A survey," *IEEE Communications Magazine*, vol. 46, no. 9, pp. 59–67, Sep. 2008.
[10] D. López-Pérez, A. Valcarce, G. de la Roche, and J. Zhang, "OFDMA femtocells: A roadmap on interference avoidance," *IEEE Communications Magazine*, vol. 47, no. 9, pp. 41–48, Sep. 2009.
[11] 3GPP, "Physical channels and modulation," 3GPP, Tech. Rep. TS 36.211 V8.6.0, Mar. 2009.
[12] Ericsson, "E-utra random access," 3GPP, Tech. Rep. R1-060584, Feb. 2006.