Fast Group Paging Algorithm for Large-Scale MTC Systems

Si Huang[1], Xiaohui Li[1(✉)], Bin Zhou[2], Yanbin Zhao[3], and Ruiyang Yuan[1]

[1] State Key Laboratory of Integrated Service Networks, Xidian University, Xi'an 710071, Shaanxi, China
xhli@mail.xidian.edu.cn

[2] AVIC Computing Technique Research Institute, Xi'an, Shaanxi, China

[3] Geographic Information Center, Yangquan City, Shanxi, China

Abstract. Group paging (GP) is an effective way to solve the serious congestion problem. Congestion problem usually is caused by lots of machine-type communication (MTC) devices communicating at the same time. A certain number of MTC devices in each time slot is been activated, and the number of MTC devices can achieve the maximum of resource utilization. First of all, the total number of MTC devices in each time slot should be calculated according to the different new arrivals in each time slot. By making the resources utilization maximum, the optimal number of total MTC devices can be obtained, from which the optimal number of arriving MTC devices in each time slot will be get. To estimate the total number of MTC devices for traffic scattering GP, a Fast Group Paging Algorithm (FGPA) is proposed, which aims to improve the performance of GP under the condition of massive MTC devices. FGPA is an iterative algorithm that converges fast and has low arithmetic complexity. The corresponding simulation results demonstrate that the proposed FGPA requires less number of iterations under the condition of the same estimation results of total number of MTC devices compared with the existing iterative algorithm.

Keywords: Machine-type communication · Group paging
Low-complexity iteration method · Severe congestion

1 Introduction

Machine-type communication has significant influence on the next generation networks, which involves lots of MTC devices to support different type of services. The future MTC cellular networks have main features, for example, low-power, low-cost, and high coverage. In order to meet these characteristics, the system design has some new challenges [1]. As the number of MTC devices has increased dramatically and MTC simultaneously access [2] the network, which may cause serious collisions and intolerable delays, and thus affect the performance of the network. In order to solve this problem, many methods of

B. Li et al. (Eds.): ChinaCom 2017, LNICST 237, pp. 352–361, 2018.
https://doi.org/10.1007/978-3-319-78139-6_36

congestion control [3] have been studied. Specifically, the main reason for the emergence of congestion is, because many MTC devices contend for the same RA resource simultaneously [4].

Paging [4], a push based method, sending a paging message over the network to the MTC device which is considered by aiming at its individual ID. However, if the paging mechanism is applied to a scenario that has large-scale MTC device, which may cause a significant reduction in paging efficiency. In order to solve this problem, the concept of group paging (GP) is presented. In group paging (GP), MTC devices grouped into groups in terms of different metrics, and each group identified by a unique, ID (GID) [5]. So that all MTC devices belonging to the same group can paging through a paging message, which greatly reduce the number of paging messages and the paging time.

The GP method in MTC systems was used in [6], where improves the performances by doing paging operations scattered in different time slots. However, the total number of MTC devices in which is estimated by ordinary iteration algorithm. And this kind of estimation method requires a large number of iterative operations, which seriously affecting the performance of the algorithm, so the algorithm needs to be improved.

Therefore, we propose a Fast GP Algorithm (FGPA) in this paper to estimate the total number of MTC devices, which greatly improves the performance of GP. In order to more accurately estimate the total number of MTC equipment in every slot, FGPA algorithm proposed converges fast and has low arithmetic complexity. And then the number of MTC devices successfully accessed in each time slot can be calculated based on the total number of MTC devices in each slot. Finally, calculate the utilization of resources according to the MTC device number of successful access to the network.

The remainder in this paper is organized as follows. In Sect. 2, system model used in our study is introduced and the analysis of our proposition for Fast GP Algorithm are detailed in Sect. 3. The performance results including the estimation accuracy and comparison of iterations number between the proposed FGPA and ordinary iteration algorithm are investigated in Sect. 4. Finally, in the Sect. 5, summarizing the conclusions for this paper.

2 System Model

In this section, through the analysis of numerous inference and calculation under different conditions, we introduce an improved scheme that reduces the complexity of the ordinary iterative algorithm. Firstly, we introduce the system model, and then present the improved algorithm that estimating the total number of MTC devices.

In our study, we consider a group of M MTC devices which share a common GID uniformly distributed in a cell, so one paging message can notify the M MTC devices to communicate with the MTC server. It is assumed that the eNB reserves R RA resources defined as RA Opportunities (RAOs) for the contention access [7]. In this paper, we assume that the number of resources is equal to the number of preambles.

When the number of new arrivals at each RA slot is same, in each situation there will be an optimal number of total MTC devices in every slot that maximizes resource utilization rate. All M MTC devices will start the RACH procedure [8], and scattering the paging operation of the MTC devices over a GP interval after receiving the paging message, instead of transmitting their access attempts at the same RA slot immediately.

The performance of group paging during a group paging interval of $I_{\max}$ RA slots is studied. The utilization of RAOs which is denoted as U is the ratio of the average number of successfully accessed RAOs to the total number of reserved RAOs and U is given by

$$U = \frac{\sum_{i=1}^{I_{\max}} \sum_{n=1}^{N_{PT_{\max}}} M_{i,S}[n]}{I_{\max} R} \tag{1}$$

where $M_{i,S}[n]$ is the number of MTC devices which transmit their n_{th} preamble at the i_{th} RA slot and successfully complete the RA procedure. From the Eq. (2), we can come to a conclusion that in order to improve the resource utilization rate in certain parameters of the situation, we should maximize the value of $M_{i,S}[n]$.

Equation (2) can be written as follows [9]:

$$M_i = M_1 \sum_{n=1}^{N_{PT_{\max}}-1} \beta_m e^{-\frac{M_i}{R}} p_k \tag{2}$$

where $\beta_m = \sum_{t=1}^{N_{PT_{\max}}-m} (-1)^m \sum_{k_1=1}^{t} \dots \sum_{k_m=k_{m-1}+1}^{t+m-1} p_{k_1} \dots p_{k_m}$ [4]. According to the exponential function e^x can be approximated by Eq. (4). And then applying Eq. (3) to Eq. (2), we can obtain Eq. (4)

$$e^x \approx 1 + x + \frac{x^2}{2!} \tag{3}$$

$$\begin{aligned}&\left(\sum_{m=0}^{N_{PT_{\max}}-1} m^2 \beta_m\right) \times M_i^2 - 2\left(\frac{R^2}{M_1} + R \sum_{m=0}^{N_{PT_{\max}}-1} m\beta_m\right) \times M_i \\ &+ 2R^2 \sum_{m=0}^{N_{PT_{\max}}-1} \beta_m = 0\end{aligned} \tag{4}$$

Due to Eq. (4) is a second order equation for M_i, which can be solved by using ordinary iteration operation. However, the estimation of M_i under ordinary iteration operation has very high complexity, so we put forward a new iteration method to improve the performance of estimation of M_i with low complexity.

3 The Fast Group Paging Algorithm

In view of the ordinary iteration method has a higher complexity and has the large number of iterations. So here we can consider using Newton iteration method instead of the ordinary iteration method, which is an approximate method of solving the equation for real number domain and complex domain. Generally speaking, the iterative method is a recursive process that with the old values of variables replace by the new value. So the accuracy of the estimated value is very important which will influence the successful number of MTC devices.

Newton iteration method is to find the equation of the root by taking some leading terms of Taylor series belong to the function. Newton iterative method is one of the important methods for equation root, whose biggest advantage is square convergence in near simple root of equation $f(x) = 0$, so Newton iterative method is used to solve the equation, which is called Fast Group Paging Algorithm (FGPA) in this paper.

First of all, we need to construct a function according to Eq. (2) and make the value of function is equal to zero

$$f(M_i) = M_i - M_1 \sum_{m=0}^{N_{PT_{\max}}-1} \beta_m e^{-\frac{mM_i}{R}} = 0 \tag{5}$$

To solve this equation we can use the Newton Iteration Estimation Algorithm which is square convergence, and we can get the derivative of $f(M_i)$

$$f'(M_i) = 1 + \frac{m}{R} M_1 \sum_{m=0}^{N_{PT_{\max}}-1} \beta_m e^{-\frac{mM_i}{R}} \tag{6}$$

which is the further improvement of the approximated value of M_i.

Then, the initial guess of the total number of MTC devices M_{ig} is assumed that the value calculated by Eq. (4) which is a quadratic equation of one unknown.

$$M_{ig} = [-\mathrm{b} \pm \sqrt{(b^2 - 4ac)}]/2a \tag{7}$$

where

$$a = (\sum_{m=0}^{N_{PT_{\max}}-1} m^2 \beta_m) \tag{8}$$

$$b = -2(\frac{R^2}{M_1} + R \sum_{m=0}^{N_{PT_{\max}}-1} m\beta_m) \tag{9}$$

$$c = 2R^2 \sum_{m=0}^{N_{PT_{\max}}-1} \beta_m \tag{10}$$

In step 2, first a general iteration is used, which will make the guess value much closer to the real solution of the equation.

$$M_{in} = M_1 \sum_{m=0}^{N_{PT_{\max}}-1} \beta_m e^{-\frac{mM_{ic}}{R}} \tag{11}$$

In the next step, according to Newton Iteration algorithm and repeating Newton Iteration operation until $|M_{in} - M_{ic}| < \delta$, which will obtain the estimation value of M_i. where δ is the tolerate error, and $\delta = 0.001$ is supposed in this paper. We can get

$$M_{ic} = M_{in} \tag{12}$$

$$M_i = M_{ic} - \frac{f(M_{ic})}{f'(M_{ic})} \tag{13}$$

Finally, the current number of MTC devices is obtained by M_{ic}. The FGPA is as follows Algorithm 1.

Algorithm 1. FGPA for the approximated value of M_i

1. Set the first guess value of M_{ig};
2. $M_{ic} = M_{ig}$, and calculate the new number of MTC devices $M_{in} = M_1 \sum_{m=0}^{N_{PT_{\max}}-1} \beta_m e^{-\frac{mM_{ic}}{R}}$;
3. Repeat operation: $M_{ic} = M_{in}$
   $M_i = M_{ic} - \frac{f(M_{ic})}{f'(M_{ic})}$
   Until $|M_{in} - M_{ic}| < \delta$;
4. Update the existing value $M_{ic} = M_{in}$.

Estimating the value by the FGPA is still accurate, and the algorithm is much simpler and has less number of iterations. After obtaining the total number of MTC devices, the optimal value of new arrival MTC number will be got by taking resource utilization into consideration according to Eq. (2). In other words, the number of new arrival MTC is the activated MTC number in every slot, and the optimal value can be obtained by simulation results.

For example, Fig. 1 shows the relationship between MTC number of new arrivals and the corresponding resource utilization rate when $R = 42$ and $R = 54$, from which we can obtain the optimal number of MTC new arrivals. The new arrivals number is the value that makes the resource utilization rate maximum, and we should activate the number of MTC devices in every slot. From the figure we can get the number of new arrivals should be 15 and 20 when $R = 42$ and $R = 54$, respectively.

4 Simulation Results Analysis

First of all, we will verify the estimation accuracy of proposed algorithm is very high by simulating the total number of MTC devices and the successful number

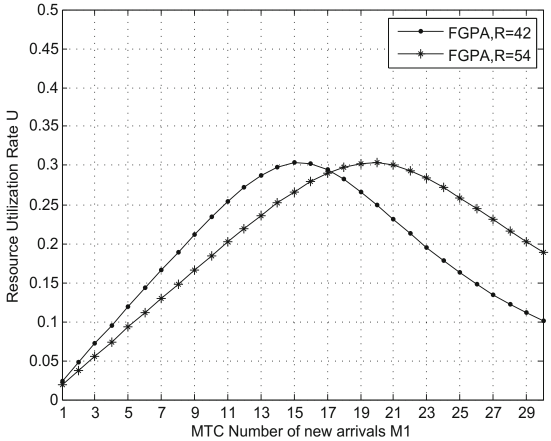

Fig. 1. The relationship between MTC number of new arrivals and the corresponding resource utilization rate when $R = 42$ and $R = 54$.

of MTC devices under certain parameters circumstance. After the true value of MTC devices number is obtained, we compare the performance of the proposed algorithm with the ordinary iteration algorithm in the FI-TSFGP. The basic parameters summarized in Table 1 are used in the simulation.

Table 1. Simulation parameters

Notions	Description	Values
M	Number of devices (each cell)	10–5000
R	Total number of preambles (per slot)	42 or 54
$N_{PT_{\max}}$	Maximum preamble transmissions	5
W_{BO}	Back-off window Size	BI+1
W_{RAR}	Size of RAR window	5
T_{RA_REP}	Interval (consecutive RA slot)	5
p_n	Preamble detection probability	$1 - e^{-n}$
N_{ACK}	Maximum number of ack (an RAR window)	$W_{RAR} * N_{RAR}$

Figures 2 and 3 illustrate the true and the approximate values of the total number of MTC and the number of successful MTC, respectively. Besides the proposed FGPA method and the true value, these figures include the results for ordinary iteration algorithm which is used in the FI-TSFGP for the sake of comparison. Moreover, different values of M_1 were considered. From these figures, we clearly see that the proposed FGPA gives a good estimation of both the total number and successful MTC devices number.

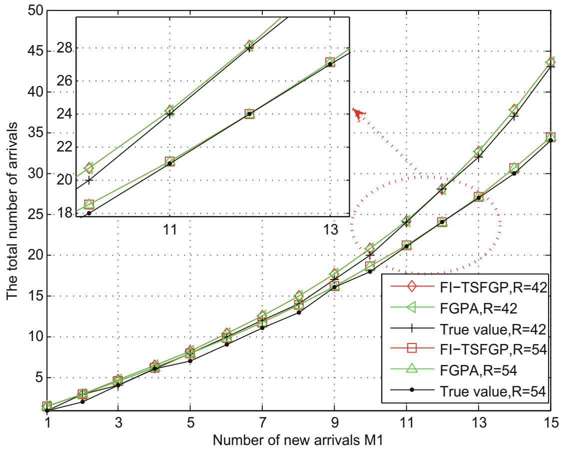

Fig. 2. Number of iterations with different number of new arrivals

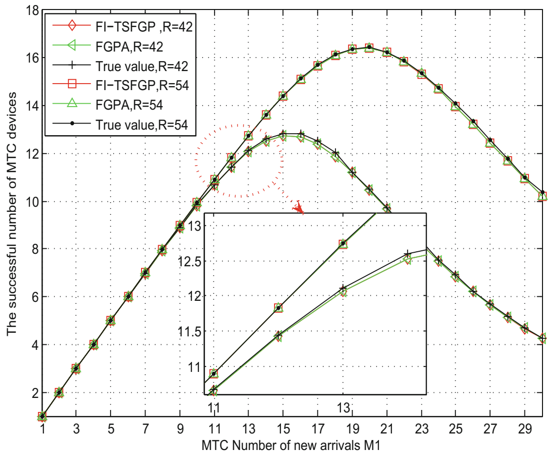

Fig. 3. The number of successful MTC devices as function of the number of new arrivals M_1 for different number of preambles

Then, the performance metrics of the iterations number is investigated, which is defined as how many times of iteration will achieve an accurately estimate of MTC devices. The performance of the proposed FGPA for group paging is evaluated by computer simulation. Figure 4 illustrates the number of iterations with different number of new arrivals. In Fig. 4, the number of new arrivals is set from 1 to 20. In generally, from the figure which is under the condition of $R = 42$ and $R = 45$, it is found that the proposed FGPA has much lower number of iterations than the ordinary iteration algorithm. From this figure, we can learn that though the proposed FGPA has a little more iteration number

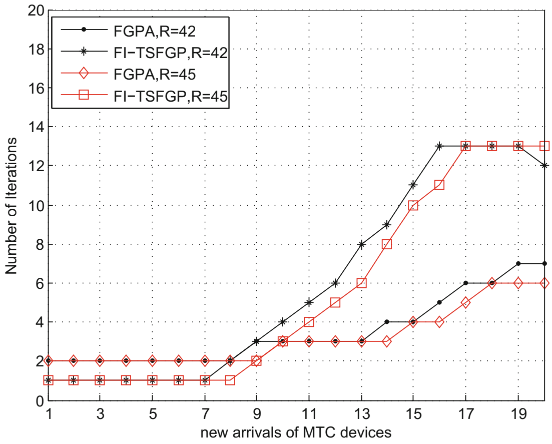

Fig. 4. Number of iterations with different number of new arrivals

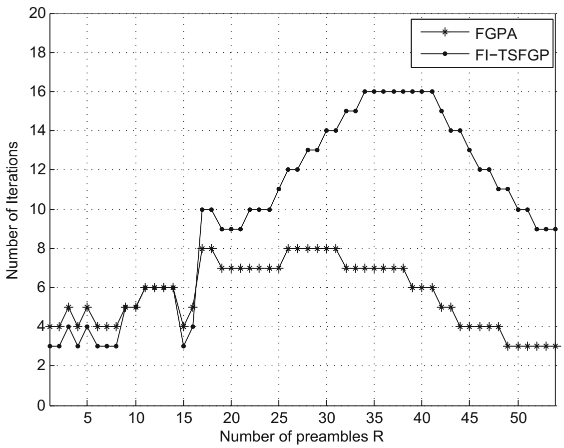

Fig. 5. Number of iterations with different number of preambles R

when new arrival number is small, the number of iterations is relatively less when new arrival number becomes bigger which will improve the performance of the algorithm. So if we want to achieve the required accuracy, the iteration number of the proposed FGPA will be much lower than the ordinary iteration algorithm.

The relationship between the number of iterations and the number of preambles R is illustrated in Fig. 5, from which we can find that the proposed FGPA is better in terms of complexity than the ordinary iteration algorithm in the FI-TSFGP. From the figure we can learn that the improved performance is not significant and could be worse when the number of preambles R is small, but the proposed FGPA has much fewer iteration times compared with the ordinary iteration algorithm in the FI-TSFGP when the number of preambles R becomes bigger. This is attributable to improvement obtained by the new iterative operation.

From the analysis of this paper, we can learn that the proposed FGPA is simple, fast and has low computational complexity. The main contribution of this paper is to estimate the total number of MTC devices by using an iterative algorithm that converges fast and has low arithmetic complexity instead of the ordinary iterative algorithm. After obtaining the total number of MTC devices M_i, the optimal value of new arrival MTC number will be got, which is the activated MTC number in every slot.

5 Conclusions

In this paper we think about reducing the collision probability. Firstly, we need to obtain the total number of MTC devices M_i in every slot when the MTC number of new arrivals follows uniform distribution. Then the optimal value of new arrivals making the resource utilization rate maximum will be got, and the number of new arrivals is the activated MTC number in every slot, and the optimal value can be obtained by simulating the relationship between MTC number of new arrivals and the corresponding resource utilization rate.

In order to obtain the total number of MTC devices M_i, we have proposed FGPA for large scale MTC systems instead of the ordinary iteration algorithm. The estimation accuracy of proposed algorithm is the same as ordinary iteration algorithm. What's more, the proposed FGPA outperforms ordinary iteration algorithm for GP mechanism, in terms of the complexity of the algorithm under the same condition compared with ordinary iteration algorithm. Furthermore, the algorithm proposed is simple, converging fast and has low computational complexity, which is the main contribution of this paper. The corresponding simulation results demonstrate that the proposed iteration algorithm FGPA requires less number of iterations under the condition of the same estimation results of total number of MTC devices.

Acknowledgment. This work was supported by the State Major Science and Technique Project (MJ-2014-S-37), National Natural Science Foundation of China (61201134) and 111 Project (B08038).

References

1. Ali, A., Hamouda, W.: Cell search evaluation: a step towards the next generation LTE-MTC systems. In: 2016 IEEE Wireless Communications and Networking Conference (WCNC), pp. 1–6. IEEE (2016)
2. Ali, M.S., Hossain, E., Kim, D.I.: LTE/LTE-a random access for massive machine-type communications in smart cities. arXiv preprint arXiv:1608.03042 (2016)
3. Chang, C.W., Lin, Y.H., Ren, Y., et al.: Congestion control for machine-type communications in LTE-a networks. In: 2016 IEEE Global Communications Conference (GLOBECOM), pp. 1–6. IEEE (2016)
4. Cheng, M.Y., Lin, G.Y., Wei, H.Y., et al.: Overload control for machine-type-communications in LTE-advanced system. IEEE Commun. Mag. **50**(6), 38–45 (2012). 34(5), pp. 1086–1102

5. Chang, C.T., Yang, S.R.: Modeling LTE group paging mechanism for machine-type communications. In: 2015 International Wireless Communications and Mobile Computing Conference (IWCMC), pp. 1295–1300. IEEE (2015)
6. Arouk, O., Ksentini, A., Taleb, T.: Group paging optimization for machine-type-communications. In: 2015 IEEE International Conference on Communications (ICC), pp. 6500–6505. IEEE (2015)
7. 3GPP R2–104870. Pull Based RAN overload control, August 2010
8. Hasan, M., Hossain, E., Niyato, D.: Random access for machine-to-machine communication in LTE-advanced networks: issues and approaches. IEEE Commun. Mag. **51**(6), 86–93 (2013)
9. Arouk, O., Ksentini, A., Taleb, T.: Group paging-based energy saving for massive MTC accesses in LTE and beyond networks. IEEE J. Sel. Areas Commun. **34**, 1086–1102 (2016)
10. Wei, C.H., Cheng, R.G., Tsao, S.L.: Performance analysis of group paging for machine-type communications in LTE networks. IEEE Trans. Veh. Technol. **62**(7), 3371–3382 (2013)