http://dx.doi.org/10.5755/j01.eee.19.10.5457 ELEKTRONIKA IR ELEKTROTECHNIKA, ISSN 1392-1215, VOL. 19, NO. 10, 2013

Smart M2M Uplink Scheduling Algorithm over LTE

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***Abstract*—As a long term evolution plan of 3G, currently Long Term Evolution (LTE) System is also the internationally recognized mobile communication standard for 4G. FD-LTE is the LTE system of Frequency Division Duplex (FDD) mode. It is also the mobile network system with the fastest transmission rate. For the uplink scheduling in the LTE system, due to the difference between the power of UE and the terminal capability level, the system might not be able to schedule users (UE) for maximum bandwidth transmission. So the uplink scheduling strategy and scheduling method is one of the hot topics of current research. We have looked into the M2M devices accessing the LTE networks. Based on the characteristics of small data volume, the large number of M2M communication nodes, the different time limit and diversified services, compared with the existing H2H communication, it is found that there are major differences between M2M communications and H2H communications. In the light of this, in this paper, we have conducted an in-depth research of M2M communication resource allocation and scheduling of LTE system and introduced a queue priority strategy based on existing LTE scheduling algorithm. This results in an optimized intelligent scheduling algorithm suitable for M2M communications to improve the system throughput and reduce the average delay of system service without affecting into the traditional voice and video communications.**

***Index Terms*—Machine-to-machine, LTE, uplink scheduling.**

I. Introduction

As a long term evolution plan of 3G, Long Term Evolution (LTE) System aims at developing a wireless access system based on low delay and high data rate [1]. LTE uplink transmission system generally uses SC-FDMA transmission mode and centralized resource allocation. The fast scheduling process of uplink base station is essential for the improvement of LTE system performance. So it becomes one of the key techniques of LTE system.

M2M communications is a smart communication based on the Internet that involves a broad area. The wireless access enhancement technique of M2M communications is one of the hot spots of M2M standardization. Currently, M2M applications are based on GPRS cellular network. In case of the small number of M2M devices, GPRS is an appropriate M2M application solution, but with the increase in the number of M2M interconnection devices, GPRS is proved to be an inappropriate solution, because of its limited bandwidth and transmission power [2]. At present conditions, cellular system with high performance is considered an appropriate platform for M2M applications. LTE and LTE-A gains more attention, because they provide all IP technique (All-IP), which is able to deal with the wireless resources flexibly. However, the design of LTE cellular system is used for Human-to-Human communications [2]–[3]. Therefore, regarding it as M2M application platform is inappropriate. Obvious characteristics include: for example, the number of communications devices of M2M communications is far greater than that of H2H communications [3]–[4]. It also holds a small amount of data and a large number of nodes, different delay requirements, diversified services, and the "tidal effect", which may cause a surge or sharp decline of traffic. Therefore, as M2M communications network, the mobile communication network designed according to the characteristics of H2H communications faces many problems. In order to realize that it can efficiently provide M2M communications service [5], the existing mobile communication network must be optimized based on M2M communications application, to avoid network congestion or overload caused by simultaneous access of huge amounts of M2M terminals to the network. Because of these reasons, several organizations for standardization and international projects are making great efforts to improve the support of LTE cellular networks for M2M applications [6]–[7].

From the relevant requirements of M2M communications, provision of huge numbers of M2M devices' service in the existing cellular network is the most challenging issue. Therefore, resource allocation plays a vital role in the deployment of M2M communications into the LTE network. As the most of M2M application deployment basically generates uplink flow, design of an efficient uplink scheduling is very important. Although some scholars have resolved LTE uplink scheduling [8]–[11], but a small amount of M2M devices scheduling based on QoS is discussed.

In this paper, an improved Smart Expansion Scheduling Algorithm based on existing LTE cellular network is proposed according to the characteristics of M2M services and LTE uplink scheduling. The algorithm integrates improved Proportional Fairness scheduling algorithm, with H2H and M2M service mix queuing model. To propose an

Manuscript received April 15, 2013; accepted September 16, 2013.

improved LTE uplink Smart Scheduling Algorithm suitable for the huge amount of M2M wireless access.

The remaining parts of this paper are arranged as follows: System and transmission model is proposed in the Section II, Smart Scheduling Algorithm is proposed in the Section III, simulation results are given in the Section IV. In Section V shows the conclusions and the expansion of future research work.

II. System and Transmission Model

In this paper, the air interface based on 3GPP LTE released 8 is studied. First of all, we consider the scenario with multi-user in a single cell. The wireless resource will be shared by LTE users and M2M users. Orthogonal Frequency Division Multiple Access (OFDMA) is regarded as LTE downlink access technique. Single Carrier FDMA (SC-FDMA) is used in the uplink, to effectively reduce the peak-to-average ratio (PAPR) caused by multi-carrier transmission, thus reducing the power amplifier cost of the terminal and power consumption. There are two implementation approaches including frequency domain and time domain for SC-FDMA signal. The realization through frequency domain or time domain can be summarized as the realization through DFT-OFDM technique or IFDMA technique. However, DFT-OFDM just adds a DFT module before IFFT part, and it can share a lot of the design of the downlink OFDMA transmitter. Therefore, LTE Organization for Standardization takes DFT-OFDM as the realization method for the uplink multiple access technique.

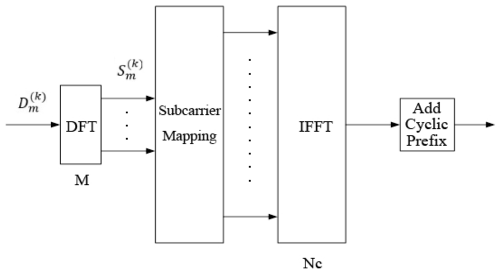


Fig. 1. Signal processing in DFT-OFDM transmitting terminal.

It is assumed that there are k users sending data at the same time in the system, and each user is assigned M sub-carriers, then the baseband signal route process of DFT-OFDM transmitting terminal is shown in Fig. 1. After the modulation of data of the nth user, the symbol sequence with the length of M can be obtained as $D_m^{(k)}$, m = 0, 1, 2,…...,m-1. These M modulated symbols are expanded through DFT with a length of M, each symbol is expanded to M sub-carrier assigned to it, so as to obtain M complex-value transmission symbols in the frequency domain, $S_m^{(k)}$, m = 0, 1, 2,…...,m-1 . The DFT transformation can be expressed as

$$\overline{S}^{(k)} = \overline{D}^{(k)} [\mathrm{C}]. \tag{1}$$

C refers to DFT matrix element, it can be expressed as

$$C_{i,j} = e^{j2\pi ij/k} / \sqrt{K}. \tag{2}$$

What's more, it can map the transmission symbols to M sub-carrier assigned to user n. The frequency domain signal will be transformed to time-domain signal through IFFT process, so as to complete orthogonal multi-carrier modulation, time-domain signal after IFFT can be expressed as

$$S_i^{(k)} = \frac{e^{\frac{j2\pi ik}{N_c}}}{\sqrt{K}} \sum_{m=0}^{K\text{-}1} S_k^{(n)} e^{\text{-}j2\pi ik/K}, \tag{3}$$

where i=-N_c,..,0,..,N_c , N_c refers to guard interval symbol. When the base station receiving terminal receives the baseband time domain signal, at first it removes the guard interval, and makes FFT calculation for the rest of the sample points, to obtain sub-carrier set assigned to the user n through frequency-domain symbols. From the output frequency domain symbol, the select symbol for user n as $R_m^{(n)}$. $R_m^{(n)}$ can be expressed as

$$R_m^{(n)} = H_{m+nM}^{(n)} S_k^{(n)} + G_{m+nM}^{(n)}, \tag{4}$$

where $H_{m+nM}^{(n)}$ refers to the channel gain of user n on the assigned m sub-carrier, $G_{m+nM}^{(n)}$ refers to the complex Gaussian noise.

III. Smart Scheduling Algorithm

Scheduling plays a key role in the LTE system. Currently, the dominant scheduling algorithms include Round Robin (RR) Algorithm, Maximum Carrier-to-Interference Ratio (Max C/I) Algorithm and Proportional Fairness (PF) Algorithm. Round Robin Algorithm circularly calls for each user and allocate resources to each user. This algorithm is the most fair. At the expense of the throughput of system, it provides the resources to each user in the system fairly. Its disadvantage is that it does not consider the condition of user's channel, so the reliability of the transmission is not high. Maximum Carrier-to-Interference Ratio Algorithm allocates resources to user who with the best channel quality. This algorithm can adapt to the time-varying characteristic of the wireless channel and take full advantage of diversity effect of multi-user, and it is able to get the limit of system throughput. However, this algorithm doesn't consider the fairness principle, i.e. user with good channel conditions are provided with service continuously, while users with poor channel conditions may have no chance to get the service. There are obvious advantages and disadvantages for these two kinds of algorithms. Therefore, they are not used in the practical application. Through simulation, in [12] the author analysis the performance of Round Robin Algorithm, Maximum Carrier-to-Interference Ratio Algorithm and Proportional Fairness Algorithm, this is shown in Table I.

This paper basically discusses Proportional Fairness Scheduling Algorithm and proposes a kind of smart Proportional Fairness Expansion Algorithm based on its advantages and disadvantages. On the basis of this algorithm, H2H and M2M service mix queue model is introduced, and finally an improved LTE uplink smart scheduling algorithm suitable for a great amount of M2M wireless access service is proposed.

TABLE I. COMPARISON OF THREE KINDS OF CLASSIC ALGORITHMS.

Scheduling algorithm	Sector throughput	UE throughput	High-speed mobile performance	Service fairness	Implementation complexity	Comprehensive performance
RR	Low	Low	Fair	Very good	Simple	Poor
Max C/I	High	Low or High	Poor	Very poor	a little complex	Fair
PF	Fair	Fair	Good	Fair	Complex	Good

Proportional Fairness Algorithm was proposed by Qualcomm in the High Data Rate (HDR) time division system [13]. This algorithm compromises between user fairness and system throughput. In this algorithm, each user will have its corresponding priority. At any time, users with the highest priority within the cell will get the service, resources and transmit data. The priority of the algorithm is expressed as

$$prio_k = \frac{(C/I)_k(t)}{T_k(t)}, \tag{5}$$

where $k = 1, 2, \ldots, N$. $(C/I)_k(t)$ refers to the carrier-to-interference ratio of kth user in time t, which reflects the channel condition of the user at the current moment. According to the current channel conditions, the user requests from the base station the service rate Rk(t). Then (1) can be rewritten as

$$prio_k = \frac{(R)_k(t)}{T_k(t)}, \tag{6}$$

where $k = 1, 2, \ldots, N$. Among them, $T_k(t)$ refers to the average throughput of the time window with t as the end. When the user makes continuous communication, the value of $T_k(t)$ increases gradually. At this time, the user's priority is getting smaller. $(C/I)_k(t)$ can be further expressed as

$$(C/I)_k(t) = \frac{P_k}{I} a_k b_k(t), \tag{7}$$

then its priority is

$$prio_k = \frac{P_k a_k b_k(t)}{I T_k(t)}, \tag{8}$$

where $k = 1, 2, \ldots, N$. P_k and I respectively refer to the transmission power of base station for the kth users and interference outside the cell of the user. In the formula, a_k refers to the part from the slow fading of wireless channel loss, b_k refers to the fast-variation part from fast fading of wireless channel loss. As $T_k(t)$ and a_k is a slow-variation process, P_k of different users in the same cell is approximately the same, and b_k of different users is regarded as independent and identically distributed. Then at any time, the probability of different users in the same cell to get service is the same. However, due to the timing of service, users can only get service when the fast fading condition is good, so the system throughput can be improved. Therefore, Proportional Fairness Algorithm realizes the compromise between the maximum system throughput and the fairness between users.

A. Smart Expansion Scheduling Algorithm

It is indicated from the above analysis that the Proportional Fairness Algorithm provides service to users with the highest priority $\frac{(R)_k(t)}{T_k(t)}$ at any time of t. when we introduce Proportional Fairness Algorithm of time domain to the frequency domain, it is required to calculate the measurement value of user k at the time of t in the resource block c, i.e. $\lambda_k^c(t) = \frac{(R)_k^c(t)}{T_k(t)}$. Therefore, the function of Proportional Fairness Algorithm for frequency domain is: $\max \sum_k \sum_c x_k^c(t) \lambda_k^c(t)$, while the measurement matrix of Proportional Fairness Algorithm for frequency domain is shown in Fig. 2.

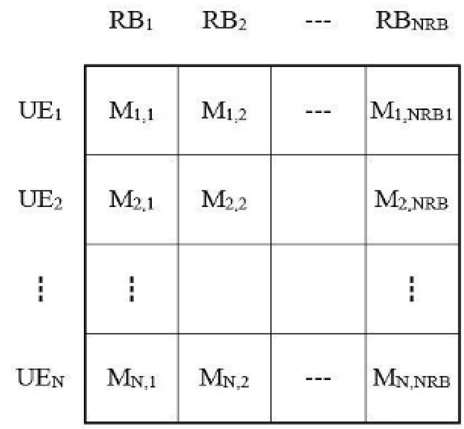


Fig. 2. Measurement matrix of proportional fairness algorithm for frequency domain.

As the Resource Block provided by the Proportional Fairness Algorithm to users is discontinuous, Proportional Fairness Algorithm is mostly used in LTE downlink rather than SC-FDMA directly. Due to the single carrier characteristic of SC-FDMA, the frequency domain of all Resource Blocks allocated to the user by SC-FDMA at a certain time should maintain the contiguity constraint, so that LTE uplink scheduling should comply with this condition [14].

We now propose a Smart Expansion Scheduling Algorithm, with a basic idea in which, if the channel quality of the user k in the resource block c is good, then the channel rate of adjacent resource blocks (c-1, c+1) is most likely good. In order to meet the requirements for continuous frequency domain of RB, resource block c and adjacent resource blocks can be connected together to form continuous resource, and then provide it to the user.

The basic process of Smart Expansion Algorithm is as follows:

Step 1. Find the user and resource with the highest measurement value from the measurement matric value λ_k^c ;

Step 2. Assign the resource block RB0 to the corresponding UE0;

Step 3. According to the selected UE0 in Step2, expand to the right and left sides of the corresponding RB0, until the other UE with the higher measurement value emerges;

Step 4. Put UE0 in a spare queue;

Step 5. Complete loop execution from Step 1 to Step 4, enabling each UE of the non-spare queue to get the corresponding continuous resource blocks, until all the UE in the spare queue or all the RBs have been assigned;

Step 6. If there are still RBs left, find the corresponding UE of the remaining RBs with the largest measurement value;

Step 7. Check whether the corresponding UE of the adjacent assigned RB is the same with the UE found in Step6;

Step 8. If two UEs are not the same in Step7, then repeat Step6. Otherwise, expand to the left and right sides of RB, until the previously allocated RB achieves continuity in one side. Stop the expansion on the other side, even if the measurement value of UE is greater in another spare queue;

Step 9. Repeat from Step6 to Step8, until all the RBs are assigned.

The computational complexity of Smart Expansion Algorithm is relatively low, and it also improves the fairness and service quality between users on LTE uplink greatly.

B. Definition of H2H and M2M Service Mixed Queue Model

According to the analysis of M2M service and communications mode, we can draw a conclusion as follows: the amount of M2M terminal in the practical application environment is very large, and the amount of data for each conversation is extremely small, which has a big difference with H2H communications. Relatively speaking, as there is no direct intervention of people for M2M communications, thus the demand on time delay is relatively lower, and the vast majority of service does not need real-time transmission. So according to the characteristics of M2M communications, we propose a discrete-time queue model to deal with H2H communications and M2M communications mixed service situation. The basic model is shown in Fig. 3.

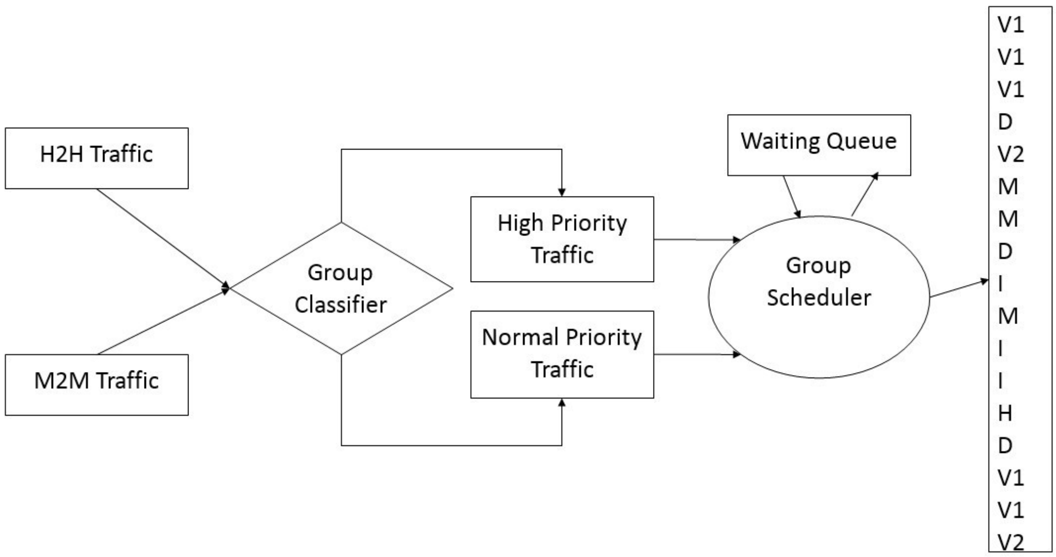


Fig. 3. H2H and M2M service mixed queue model (V1: Voice Service V2: Video Service D: Data Service M：M2M Service I: Idle)

Here High Priority Traffic includes voice and video communications service of H2H, and M2M service of real-time communications; Normal Priority Traffic includes buffer video and data service of H2H, etc.; Waiting Queue includes all of the remaining M2M non real-time communications data service.

The advantage of mixed queue model is to optimize and utilize network resources, to improve the throughput of the system. Traditional service of H2H under this model will be affected slightly, it is no longer the main service occupied by the resource, but the data service will be more. However, the service rate of M2M data service can be highly improved, which can guarantee the fairness of using the network by H2H traditional service user and M2M non real-time service user. It can guarantee the basic service of H2H user and optimize network transmission, thus reducing the average blocking rate of integral data service based on the original rate.

C. Smart M2M Uplink Scheduling Algorithm

Based on the great number of M2M service, the amount of M2M communications data size is very small, the terminal numbers is large and service is diversified, we proposed improvement in LTE Uplink Smart Scheduling Algorithm. This is according to the above mentioned Smart Expansion Algorithm and H2H/M2M mixed queue model, which rely on in-depth research on M2M communications service, and the characteristics of M2M service communications.

The basic idea is to use Smart Expansion Algorithm and H2H/M2M mixed queue model for optimized design, so as to realize the fairness of scheduling and increase the throughput of M2M communications under the LTE system. However, the static priority scheduling strategy of queue model is very complicated, which will be simplified and Smart Expansion Scheduling Algorithm is introduced. The basic process is as follows:

Step 1. Add H2H service and M2M service in the network;

Step 2. Classify the priority of H2H service and M2M service. According to the rule of priority service order, H2H communications and M2M communications service are grouped into the corresponding high priority service queue and common service queue;

Step 3. Make Smart Expansion Scheduling for high priority service and common priority service;

Step 4. At the end of high priority service and common priority service scheduling, judge whether there is any remaining resource block, if so, continue Step5, otherwise, end and return;

Step 5. On the basis of remaining resource block, continue Round Robin scheduling for M2M waiting queue. Until all the resource blocks are assigned, or all the data in waiting queue has been transmitted by user sent out, and then go to Step 3 to perform Smart Expansion Scheduling.

The overall process of Smart M2M Uplink Scheduling Algorithm is shown in Fig. 4.

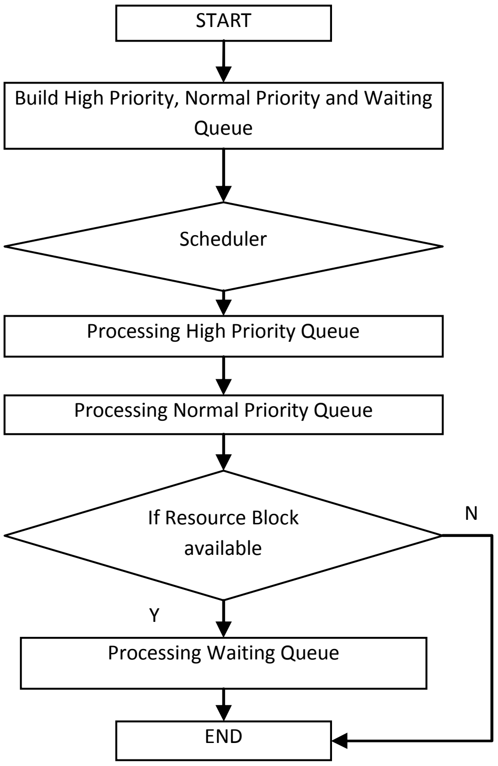


Fig. 4. Flow Chart of Smart M2M Uplink Scheduling Algorithm.

IV. RESULT AND DISCUSSION

In order to assess the performance of our algorithm, SC-FDMA uplink system simulation is based on the 3GPP LTE system model, we use trace generation type for assessment of 3GPP deployment based on the typical urban channel model [15]. According to 3GPP TR25.814 specification, default simulation parameters and assumptions are presented in Table II.

TABLE II. SYSTEM CONFIGURATION PARAMETERS.

Parameter	Parameter Values
System bandwidth	5MHz
Numbers of cells	7
Sub-carrier bandwidth	15KHz
Distance between BS	500m
Numbers of System RB	25RBs
RB bandwidth	180KHz
Sub-carriers per RB	12
Parameter	Parameter Values
Path fading	128.1+37.6log10(R)
Noise power spectral density	-174dBm/Hz
TTI time Channel Model	1ms Typical Urban
Max receiving antenna gain	20dBi
BS transmission power	43dBm
User speed	120Km/h

In the LTE system, we first consider making comparison of Smart Expansion Algorithm and classic PF Algorithm only under the condition of traditional voice and video service, so as to basically analyse the system throughput and the packet loss probability of traditional uplink service under these two kinds of algorithms.

Figure 5 shows the packet loss probability of voice service along with the increasing number of H2H users; Fig. 6 shows the packet loss probability of video service along with the increasing number of H2H users; Fig. 7 shows the variation of system throughput along with the increasing number of H2H users under the traditional voice and video mixed service.

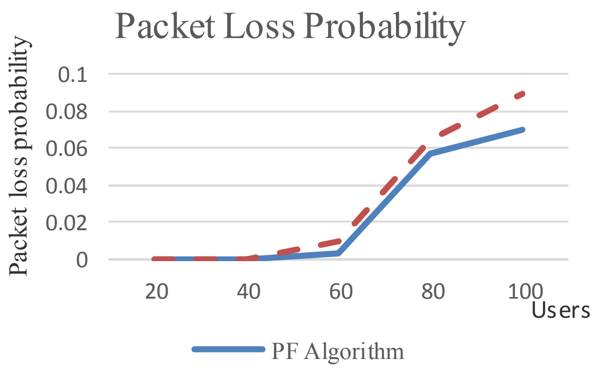


Fig. 5. Packet loss probability of voice service with the increasing number of users.

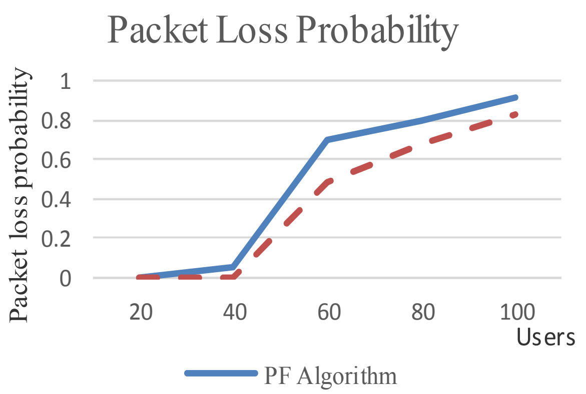


Fig. 6. Packet loss probability of video service with the increasing number of users.

The above simulation results shows that compared with PF algorithm, Smart Expansion Algorithm shows significant improvements. Now combine Smart Expansion Scheduling Algorithm with M2M scheduling, and consider that the cell has a certain number of M2M users, we observe and compare the average time delay variation by groups of H2H service of a great amount of Smart M2M Uplink Scheduling Algorithm and Smart Expansion Algorithm. This is done through the continuous increment of the number of H2H users.

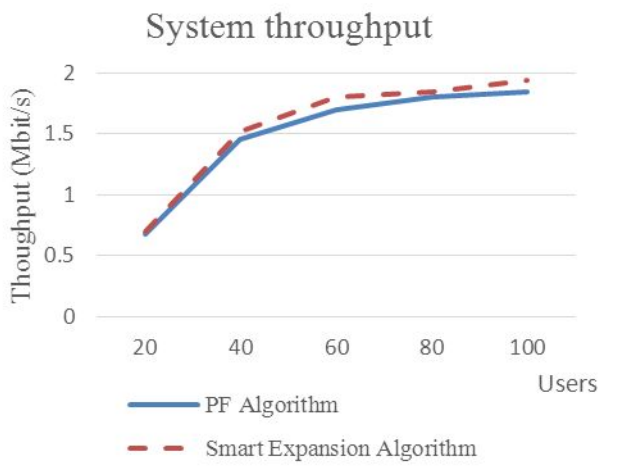
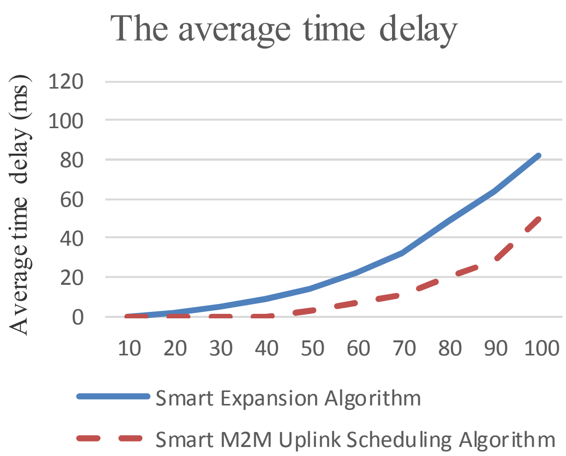
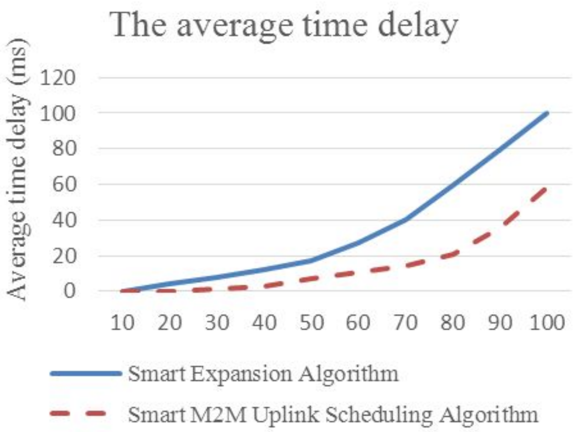


Fig. 7. System throughput variation under traditional voice and video mixed service.



(a)

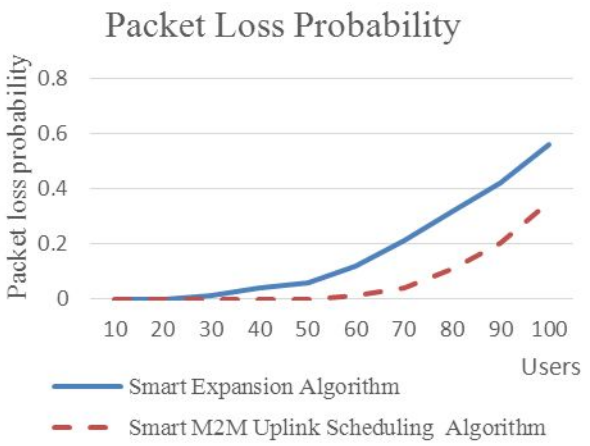


(b)

Fig. 8. Time Delay of H2H Service under the Background of 500 M2M Users (a) and 1000 M2M Users (b).

To get the average time delay variation of user groups under two kinds of algorithms, the number of H2H service users is increased such that the cell has 500 to 1000 users respectively. Figure 8 shows the time delay distribution under the background of 500 M2M users and 1000 M2M users respectively.

Figure 8 shows that the average time delay of H2H service group for Smart Expansion Algorithm, which will increase significantly with the increasing number of H2H users. This is because the number of M2M users is too large, which will compete for resources with H2H service at the time of scheduling. This results in insufficient resources for H2H service and larger group time delay. However, the M2M Uplink Scheduling Algorithm can fundamentally solve the problem, through the queue priority grouping strategy and queue scheduling. It can initially provide H2H users with service and effectively reduce the time delay of H2H user groups.



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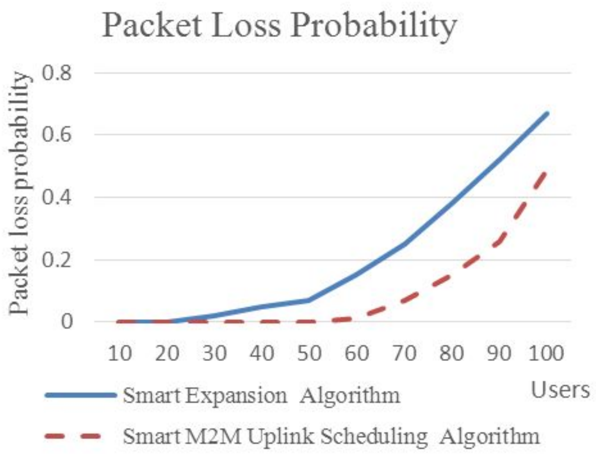
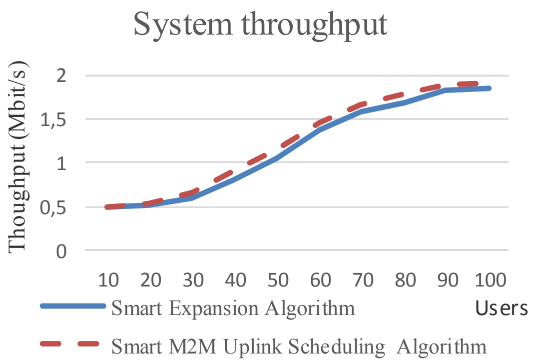


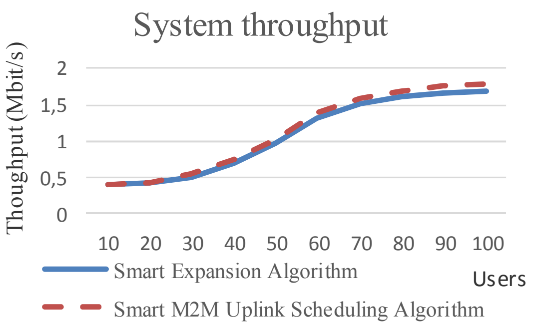
(b)

Fig. 9. Packet loss probability of H2H service under the background of 500 M2M users (a) and 1000 M2M users (b).

Figure 9 shows the variation of packet loss probability of H2H service under the background that the cell has 500 and 1000 M2M users respectively. It shows the packet loss probability of H2H service to M2M Uplink Scheduling Algorithm. This is obviously smaller than that of Smart Expansion Algorithm. Also the packet loss probability of a great amount of M2M Uplink Scheduling Algorithm, which is basically to be zero when there is a small amount of H2H users on the internet. In LTE network, the disadvantage of Smart Expansion Algorithm is that it has more M2M users. So these M2M users may preempt resources of H2H users, thus making H2H service tough to allocate resources required and result in bigger group time delay and also higher packet loss probability. However, the Smart M2M Uplink Scheduling Algorithm will use queue scheduling model to firstly provide H2H users with service. This makes H2H users get sufficient resources, so the group time delay will be effectively reduced, and the packet loss probability will be improved greatly.



(a)



(b)

Fig. 10. System throughput variation under the background of 500 M2M users (a) and 1000 M2M users (b).

Figure 10 shows that the system throughput will change with the increasing number of H2H users under the background that the cell has are 500 and 1000 M2M users respectively. The throughput of a great amount of M2M Uplink Scheduling Algorithm is much higher than that of Smart Expansion Algorithm. This is the advantage of using waiting queue and phased scheduling when M2M scheduling is ongoing, so as to maximally use channel quality for data transmission. But in turn, the M2M group time delay of M2M is bigger, which is acceptable by M2M service.

V. CONCLUSIONS

This paper introduces Smart Scheduling Algorithm, which is based on LTE uplink and supports M2M communications. Throughput and the maximum allowable time delay of LTE system will be taken into account respectively when a great amount of M2M device exists. The result shows that the Smart Expansion Algorithm has obvious advantages than PF Algorithm, and Smart M2M Uplink Scheduling Algorithm is based on the Smart Expansion Algorithm. This is done through group queue and queue priority scheduling strategy. The system throughput can be significantly improved, and the maximum time delay as well as the packet loss probability of H2H service can be reduced. This enables the system to have better performance. Currently, the research of distribution of LTE resource scheduling focuses on the downlink OFDMA system. The resource scheduling of the uplink SC-FDMA system is relatively small and the uplink scheduling is more complicated than the downlink scheduling. Also, there is no optimal solution found at the moment. Based on the research of this paper, we will proceed for future work in the following directions, for example: LTE random access is competitive, when the great amount of M2M terminal exists in the system, and the collision probability of current random access mechanism will dramatically increase, the collision probability of current random access mechanism will increase sharply. It is a very relevant research subject to improve or propose an adaptive M2M access control algorithm. Meanwhile, in LTE uplink system simulation, in order to simplify the difficulty of simulation, power allocation strategy has not been taken into account in this paper. The transmission power for all users is the same, as there is no artificial participation, the transmission power for M2M devices can be improved or reduced according to the application environment. This is to obtain better data transmission rate or occupy smaller bandwidth, thus achieving the goal of green energy saving.

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