

PAPER

An Adaptive Fairness and Throughput Control Approach for Resource Scheduling in Multiuser Wireless Networks

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SUMMARY The important issue of an adaptive scheduling scheme is to maximize throughput while providing fair services to all users, especially under strict quality of service requirements. To achieve this goal, we consider the problem of multiuser scheduling under a given fairness constraint. A novel Adaptive Fairness and Throughput Control (AFTC) approach is proposed to maximize the network throughput while attaining a given min-max fairness index. Simulation results reveal that comparing to straightforward methods, the proposed AFTC approach can achieve the desired fairness while maximizing the throughput with short convergence time, and is stable in dynamic scenarios. The trade-off between fairness and throughput can be accurately controlled by adjusting the scheduler's parameters.

key words: multiuser diversity, multiuser scheduling, proportional fairness, fairness index, adaptive fairness, throughput control

1. Introduction

Multiuser diversity is a fundamental characteristic of multiuser network established by the independently time-varying fading channels among users. This diversity can be exploited to improve the throughput performance by opportunistically scheduling users on favorable resources [1]. However, focusing only on the possible diversity gain can lead to unfair treatment of individual users. If the system has a certain fairness constraint such as in emergency situations, e.g., in a major natural disaster, providing a target fairness such as equal throughput allocation to users is more important. For an adaptive and efficient scheduling scheme, we need a mechanism of adjustable fairness and throughput [2], [3].

For the purpose of controlling the trade-off between network throughput and fairness, various scheduling schemes have been proposed and used in many applications. The proportional fairness (PF) scheduling scheme is a notable algorithm that can maximize the logarithmic total throughput by exploiting multiuser diversity [4]. A modified PF scheme called weighted PF (WPF) can control the throughput-fairness trade-off by adjusting the scheduler's parameter [5]. Recently, a scheduling and resource sharing scheme referred to as adaptive PF (APF) was proposed in [6], [7], that maps the channel quality of each user into a

defined utility function and controls the throughput-fairness trade-off in a more adaptive and efficient way.

These existing scheduling schemes can provide some control on the trade-off between throughput and fairness. However, it is not trivial to apply them to obtain a given fairness target, because they lack the features to precisely control the system fairness performance. Moreover, they cannot provide a robust control of fairness in dynamic scenarios [8]. For example, varying the number of users or their locations may lead to significantly different results. In order to achieve a given fairness, a natural solution for WPF and APF is to adjust the scheduler's parameter using binary search. However, such a straightforward method is not efficient, because the convergence time is long and it is ineffective in dynamic scenarios.

Therefore, Schwarz et al. proposed a downlink multiuser scheduling scheme based on WPF to obtain the desired fairness specified in terms of the Jain fairness index [3]. However, their approach is designed only for the Jain fairness index. On the other hand, we consider that the min-max fairness index [9] is more appropriate, especially in emergency situations, because the Jain fairness index [10] and other indexes such as the Gini index [11] might ignore the minor lowest-throughput users. Moreover, comparing to WPF, APF is a newer and better scheme. Therefore, this work aims at an APF-based scheduling scheme of adjustable fairness and throughput.

In this paper, we propose a novel adaptive fairness and throughput control (AFTC) approach based APF, to maximize the network throughput while attaining a given fairness quantified by the min-max fairness index. In the proposed AFTC approach, an updating module is introduced to track the data rate allocated to users and update the scheduler's parameters. The purpose of this approach is to make the achieved fairness index equal to the desired index and assure robustness in dynamic scenarios. The trade-off between fairness and throughput can be accurately controlled by the given fairness index.

The remainder of this paper is organized as follows. Section 2 describes the proportional fairness based multiuser scheduling schemes and fairness measurement. Section 3 describes the proposed AFTC approach. Section 4 presents the system assumption and the simulation results. Section 5 includes our concluding remarks.

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2. Proportional Fairness Based Scheduling and Fairness Measurement

In this section, we describe the above-mentioned proportional fairness (PF) based multiuser scheduling schemes and present a general definition of fairness in the resource allocation to the users. Herein, we assume that the scheduler selects only one user in each transmission time interval (TTI), which is equal to the length of one transmission frame. The complex channel gains for the fading links from all users $h_n, n \in \{1, \dots, N\}$ to the serving base station (BS) are assumed to be i.i.d. $CN(0, 1)$, i.e., distributed according to Rayleigh model, and to be constant within each TTI, where N is the total number of users.

2.1 Proportional Fairness Based Scheduling

The user selection criterion according to the Weighted Proportional Fairness (WPF) scheduling scheme is given by [5]:

$$n^* = \arg \max_{n \in \{1, \dots, N\}} \frac{(r_n)^e}{R_n}, \quad (1)$$

where r_n is the instantaneous rate of user n , R_n is the average achievable rate of user n , and e is the exponent parameter used to control the trade-off between throughput and fairness. A special case of the WPF scheduling scheme when $e = 1$ in (1), corresponds to the original PF scheduling scheme [4]. The instantaneous rate of user n can be expressed as

$$r_n = \log_2(1 + |h_n|^2 \gamma_n), \quad (2)$$

where γ_n denotes the average received signal-to-noise ratio (SNR) at the BS for the link between user n and the BS.

The average achievable rate R_n is updated at each TTI according to the following rule:

$$\begin{cases} R_n = \left(1 - \frac{1}{L}\right) R_n + \frac{1}{L} r_n, & \text{if } n = n^* \\ R_n = \left(1 - \frac{1}{L}\right) R_n, & \text{if } n \neq n^*, \end{cases} \quad (3)$$

where L ($0 < 1/L < 1$) is the average time window size over which fairness is reflected.

Since the exponent parameter e in (1) takes a fixed value for all users, this approach gives rise to two problems, demonstrated in [6]: (i) The time-varying diversity of each user cannot be adapted because of the exponent parameter being fixed in time, and (ii) It is not possible to fix a certain value for e that ensures fairness among all users at the same time because this parameter takes a unique value for all users.

Tackling these issues, a modified PF based multiuser scheduling called adaptive proportional fairness (APF) was proposed in [6], in which the user selection criterion is given by:

$$n^* = \arg \max_{n \in \{1, \dots, N\}} \frac{(r_n)^{c_n}}{R_n}, \quad (4)$$

where c_n is an independent exponent parameter corresponding to user n . This parameter is particular to each user and determined in order to avoid the dependency between different users. The updating of the average achievable rate R_n is as shown in (3).

To achieve long-term fairness among users, the updating of each user's exponent parameter c_n is done at a larger time-scale. Indeed, the updating of the exponent parameters is done only when necessary for achieving proportional fairness among users. The updating module verifies whether the difference between normalized throughput, defined as $R_n/\bar{r}_n$, and the average value of all users is within acceptable values defined by the interval $[-\varepsilon, \varepsilon]$. Parameter $\bar{r}_n$ represents the average achievable channel capacity of user n , and ε is a fairness tuning parameter that defines the degree of fairness requirement. Herein, the exponent parameter c_n is updated according to [6]:

$$\begin{cases} c_n = c_n + \Delta c, & \text{if } \left(\frac{R_n}{\bar{r}_n} - \frac{1}{N} \sum_{n=1}^N \frac{R_n}{\bar{r}_n}\right) < -\varepsilon \\ c_n = c_n - \Delta c, & \text{if } \left(\frac{R_n}{\bar{r}_n} - \frac{1}{N} \sum_{n=1}^N \frac{R_n}{\bar{r}_n}\right) > \varepsilon, \end{cases} \quad (5)$$

where the choice of Δc depends on the speed of the convergence requirement. We note that when the value of ε is large enough such as $\varepsilon = 100$, no updating of each user's exponent parameter c_n is performed, and the fairness and throughput achieved by APF completely depends on the initial values of parameters $c_n, n = 1, \dots, N$.

2.2 Fairness Measurement

In multiuser networks, the measurement of fairness has been extensively studied in the literature. In this paper, we rely on a general fairness measure called min-max fairness index, which has been usually used to measure the achieved fairness of resource scheduling schemes. The min-max fairness index is defined as the ratio of the minimum and the maximum throughput allocated to users, and is given by [9]:

$$f_{\min-\max} = \frac{\min\{\hat{T}_n\}}{\max\{\hat{T}_n\}}, \quad n \in \{1, \dots, N\}, \quad (6)$$

where $\hat{T}_n$ is the achieved total throughput of user n . The numerator of (6) expresses the smallest throughput allocated among users, and the denominator expresses the largest throughput allocated among users. The value of the min-max fairness index $f_{\min-\max}$ is between 0 and 1. Note that $f_{\min-\max} = 0$ expresses extremely unfair resource allocation to the users, whereas $f_{\min-\max} = 1$ indicates a perfectly fair resource allocation to the users.

Note that this paper does not focus on the discussion in the definition of fairness index. We focus on that, given a certain index, how to guarantee it while achieving fast convergence and high throughput. This is a feature that existing

scheduling schemes WPF and APF lack.

3. Proposed Adaptive Fairness and Throughput Control Scheme

In this section, we consider the problem of multiuser scheduling under a given fairness constraint, and propose a novel adaptive fairness and throughput control (AFTC) approach to maximize the network throughput while attaining a given fairness quantified by the min-max fairness index. The proposed AFTC approach creates a relation between the min-max fairness index and the multiuser scheduling scheme.

We describe the proposed AFTC approach, which is based on the above-described APF scheduling scheme. The concept of the AFTC approach is illustrated in Fig. 1. In particular, the user selection criterion is given by:

$$n^* = \arg \max_{n \in \{1, \dots, N\}} \frac{(r_n)^{\psi_n}}{R_n}, \quad (7)$$

where r_n , R_n , and ψ_n are the instantaneous rate of user n , the average achievable rate of user n , and the exponent parameter corresponding to user n , respectively. The update rule of the user's average achievable rate R_n is the same as that of APF. However, the updating rule of ψ_n is different from that of APF, which is the most important part for the fairness and throughput control that we target. The aim of the proposed approach is to make the achieved min-max fairness index

$f_{\min-\max}$ ($0 \leq f_{\min-\max} \leq 1$) equal to the desired fairness index and maintain the total throughput at a high level. Here, we define η ($0 \leq \eta \leq 1$) as the desired fairness specified in terms of the min-max fairness index.

In order to make the achieved fairness index $f_{\min-\max}$ equal to a desired fairness index η , the selection criterion in (7) should also be based on η . Since r_n and R_n do not have an explicit relation with η , we focus on the updating rule of each user's control parameter ψ_n . Herein, the updating rule of ψ_n is designed based on the desired fairness index η . For instance, if the achieved fairness $f_{\min-\max}$ is less than the desired fairness η , that means some users are not served with enough resources while other get most of the resources. Therefore, we should increase the probability for selecting the former kind of users, and decrease the probability for selecting the users of the latter type. The selection probability of each user n , can be controlled by adjusting the value of ψ_n shown in (7). Indeed, increasing the value of ψ_n can increase the selection probability of user n and decreasing the value of ψ_n can decrease the selection probability of that user.

Now, we elaborate on the updating rule of ψ_n . To achieve long-term fairness among users, we consider that the value of ψ_n is updated at a larger time-scale than that of R_n . Indeed, the updating of each user's ψ_n is only performed if the achieved fairness $f_{\min-\max}$ has reached a stationary state. Such a stationary state is decided through measurement of the changes exhibited by the achieved fairness $f_{\min-\max}$ between consecutive TTIs. If $|f_{\min-\max}(t) - f_{\min-\max}(t-1)| < \delta$, where δ is a system parameter which is decided by the system operator, then this indicates that $f_{\min-\max}$ is specified to have reached a stationary state. A small value of δ results in a long-term but precise decision, whereas a large value of δ results in a short-term but approximate decision. When the stationary state of $f_{\min-\max}$ is reached, the user control parameter ψ_n is updated using the following algorithm, where without loss of generality, we suppose $\hat{T}_1 \leq \hat{T}_2 \leq \dots \leq \hat{T}_N$.

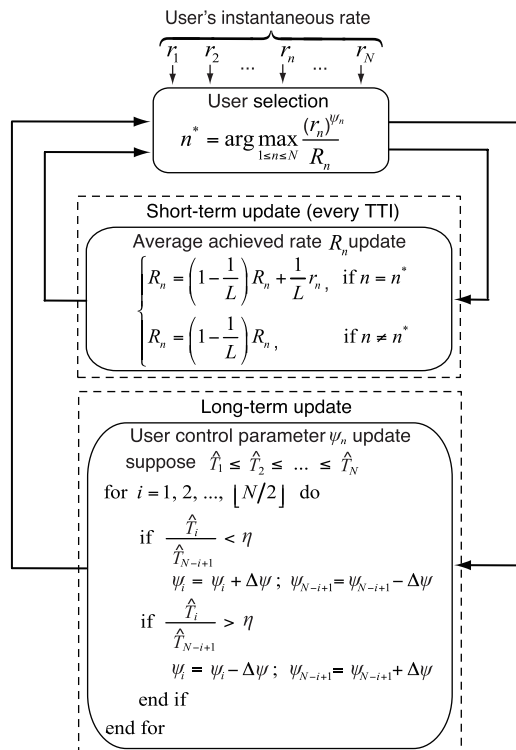


Fig. 1 The procedure of the Adaptive Throughput and Fairness Control (AFTC) approach, where η is the desired min-max fairness index.

User Control Parameter ψ_n Update Algorithm

for $i = 1, 2, \dots, \lfloor N/2 \rfloor$ do

if $\frac{\hat{T}_i}{\hat{T}_{N-i+1}} < \eta$

$\psi_i = \psi_i + \Delta\psi$; $\psi_{N-i+1} = \psi_{N-i+1} - \Delta\psi$

elseif $\frac{\hat{T}_i}{\hat{T}_{N-i+1}} > \eta$

$\psi_i = \psi_i - \Delta\psi$; $\psi_{N-i+1} = \psi_{N-i+1} + \Delta\psi$

end if

end for

The choice of $\Delta\psi$ depends on the required convergence speed. By increasing the value of $\Delta\psi$, faster convergence to the target fairness η can be achieved but the convergence has more oscillations around this value. To avoid these oscillations and make a precise decision on achieved fairness, in

our computer simulations, we assume $\Delta\psi = 0.1$ and $\delta = 0.1$.

Here we explain how to update the user control parameter ψ_n to achieve the required fairness target and comparatively higher network throughput. We first discuss how to make the achieved min-max fairness equal to the target fairness η using this update algorithm. If $\hat{T}_i/\hat{T}_{N-i+1} < \eta$, ψ_i is updated to $\psi_i + \Delta\psi$ and ψ_{N-i+1} is updated to $\psi_{N-i+1} - \Delta\psi$. The selection probability of user i increases with increasing ψ_i and decreases with decreasing ψ_i . Hence, $\hat{T}_i$ increases and $\hat{T}_{N-i+1}$ decreases after the updating of ψ_i and ψ_{N-i+1} . Consequently, $\hat{T}_i/\hat{T}_{N-i+1}$ becomes large. In case $\hat{T}_i/\hat{T}_{N-i+1} > \eta$, ψ_i is updated to $\psi_i - \Delta\psi$ and ψ_{N-i+1} is updated to $\psi_{N-i+1} + \Delta\psi$. Hence, $\hat{T}_i/\hat{T}_{N-i+1}$ becomes small. As a result, the achieved min-max fairness $f_{\min-\max}$ can be equal to the target fairness η . In contrast to APF, the achieved fairness and throughput by AFTC do not depend on the initial value of each user's exponent parameter ψ_n , which is a major difference with the APF technique.

A straightforward method for updating ψ , would refer to the case when $i = 1$ only. However, it does not exploit the temporal and multiuser diversities and this may lead to poor throughput performance. For example, if the instantaneous rate of user with throughput $\hat{T}_1$ is very low, the network overall throughput is also low. By considering all user pairs that can exploit full temporal and multiuser diversities, because parameter ψ_n has a strong relation with user selection part (7) and updating ψ_n can control the user's selection priority. Thus, we can achieve not only desired fairness, but also improved network throughput.

4. Simulation Results

In this section, we show simulation results using the proposed AFTC technique and compare the results with those of several conventional schemes both in dynamic and static scenarios.

We assume a full buffer traffic model in which each user (or base station) has packets awaiting transmission to base station (or users). The maximum possible system throughput can be evaluated for the full buffer traffic model, reflecting the multiuser and temporal diversity gain on the throughput performance. We consider a block Rayleigh fading channel model with independent channel realizations and take into account the path loss with exponent $\alpha = 3$. For the sake of simplicity, the effect of shadowing is not considered. The users are assumed to be randomly and uniformly located in a cell area, and the total number of users N in a cell is variable in different simulation situations. The cell radius is normalized to 1, and the cell edge average SNR is assumed to be 0 dB. We assume that the initial value of each user's exponent parameter ψ_n in AFTC and c_n in APF, are equal to 1 unless otherwise mentioned, which corresponds to the original PF method.

4.1 Performance Evaluation in Dynamic Scenario

We first investigate the effects of the users' location and

Table 1 Comparison of achieved min-max fairness index between the proposed AFTC approach and two PF based scheduling schemes in different users' location cases, where the number of users is fixed to $N = 10$.

Users' location	AFTC		WPF		APF	
	$\eta = 0.5$	$\eta = 0.9$	$e = 1$	$e = 0.1$	$\varepsilon = 1$	$\varepsilon = 0.1$
Case 1	0.50	0.90	0.41	0.82	0.77	0.91
Case 2	0.49	0.89	0.25	0.78	0.80	0.90
Case 3	0.51	0.91	0.38	0.81	0.72	0.94
Case 4	0.51	0.91	0.53	0.77	0.68	0.92
Case 5	0.49	0.90	0.31	0.92	0.66	0.87
Case 6	0.50	0.90	0.43	0.69	0.71	0.91
Case 7	0.50	0.90	0.36	0.92	0.78	0.93
Case 8	0.50	0.90	0.42	0.76	0.81	0.92
Case 9	0.49	0.89	0.16	0.83	0.70	0.85
Case 10	0.50	0.90	0.26	0.76	0.69	0.88

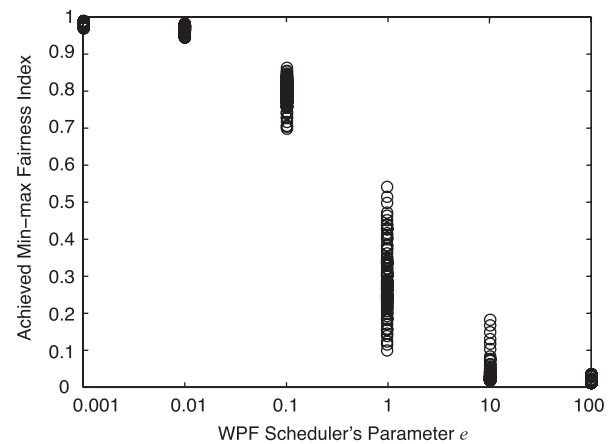


Fig. 2 Fairness performance of WPF where the number of users is fixed to $N = 10$. For each control parameter $e \geq 0$, the results are calculated for 100 different users' locations.

the scheduler's parameters on the achieved fairness performance of the proposed AFTC, the WPF and the APF scheduling schemes. Table 1 shows a comparison of the achieved fairness index by each scheduling scheme for different cases of users' location, where the number of users is fixed to $N = 10$. η , e and ε are the scheduler parameters of AFTC, WPF and APF, respectively, and the achieved fairness index can be controlled by adjusting these values. The achieved fairness is quantified by the min-max fairness index and calculated by taking 10,000 frames until the achieved fairness index becomes stable for each location case. From Table 1, we find that the achieved fairness index of AFTC is almost equal to the value of η regardless of changing the users' location. However, for WPF and APF, although the values of the WPF parameter e and the APF parameter ε are fixed, the achieved fairness index changes when varying the users' locations.

To analyze the achieved fairness performance of AFTC, WPF and APF in more details, Figs. 2, 3 and 4 show the achieved fairness performance of each scheduling scheme with different values of the scheduler's parameter and the users' locations, where we measure the fairness for users' 100 different locations.

For the WPF scheduling scheme shown in Fig. 2, we

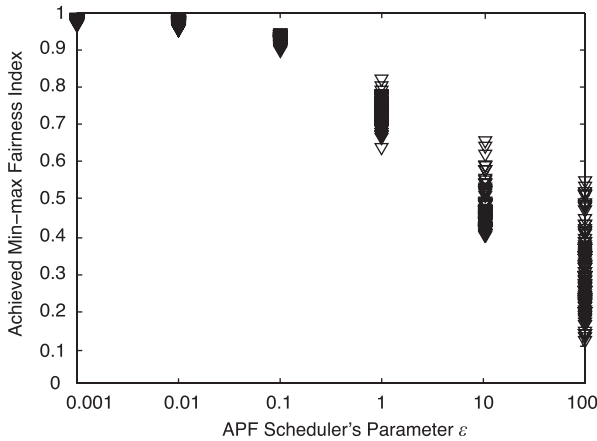


Fig. 3 Fairness performance of APF where the number of users is fixed to $N = 10$. For each control parameter $\varepsilon \geq 0$, the results are calculated for 100 different users' locations.

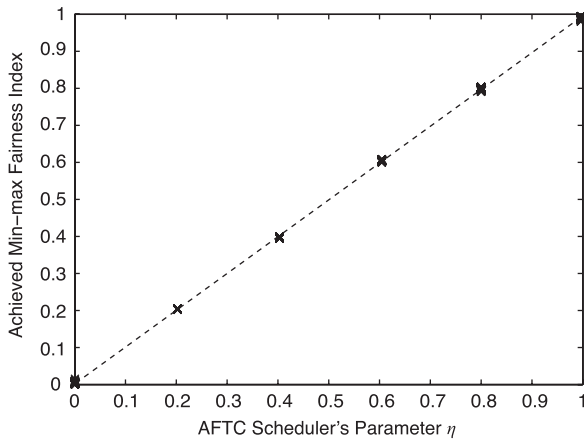


Fig. 4 Achieved fairness performance vs. desired fairness η by applying the proposed AFTC approach. The number of users is $N = 10$ and the results are calculated for 100 different users' locations.

observe that the achieved min-max fairness index decreases with increasing value of e . The achieved fairness index can be approximately controlled by adjusting the value of e . However, we find that even when the value of the WPF parameter e is fixed, the achieved fairness index changes by changing the users' locations in the cases for $0.001 \ll e \ll 100$. The achieved fairness becomes stable only when $e = 0.001$ and $e = 100$. As a result, it is very difficult to apply WPF to obtain a desired fairness in dynamic scenarios such as varying users' locations.

For the APF scheduling scheme considered in Fig. 3, the achieved min-max fairness index decreases when increasing value of the APF parameter ε . We observe that the dispersion of the achieved fairness index increases with increasing ε . This result means that the fairness control becomes non-robust with larger ε . Only for the case when $\varepsilon = 0.001$, the achieved fairness becomes stable and close to 1, which expresses perfect fairness performance. Since APF also cannot provide a desired fairness and a robust fairness control in such a dynamic scenario, it is unreasonable

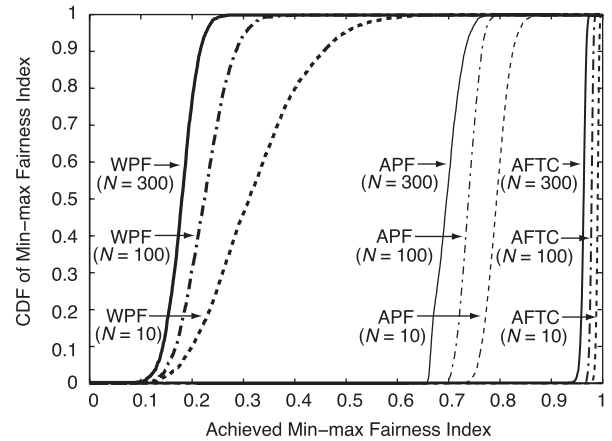


Fig. 5 CDF of achieved min-max fairness index applying the proposed AFTC with $\eta = 1$, WPF with $e = 1$, and APF with $\varepsilon = 1$. The results are calculated for variable number of users and 1000 different users' locations.

to apply the WPF and the APF scheduling schemes to obtain a given fairness, because these schemes lack the features to achieve that.

Figure 4 shows the achieved fairness performance of our proposed AFTC approach, where we measure the fairness quantified by the min-max fairness index for users' 100 different locations and $N = 10$. We observe that the min-max fairness index achieved by applying AFTC is almost equal to any desired fairness index η for different scenarios of users' locations. This result demonstrates that our proposed AFTC approach can provide any desired min-max fairness index and a robust fairness control in dynamic scenarios.

Next, we consider that the number and location of users are both variable at a cell area in the simulation assumption. We use the cumulative distribution function (CDF) to calculate the probability of the achieved fairness index. Figure 5 shows the CDF of the achieved min-max fairness index when applying the following schemes: the proposed AFTC with $\eta = 1$, WPF with $e = 1$, and APF with $\varepsilon = 1$. We calculate the results for a variable number of users N and 1000 different users' locations. We observe that for the WPF, the value of the achieved fairness index decreases as the number of users N increases, and the dispersion of achieved fairness indexes increases with decreasing the number of users. As a result, it is very difficult to provide a stable fairness service using WPF, especially when the number of users in a cell is small. For APF, the value of the achieved fairness index also decreases with increasing number of users, but the dispersion of the achieved fairness indexes does not significantly change when varying the number of users. The proposed AFTC can provide a stable fairness index regardless of the impact of varying the number and the location of users.

As a conclusion, in order to guarantee a desired fairness index, WPF and APF require nontrivial additional mechanism to adapt to the dynamic scenarios, whereas AFTC can automatically do the adaptation. We note that, due to this

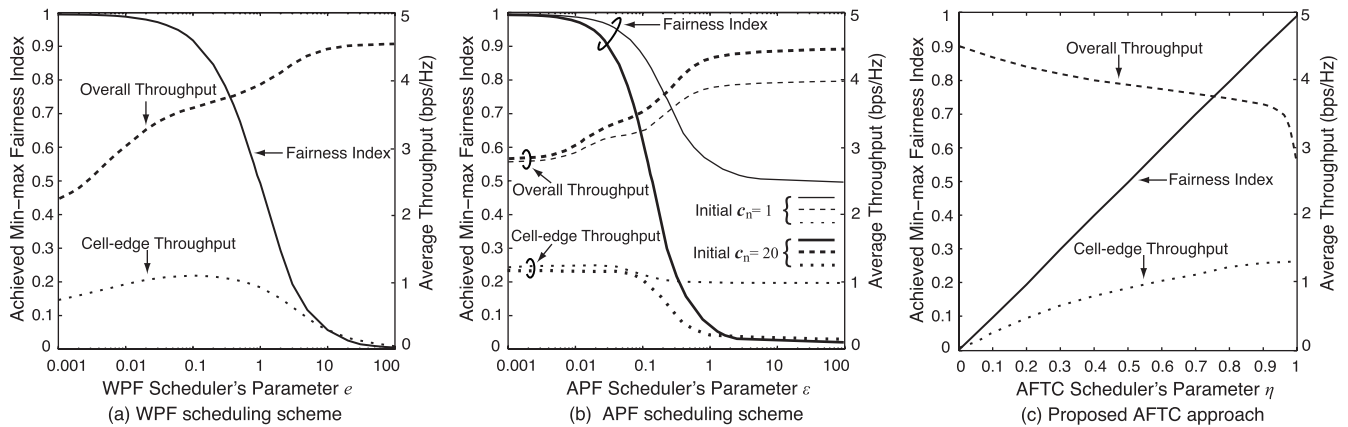


Fig. 6 Trade-off between achieved min-max fairness index and average throughput when applying WPF, APF and proposed AFTC. The users' locations are fixed during the simulation and the number of users is $N = 10$. The fairness index and the throughput are calculated for 10,000 frames.

reason, there is no need to compare their throughput performance here.

4.2 Performance Evaluation in Static Scenario

We evaluate the fairness and throughput performance of these schemes in a static scenario, where the users' locations are fixed during the simulation and the number of users is $N = 10$. We show the trade-off between the achieved min-max fairness index and the average throughput for WPF, APF and proposed AFTC in Fig. 6. The trade-off measures are obtained by adjusting the scheduler parameters ϵ , ϵ and η , respectively.

We first focus on the relationship between the achieved min-max fairness index and scheduler parameters. In Figs. 6(a) and (b), we observe that the achieved min-max fairness index does not have a trivial relationship with ϵ and ϵ . Thus WPF and APF cannot easily achieve the target fairness index by adjusting the value of ϵ and ϵ . On the other hand, in Fig. 6(c), we observe that the achieved min-max fairness index for our proposed AFTC is equal to the target fairness degree η . This shows that even for a static scenario, AFTC is superior to WPF and APF.

Next, we focus on the network overall throughput and cell-edge user throughput[†]. The overall throughput of each scheme decreases when the achieved min-max fairness index increases, whereas the cell-edge throughput almost increases when the achieved min-max fairness index increases. We also observe that AFTC and APF can achieve higher overall throughput and cell-edge throughput than WPF in the case of perfect fairness ($f_{\min-\max} = 1$). This is one of the reasons why our proposed scheme is based on APF instead of WPF.

For APF, as shown in Fig. 6(b), we note that the achieved fairness and throughput depends on the initial values of parameters c_n , $n = 1, \dots, N$. Setting a larger initial value such as $c_n = 20$ can achieve higher throughput, but the convergence time is longer than using smaller initial value, which will be shown later. However, the range of achieved

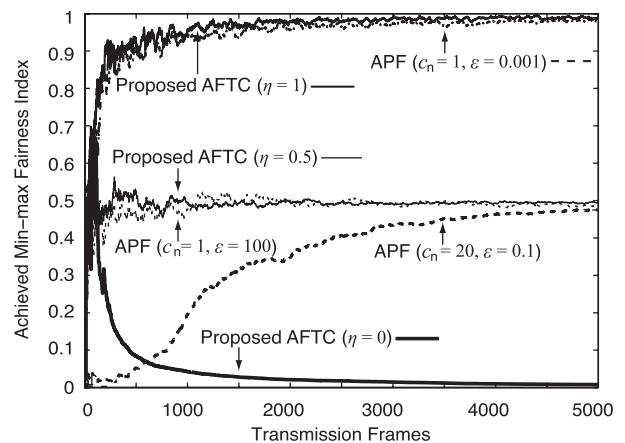


Fig. 7 Temporal behavior of the min-max fairness index obtained by the APF and the proposed AFTC. The users' locations are fixed during the simulation and the number of users is $N = 10$.

min-max fairness index is limited if a small initial value of c_n is used. For AFTC, it is not necessary to modify the initial value of ψ_n , because using the original initial value of $\psi_n = 1$ can achieve all desired fairness indexes as shown in Fig. 6(c). In the following, we further investigate the above fact and show the results.

In Fig. 7, we show the temporal behavior of the achieved min-max fairness index obtained by APF and AFTC. We can find a certain value of ϵ and η to achieve a given min-max fairness index, e.g., $f_{\min-\max} = 0.5$. We observe that the convergence time of APF with large initial value for $c_n = 20$ is significantly longer than that of using small initial value for $c_n = 1$. Therefore, AFTC is much easier to use than APF even in static scenarios.

Finally, we show the temporal behavior of the network overall throughput obtained by APF and AFTC in Fig. 8. Herein, we introduce three classic scheduling schemes for

[†]To evaluate the cell-edge user throughput, in our simulation the cell-edge user is defined as the user at the cell-edge when the received average SNR is lower than 5 dB.

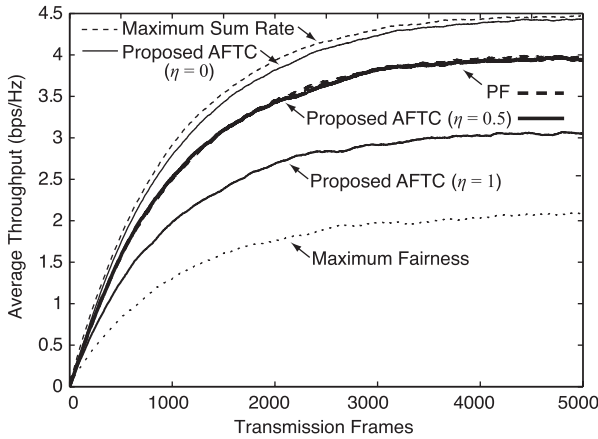


Fig. 8 Temporal behavior of the throughput obtained by the proposed AFTC and several conventional scheduling schemes. The number of users is $N = 10$, and the throughput is the sum rate of all users $\sum_{n=1}^N \hat{T}_n$ which is computed with a moving average filter of length $L = 1000$ frames.

comparison. The first one is the maximum sum rate (MSR) scheduling scheme [12], which yields the largest throughput but the worst fairness. The second one is the maximum fairness (MF) scheduling scheme [13], which provides perfect fairness but poor throughput. The third one is the aforementioned PF scheduling scheme, which can maximize the logarithmic total throughput by exploiting multiuser diversity.

In Fig. 8, we observe that the proposed AFTC with $\eta = 0$ achieves almost the same throughput performance as MSR. This means the policy of MSR can be encompassed in AFTC by setting $\eta = 0$. The achieved throughput of the proposed AFTC with $\eta = 1$ is higher than that of MF, as shown in Fig. 8. This is because AFTC, like PF, can exploit multiuser diversity and temporal diversity, but MF cannot exploit either.

From the above results, it is demonstrated that like WPF and APF, the proposed AFTC is able to encompass the features of the PF policy, MSR, and MF by adjusting the scheduler's parameter. Moreover, AFTC can do the adjustment automatically to achieve the target fairness using the parameter η , whereas WPF and APF require nontrivial additional mechanism to adapt to the static scenarios.

5. Conclusions

We proposed a novel fairness and throughput control approach for resource scheduling in multiuser networks in order to maximize the network throughput while attaining a desired fairness quantified by the min-max fairness index. The proposed approach, called AFTC, directly relates the user selection criterion to the desired fairness. Numerical results indicate that AFTC can provide high throughput while achieving the desired fairness index. We demonstrated that the tradeoff between throughput and fairness can be accurately controlled by adjusting the scheduler's parameters. The long-term average fairness achieved by applying our proposed approach is equal to the desired fairness index and

is robust in time-varying network conditions. In order to achieve a desired min-max fairness index, the conventional schemes WPF and APF require nontrivial additional mechanism to adapt to the static and dynamic scenarios, whereas AFTC can automatically do the adaptation.

In our future research, we would focus on other fairness indexes and the challenges towards much more complicated traffic model.

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