Balanced Uplink Scheduling for Dedicated Return Channel of Future Broadcast TV

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***Abstract*—To satisfy interaction between users and service providers (SP) in lots of rural areas without enough communication infrastructure, a dedicated return channel for the terrestrial digital TV is demanded. Therefore, we propose a specification on Dedicated Return Channel (DRC) based on SC-OFDMA technique for future broadcast, and promote it to Advanced Television Systems Committee (ATSC). To efficiently utilize the wireless resources of the uplink channel and support large number of users and wide coverage areas, scheduling among multiple users is the most important part. In this paper, we propose a balanced uplink scheduling (BUS) algorithm in order to meet Quality of service (QoS) requirements of large amount of users and make full use of user diversity, frequency diversity and time diversity at the same time.**

I. Introduction

Nowadays, Digital TV technology is rapidly developing. In today's information society, interaction between users and service provider (SP) becomes increasingly important. However, in lots of rural areas without enough communication infrastructure, it is hard to realize interaction in TV. Otherwise, with the transition of analog technology to digital technology for TV broadcasting, there will be a lot of spectrum resources to be saved. Therefore, to satisfy this requirement, we promote a proposal on Dedicated Return Channel (DRC) for future broadcast to Advanced Television Systems Committee (ATSC). As the demand of multi-user access, we should introduce MAC layer for our Dedicated Return Channel (DRC), and uplink scheduling of DRC play an important role in MAC layer for a system.

There are many scheduling algorithms and papers about LTE, CDMA and so on in cellular network . The paper [1], [2] mainly introduce the frequency resource allocation algorithms such as the First Maximum Expansion (FME), Recursive Maximum Expansion (RME), Minimum Area D-ifference (MAD), and Search-Tree Based Packet Scheduling (STBPS) in uplink of LTE with the constraints of carrier contiguity. Yang, Hongkun and Ren, Fengyuan indicate the uplink scheduling is a NP-Hard problem and only can be constantly approaching [3] . Iturralde, Mauricio and Martin introduces a Pondering Parameters Scheduling (POPAS) algorithm in order to meet different QoS requirement in LTE [4]. The algorithm takes channel conditions, packet delays, packet queue lengths and service bit-rate as part of weights to make scheduling decision and achieve good performance. The paper [5]–[7] mainly introduce an Optimized Service Aware (QSA) scheduling algorithm in LTE. It divides services into Guaranteed Bit Rate (GBR) classes and Non-Guaranteed Bit Rate (Non-GBR) classes, and meet the requirements of GBR in priority, the allocate resources among Non-GBR classes. The paper [8] introduce a simple mechanism to meet different QoS requirements of different users in 802.16. For Unsolicited Grant Service (UGS) service, the scheduler allocates resources constantly; and for RealTime Polling Service (rtPS) service, it adopts earliest deadline first (EDF) algorithms; and for Non Real Time Polling Service (nrtPS) service, it uses Weight fair queue (WFQ) algorithms, and at last for Best Effort (BE) service, it allocates resources equally among users.

But Compared with cellular network, DRC is quite different. First, DRC should work wherever the broadcast signal is received, which means that DRC should cover 100km at most. Secondly, because of the huge coverage radius, hundreds of users should be supported at the same time. Furthermore, the service supported in DRC are mainly busty and have small packet sizes, such as video on demand, TV reviews, TV voting, etc. Because of the specific features of DRC, we can see that the scheduling algorithms for cellular system cannot be directly applied in DRC.

Therefore, in this paper, we propose a specific scheduling algorithm for future broadcast uplink, named as Balanced Uplink Scheduling for DRC. We introduce the buffer status and service time of user as the scheduling decision-make weights in order to balance the number of users served and fairness. Furthermore, we also take the channel conditions of users as part of decision-make weight in order to make full use of frequency diversity and user diversity. Its key features are that it can accommodate different quality-of-service (QoS) classes and serve users as many as possible and that it has a tunable fairness level. It also can make full use the diversity among users to increase the cell throughput.

The rest of the paper is organized as follows: Section II introduces the overview of DRC system; Section III gives the scheduler in the DRC system; In Section IV, the scheduling algorithms is proposed; Section V presents the performance evaluation of our proposed algorithms; Section VI is the conclusion.

II. The Overview of DRC System

The Dedicated Return Channel (DRC) is a return channel between users and TV tower to interact with the service

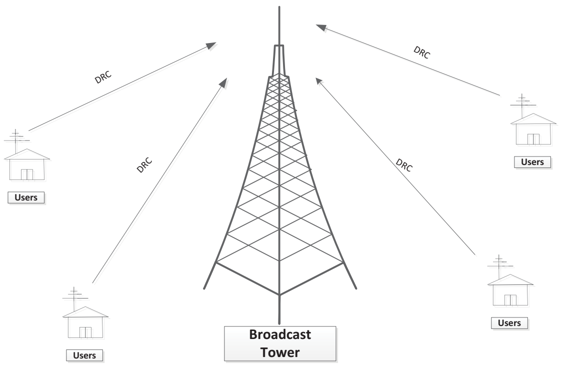

Fig. 1. The position of DRC in ATSC

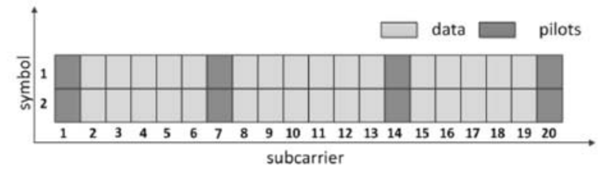

Fig. 2. Tile structure

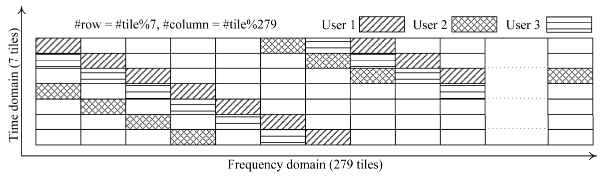

Fig. 3. Uplink resource allocation

provider. The position of DRC in ATSC system is shown in Fig. 1.

The physical layer of DRC uses SC-OFDMA technology [9]. Orthogonal Frequency Division Multiple Access (OFDMA) is a multiple-access scheme which provides multiple channels for different users. The data symbols of each user are spread over the entire frequency band. Each subcarrier is orthogonal to the others and carries the data symbol of one user. Therefore, an OFDMA system is robust to time delays caused by multipath fading i.e., frequency selectivity of the radio channel. SC-FDMA can also be called DFT-spread OFDMA, thus the same benefits in terms of multipath mitigation and low-complexity equalization are achievable. The difference though is that in SC-FDMA the DFT is performed prior to the IFFT operation, which spreads the data symbols over all the subcarriers carrying information and produces a virtual single-carrier structure. As a consequence, SC-FDMA presents a lower PAPR than OFDMA [10]. To avoid high power consumption or high signal distortion in uplink system, the PAPR should be limited to some extent. Thus, SC-FDMA is preferred when PAPR and system throughput is considered.

In DRC, one 10 ms SC-FDMA frame consists of 4 sub-frames equaling to 2.5ms. Each sub-frame contains 2048 subcarriers in the frequency domain and 14 symbols in the time domain. The minimum unit in DRC is title which includes 20 subcarriers in the frequency domain and 2 symbols in the time domain. Its structure is depicted in Fig. 2. There are 279*7 = 1953 tiles for user data except 63 tiles for random access channel. The tile location including row and column number are determined by tile-number which is from 0 to 1952 to mod 7 and 279, respectively.

In the PHY design, 3 tiles called as Resource Block (RB) are the minimum number of resources allocated to each user according to scheduling algorithm. The user data can be mapped to certain tiles according to modulation and coding types, tile beginning index and number of tiles. The uplink allocation among users is illustrated in Fig. 3.

The physical layer of DRC utilizes adaptive modulation and coding scheme (AMC) to improve the network throughput, and adopt Convolution Turbo Coding (CTC) as its encoding. The parameters are depicted in table I.

III. The Scheduler in DRC System

Multi-user scheduling is one of the main part in DRC systems because it is in charge of allocating uplink resources among active users to satisfy their QoS requirements.

In fact, the uplink channel is shared among active users, indicating that parts of spectrum of each frame should be allocated among them. Scheduler are deployed at the TV tower, and SC-FDMA ideally provides no inter-channel interference. The granularity of resources allocated is one RB in the time and frequency domain, respectively.

Let's define the metrics of j-th user in i-th RB is $k(i,j)$ and suppose there are N users. Resource distributed for each user is always based on the comparison of per-RB metrics, that is, the i-th RB is allocated to the j-th user if its metrics $k(i,j)$ is the biggest one, i.e., if it satisfies the equation in the following.

$$k(i,j) = \arg\max\{k(i,l)\}, l \in \{1, 2, ..., N\} \tag{1}$$

The metric can be interpreted as the allocation of each user on a specific RB. Their decision-metrics usually consist of information related to each user and suitable for making the allocation decision such as:

1) Buffer State: It is usually reported by users to tell how many bits they want to upload;

2) Channel conditions: The reported channel conditions value can be used to allocate resources to users experiencing better channel conditions in order to improve the cell throughput;

3) Past Rate: The message about the previous achieved rate which can be used to balance fairness between users;

TABLE I
AMC PARAMETERS

Modulation	Encoding Rate	Bit Error Rate(BER)	Demodulation Threshold (dB)	Tile Capability (bits)	Resource Block (RB) Capability (bits)
QPSK	1/3	10^{-5}	2.1	21	64
QPSK	1/2	10^{-5}	7.8	32	96
16QAM	1/3	10^{-5}	14.1	42	126
16QAM	1/2	10^{-5}	19.8	64	192

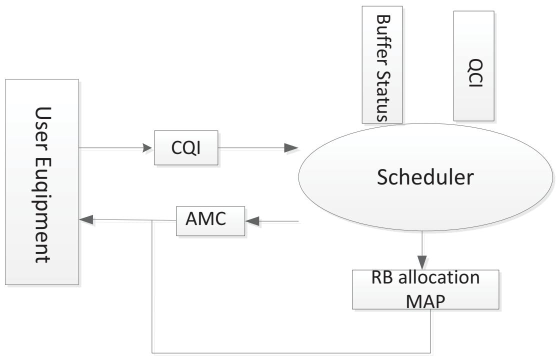

Fig. 4. Simplified model of the scheduler

TABLE II
SERVICES CONSIDERED IN BUS-DRC

Service Considered	Packet Size (bit)	More
(Video on Demand) VOD	120	Regular
E-advertisement	120	Regular
Realtime Comments	1200	Regular
E-game	184	Regular
TV Polling	92	Regular
E-education	1208	Regular
Realtime Video Conference	64k bit/s	Emergency
Traffic Sharing for Voice Call	12.2 kbit/s	Emergency

4) Quality of Service Requirements: The QoS requirements of each flow that can be used to force scheduler to meet service requirements.

A simplified model of a scheduler is depicted in Fig. 4.

There are two constraints for uplink scheduler in DRC of ATSC.

(1) There are large variation among channel conditions of different users in digital TV cell.

As we all know, the radius of digital TV cell is as long as 100km. The path loss of users in different distance from TV tower vary a lot. The path loss of users in the cell edge is 70 db more than users close to the TV tower. How to ensure the throughput for users in the cell edge is a big challenge to uplink scheduling in DRC.

(2) The services that our DRC support are mainly bursty and with small packet sizes.

The services supported by DRC are listed in Table II. From the table, we can get that the packet size of our services, except emergency service such as realtime video conference and traffic sharing for voice call, are no more than 1.2kbits. So we can not assume user who has full buffer status, how to avoid resource waste in order to serve more users is the main target for DRC uplink scheduling.

TABLE III
THE CLASSIFICATION OF SERVICE

GBR	Realtime Video Conference, Traffic Sharing for Voice Call
Non-GBR	VOD, E-advertisement, Realtime Comments, E-game, TV polling, E-education

IV. SCHEDULING ALGORITHMS

According to previous sections, we propose a Balanced Uplink Scheduling (BUS) scheduling algorithm. First, we classify packets as Guaranteed Bit Rate (GBR) classes and Non-Guaranteed Bit Rate (Non- GBR) classes. The classification is depicted in Table III. Because realtime video conference and traffic sharing for voice call is for emergency such as communication for natural disaster, we allocate them as GBR classes and give highest priority. We first meet the resource requirement of Guaranteed Bit Rate (GBR) classes, then we allocate the rest resource following the next algorithms.

For Non-GBR classes, the objective of BUS-DRC is to support more users while keeping high throughput and reasonable fairness. The objective is achieved by three ways. First, with high priority, BUS-DRC serves users with good channel conditions and small buffer sizes. Thus the scheduler can serve more users in one scheduling time unit. Secondly, considering services with bursty and small packets, BUS-DRC allocates resources according to their buffer status reported to the TV tower in order to avoid resource waste. Finally, BUS-DRC introduce Head of Line (HOL) delay as part of the decision-making to consider fairness and decrease packet loss.

We suppose there are N users with M minimum allocated Resource Block (RB) in the system. Let $S(j,t)$ and $T(j)$ denote the Buffer Status (BS) and Head of Line (HOL) delay time of user j at time t, respectively. Let $M(j,k,t)$ denote the Modulation and Coding Scheme (MCS) of user j on resource block k at time t, and $B(M)$ denote the Transport Block (TB) size consistent with the MCS. We start from the first RB, and the second, the third, until the last one, and determine which user it should be allocated to. Denote $j^*(k,t)$ as the index of user allocated with k th RB at time t, then $j^*(k,t)$ can be defined as:

$$j^*(k,t) = \arg\min\{\frac{S(j,t)}{T(j) \cdot B(M(j,k,t)}\}, j \in \{j : I(j) < 1\} \tag{2}$$

We should take care whether the buffer of $j^*(k,t)$th user is meet or not. So we define $I(j)$ which indicates the ratio of

TABLE IV
SIMULATION PARAMETERS

Parameters	Assumption
Number of TV tower	1 TV tower with one cell of radius = 100 km
Spectrum	8 MHz (corresponds to about 65 PRBs)
Mobility model	Random Way Point(RWP)
Channel model	Okumura-Hata
Shadow fading	Log normal shadow fading with 8 db std
Transmit antenna gain	14 dbi
Receive antenna gain	14 dbi
Frequency	700 Mhz
Transmit antenna height	5 m
Receive antenna height	60 m
Propagation channel	Rice
Thermal noise density	-174 dBm/Hz
Frame	10 ms
Scheduling times	1000

resources allocated and buffer status of jth user. If $I(j) \geq 1$, it means the buffer of user j is meet till now, then we will not allocate resources to user j any more . If $I(j) < 1$, which means the buffer is not meet, then we should allocate RB to user j continually. We specify the definition of $I(j)$ as:

$$I(j) = \sum_{k} \frac{B(M(j,k,t))}{S(j,t)}, k \in \{k : j^*(k,t) = j\} \tag{3}$$

V. PERFORMANCE EVALUATION

A. *Simulation Setup [11]*

We evaluate the performance of BUS-DRC in a single broadcast cell with 100km radius and no inter-cell interference. User Equipments (UEs) are randomly distributed within the cell. DRC is used as the physical layer specification (PHY). We use Okumura-Hata rural channel model and assume that the TV center has perfect knowledge on channel statuses of all users. The parameters are shown in Table IV.

B. *Simulation Results*

1) Mix of VOD and Realtime Comments services: First, we consider two classes of services as shown in Table V. In our simulation, we assume half of the services are from the first class and the other are from the second class. Users arrive in the form of Poisson distribution. We introduce Modified-Best CQI Scheduler (M-BCQI), Modified-Round Robin Scheduler (M-RR) and Modified-Proportional Fair Scheduler (M-PF) for comparison. M-BCQI, M-RR and M-PF mean that once user's buffer status is meet, we end to allocate resource for it using traditional BCQI, RR, and PF algorithms [12] in order to serve large amount of users with small packet size. The results are shown in Fig. 5-Fig. 8. From Fig. 5, we can see that our scheduling algorithm serve more users than Modified-Best CQI Scheduler (M-BCQI), Modified-Round Robin Scheduler (M-RR) and Modified-Proportional Fair Scheduler (M-PF), which is for the reason that we serve users with small buffer in priority. From Fig. 6, we can find that averaged end-to-end delay of BUS algorithm is a little large than that of M-BCQI but better than the other scheduling algorithms. This is because our scheduling algorithm serve users who have not been served

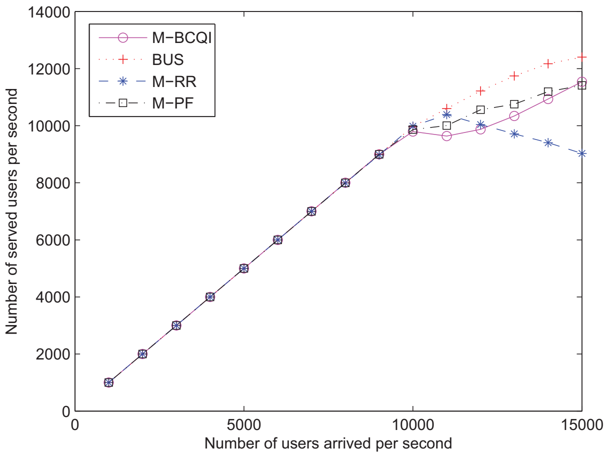

Fig. 5. Number of users accessed of different arriving rate

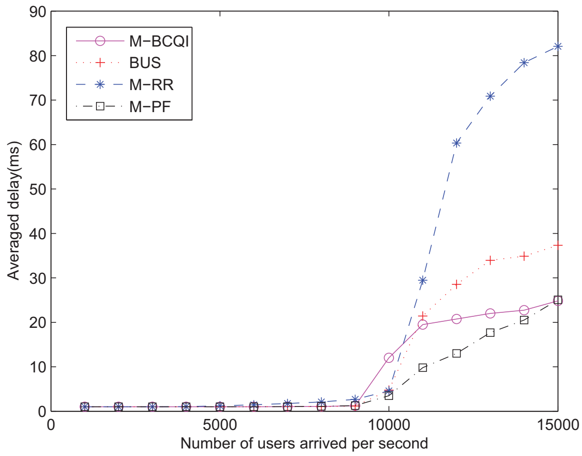

Fig. 6. Users' averaged delay of different arriving rate

for a long time. From Fig. 7, we can find that packet loss rate of BUS algorithm is also smaller than the other scheduling algorithms because BUS algorithm serves users beyond the time limit with high priority. From Fig. 8, we can see that cell throughput of BUS algorithm is also smaller than that of M-BCQI, but larger than that of M-PF and M-RR. The fairness of BUS algorithm is also lower than that of M-RR, but better than that of M-PF and M-BCQI. That is because for users distributed in large area cell with small packet size, we introduce time factor to adjust fairness is better than other factors such as previous achieved rates. The area divided is shown in Table V.

TABLE V
THE AREA DIVIDED

ALL	Area1	Area2	Area3	Area4
1-100km	1-25km	25-50km	50-75km	75-100km

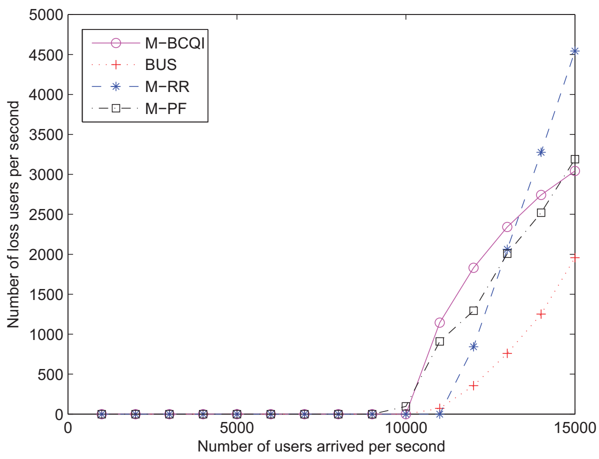

Fig. 7. Loss users of different arriving rate

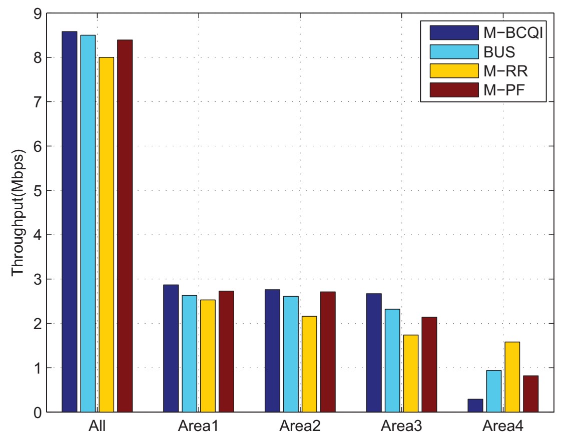

Fig. 8. Throughput of different area

2) Large amount of mix of VOD and Realtime Comments services accidently: Second, we evaluate different algorithms' performance when there exists large amount of bursty users. Fig. 9 show the arriving rate of users, and Table VI shows the performance of different algorithms. From Table VI, we can see that BUS algorithm performs better than the other algorithms when there are large amount of users in burst. This is because we serve users with better channel conditions and small buffer status results, which reduces the congestion.

3) VOD service: At last , we evaluate the situation in which all users have packet size of 120 bits. The results are shown

TABLE VI
RESULTS

	M-BCQI	BUS	M-RR	M-PF
Delay(ms)	58.25	35.86	75.46	54.43
Served users	1551	2079	1433	1789
Loss users	999	471	1117	761

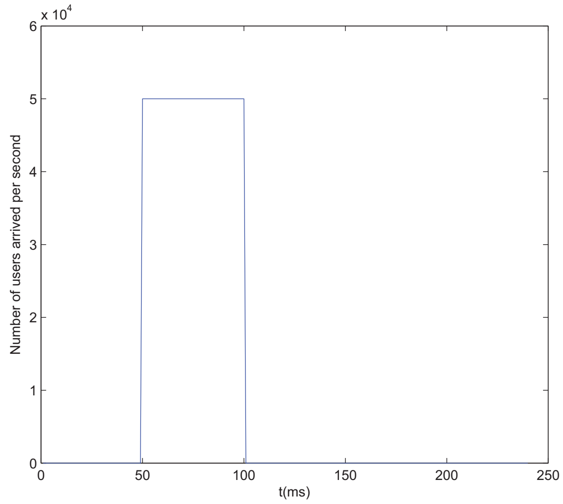

Fig. 9. Arriving rate

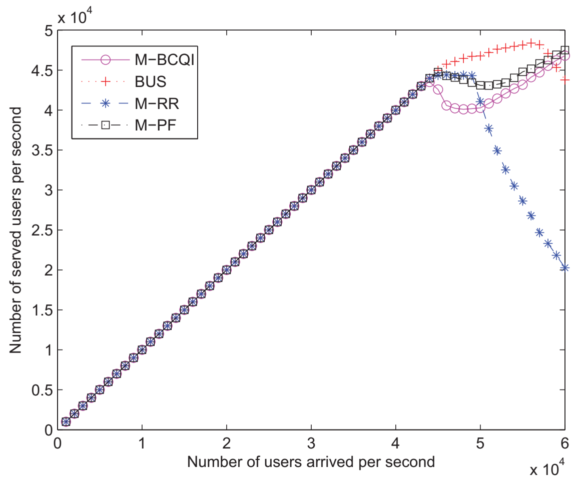

Fig. 10. Number of users accessed of different arriving rate

in Fig. 10-Fig. 13. From Fig. 10, we can see that the served number of users in our BUS algorithm is at the largest because of the lowest loss expected when the arriving rate is high. From Fig.11, we can see that our BUS algorithms are about 60ms lower than the delay target 100ms, and this is not have big influence on users when the delay are not beyond the packet delay budget. From Fig.12, we can find that the loss number of users in our BUS algorithm is also the lowest. From Fig.13, we can see that the fairness of our BUS algorithm is lower than that of M-RR algorithm but better than M-BCQI and M-PF. From above, we can find that the overall performance of our BUS algorithm is the best and can meet the requirement of digital TV uplink scheduling.

VI. Conclusion

In this paper, we analyse the service requirement, channel conditions, and number of users in the DRC system of future

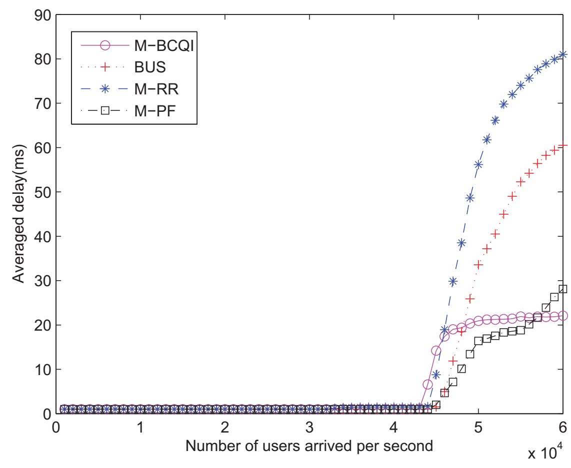

Fig. 11. Users' averaged delay of different arriving rate

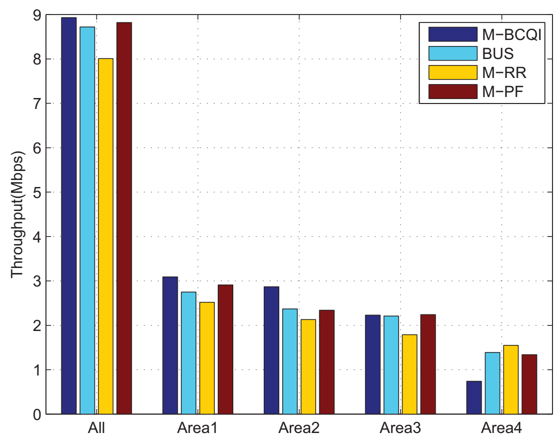

Fig. 13. Throughput of different area

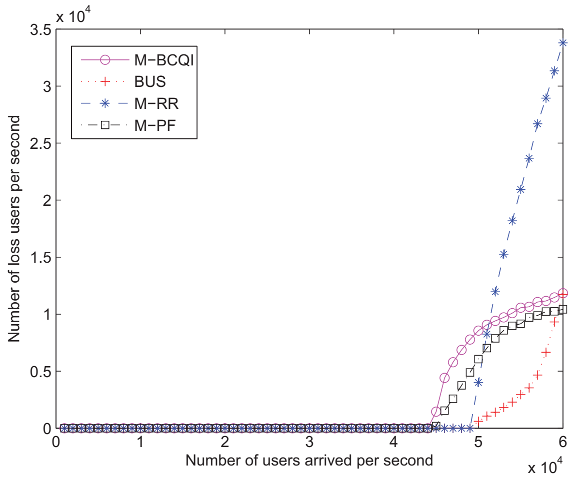

Fig. 12. Loss users of different arriving rate

broadcast TV, and indicate the difference between broadcast system with the cellular network. Based on this analysis, we propose a BUS scheduling algorithm that is suitable for DRC system and then we compare it with modified traditional RR, PF, and BCQI algorithms. We evaluate the algorithm in all kinds of aspects including fairness, the number of users served, averaged delay and the number of loss users. The results show that the performance of proposed algorithm is better than the the modified traditional RR, PF, and BCQI algorithms and satisfies the requirement on the MAC layer of DRC for the future broadcast television.

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REFERENCES

[1] K. Elgazzar, M. Salah, A.-E. M. Taha, and H. Hassanein, "Comparing uplink schedulers for lte," in *Proceedings of the 6th International Wireless Communications and Mobile Computing Conference*. ACM, 2010, pp. 189–193.

[2] L. Ruiz de Temino, G. Berardinelli, S. Frattasi, and P. Mogensen, "Channel-aware scheduling algorithms for sc-fdma in lte uplink," in *Personal, Indoor and Mobile Radio Communications, 2008. PIMRC 2008. IEEE 19th International Symposium on*. IEEE, 2008, pp. 1–6.

[3] H. Yang, F. Ren, C. Lin, and J. Zhang, "Frequency-domain packet scheduling for 3gpp lte uplink," in *INFOCOM, 2010 Proceedings IEEE*. IEEE, 2010, pp. 1–9.

[4] M. Iturralde, S. Martin, and T. A. Yahiya, "Resource allocation by pondering parameters for uplink system in lte networks."

[5] N. Zahariev, Y. Zaki, X. Li, C. Goerg, T. Weerawardane, and A. Timm-Giel, "Optimized service aware lte mac scheduler with comparison against other well known schedulers," in *Wired/Wireless Internet Communication*. Springer, 2012, pp. 323–331.

[6] Y. Zaki, N. Zahariev, T. Weerawardane, C. Görg, and A. Timm-Giel, "Optimized service aware lte mac scheduler: Design, implementation and performance evaluation," in *OPNET workshop*, 2011.

[7] Y. Zaki, T. Weerawardane, C. Gorg, and A. Timm-Giel, "Multi-qos-aware fair scheduling for lte," in *Vehicular technology conference (VTC spring), 2011 IEEE 73rd*. IEEE, 2011, pp. 1–5.

[8] K. Wongthavarawat and A. Ganz, "Packet scheduling for qos support in ieee 802.16 broadband wireless access systems," *International Journal of Communication Systems*, vol. 16, no. 1, pp. 81–96, 2003.

[9] H. G. Myung, J. Lim, and D. Goodman, "Single carrier fdma for uplink wireless transmission," *Vehicular Technology Magazine, IEEE*, vol. 1, no. 3, pp. 30–38, 2006.

[10] G. Berardinelli, L. Ruiz de Temino, S. Frattasi, M. I. Rahman, and P. Mogensen, "Ofdma vs. sc-fdma: performance comparison in local area imt-a scenarios," *Wireless Communications, IEEE*, vol. 15, no. 5, pp. 64–72, 2008.

[11] R. Srinivasan, J. Zhuang, L. Jalloul, R. Novak, and J. Park, "Ieee 802.16 m evaluation methodology document (emd)," *IEEE 802.16 Broadband Wireless Access Working Group*, 2008.

[12] S. A. AlQahtani and M. Alhassany, "Comparing different lte scheduling schemes," in *Wireless Communications and Mobile Computing Conference (IWCMC), 2013 9th International*. IEEE, 2013, pp. 264–269.