Delay-Concerned Opportunistic Scheduling Algorithm in Wireless Communication Networks

Rui Yin, *Student Member, IEEE, Student Member SAIEE.* Dawoud and Hongjun Xu

***Abstract*—In this paper we examine the packets' delay performance under the temporal fairness opportunistic scheduling (TFOS) algorithm which is first introduced in [1]. We also simulate the earliest deadline-first (EDF) scheduling algorithm in the wireless environment. We find that the opportunistic scheduling algorithm biases the users who always experience the good channel condition in packets' delay to improve system performance and the EDF which works well in wireline networks on delay performance [2] does not perform well in wireless communication networks. So we propose a new scheme which considers both users channel condition and packets' delay. The simulation results show that the new scheme works well with respect to both system performance improvement and the balance of packet delay distribution.**

***Index Terms*—opportunistic scheduling, EDF, CDMA, QoS**

I. Introduction

In wire-line networks, fluid queueing has long been a popular paradigm for achieving instantaneous fairness and bounded delays in channel access [3]~[5]. However, adapting wireline scheduling algorithms to the wireless domain is nontrivial because of the unique problems in wireless channel, such as location and time dependence and bursty errors. Consequently the scheduling algorithms for wire-line networks are not directly applied to wireless networks. Several wire-line scheduling algorithms have been extended to the wireless domain [6-7]. The main idea in these scheduling mechanisms is to swap channel access between a backlogged flow that perceives channel error and backlogged flows that do not, and compensate the former when it perceives a good channel. These policies consider short term fairness, long term fairness, and delay bound service. In these algorithms the authors assumed error-prone wireless link is a binary channel, is too simple to characterize realistic wireless channel which is continuous in time.

Opportunistic scheduling mechanisms for wireless communication networks are gaining popularity in recent years as they have potentials of achieving high system performance which satisfies different QoS constraints. Because wireless channels have time varying location dependent characteristics, different users perceive different channel conditions at the same time slot. We call a scheduling algorithm that can take advantage of channel variations by giving some priorities to users with better channel condition in current time slot opportunistic scheduling. But if we only serve the users who experience better channel condition, it will starve other users, which is unfair. So there is a lot of work discussing the opportunistic scheduling algorithm under different fairness constraints.

In [1], [8] and [9] Xin Liu proposed scheduling algorithms under two fairness constraints-temporal fairness constraint and utilitarian fairness constraint, respectively. The main contributions are that the author used the stochastic approximation method to estimate the users' parameters so that the algorithm maximizes the system throughput with minimum-throughput requirements. The author only discussed the opportunistic scheduling schemes under fairness constraint in long term. In [10] we proved that the temporal fairness opportunistic scheduling is actually unfair in short term. On the other hand in all of these papers authors simulated and analyzed the opportunistic scheduling algorithm on the user level and only consider the users' fairness constraint and system performance. In this paper firstly we simulated the opportunistic scheduling algorithm in packet level and examine the packets' delay performance. From the results we found that the opportunistic scheduling algorithm bias users who experience the good channel condition in delay violation probability. So in the second step we simulated the *EDF* scheduling algorithm which performs excellent in the wire-line system on users' packets' delay bound under the wireless circumstance. But we found that *EDF* scheduling algorithm works even worse than the opportunistic scheduling in packets' delay bound. Motivated by our observation we propose a new scheme named delay-concerned opportunistic scheduling algorithm, which takes both the users' channel condition (opportunistic) and users' packets' delay into account.

The paper is organized as follows. In section II we introduce our system model and *QoS* constraint. The temporal fairness opportunistic and *EDF* scheduling algorithms are simulated in packet level in wireless communication networks in section III. In section IV we present our new scheme and conclusions are drawn in section V.

II. System Model & QoS Constraint

a. System model

Rui Yin is with the School of Electrical, Electronic & Computer Engineering, University of KwuaZulu-Natal, Durban 4001, SA, (e-mail: yin@ukzn.ac.za).

In this paper we consider the forward link of time slotted code division multiple access ($T-CDMA$) cell that supports real time data users [11]. The scheduler in the base station dominates the downlink transmissions in this system. In a cell the total transmission power is limited to 1. In our system the total transmission power is treated as a system resource constraint and user's power consumption per bit is the indication of its channel condition.

Because the wireless channel is a time-varying process driven by user mobility and channel shadowing we model the fading process of users' channel by a *Markov* chain**.** We normalize the transmission power and generate the mean of user's power consumption per bit which is the same as [11]. Suppose that all base stations transmit signals at maximum power at all times, which is equal to 1. Let I_{ext} be the relative out-of-cell interference, which a user experiences. The interference is a random variable, which is distributed over all positions in the cell and over log-normal fading. An assumption is made that each base station has a maximum transmit power of 2, but only half of this power is dedicated to data. The in-cell interference is also simply assumed to be equal to the in-cell received power. The target signal-to-interference ratio E_b / I_o is assumed to be $7dB$ and system bandwidth is $4MH_z$. Through the following equation:

$$\frac{E_b}{I_o} = \frac{Bandwidth}{Transmit\_Rate} Signal - Noise\_Ratio ,$$

we generate the mean of users' power consumption per bit which is tabulated in **Table 1**.

i	Mean of c(t)	i	Mean of c(t)	i	Mean of c(t)
1	2.508 10^{-6}	6	2.924 10^{-6}	11	5.229 10^{-6}
2	2.518 10^{-6}	7	3.623 10^{-6}	12	6.482 10^{-6}
3	2.518 10^{-6}	8	4.142 10^{-6}	13	6.635 10^{-6}
4	2.598 10^{-6}	9	4.307 10^{-6}	14	7.257 10^{-6}
5	2.771 10^{-6}	10	4.533 10^{-6}	15	7.395 10^{-6}
				16	7.470 10^{-6}

Table 1: Users' Mean Power Consumption per Bit(N=16)

In this paper we are mainly interested in scheduling users with time sensitive traffic under the wireless channel condition, so we assume:

1. Traffic model: we suppose there are $N = 16$ users in the system and packets for each mobile user are generated by a Possion process. The flow of packets is generated at the rate 28packets/s and the packet size is constant, 1024 bits, which are corresponding to the typical rate required for the real time users like audio [12].
2. Wireless channel model: because the wireless channel is a time-varying process driven by user mobility and channel shadowing we model the fading process of users' channel by a five states *Markov* chain**.** The state**-**transition diagram for the channel model is given in **Fig. 1**.

The scheduler makes a decision in every 2 millisecond and we run our simulation 500000 time slots. We also assume that performance values for different users are comparable and additive, here we using the throughput (data rate) to stand for the performance, and the buffer of base station is infinite.

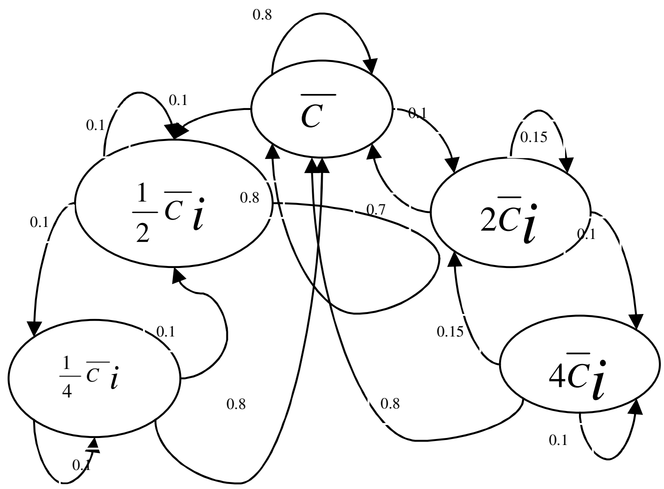

Fig. 1. Five states Markov Chain

b. Quality of service constraint

There are two main classes of QoS constraints that the opportunistic scheduling algorithms try to satisfy. The first one is **fairness** constraints which include two main classes:

1. Temporal fairness (resource sharing fairness): we suppose that there are *N* users in a cell, user *i* is assigned a fixed fraction of resource (in our system it is time slot), denoted as ϕ_i, where $0 < \phi_i < 1$ and $\sum_{i=1}^{N} \phi_i \le 1$.
2. Generalized Processor Sharing fairness (GPS) [12]: there are N users to request the service in the system and user i has a weight σ_i . Let $S_i(\tau, t)$ be the amount of user i traffic served in the interval $[\tau, t]$. The GPS fairness is defined as $\frac{S_i(\tau,t)}{S_j(\tau,t)} \ge \frac{\sigma_i}{\sigma_j}$ for any user i $(i \ne j)$.

The second is for the real time users. There are **packets' delay** and **packet drop ratio. T**he delay bound for the users' packets is expressed as:

$$P_r\{d_i > T_i\} \le \delta_i$$

where d_i is the steady state packet delay for user i , and parameters T_i and δ_i are the delay threshold and the maximum probability of exceeding delay threshold, respectively. $P_r\{\}$ is probability function. The packet loss ratio is the number of packets which are dropped because of the deadline violation. It is stated as:

$$\text{Packet Drop Ratio} = \frac{number\_loss\_packet}{total\_number\_packet}$$

In our paper we consider temporal fairness criterion, packets' delay and packet drop ratio because we use the opportunistic method and consider the time sensitive traffic.

III. TEMPORAL OPPORTUNISTIC & EDF SCHEDULING ALGORITHM

a. The definition of schemes

Temporal fairness opportunistic scheduling algorithm: The objective of the temporal fairness opportunistic scheduling algorithm is to maximize the system performance (throughput) under the temporal fairness constraint. So the scheduling problem can be formulated as:

$$\max \sum_{i=1}^{N} E\{r_i \times I_{\{Q(\vec{r})=i\}}\}$$

Subject to:

$$E\{I_{\{Q(\vec{r})=i\}}\} \geq \phi_i$$

where $E()$ is the expectation function, $I()$ is the indication function, $Q()$ is the scheduling policy, r_i is user $i's$ data rate, $\vec{r}$ is users' data rate vector, ϕ_i is user $i's$ system resource (time slots) requirement. The optimal solution [11] for this problem is:

$$Q^*(\vec{r}) = \arg\max_i (r_i + v_i)$$

where v_i is a parameter determined by the distribution of user's data rate r_i and fairness constraint. v_i is updated in each time slot using the stochastic approximation method, which can be stated as

$$v_i^{k+1} = v_i^k - a^k (I_{\{Q_i^*(\vec{r})=i\}} - \phi_i)$$

, where a^k is the step size in slot k . In every slot we use policy $Q()$ to decide to which user the server should transmit the data.

EDF scheduling algorithm: intuitively in every time slot the scheduler chooses the users for which the deadline of the packet at the head of the queue is closest to serve:

$$Q(\bar{d}) = \arg\min_i (T_i - d_i)$$

, where d_i is the delay experienced by the head of packet since its entrance to the user $i's$ queue in the base station, $\bar{d}$ is users' delay vector, T_i is deadline or delay threshold.

b. Simulation results

In our experiments we examine the packets' delay distribution, packet loss ratio and system resource (time slots) allocation. Under the temporal fairness opportunistic scheduling we set all users have the same system resource requirement, $\phi_i = \phi_j$ for any $i \neq j$.

1. **Packets' delay distribution**: in the temporal fairness opportunistic scheduling algorithm all the users would be allocated the same portion of system resource (time slot). In **Table 1** user one's mean power consumption per bit is smallest and user sixteen's mean power consumption per bit is biggest. So provided the same time slots the user who experience best channel condition would have better packets' delay performance than the user who experience worse channel condition. We show the packets' delay distribution of user one and user sixteen in **Fig. 2.** The result proves our analysis that user one has much better packets' delay performance than user sixteen. In the **EDF** user's delay is only the factor to be concerned so packets' delay distributions for users who have different channel conditions would not deviate too much. **Fig. 3** shows the delay distribution of user one and user sixteen in the **EDF**. User one (best channel condition) and user sixteen (worst channel condition) have almost same delay distribution but both of them are worse than opportunistic scheduling algorithm.
2. **Packets' drop ratio**: the packets drop ratios in different deadline for opportunistic scheduling algorithm are displayed in **Fig. 4.** As the deadline increases the packet drop ratio of both user one and user sixteen decreases. User one still has better performance than user sixteen in terms of packet drop ratio because of the same reason we analyzed in 1.

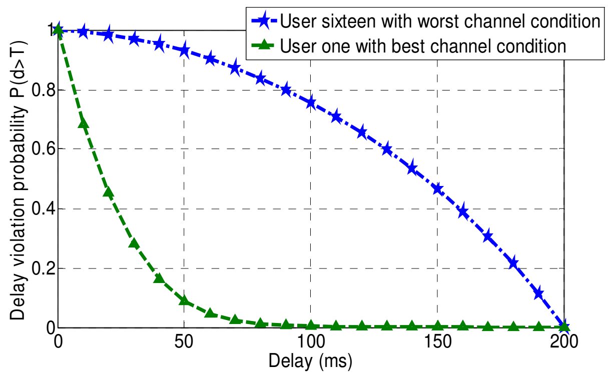

Fig. 2. The packets' delay violation probability of user one who has the best channel condition and user sixteen who has the worst channel condition in the opportunistic scheduling algorithm when the deadline is 200 ms.

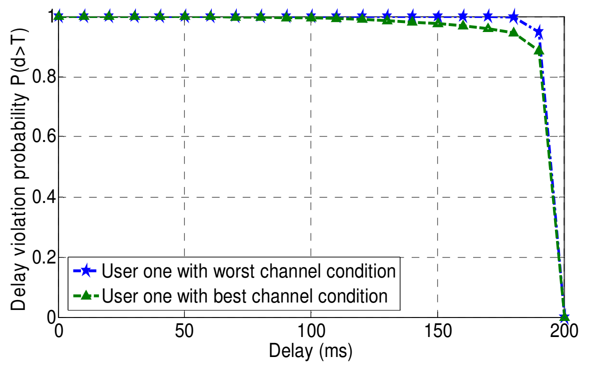

Fig. 3. The packets' delay violation probability of user one who has the best channel condition and user sixteen who has the worst channel condition in the **EDF** scheduling algorithm when the deadline is 200 ms.

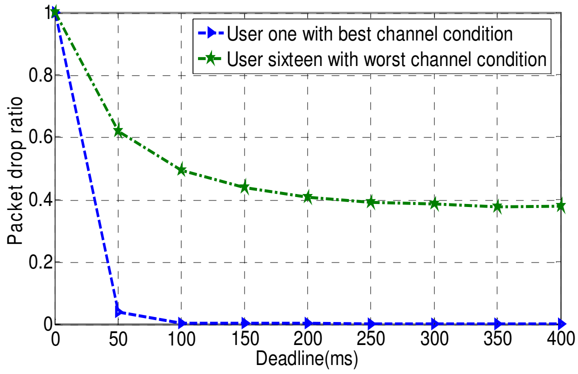

Fig. 4. The packet drop ratio of user one and user sixteen when the deadline changes from 0 to 400 in the temporal fairness opportunistic scheduling algorithm.

Conclusion: through experiment one and two we found:

1. The temporal fairness opportunistic scheduling algorithm is unfair in terms of packets' delay. The user who always experiences good channel condition performs much better than the user who always experiences bad channel condition in packets' delay and packet drop ratio. The reason is that the temporal fairness opportunistic scheduling algorithm only considers the users' channel condition and the fairness constraint in time slots allocation.
2. Though the **EDF** is fair for users in packets' delay it does work well like it works under the wireline situation in packets' delay (worse than opportunistic scheduling). That is because the **EDF** does not take users' channel condition into account.

IV. DELAY CONCERNED OPPORTUNISTIC SCHEDULING

In this section we propose a new scheduling scheme to improve the fairness in packets' delay for users who have different channel condition while increasing the system performance. In the new scheduling scheme we take both the users' channel condition and packet's delay into consideration.

a. New scheme

The new scheme is stated as:

$$Q(\vec{d},c) = \arg\max_i \frac{d_i}{D_i} \times \frac{\overline{C_i}}{c_i}$$

D_i : deadline of packets in user $i's$ queue in base station.

d_i :delay experienced by the head of packet in user *ith* packets' queue.

c_i : user $i's$ power consumption per bit.

$\overline{C_i}$: user $i's$ mean power consumption per bit. **(Table 1)**

In the new algorithm the packet delay and user channel condition have the same power in the equation $(d_i / D_i) \times (\overline{C_i} / c_i)$. When a certain queue has its HoL packet waiting in the base station for a relatively long period, the weight of delay in the equation would grow significantly due to the contribution of d_i until it overcomes other factors in equation. This factor is to balance the user's packets' delay difference and decrease packet drop ratio. On the other hand, when all users' HoL packets' delays are almost the same, another factor $\overline{C_i} / c_i$ dominates the equation. So the policy reduces to a proportional fairness algorithm which exploits the diversity of users' channel condition to improve the system performance.

b. Simulation result

In this section we examine the new scheme in packet's delay distribution, packet drop ratio, temporal fairness, user performance and system performance respectively and then compare to the TFOS algorithm and EDF scheduling algorithm.

1. **Packets' delay distribution**: we display the delay distribution by TFOS algorithm and our new scheme on the same graph for comparison. We set the deadline 200ms. **Fig.5** shows that the difference between user one (best channel condition) and user sixteen (worst channel condition) in packets' delay distribution decreases tremendously comparing to the TFOS algorithm. This is because our new algorithm not only takes the users' channel condition into account but also considers users' packets' delay.

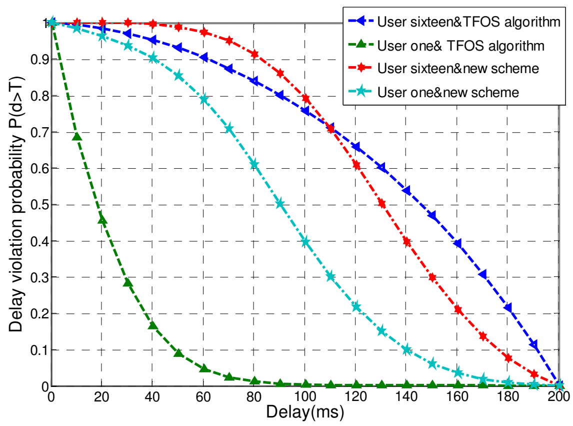

Fig. 5. The packets' delay violation probability of user one who has the best channel condition and user sixteen who has the worst channel condition by the **TFOS** algorithm and new scheme when the deadline is 200 ms.

2. **Packet drop ratio:** as we expect that the packet drop ratio of user one (best channel condition) and sixteen (worst channel condition) trends to zero as the deadline increases in **Fig.6**. The packet drop rate due to the deadline violation has a direct relationship to the packets' delay distribution. In the new scheme the packet delay and users' channel condition are considered equally. Though if the delay characteristics of all users are about the same, then the algorithm will reduce to the proportional fairness scheduling algorithm, the fairness in this algorithm is still the second consideration. But in TFOS algorithm the fairness in resource (time slots) allocation and user's channel condition are the first concerned. For satisfying the fairness the base station has

to allocate time slot to users with good channel condition though it's packet drop ratio is low.

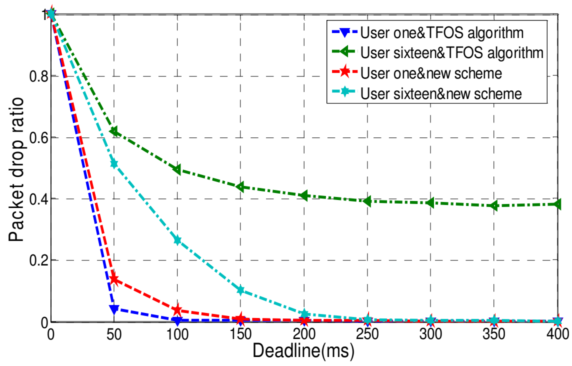

Fig. 6. The packet drop ratio of user one and user sixteen when the deadline changes from 0 to 400 by the TFOS algorithm and new scheme.

3. **Fairness:** the TFOS algorithm is designed for the fairness of system resource allocation. But the new scheme concerns the packets' delay more than the fairness. Time slot allocation with 200ms deadline is displayed in **Fig. 7**. In the TFOS algorithm users' system resource requirement is the same. So in the graph the time slots allocated to different users in TFOS are more even than those in the new scheme. If users are assumed always on and the simulation is run on user level, the number of time slots allocated to different users are almost equal [10] by TFOS algorithm. In **Fig. 7** there are deviations from the ideal one on the time slot allocation in the TFOS algorithm because if there are no packets in the queue of users with good channel condition the time slots have to be allocated users with bad channel condition, which incurs the fairness violation. But packets' delay and users' channel condition are the mean influencing factors in the new scheme. So packets allocated to users are quite different. Users with bad channel condition (user 16, 15, 14, 13) are received more time slots to guarantee their packets' delay distribution not varying too much from users with good channel condition. So the new scheme sacrifices the temporal fairness to gain the balance in users' packets' delay distribution.

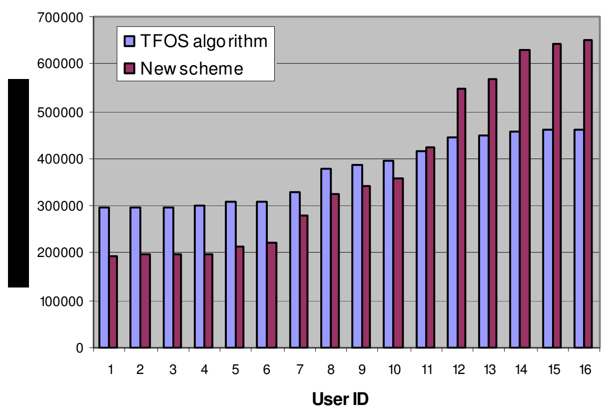

Fig. 7. The number of time slots allocated to sixteen users by the TFOS algorithm and the new scheme respectively, the left bar is by TFOS algorithm and right bar is by the new scheme.

4. System performance & user performance: in the new scheme the users' channel is considered to improve the system performance (the utility of the system resource-band width). So the system performance and users' performance should be greater than those non-opportunistic scheduling algorithm (EDF, Round Robin, Short remained time first and so on). In our simulations throughput is used to stand for performance. In **Fig. 8** and **Fig. 9** the users' performance and system performance for TFOS algorithm, EDF and the new scheme are shown, respectively. Both the system performance and users' performance achieved by the new scheme are much higher than the **EDF** (non-opportunistic scheduling), with gains of 25% to 146%. But users' performance and system performance achieved by TFOS algorithm are better than the new scheme. The packets' delay constraint is more constraint than the fairness constraint so the new scheme has less chance to exploit the users' channel diversity than the TFOS scheme.

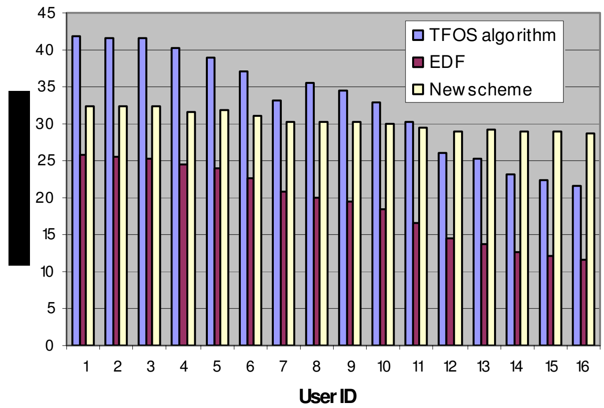

Fig. 8. Users' data throughput by the TFOS algorithm, EDF, the new scheme respectively, the left bar is by TFOS algorithm, the middle bar is by EDF and right bar is by the new scheme.

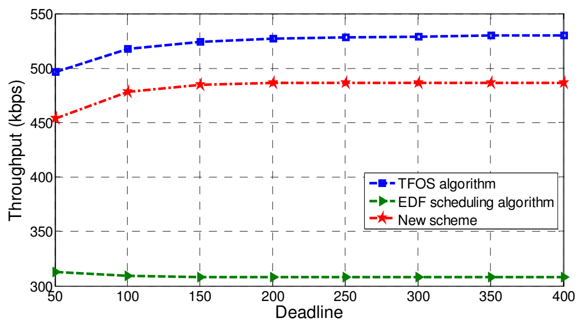

Fig. 9. System throughput by the TFOS algorithm, EDF, the new scheme respectively, x axis is packets' deadline, y axis is system throughput.

V. Conclusion

In this paper firstly the performance of temporal opportunistic and **EDF** scheduling algorithm in packets' delay and packet drop ratio are given. The TFOS algorithm biases users with good channel condition in packets' delay and packet drop ratio. The EDF scheduling algorithm does not work well in delay under the wireless channel circumstance. So the new scheme which considers both users' channel condition and packets' delay is proposed. Through the analysis and simulation we prove that the new scheme works well in both packets' delay and packet drop. But there are also some shortages of this algorithm. Firstly for guaranteeing the balance of packets' delay between users with good channel condition and users with bad channel condition the new algorithm has to sacrifice the fairness. Secondly because the delay constraint is more strict than the fairness constraint, the system performance gain achieved by new scheme is as good as TFOS algorithm.

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