An Adaptive Uplink Resource Allocation Scheme for LTE in Smart Grid

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Abstract—Data transmission is crucial for smart grid. Long Term Evolution (LTE) is considered to be a promising solution for smart grid communication because it uses a variety of new technologies to improve communication efficiency. Resource Blocks (RBs) allocation is applied to provide different levels of Quality-of-Service (QoS) in LTE. In this paper, we propose an Adaptive Wireless Resource Allocation (AWRA) scheme for the uplink of LTE-based cellular systems, which takes into account the user's priority and fairness. According to QoS requirements, users are assigned three different priorities, so that AWRA performs flexible and efficient RBs allocation based on users' priorities, thus satisfying a specific QoS requirement. Given Packet Loss Rate (PLR), a mathematical optimization framework is formulated for maximizing the total capacity. The proposed scheme allocates the RBs to the predefined user types with considering Signal Noise Ratio (SNR). An adaptive-scheduling scheme based on the delay time of the queues and the length of the queues is further introduced. Simulation results show that the proposed algorithm has better throughout and fairness than the conventional algorithms, it considerably reduce the data drop rate and satisfies the users' QoS requirements of smart grid.

Index Terms—resource allocation, QoS, LTE uplink, smart grid.

I. INTRODUCTION

The emergence of the smart grid is based on the development of high-speed communication network. It can apply modern technologies of communication, information, computer and control to meet the user's electrical demand and optimize the resource allocation to ensure the security, reliability and economy of electricity supply. In order to adapt to the development of electricity market, it provides the reliable, economic power supplying and interactive value-added services. Table I depicts the salient features of the smart grid in comparison with the existing grid [1].

3GPP Long Term Evolution (LTE) [2], the latest mobile communication network, is a promising option for a smart grid [3]. LTE employs Single-carrier Frequency Division Multiple Accessing (SC-FDMA) in the uplink and Orthogonal Frequency Division Multiple Access (ODFMA) in the downlink [4]. The uplink scheduling is performed by the evolved NodeB (eNodeB), which is the base-station in the LTE architecture. The eNodeB can provide a higher transmission rate of the uplink data to meet the Quality of Service (QoS) requirement of different users in the limited spectrum bandwidth.

TABLE I: THE SMART GRID COMPARED WITH THE EXISTING GRID.

Current grid	Smart grid
Electromechanical	Digital
Centralized Generation	Centralized or Distributed
Hierarchical	Network
Few Sensors	Sensors Throughout
Blind	Self-Monitoring
Manual Restoration	Self-Healing
Manual Check/Test	Remote Check/Test
Limited Control	Pervasive Control
Few Customer Choices	Many Customer Choices

Because of the different varieties of grid data acquisition, there are some periodic data, such as: voltage, current, the requirement of delay is not much strict. But there are some unexpected data, such as: power outages, equipment failures, need to reach instantly. There are some services including real-time services and non-real-time services. Real-time services requires low latency and can tolerate a certain amount of packet loss rate, while non-real-time services requires low packet loss rate and less harsh latency requirements. Meanwhile, due to the large number of users in the grid, it is unreality to send those messages together because of insufficient resource. There must exits some data should be sent firstly and other later, therefore, how to allocate resource is worth researching. Resource allocation schemes are necessary to enhance the performance of wireless network in smart grid in order to guarantee successful data transmission and to satisfy the users' requirements [5]. Although there is a complete QoS mechanism which has been defined in the relevant standard of the 3GPP LTE, there is only a few uplink resource allocation schemes to guarantee QoS

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of different users. According to different QoS requirements and the conditions of link, allocating spectrum resources efficiently becomes a very challenging problem [1].

There are three classic kinds of algorithm about the resource scheduling of only considering PHY-layer: Round Robin (RR) scheduling algorithm, Max Carrier to interference ratio (C/I) scheduling algorithm, Proportional Fairness (PF) scheduling algorithm [6]-[8]. In smart grid, these algorithms have some disadvantages [9]. First of all, the essence of the above algorithms are fixed priority algorithms, it means that each packet's priority is given, resource is allocated according to the pre-defined proportion of weight, the allocation of resource does not change compared to other algorithms which have dynamic priority. Therefore such algorithm results in a declining system throughput. Secondly, these algorithms only consider the requirements of Bit Error Rate (BER) and the minimum transmission rate. However, in the coexistence of multiple services network, the resource allocation algorithm takes into account of the characteristic of delay, the packet should be sent subject to the delay time below a desired threshold. Besides the delay time, Packet Lost Rate (PLR) should also be considered. Researching on resource scheduling algorithm which can meet different users with different QoS is of great significance [10]. How to allocate resource to meet the need of different users which have different bandwidth requirements, different delay protection and different QoS level is a critical issue. In order to complete the task, the resource allocation algorithm considers the different resource requirements of different users, rather than a fair share of resources for the users absolutely. Therefore in this paper, we propose a scheme which is described in next section to adhere to the above-mentioned desired properties. However, it is worth noting that the wireless resource allocation scheme can be only appropriate for control purposes, but not be used for protection purposes in the smart grid.

In this paper, we propose an Adaptive Wireless Resource Allocation (AWRA) algorithm with QoS guarantee in communication network of smart grid. The algorithm not only considers the information of physical layer information, but also takes account of the characteristic of messages from the media access control layer and the QoS requirements to allocate the resources. We allocate wireless resource adaptively based on not only user's priority, but also the delay time of the queues in order to satisfy QoS requirements.

The rest of this paper is organized as follows. In Section II we describe related work for smart grid. System model is presented in Section III. An AWRA scheme is developed to improve the level of service quality in Section IV. Some mathematical analysis for the proposed system is presented and simulation results are provided in Section V. We conclude with the summary and future work discussion in Section VI.

II. System and Channel Model

In this paper, we propose an Adaptive Wireless Resource Allocation (AWRA) scheme with Quality of Service (QoS) guarantee. We assume that the total transmission power of the base station in the RBs is average distribution. Because, on the one hand, the loss of throughput of the system is very small through the average distribution of power among RBs, on the other hand such distribution greatly reduces the computational complexity of the algorithm. We assumed that there are N RBs and K users. Each eNB has perfect and instant channel condition for all uplink transmissions via the feedback channel. Resource allocation scenario is shown in Fig. 1.

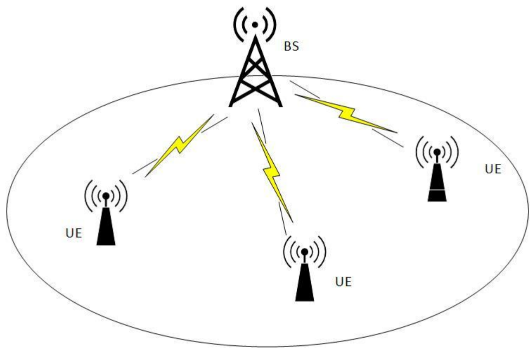

Figure 1. Resource allocation scenario.

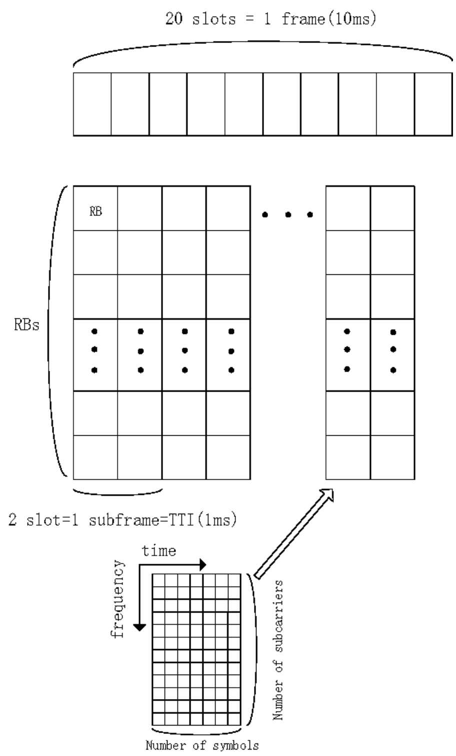

Figure 2. The LTE frame structure and the available resource blocks

In LTE, the downlink and uplink resource blocks are divided into a number of elements as shown in Fig. 2. According to the time and frequency, the structure of resource blocks divided as follows: The maximum time unit is a radio frame of 10ms which is divided into 10 sub-frames of 1ms, each sub-frame is divided into two slots of 0.5ms. Each slot consists of 7 OFDM symbols. Every 12 sub-carriers in the frequency domain form a unit resource (the total occupied 180 kHz resources). Thus, a unit resource in the frequency and the time on a continuous time slot is called a resource block (RB) [11]. Two consecutive RBs are the smallest resource unit that a scheduler can allocate to a user [12].

The eNB can allocate resource blocks for users, in each time slot, a number of RBs can be allocated to a single user. However, each RB can only be assigned to one user.

We consider all users which have infinite data to allocate resource. We use K represents the number of all the users and N represents the number of all resource blocks.

We define the variables $x_k^n(t)$ denote whether the *n*th resource block is assigned to the *k*th user at slot *t*. When $x_k^n(t)$ =1, the *n*th resource block is assigned to the *k*th user at slot *t*. When $x_k^n(t)$ =0, the nth resource block is not assigned to the *k*th user at slot *t*. The information of channel changes with the resource block, the user, as well as the time, so different RBs have different channel information which is based on the time slot.

We use $r_k^n(t)$ denote instantaneous channel rate about the *n*th resource block which is assigned to the *k*th packet at slot *t*. For convenience, we call each chosen adjacent RB set as a resource pattern. Hence, the weighted throughout of the *k*th packet with the *n*th resource block in the *t*th time-slot can be expressed as

$$r_k^n(t) = \rho_k(t)\log_2(1+P_{k,n}\gamma_{k,n}) \tag{1}$$

where $\gamma_{k,n}$ is the signal noise ratio (SNR) for the *k*th user on the *n*th resource block, according to [13], with the average SNR for each user depending on the distance from the eNB. $\rho_k(t)$ is weighted factor which can indicates the user priority and fairness, it can be adjusted according to system requirements [14]. $P_{k,n}$ is the transmitting power when the *k*th user is transmitted on the *n*th resource block, In this paper, we set

$$\rho_k(t) = \frac{1}{\overline{r}_k(t)} \tag{2}$$

$\overline{r}_k(t)$ is the Long-term average service rate for the *k*th user at the time *t*. PF algorithm can get high throughput and good proportional fairness by giving the user the RBs which have the different quality.

For the assigned users, *T* denotes the window length, after the *k*th user has been transmitted, $\overline{r}_k(t)$ is updated every time slot using following equation.

$$\overline{r}_k(t) = (1-\frac{1}{T})\overline{r}_k(t-1) + \frac{1}{T}\sum_n r_k^n(t) \tag{3}$$

In other situations, $\overline{r}_k(t)$ is updated every time slot using following equation:

$$\overline{r}_k(t) = (1-\frac{1}{T})\overline{r}_k(t-1) \tag{4}$$

Considering the real-time services, packet loss rata is often an important indicator of the QoS measurement. If the waiting time of the data exceeds the waiting time threshold, the packets will be dropped. In a period of time, the percentage of the lost packets denotes by PLR, expressed as η_k . As considering the non-real-time services, throughout is an important indicator of QoS. Services are divided into real-time services and non-real-time services, as well as best-effort services. Such as voice services and warning messages are real-time services, delay, rate and bit error rate requirements of these services are relatively high; multimedia industry services are the rate-sensitive services with lower latency; data services are best-effort services. Therefore we provide an algorithm which considers the different QoS of different services. In the LTE resource allocation process, a user may transfer a variety of services, we classified the different variety of services, create multiple queues, different queues have different priorities. For example, voice services have higher priority than multimedia services, multimedia services have higher priority than data services. We divide users into three categories which are denoted as Φ_1, Φ_2, Φ_3, according to the degree of priority. α_{Φ_i} ($i \in \{1,2,3\}$) denotes the utility parameters of messages from high priority to low. We set α_{Φ_1} = 0.6, α_{Φ_2} = 0.3, α_{Φ_3} = 0.1. Based on the above analysis, the optimization model of maximizing the total capacity of a resource allocation problem can be defined as follows:

$$\max \sum_{k=1}^{K}\sum_{n=1}^{N}\alpha_{\Phi_i} x_k^n(t) r_k^n(t) \tag{5}$$

$$\text{S.t.} \qquad \eta_k < \eta_k^{req} \tag{6}$$

$$\sum_{k=1}^{K} x_k^n = 1,\ n \in \{1,2,\cdots,N\} \tag{7}$$

$$\sum_{n=1}^{N} x_k^n \le M,\ k \in \{1,2,\cdots,K\} \tag{8}$$

Formula (6) indicates that the PLR in a queue can’t surpass the threshold η_k^{req} . Formula (7) indicates that each RB can only be assigned to one user. Formula (8) indicates that the number of RBs which are allocated to each user can’t exceed the maximum value M.

III. Resource Allocation Scheme

In this section, we introduce a LTE uplink scheduling algorithm for smart grid communication, which takes into account both the channel conditions and the maximum delay tolerance of the user queue.

Formula (5) expresses a problem of assembly optimization. There is no effective way to obtain the optimal solution for this problem currently. We propose an Adaptive Wireless Resource Allocation (AWRA) scheme which takes into account of the delay of the queue and the packet loss rate to obtain a better resources allocation.

A. Predict the Packet Loss Rate

The PF algorithm has a good application effect on non-real-time services of low-speed, it accounts of the fairness of users and the channel quality. But it can't take into account the requirements of real-time services. On the basis of the PF algorithm, we can proposed an improved delay-based proportional fairness algorithm, the algorithm distinguish real-time services and non-real-time services. We can create a model to provide better services to ensure fairness and delay requirements. We added a delay factor based on the original proportional fairness algorithm. T_k denotes the maximum allowable delay of the queue about the k^{th} user. $\mathrm{U_k}(t)$ denotes the delay of the first packet about the k^{th} user queue at time t. $\mathrm{U_k}(t)/T_k$ denotes the ratio about the first packet delay and the maximum allowable delay, the greater the ratio, the greater the possibility of packet lost, the higher the proportional fairness factor when making resource allocation, it means the priority is higher, avoid the services waiting long time. It reflects the character of real-time services and reaches the purpose of having a priority on resource allocation.

However, on the condition of relatively low delay requirements, the length of the queue determines the priority of the resource allocation, in that case, we can proposed an algorithm which adds the predict PLR to the priority factor. The larger the predict PLR, the higher the predict priority factor. So you can get more resources, in order to reduce PLR. Different services require different QoS in smart grid. Current channel information and delay are only for delay-sensitive services.

We assumed that in a cycle of resource allocation, L denotes the length of total queue, obey the exponential distribution about the value of λ. The probability density function of L is as follows:

$$p(L)=\begin{cases}\dfrac{1}{\lambda}e^{\frac{1}{\lambda}L} & \lambda>0\\ 0 & otherwise\end{cases} \tag{9}$$

When the length of the queue is Q, the possibility of packet loss is

$$P_{lose}=p(L>(Q_{\max}-Q)) \tag{10}$$

where L denotes the total length of different services queues, $Q_{\max}$ denotes the maximum length of the queue, Q denotes the current length at the resource allocation time. So the formula (9) indicates that the probability that the length of current services queue is greater than the length that the queue are able to tolerate.

$$\begin{aligned}P_{lose}&=p(L>(Q_{\max}-Q))\\&=\int_{(Q_{\max}-Q)}^{\infty}e^{\frac{1}{\lambda}L}dL=e^{\frac{Q_{\max}-Q}{\lambda}}=e^{\frac{Q}{\lambda}}\Big/e^{\frac{Q_{\max}}{\lambda}}\end{aligned} \tag{11}$$

The formula (10) indicates the probability of prediction packet lost, in order to simplify the formula(10), we can make the probability convert to the linear relationship.

$$(P_{lose})_{line}=\frac{\log(e^{\frac{Q}{\lambda}})}{\log(e^{\frac{Q_{\max}}{\lambda}})}=\frac{\frac{Q}{\lambda}}{\frac{Q_{\max}}{\lambda}}=\frac{Q}{Q_{\max}} \tag{12}$$

By linear conversion we transform the packet loss rate to the linear packet loss rate, it greatly simplifies the complexity of computation and improves the system efficiency. Of the linear packet loss rate and the original calculated packet loss rate in the range is the same.

We can use $Q_k(t)$ denotes the length of the queue about the *k*th user at time t. $Q_k^{\max}$ denotes the maximum length of the queue about the *k*th user. $Q_k(t)/Q_k^{\max}$ denotes the rate about the length of the queue about the *k*th user at time *t* and the maximum allowance length of the *k*th user. When $Q_k(t)>Q_k^{\max}$, it means the length of the queue about the *k*th user is over the maximum allowance length of the queue about the *k*th user, and may lead to packet lost. The formula reflects the possibility of packet lost. The higher the possibility of packet lost, the larger the factor of proportional fairness. We can improve the factor of the proportional fairness, improve the speed to allocate resource, and reduce the possibility of packet lost.

For a variety of services, we can determine by the priority factor of each service. The resource allocation rules are the same no matter what kind of resource allocation algorithm used, to get the factors of proportional fairness about all resource blocks corresponding to each user, then to get the user which corresponding to the largest predictor factor.

B. The Adaptive Algorithm

In this paper, we put up a adaptive algorithm, the steps of the algorithm are described as follows:

1) Information Classification: At time *t*, dividing the users into three categories according to the degree of services requirement, denote as Φ_1, Φ_2, Φ_3. $U_k(t)/T_k$ denotes the priority of the user. The steps of classify users as follows:

(1) Initialization: Let $\Phi_1=\Phi_2=\Phi_3=\phi$, we define the set of available RBs as $\Omega=\{1,2,\cdots,N\}$, where N is the sequence number of available RBs, $n\in\Omega$, and we define the set of available users $\Phi=\{1,2,\cdots,K\}$, where K is the total number of available users, $k\in\Phi$. Let $x_k^n(t)$ =0.

(2) As every $k \in \Phi$: If $U_k(t)/T_k < \sigma_1$, we set $\Phi_1 = \Phi_1 + \{k\}$, $\sigma_1 \in (0,1)$ denotes the factor of delay control. If $\sigma_1 < U_k(t)/T_k < \sigma_2$, we set $\Phi_2 = \Phi_2 + \{k\}$. $\sigma_2 \in [1,10]$ denotes the factor of delay control. Adjusting these factors can change the number of users belong to Φ_1, Φ_2. If the above conditions are not met, we set $\Phi_3 = \Phi_3 + \{k\}$.

2) Resource Allocation: Then we allocation RBs for the users belong to Φ_1, Φ_2, Φ_3:

(1) According to the priority, we should allocate resource blocks for the users $k \in \Phi_1$. The users belong to Φ_1 are emergency data generally, so the packet should not be lost and we should guarantee the data arrive on time. We propose an algorithm which may considerably reduce the PLR and satisfies the users' QoS requirements of smart grid as follows: we allocate RBs for the user $k \in \Phi_1$, we should seek $k^* = \arg\max_{k \in \Phi_1} \{Q_k(t)/Q_k^{\max}\}$, then allocate resource blocks for k^* , seek $n^* = \arg\max_{n \in \Omega} \{\gamma_{n,k^*}\}$, γ_{n,k^*} denote the Signal Noise Ratio about the k^* user transmit the n^{th} RB. Therefore $x_{k^*}^{n^*} = 1$, set $\Omega = \Omega \setminus n^*$, until the user in the buffer queue have be fully transmitted, let $\Phi_1 = \Phi_1 \setminus \{k^*\}$, until $\Omega = \phi$ or $\Phi_1 = \phi$.

(2) The users $k \in \Phi_2$ are control information or multimedia industry services, the priority is lower than the users belong to Φ_1, we try to reduce PLR, so that there are as much packets as possible to arrive on time. we allocate RBs for the users $k \in \Phi_2$, we should seek $k^* = \arg\max_{k \in \Phi_2} \{U_k(t)/T_k\}$, then allocate resource blocks for k^* , seek $n^* = \arg\max_{n \in \Omega} \{\gamma_{n,k^*}\}$, Therefore $x_{k^*}^{n^*} = 1$,set $\Omega = \Omega \setminus n^*$, until the user in the buffer queue have be fully transmitted, let $\Phi_2 = \Phi_2 \setminus \{k^*\}$, until $\Omega = \phi$ or $\Phi_2 = \phi$.

(3) The packets $k \in \Phi_3$ are data information, we can endure a certain amount of packet losing, our purpose is to improve throughput as far as possible. we allocate RBs for the users $k \in \Phi_3$, we should seek $k^* = \arg\max_{k \in \Phi_3} \{r_k^n / \bar{r}_k\}$, then allocate resource blocks for k^* , the average rate for the k^* user updates based on $\bar{r}_k(t) = (1 - 1/T)\bar{r}_k(t-1) + 1/T \sum_n r_k^n(t)$, then allocate resource blocks for k^* , seek $n^* = \arg\max_{n \in \Omega} \{\gamma_{n,k^*}\}$, Therefore $x_{k^*}^{n^*} = 1$,set $\Omega = \Omega \setminus n^*$, until the user in the buffer queue have be fully transmitted, let $\Phi_3 = \Phi_3 \setminus \{k^*\}$, until $\Omega = \phi$ or $\Phi_3 = \phi$.

IV. Simulation Results and Performance Analysis

In this section, we verify the performance of the proposed resource allocation algorithm through numerical simulation and comparing with traditional PF algorithm. The simulation parameters are shown in Table II. In order to reflect the intuitive nature of the simulation performance, we defined that η_k < 0.02 is satisfied by real-time users. In order to evaluate the performance of the proposed algorithm, we define five metrics, including the average PLR, the average delay time of packet, average transmitting rate, the fairness index and overall system throughput. We will compare our algorithm with the following PR algorithm in these metrics respectively. The first two evaluation metrics are used for real-time services and we use the messages of VoIP as representatives of real-time services. The third evaluation metric is used for non-real-time services and we use the messages of FTP as representatives of non-real-time services. The results for the various evaluation criterions were given in the following figures.

TABLE II: Simulation Parameters

Simulation parameters	Value
Residential structure	19 plots,3 sectors
Carrier frequency	2GHz
Bandwidth	10MHz
The maximum transmit power on base station	46dbm
The noise index on base station	5dbm
The number of RBs	50
Latency threshold	30ms
PLR threshold	0.02

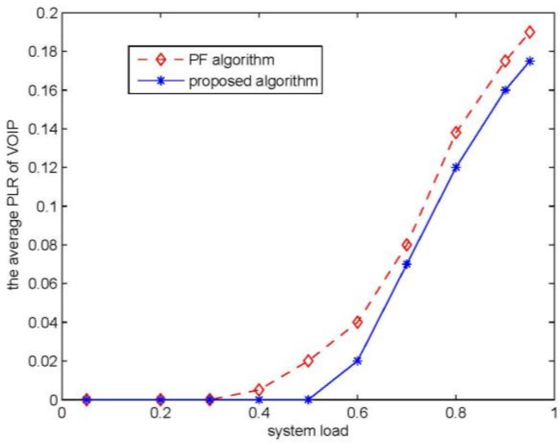

Figure 3. The average PLR of real-time services

Fig. 3 shows that when the system load in the range of 0.1 to 0.5, the PLR of VOIP is almost zero. When the system load is less than 0.6, the average PLR under the algorithm is less than the maximum value of the services can be tolerated (VoIP services is 0.03). However, when the system load increases, the PLR of services is rising rapidly. This is because most of RBs are used to request real-time services transmission, thus some of the other's users must wait for a very long period of time to occupy RBs and the load has been far beyond the system capacity. In addition, it can be observed that the PLR of the proposed algorithm is always lower than the PF algorithm. This is flexible because the algorithm provides a more flexible priority calculation. According to the number of users and the delay time, the priority is adjusted to meet the requirements of the real-time services.

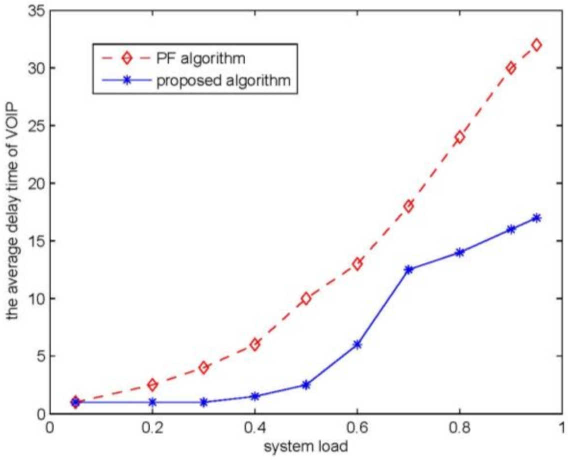

Figure 4. The average delay time of real-time services

Fig. 4 shows that the average delay time of real-time services under the proposed algorithm is lower than the PF algorithm. The reason is similar with the average PLR, because the algorithm gives higher priority to the real-time services. Actual system generally does not allow the load is too high, so the main consideration of system load range is from 0.2 to 0.7. Therefore, considering the average PLR and average packet delay requirements of the real-time services, this algorithm basically meets the QoS requirements.

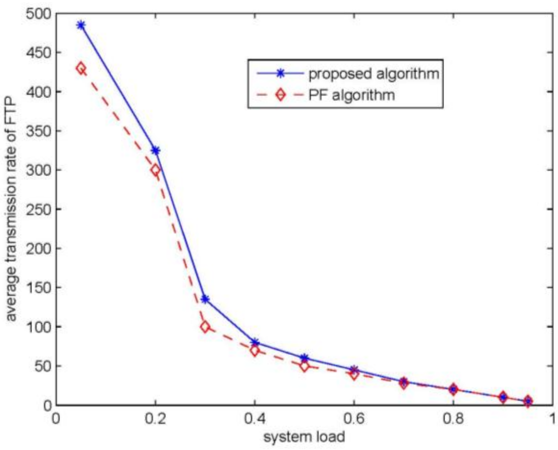

Figure 5. The average transmitting rate of non-real-time services

Fig. 5 shows the average transmission rate of the FTP service performance. FTP services do not request a minimum transmission rate, but the algorithm in the system load is still able to provide higher transmission rates. as the system load increases, the average transmission rate decreases rapidly, however, compared provide a better average transmission rate. This is because this algorithm makes a better utilization of the multiuser diversity.

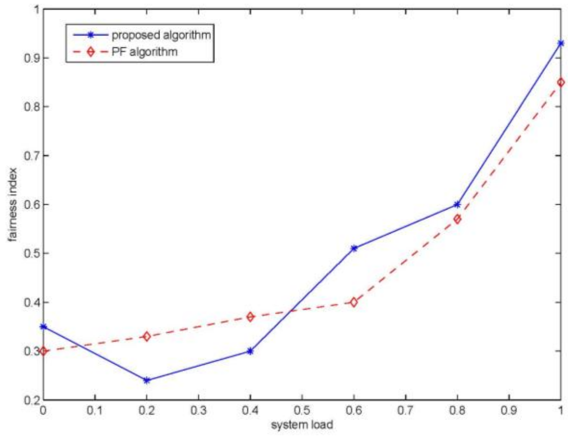

Figure 6. The fairness index graph

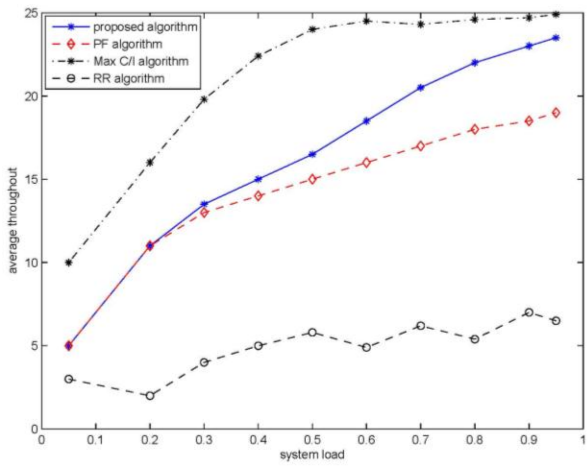

Figure 7. System throughput.

Fig. 6 shows that the fairness index graph of different algorithms in LTE uplink. When system load is low, the fairness index is relatively low. With the system load increasing, the fairness index gradually increased. The fairness index in the proposed algorithm is higher than PF algorithm. The main reason is that the proposed algorithm considers the delay time and the PLR of the queue, so the fairness index is higher, while PF algorithm is only the proportional fairness algorithm based on the largest fairness index of the system, so the fairness index is lower.

Fig. 7 shows that the proposed algorithm can provide higher system throughput. When the system load is high, the system throughput can reach at 23 Mbps which is much closed to the maximum throughput under ideal conditions. The system throughput of Max C/I algorithm is the highest while the RR algorithm is the lowest. In summary, when the system load is less than 0.7, the proposed algorithm can basically meet the different QoS requirements of different services. The proposed algorithm gives the real-time services a higher priority, thereby improves the perception of the real-time services, and makes better use of the non-real-time services which demands less delay requirements, finally improves the spectrum utilization of the system. From the above simulation, the proposed resource allocation algorithm can not only reduce the PLR of packets significantly, but also improve the throughput performance and fairness.

V. CONCLUSIONS

In this paper, based on the different QoS requirements of users in smart grid, we proposed an AWRA algorithm which classifies the users into three categories and optimally allocated RBs for these users. The process of resource allocation considers the maximum delay time of the queue, the length of the queue, PLR, the QoS requirements of users and the channel conditions. Simulation results show that the proposed algorithm has better throughout and fairness than the conventional algorithms, it can reduce the PLR of real-time services and satisfy the users' QoS requirements of smart grid.

REFERENCES

[1] H. Farhangi, "The path of the smart grid[J]," *IEEE Power and Energy Magazine*, vol. 8, no. 1, pp. 18-28, 2010.

[2] S. Sesia, I. Toufik, and M. Baker, *LTE: The UMTS Long Term Evolution*[M], New York: John Wiley & Sons, 2009.

[3] P. Lescuyer and T. Lucidarme, *Evolved Packet System (EPS): The LTE and SAE evolution of 3G UMTS*, Wiley, 2008.

[4] D. Kivanc, G. Li, and H. Liu, "Computationally efficient bandwidth allocation and power control for OFDMA," *Wireless Communications, IEEE Transactions on*, vol. 2, no. 6, pp. 1150-1158, 2003.

[5] A. Clark and C. J. Pavlovski, "Wireless networks for the smart energy grid: Application aware networks," in *Proc. International Multi Conference of Engineers and Computer Scientists*, vol. 2, 2010.

[6] N. Ericsson, "Adaptive modulation and scheduling of ip traffic over fading channels," in *Proc. 50th Vehicular Technology Conference, IEEE*, vol. 2, 1999, pp. 849–853.

[7] C. Wengerter, J. Ohlhorst, and A. G. E. von Elbwart, "Fairness and throughput analysis for generalized proportional fair frequency scheduling in OFDMA," in *Proc. Vehicular Technology Conference IEEE*, A. Jalali, R. Padovani, and R. Pankaj, Data Throughput Spring, 61st, vol. 3, 2005, pp. 1903–1907.

[8] OCDMA-HDR a High Efficiency-High Data Rate Personal Communication Wireless System, *Vehicular Technology Conference Proceedings IEEE*, Spring Tokyo, 51st, vol. 3, 2000, pp. 1854 – 1858.

[9] K. Kim, I. Koo, S. Sung, and K. Kim, "Multiple QoS support using MLWDF in OFDMA adaptive resource allocation," in *Proc. 13th IEEE Workshop on Local and Metropolitan Area Networks*, 2004, pp. 217 – 222.

[10] H. Seo and B. G. Lee, "A proportional-fair power allocation scheme for fair and efficient multiuser OFDM systems," in *Proc. IEEE Global Telecommunications Conference*, vol. 6, 2004, pp. 3737 – 3741.

[11] A. S. Lioumpas and A. Alexiou, " Uplink scheduling for machine-to-machine communications in LTE-based cellular systems," in *GLOBECOM Workshops (GC Wkshps) IEEE*, 2011, pp. 353 – 357.

[12] E. U. T. R, *Access and Evolved Universal Terrestrial Radio Access Network (E-UTRAN)*, Overall Description, 2009, pp. 1 – 69.

[13] K. E. Baddour and N. C. Beaulieu, "Autoregressive modeling for fading channel simulation," *IEEE Transactions on Wireless Communications*, vol. 4, no. 4, pp. 1650 – 1662, 2005.

[14] J. Fan, G. Y. Li, Q. Yin, B. Peng, and X. Zhu, "Joint user pairing and resource allocation for LTE uplink transmission," *IEEE Transactions* on *Wireless Communications,* vol. 11, no. 8, pp. 2838 – 2847, 2012.

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