Optimization of Large-scaled Random Access Congestion Control Oriented to Narrow Band Internet of Things

Li Wang¹, Wei Wang¹, Xianhua Hu²* and Tairong Xie²

¹ Guangzhou Power Supply Bureau Co., Ltd, Guangzhou, Guangdong, 510620, China
² Guangdong Yuanpeng Network Technology Co., Ltd, Guangzhou, Guangdong, 510000, China
*Corresponding author’s e-mail: 15602279647@163.com

Abstract. Narrow band internet of things (NB-IoT), as an important low-power wide-area coverage of 5G with independent intellectual property rights, has great potential in small data monitoring of urban power transmission and distribution. However, it is extremely easy to cause congestion and overloading of the system upon large-scaled terminal requests for random access, which will decrease network access performance and bring great challenges to promote NB-IoT in urban power Internet of Things. On this basis, a mathematical model of network load was constructed to estimate and predict load changes. Then, a dynamic adjustment functional model was set up according to dynamic adjustment of access parameter optimization based on loads. Based on above idea, a random access algorithm based on dynamic parameter adjustment in accordance to dynamic priority was developed. It increases the success rate of devices access to NB-IoT system, decreases access delay of devices, and relieves network congestion. According to simulation results, the proposed algorithm has higher access success rate, lower total delay. And it guarantees delay for important node users and more optimized network performances compared with traditional network access algorithms.

1. Introduction

The development of mobile information technology, information world and physical world are integrated deeply, which brings prominent demands for Internet of Things (IoT) with low power consumption, wide coverage, long distance and low bandwidth. Low Power Wide Area (LPWA) develops quickly [1]. LPWA can be divided into LoRa[2], Sigfox[3] and Narrow Band Internet of Things (NB-IoT)[4] according to whether frequency spectrum in the communication is authorized frequency band or public frequency band. Power transmission and distribution is mainly in field investigations. LPWA is very applicable to similar monitoring and applications[5].

NB-IoT is an IoT which is proposed by 3rd Generation Partnership Project (3GPP) and supports ultralow complexity and low throughput capacity. It is based on a cellular system[6]. With low data transmission rate, low power consumption and low bandwidth, NB-IoT has a simpler structure and lower cost, which are convenient for popularization of operators. NB-IoT can be deployed directly into existing LTE-A network and coming 5G[7][8].

Currently, NB-IoT applications mainly orient to Machine Type Communications (MTC) businesses [9]. When a lot of MTC terminals request simultaneous access into NB-IoT, it often causes congestion and over-loading of the NB-IoT network as well as low access probability of devices, thus influencing performance of the NB-IoT network[10]. Therefore, how to optimize and
coordinate access of MTC terminals, improve access probability and shorten waiting time, and decrease delay becomes an important problem that has to be solved urgently in current studies of NB-IoT system. Many schemes have been proposed in 4G cellular system to control sudden large-scale access congestion of Radio Access Network (RAN) [11][12]. The Access Class Barring (ACB) strategy suggested by 3GPP is viewed as an effective and feasible overloading control scheme[13].

When terminal loads exceed the network capacity, ACB strategy can restrict access requests of some terminals to decrease PRACH loads and collision of leader sequences. Based on ACB strategy, a more effective mechanism to improve mass terminal access congestion, which is known as the extend access barring (EAB) mechanism[14][15]. Although EAB mechanism can relieve access over-loading to some extent, it has to update access barring parameters very quickly upon extremely serious congestion. This is difficult to be realized in practical application, resulting in the limited effects of EAB mechanism. To address this problem, CHOU[16] predicted random access (RA) loads according to number of lead code sequences and previous number, and then adjusted ACB parameters with the prediction results. Based on delay model of collision, HE [17] constructed an access load estimation scheme based on Markov chain and adjust the access barring parameters flexibly according to load estimation. KAO [18] divided user devices (UE) into several groups and assigned a leader to each group to distribute and call random access channel (RACH) resources to reduce competition among group members, thus enabling to decrease direct competition and net-work overloading. WANG [19] proposed another ACB optimization program, which determined the optimal ACB parameters for each random access according to ACB and regular advanced information. Kim [20] put forward a new backspacing state generation algorithm—adaptive virtual backspacing algorithm to solve data conflict and it was mainly to guarantee fairness of channel. Ryu [21] investigated performances of channel adaptive random access which had discontinuous and relevant channel measurement. Performances was ac-essed according to detection performance, transmission delay and power consumption of receiver of channel adaptive random access. Results demonstrated that this channel provide an accurate performance estimation for channel adaptive random access. Jeon [22] pointed out that nodes based on local channel state in-formation (CSI) made random access through a dispersed way, which was called channel aware random access (CARA).

The above mechanism is mainly improved on the basis of ACB mechanism. In the case of access overload, the performance of LTE system is improved to a certain extent. However, these mechanisms hardly consider priority of business and fairness of overall UE. Hence, a priority NB-IoT system-devices access congestion control problem was discussed on the basis of ACB mechanism. A random access algorithm ACB based on dynamic priority was proposed by designing a new access priority class mechanism with delay consciousness. The proposed ACB increases success rate of access of NB-IoT system, devices shortens access delay and relieves network congestion.

2. Modeling for random access system

ACB factor $p$ can manage network congestion effectively. However, it is a difficulty to select a reasonable $p$. When $p$ is too high, many users are accessed in, causing continuous conflicts of lead codes. When $P$ is too low, the utilization of network resources is insufficient although there are few conflicts. Therefore, a network congestion optimization framework is suggested according to previous evolution and deduction model. This framework is shown in figure 1.

![Figure 1. Framework of ACB algorithm.](image)

Therefore, $\hat{y}$ can be gained:
Therefore, the optimal $p$ of the system when the number of access devices $i$ is higher than the number of lead code can be calculated:

$$ p_i = K \left( 1 - e^{-\frac{1}{A}} \right) $$

(2)

The best $p$ function of the system is:

$$ p^* = \begin{cases} 1 & A < K \\ p_i & A > K \end{cases} $$

(3)

3. Design of an access optimization algorithm $\mu$ACB

The relationship between optimal value of ACB factor and user loads was analyzed in the above text. However, when the ACB factor is restricted for terminal users, all terminal users are forbidden randomly. When network load increases, it is easy to prolong delay at some terminals, thus impairing fairness of terminal users. Hence, it plans to optimize delay of different users, protect relative fairness and optimize network performances. It is a good idea to divide priority levels according to delay and protect network performances. Network fairness can be realized by dividing priority levels in according to priority of different businesses, network differences and delay values.

3.1 UE Classification based on delay and task priority

Suppose there are $N$ devices waiting for access to the current NB-IoT and the device set for accessing is recorded as $U = \{U_1, U_2, \ldots, U_i\}$, where $U_i$ is the $i$th device waiting for access. Since different types of businesses in the power transmission and distribution network have different requirements on delay, different UEs show different sensitivity to delay. This study plans to make a dynamic adjustment of access level according to current delay state of UE and priority of businesses, aiming to meet demands of different users.

If priority of UE is set $g$ according to business, the number of businesses at each priority level is $g_i$ and the total number of business is $N = \sum_{i=1}^{m} g_i$. Secondly, delay is related with the preset maximum times of backoff $\phi$. The number of backoff of each user is expressed as $\phi$. Therefore, the priority of each piece of device is defined as:

$$ \eta = \alpha g_i + \beta \phi $$(4)

The priority division rule considers delay fairness and business priority comprehensively to guarantee unified fairness and efficiency of network flow. Based on above analysis, an algorithm was proposed based on above analysis.

3.2 Steps of the algorithm

The dynamic access steps of algorithm are introduced as follows:

**Step 1:** All UEs in a cell access to the current station eNB randomly.

**Step 2:** Based on current network flow, it can predict that when UE is smaller than number of lead codes, $p_i$ reaches the maximum value and all UE access competitively.

**Step 3:** When number of network UE is higher than the number of lead codes, $p_i$ is calculated according to the Eq.(3).

**Step 4:** When UEs have conflicts, they are access in randomly according to priority $g_i$. After the occurrence of conflicts, users record the number of delays ($\phi$) and the priority factor of users ($\eta$) can be calculated from the Eq.(4). Users can adjust their own delay according to $\eta$. 

\[ A = -\frac{1}{\log(1 - \frac{p_i}{K})} \]
Step 5: UEs calculates $\eta$ in the time slot and are accessed until normal access or reaching the maximum number of backoff ($\phi$).

4. Performance evaluation
Since one cell of NB-IoT contains one eNB station and multiple UEs, access requests of all UEs conform to a uniform distribution in time. For simplified analysis, UEs waiting for access in simulation are divided into several priority groups: $g = 9$. Other simulation parameters are listed in Table 1.

| Parameters             | Values |
|------------------------|--------|
| System bandwidth /MHz  | 20     |
| Channel bandwidth /MHz | 180    |
| Backoff time /ms       | 20     |
| Maximum number of backoff $\phi$ | 8    |
| Number of accessed leads | 48   |
| Number of priority groups $g$ | 9    |
| Random access duration /ms | 5000 |
| Maximum of accessed devices $N$ | 3000 |
| Access barring parameter $p$ | $[0,10]$ |
| Weight $\alpha$        | 0.6    |
| Weight $\beta$         | 0.4    |

For congestion control based on access algorithm, success access rate and delay are core indexes to evaluate quality of an access algorithm. In this study, performance of access algorithm was evaluated by access success rate and average delay. The calculation formulas of access success rate and average delay are shown in Eq.(5), Eq.(6) and Eq.(7). The access success rate of UE is:

$$P_s = \frac{n}{D}$$

where $n$ is the number of successfully accessed UE and $D$ is the number of access requests.

The delay at access of devices is defined as:

$$T_{k,i} = t_i - \hat{t}_i$$

where $t_i$ is the time slot of successful access and $\hat{t}_i$ is the time slot at first access.

Then, the average access delay can be expressed as:

$$T_i = \frac{\sum_{i=1}^{n} T_{k,i}}{n}$$

Based on above hypothesis, delay of the proposed algorithm is tested. Similar ACB algorithms for comparison include ACB and EAB.

The relation curves between access success rate and number of accessed devices are shown in figure 2. It can be seen from figure 2 that with the increase of number of accessed devices, the access success rates of the proposed algorithm, ACB and access algorithm based on EAB mechanism decline gradually. The access success rate of algorithm declines more slowly than those of ACB and EAB. The access success rates of ACB and EAB decrease significantly with the increase of number of accessed devices. This demonstrates that the proposed algorithm can cope with sudden access of mass users through prediction and user priority class mechanism, thus enabling to relieve congestion of user access.
The relation curves between average access delay and number of accessed devices are shown in figure 3. It can be seen from Fig.8 that compared with ACB and EAB, the number of accessed UE of the algorithm increases gradually, which causes increasingly average access delay of UE. This is because the probability of conflicts among different UEs increases when more UEs compete for access to resources. Moreover, UE is more probably to retreat under the regulation of backoff mechanism. The proposed algorithm has significantly shorter delay in facing with competitive access of mass UEs than the traditional ACB and EAB. However, delay of different algorithms is similar when there are few accessed UEs. This demonstrates that the proposed algorithm can decrease delay in facing with access of mass UEs more effectively.

In applications of electricity IoT, various types of nodes often assume tasks of different propriety levels. The actual access success rate and delay of these nodes are important performance indexes. Terminal delay was going to be tested by average delay at 9 types of priority nodes and compared as figure 4. In actual terminals, 9 types of delay terminals were set, which were defined as \((p_1, p_2, \ldots, p_9)\). Among them, five types of terminals were chosen to test and compare the above three access algorithms.
According to experiment, there’s a small difference among different priority levels when the number of access requests is small. However, the access success rate of high-priority UE can be assured when the number of access requests increases, while, the access success rate of low-priority UE declines.

5. Conclusions
This study investigates network overloading of the NB-IoT system at the mass access requests of devices. An optimized random access algorithm based on prediction of number of UE access requests and priority level of access businesses is proposed. This algorithm identifies delay of different UEs according to waiting delay and weighted value of business priority. Meanwhile, it predicts the number of successfully accessed UEs according to the predicted number of accessed users and number of conflicts. On this basis, the optimal access barring parameters can be set dynamically and the access performance is optimized.

Acknowledgments
This work was supported in part by Guangzhou Science and Technology Planning Project under Grant 201902020003, in part by China Southern Power Grid Science and Technology Project under Grant GZJKJXM20170032.

References
[1] Guizar, A., Maman, M., Mannoni, V., et al. (2018) Adaptive lpwa networks based on turbo-fsk: from phy to mac layer performance evaluation. In: 2018 IEEE Global Communications Conference (GLOBECOM). Abu Dhabi. pp. 206-212.
[2] Elshabrawy, T., Robert, J. (2019) Interleaved chirp spreading lora-based modulation. IEEE Internet of Things Journal, 6(2): 3855-3863.
[3] Lavric, A., Petrariu, A. I., Popa, V. (2019) Long range sigfox communication protocol scalability analysis under large-scale, high-density conditions. IEEE Access, 7: 35816-35825.
[4] Tsoukaneri, G., Condoluci, M., Mahmoodi, T., et al. (2018) Group communications in narrowband-IoT: Architecture, procedures, and evaluation. IEEE Internet of things Journal, 5(3): 1539-1549.
[5] Tat, Y. T., Liu, Y., Zhu, H., et al. (2018) Feasibility studies on smart pole connectivity based on lpwa iot communication platform for industrial applications. In: IECION 2018-44th Annual Conference of the IEEE Industrial Electronics Society. Washington, DC. pp. 4131-4134.
[6] Adhikary, A., Lin, X., Wang, Y. P. E. (2016) Performance evaluation of NB-IoT coverage. In: 2016 IEEE 84th Vehicular Technology Conference (VTC-Fall). Montreal, QC. pp. 1-5.
[7] Cao, J., Yu, P., Ma, M., et al. (2018) Fast authentication and data transfer scheme for massive NB-IoT devices in 3GPP 5G network. IEEE Internet of Things Journal, 6(2): 1561-1575.

[8] Zhang, Y., Ren, F., Wu, A., et al. (2019) Certificateless multi-party authenticated encryption for NB-IoT terminals in 5G networks. IEEE Access, 7: 114721-114730.

[9] Popli, S., Jha, R. K., Jain, S. (2019) A survey on energy efficient narrowband internet of things (NB-IoT): Architecture, application and challenges. IEEE Access, 7: 16739-16776.

[10] Yang, X., Wang, X., Wu, Y., et al. (2017) Small-cell assisted secure traffic offloading for narrowband Internet of Thing (NB-IoT) systems. IEEE Internet of things Journal, 5(3): 1516-1526.

[11] Hussain, F., Anpalagan, A., Vannithamby, R. (2014) Medium access control techniques in M2M communication: survey and critical review. Transactions on Emerging Telecommunications Technologies, 28(1): e2869.

[12] Ling, X., Wang, J., Bouchoucha, T., et al. (2019) Blockchain radio access network (B-RAN): Towards decentralized secure radio access paradigm. IEEE Access, 7: 9714-9723. 3GPP. Study on RAN improvements for machine-type communications: TR 37.868.2011.

[13] 3GPP. Study on RAN Improvements for Machine-Type Communications. (2011) TR 37.868 V11.0.0.

[14] Wali, P. K., Das, D. (2018) Optimization of barring factor enabled extended access barring for energy efficiency in LTE-advanced base station. IEEE Transactions on Green Communications and Networking, 2(3): 830-843.

[15] Cheng, R. G., Chen, J., Chen, D. W., et al. (2015) Modeling and analysis of an extended access barring algorithm for machine-type communications in LTE-A networks. IEEE Transactions on Wireless Communications, 14(6): 2956-2968.

[16] Chou, C. M., Huang, C. Y., Chiu, C. Y. (2013) Loading prediction and barring controls for machine type communication. In: 2013 IEEE International Conference on Communications (ICC). Budapest. pp. 5168-5172.

[17] He, H., Du, Q., Song, H., et al. (2015) Traffic-aware ACB scheme for massive access in machine-to-machine networks. In: 2015 IEEE international conference on communications (ICC). London. pp. 617-62.

[18] Kao, H. W., Ju, Y. H., Tsai, M. H. (2015) Two-stage radio access for group-based machine type communication in LTE-A. In: 2015 IEEE International Conference on Communications (ICC). London. pp. 3825-3830.

[19] Wang, Z., Wong, V. W. S. (2015) Optimal access class barring for stationary machine type communication devices with timing advance information. IEEE Transactions on Wireless communications, 14(10): 5374-5387.

[20] Kim, J. D., Laurenson, D. I., Thompson, J. S. (2019) Adaptive centralized random access for collision free wireless local area networks. IEEE Access, 7: 37381-37393.

[21] Ryu, I., Moon, H. (2018) Channel-Adaptive Random Access Using Discontinuous and Correlated Channel Measurements. IEEE Transactions on Vehicular Technology, 67(7): 6193-6202.

[22] Jeon, J., Ephremides, A. (2015) Channel-Aware Random Access in the Presence of Channel Estimation Errors. IEEE Transactions on Control of Network Systems, 4(3): 439-450.