Fairness-Aware Scheduling for Dynamic Point Selection in CoMP-Based Networks with Hotspots

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***Abstract*—To support high data rates, cells in mobile networks tend to be miniaturized, which exacerbates inter-cell interference. The *coordinated multipoint (CoMP)* technique makes a set of *base stations (BSs)* share channel state information of *user equipments (UEs)* to mitigate interference by coordinating their transmission. Such a set of BSs is known as a *coordinated set (CoS)*. This paper focuses on *dynamic point selection (DPS)* in CoMP, which allows UEs to flexibly switch their serving BSs in a CoS, and studies a fair scheduling problem. The issue asks how to select BSs for allocating resources to UEs to improve fairness among UEs while maintaining high network throughput. To address this issue, the paper proposes a *fairness-aware scheduling (FAS)* scheme. In view that UEs may assemble in some small regions to form hotspots, FAS regulates the period length for UEs to switch BSs adaptively. Moreover, it uses different strategies for resource allocation based on cell situations. Simulation results reveal that the FAS scheme can significantly increase UE fairness and still keep high network throughput, as compared with existing solutions.**

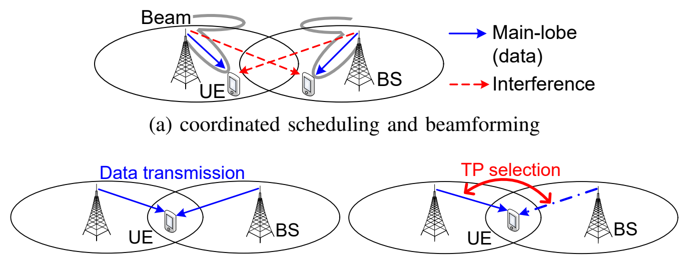
***Index Terms*—coordinated multipoint (CoMP), dynamic point selection (DPS), fairness, hotspot, scheduling.**

I. Introduction

In 5G/B5G networks, many small cells have been deployed to satisfy the growing demand for high data rates, low latency, and massive connectivity [1]. This deployment makes inter-cell interference worse, where *user equipments (UEs)*, particularly those close to cell boundaries, are bothered by transmission of adjoining cells [2]. Hence, the *coordinated multipoint (CoMP)* technique is proposed to let *base stations (BSs)* exchange UEs' *channel state information (CSI)* for coordinating transmission between each other [3]. The collection of BSs sharing information is known as a *coordinated set (CoS)*. CoMP can improve spectrum efficiency in addition to reducing interference.

In CoMP, the BS in charge of sending data to a UE is called its *transmission point (TP)*. There are three CoMP methods for downlink communications, as shown in Fig. 1. In *coordinated scheduling and beamforming*, the BSs of a CoS can collaborate to decide scheduling as well as beamforming. However, each UE has no choice but to use the BS in its serving cell as the TP. In *joint transmission*, a UE obtains data from multiple TPs in a CoS. This is done using precoding and spatial multiplexing of data streams sent from these BSs. For *dynamic point selection (DPS)*, each UE can switch to different TPs to receive data in different subframes. This allows the UE to flexibly select a BS with better conditions (e.g., larger SNR) for communications.

In light of its flexibility, this paper chooses DPS and looks at a fair scheduling issue in CoMP-based networks. The problem



(a) coordinated scheduling and beamforming

(b) joint transmission

(c) dynamic point selection (DPS)

Fig. 1. Three CoMP methods for downlink communications.

determines how to pick out BSs to be TPs and give resources to UEs. The objectives are to improve throughput fairness among UEs in each CoS while maintaining high network throughput. As discussed later in Section II, some studies seek to achieve proportional fairness among UEs. Nevertheless, they consider that UEs are randomly distributed in a network. In practice, certain activities (e.g., concerts or sporting events) could make many UEs concentrated in some small regions, referred to as *hotspots* [4]. Such a non-uniform distribution may degrade the performance of these methods.

As a result, this paper proposes a *fairness-aware scheduling (FAS)* scheme. It can adjust the period length for UEs to switch TPs by referring to the network load. After deciding on TPs, FAS groups UEs based on their data rates and picks out UEs for resource allocation. When a BS is in the hotspot, a *round-robin (RR)* mechanism is used to allocate resources in its cell. Through simulations, we demonstrate that the FAS scheme can improve UE fairness while keeping high network throughput.

The residual of this paper is organized as follows: Section II surveys related work, and Section III gives the system model. Then, we elaborate the FAS scheme in Section IV, followed by the performance evaluation in Section V. Finally, Section VI concludes this paper.

II. Related Work

Various DPS issues are discussed. The study [5] combines both DPS and frequency selection to reduce 5G URLLC delay. In [6], a clustering approach is designed to save energy of BSs in each cluster without compromising the DPS operation. The work [7] shows that DPS can mitigate the vehicular blockage effect on a 5G mmWave system, which improves the coverage probability and reduces latency caused by the blockage. Kim

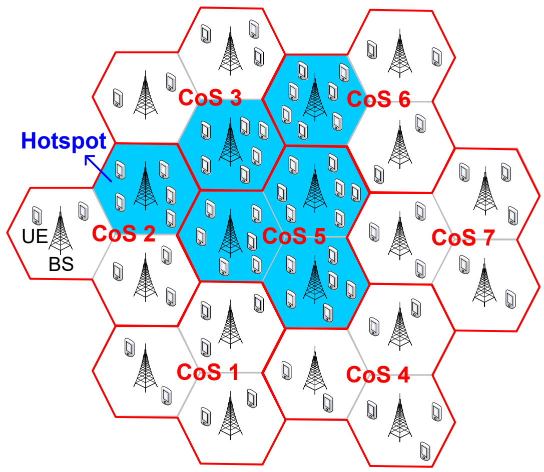


Fig. 2. A CoMP-based network containing a hotspot.

et al. [8] apply the deep learning technique to DPS for raising spectral and energy efficiency. Apparently, these studies have different objectives from our work.

Some studies aim at how to select TPs in DPS. The work [9] seeks to mitigate the ping-pong effect by avoiding unnecessary TP switching. Both [10] and [11] consider traffic loads of cells as well as signal quality of UEs to be the TP selection criterion. The study [12] investigates the effect of TP switching period and SINR margin on DPS performance. However, they do not take account of resource allocation for UEs.

Kotake et al. [13] propose a *stochastic proportional fairness (SPF)* method to handle the fair scheduling problem in DPS, which attempts to improve the communication quality for the UEs close to cell edges. The work [14] employs the *multiple-input multiple-output (MIMO)* technique for SPF (called *SPF-MIMO*) and also suggests an advanced version of SPF (named *ASPF-MIMO*) to reduce the computation cost. However, SPF-MIMO and ASPF-MIMO assume that UEs are uniformly and randomly distributed. As a result, this motivates us to design the FAS scheme that can strike a good balance between UE fairness and network throughput for a CoMP-based network with hotspots.

III. System Model

Let us consider a CoMP-based network with multiple CoSs. Each CoS contains K BSs, where $K > 1$. There are a number of UEs in the network. They may not be necessarily randomly distributed. Instead, some UEs may gather in small areas called hotspots. Hence, the cells within a hotspot have more UEs than other cells. A hotspot can span multiple CoSs. However, some CoSs may be merely covered by the hotspot *partially*. Fig. 2 illustrates an example. The network has seven CoSs, and each CoS contains three BSs (i.e., $K = 3$). In addition, CoSs 2, 3, and 6 are partially covered by the hotspot.

Each UE u_i can support MIMO communications and report CSI to BSs in its CoS via an uplink channel [15]. Then, BSs coordinate who acts as u_i's TP. The TP's spectrum resource is partitioned into *resource blocks (RBs)* as units for allocation.

TABLE I
Summary of Acronyms.

acronym	full name
BS	base station
CoMP	coordinated multipoint
CoS	coordinated set
CSI	channel state information
DPS	dynamic point selection
FAS	fairness-aware scheduling
JFI	Jain's fairness index
MIMO	multiple-input multiple-output
RB	resource block
RR	round-robin
SPF[†]	stochastic proportional fairness
TP	transmission point
TTI	transmission time interval
UE	user equipment

[†]ASPF: advanced SPF, M-SPF: modified SPF

TABLE II
Summary of Notations.

notation	definition
$\hat{\mathcal{U}}$, $\hat{\mathcal{B}}$	sets of UEs and BSs in a CoS
$\hat{\mathcal{U}}_k$	set of UEs served by a BS $b_k \in \hat{\mathcal{B}}$
$\hat{\mathcal{R}}_k$	set of RBs provided by b_k
T	length of a TP-switching period ($T_{\texttt{ref}}$: reference length)
r_i	estimated data rate of a UE $u_i \in \hat{\mathcal{U}}$
$\Omega(u_i)$	u_i's PF-MIMO value
λ_x	average data rate of UEs in a group g_x
$\phi_{x,y}$	parameter for two groups g_x and g_y

Each RB is capable of carrying a different number of data bits by using a different modulation and coding scheme, depending on the UE's signal quality. An RB can be allocated to at most one UE. There are three indicators in CSI. The *channel quality indicator (CQI)* informs the TP about u_i's channel situation, helping the TP determine some transmission parameters (e.g., modulation and coding scheme) for RBs allocated to u_i [16]. The *rank indicator* suggests the number of transmission layers used to implement space division multiplexing in MIMO [17]. The *precoder matrix indicator* helps the TP select a codebook to conduct precoding of u_i's data stream [18].

Then, the fair scheduling problem asks how to pick a TP for each UE and allocate RBs to it, such that throughput fairness among UEs in each CoS is improved while maintaining high network throughput. Specifically, *Jain's fairness index (JFI)* is used to assess the fairness degree [19]:

$$J(\hat{\mathcal{U}}) = \left(\sum\nolimits_{u_i \in \hat{\mathcal{U}}} \tau_i\right)^2 / \left(|\hat{\mathcal{U}}| \sum\nolimits_{u_i \in \hat{\mathcal{U}}} \tau_i^2\right), \tag{1}$$

where $\hat{\mathcal{U}}$ is the set of UEs in a CoS, and τ_i is the amount of UE u_i's throughput. Based on Eq. (1), we have $1/|\hat{\mathcal{U}}| \leq J(\hat{\mathcal{U}}) \leq 1$. A larger $J(\hat{\mathcal{U}})$ value implies that the CoS's BSs achieve more fair transmission for UEs.

In Table I, we list acronyms together with their full names. Table II summarizes the notations used in this paper.

IV. The Proposed FAS Scheme

Given a CoS with set $\hat{\mathcal{U}}$ of UEs and set $\hat{\mathcal{B}}$ of BSs, Algo. 1 presents FAS's pseudocode to find the TP and RB(s) for each

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Algorithm 1: The FAS Scheme
  Data: set Û of UEs and set B̂ of BSs in a CoS
  Result: TP and RB(s) for each UE in Û
1 Compute the next TP-switching period;
2 foreach u_i ∈ Û do
3     Select a BS in B̂ as its TP;
4 foreach b_k ∈ B̂ do
5     if |R̂_k|/|Û_k| ≥ 1 then
6         Group UEs in Û_k;
7         Call M-SPF allocation procedure;
8     else
9         Call RR-based allocation procedure;
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Algorithm 2: Grouping UEs via K-means
  Data: UEs in Û_k with their estimated data rates
  Result: η groups of UEs
  Arbitrarily pick out two UEs to be the initial members
    of two groups;
  repeat
      Assign each UE u_i to a group whose average data
        rate is the closest to r_i (i.e., u_i's data rate);
      Update the average data rate of each group;
  until UEs in each group are no longer change, or the
    number of run iterations exceeds an upper bound;
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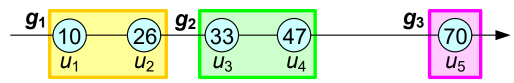


Fig. 3. Example of grouping UEs.

UE in $\hat{\mathcal{U}}$. In line 1, we first compute the next period length for UEs in this CoS to switch their TPs. The for-loop in lines 2–3 picks a BS in $\hat{\mathcal{B}}$ for each UE in $\hat{\mathcal{U}}$ as its TP. Both issues will be discussed later in Section IV-A. The for-loop in lines 4–9 helps each BS b_k allocate RBs to its serving UEs (as denoted by $\hat{\mathcal{U}}_k$). Let $\hat{\mathcal{R}}_k$ be the set of b_k's available RBs. If $|\hat{\mathcal{R}}_k|/|\hat{\mathcal{U}}_k| \geq 1$, b_k has sufficient RBs to serve UEs. Consequently, we group UEs in $\hat{\mathcal{U}}_k$ (detailed in Section IV-B) and use the *modified SPF (M-SPF) allocation procedure* in Section IV-C for RB assignment. Otherwise, some UEs cannot obtain RBs, meaning that b_k may be located in a hotspot. In this case, the *RR-based allocation procedure* in Section IV-D is used to allot RBs to UEs in $\hat{\mathcal{U}}_k$.

A. Period Length and TP Selection

A TP-switching period is the interval between two successive TP decision-making processes, whose unit is a *transmission time interval (TTI)*. Unless a UE u_i leaves its CoS, u_i's serving BS cannot change in the period. Moreover, the number of RBs that a BS offers in each TTI is fixed. Thus, the length of a TP-switching period affects system performance, especially when there are numerous UEs (i.e., in a hotspot) [12]. In light of this, we calculate the length for the next period as follows:

$$T = \left\lceil \frac{T_{\texttt{ref}}}{|\hat{\mathcal{U}}| / \sum_{b_k \in \hat{\mathcal{B}}} |\hat{\mathcal{R}}_k|} \right\rceil . \quad (2)$$

$T_{\texttt{ref}}$ is the period length for reference (e.g., $T_{\texttt{ref}} = 20$ TTIs). If there are more UEs (i.e., $|\hat{\mathcal{U}}|$ is larger) or BSs have fewer RBs (i.e., $\sum_{b_k \in \hat{\mathcal{B}}} |\hat{\mathcal{R}}_k|$ is smaller), Eq. (2) shrinks the TP-switching period to reallocate resources to UEs more frequently. Doing so helps improve throughput fairness among UEs in a CoS.

At the beginning of a period, for each UE u_i in $\hat{\mathcal{U}}$, we select a BS b_k from $\hat{\mathcal{B}}$ to act as its TP. The selection is based on u_i's signal quality (that is, u_i has the best SNR with b_k). However, if the difference between u_i's SNR from two or more BSs is not significant (i.e., below a threshold ϱ), we pick out the BS that serves the fewest UEs (i.e., $|\hat{\mathcal{U}}_k|$ is the minimum) due to the consideration of load balance. Then, we add u_i to $\hat{\mathcal{U}}_k$.

B. Grouping UEs

Let m and n be the number of antennas of a BS and a UE. We also denote by $\mathbf{I}$ the identity matrix whose size is $n \times n$, $\mathbf{G}$ the channel matrix whose size is $n \times m$, and $\mathbf{G}^{\mathrm{H}}$ the complex conjugate transpose matrix of $\mathbf{G}$. Supposing that UE u_i's SNR is σ, we can estimate its data rate via the Shannon equation:

$$r_i = \theta \times \log_2 \left[\det \left(\mathbf{I} + \frac{\sigma}{n} \mathbf{G} \times \mathbf{G}^{\mathrm{H}} \right) \right], \quad (3)$$

where θ is the bandwidth, and $\det(\cdot)$ is the determinant value of a matrix. Then, for each BS $b_k \in \hat{\mathcal{B}}$, its serving UEs (i.e., $\hat{\mathcal{U}}_k$) are divided into η groups based on UEs' data rates, where η is a small number (e.g., $\eta = 3$). This can be carried out via K-means [20], whose pseudocode is given in Algo. 2. Fig. 3 shows an example, where the number in each circle indicates the r_i value of a UE. Three groups are found: $g_1 = \{u_1, u_2\}$, $g_2 = \{u_3, u_4\}$, and $g_3 = \{u_5\}$. Notice that g_1 has the lowest average data rate, while g_3 has the highest average data rate.

Then, we categorize groups into the priority class (P-class) and non-priority class (N-class). A group with a high average data rate of UEs belongs to N-class; otherwise, it is in P-class. According to SPF [13], we compute a parameter $\phi_{x,y}$ for two groups g_x and g_y, where g_x and g_y are in N-class and P-class, respectively, as follows:

$$\phi_{x,y} = \frac{(\lambda_x - \lambda_y) \times (|\hat{\mathcal{U}}_k| - 1)}{\lambda_x \times |g_y| + \lambda_y \times |g_x|}, \quad (4)$$

where λ_x is the average data rate of UEs in g_x. Let $P(x)$ be the probability of giving RBs to g_x's UEs. The idea of Eq. (4) is to let $\frac{P(x)}{|g_x|} : \frac{P(y)}{|g_y|} \approx \frac{1}{\lambda_x} : \frac{1}{\lambda_y}$. The $\phi_{x,y}$ parameter provides a reference for the M-SPF allocation procedure to assign RBs. Based on the example in Fig. 3, Table III lists all combinations of any two groups and gives their corresponding $\phi_{x,y}$ values.

C. M-SPF Allocation Procedure

Based on the if-condition in line 5 of Algo. 1, this procedure is called only when $|\hat{\mathcal{R}}_k|/|\hat{\mathcal{U}}_k| \geq 1$. In other words, BS b_k can

TABLE III
GROUP COMBINATIONS AND THEIR PARAMETERS.

N-class	P-class	$\phi_{x,y}$
g_3	g_1	1.32
g_3	g_2	0.67
g_2	g_1	0.76

have enough RBs to serve UEs in $\hat{\mathcal{U}}_k$. Hence, we first use the max-CQI strategy [21] to assign RBs. For each RB in $\hat{\mathcal{R}}_k$, b_k gives it to the UE in $\hat{\mathcal{U}}_k$ that has not obtained any RB yet and has the maximum CQI value for that RB. The above process is repeated until each UE in $\hat{\mathcal{U}}_k$ can acquire an RB.

If there are remaining RBs in $\hat{\mathcal{R}}_k$, we then borrow the notion of ASPF-MIMO [14] to assign them. For each remaining RB, we compute a PF-MIMO value for each UE $u_i \in \hat{\mathcal{U}}_k$: $\Omega(u_i) = r_i^{\texttt{RB}}/r_i^{\texttt{avg}}$, where $r_i^{\texttt{RB}}$ is u_i's data rate in terms of that RB and $r_i^{\texttt{avg}}$ is u_i's past (average) data rate. Then, we pick UEs with the 1st and 2nd highest PF-MIMO values (as denoted by $u_1^{\texttt{CAN}}$ and $u_2^{\texttt{CAN}}$) to compete for that RB according to four cases:

Case 1. Both $u_1^{\texttt{CAN}}$ and $u_2^{\texttt{CAN}}$ are in a group g_x: Let $\Psi(u_i, g_x)$ be the ranking of a UE u_i in terms of its data rate in g_x. The RB is given to $u_2^{\texttt{CAN}}$ if $\Psi(u_1^{\texttt{CAN}}, g_x) + \alpha < \Psi(u_2^{\texttt{CAN}}, g_x)$, where α is a constant (e.g., α is set to $\lfloor |g_x|/2 \rfloor$ as suggested in [14]). Otherwise, we allot the RB to $u_1^{\texttt{CAN}}$.

Case 2. $u_1^{\texttt{CAN}}$ and $u_2^{\texttt{CAN}}$ belong to the same class (not in the same group): The RB is allocated to $u_1^{\texttt{CAN}}$.

Case 3. $u_1^{\texttt{CAN}}$ belongs to P-class and $u_2^{\texttt{CAN}}$ belongs to N-class: The RB is given to $u_1^{\texttt{CAN}}$.

Case 4. $u_1^{\texttt{CAN}}$ belongs to N-class and $u_2^{\texttt{CAN}}$ belongs to P-class: Suppose that $u_1^{\texttt{CAN}}$ is in group g_x and $u_2^{\texttt{CAN}}$ is in group g_y. We pick a random number β, where $0 \leq \beta \leq 1$. If $\phi_{x,y} > \beta$, the RB is allocated to $u_2^{\texttt{CAN}}$. Otherwise, we give the RB to $u_1^{\texttt{CAN}}$.

We remark that the original ASPF-MIMO method may not necessarily allot RB(s) to each UE in $\hat{\mathcal{U}}_k$ due to its stochastic nature. In light of this, we first give each UE one RB through max-CQI to avoid starvation and then allocate the residual RBs using ASPF-MIMO to achieve the PF property. Doing so has two benefits. First, we can better balance between throughput and fairness. Second, as ASPF-MIMO is much more complex than max-CQI, the computation cost can be significantly saved.

D. RR-based Allocation Procedure

When a BS b_k is within a hotspot, it has insufficient RBs to serve all UEs (i.e., $|\hat{\mathcal{R}}_k|/|\hat{\mathcal{U}}_k| < 1$). In this case, the stochastic property of ASPF-MIMO could exacerbate the uncertainty of RB acquisition for some UEs, especially those with relatively bad channel conditions. This may result in a negative impact on UE fairness.

Therefore, we apply the RR mechanism to resource allocation in a hotspot. To do so, BS b_k maintains a list of *unserved UEs* $\hat{\mathcal{U}}_k^{\texttt{RR}}$, which is initially set to $\hat{\mathcal{U}}_k$. For every RB in $\hat{\mathcal{R}}_k$, b_k chooses a UE, say, u_i from $\hat{\mathcal{U}}_k^{\texttt{RR}}$ that has the maximum $\Omega(u_i)$ value (i.e., PF-MIMO value). Afterward, we assign the RB to u_i and remove u_i from $\hat{\mathcal{U}}_k^{\texttt{RR}}$. This process is repeated until all RBs in $\hat{\mathcal{R}}_k$ have been dealt out in the current period.

TABLE IV
SIMULATION PARAMETERS.

BS-related parameters:	
bandwidth	10 MHz
cell range	500 m
carrier frequency	2.14 GHz
transmission power	46 dBm
antenna configuration	4×2
UE-related parameters:	
number of UEs (per cell)	normal: 30, hotspot: 150
moving speed	3 km/h
mobility model	random waypoint
traffic model	full-buffer traffic
Channel-related parameter:	
path loss	$128.1 + 37.6 \log_{10} D(\text{BS}, \text{UE})$
shadowing fading	Claussen model

Because of $|\hat{\mathcal{R}}_k|/|\hat{\mathcal{U}}_k| < 1$, there will remain some unserved UEs in $\hat{\mathcal{U}}_k^{\texttt{RR}}$ after the above process. These UEs have a high priority to get UEs in the next period (due to the RR property). However, if some of these UEs leave their CoS in the next period, they need to be removed from $\hat{\mathcal{U}}_k^{\texttt{RR}}$. When $\hat{\mathcal{U}}_k^{\texttt{RR}}$ becomes empty, which means that each UE in $\hat{\mathcal{U}}_k$ has obtained an RB, we then set $\hat{\mathcal{U}}_k^{\texttt{RR}}$ to $\hat{\mathcal{U}}_k$ again and execute the process. Doing so can help improve the fairness among UEs in a hotspot.

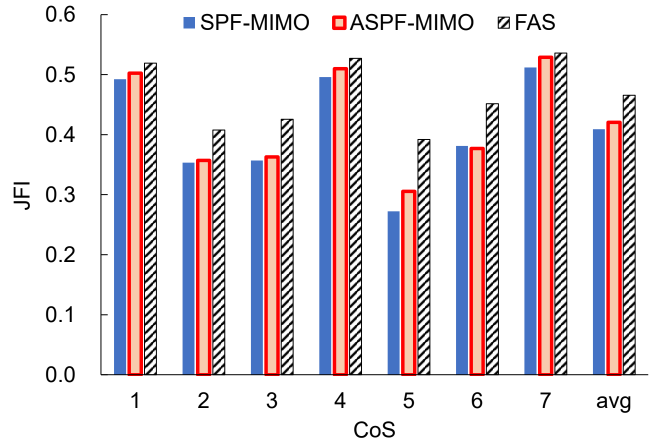
V. PERFORMANCE EVALUATION

For performance evaluation, we employ the Vienna cellular communications simulator [22], a suite of programs written in MATLAB that support link-level and system-level simulation for both 4G and 5G communications. Our simulation considers a CoMP-based network with seven CoSs, as shown in Fig. 2. Each CoS has three BSs. Table IV lists simulation parameters.

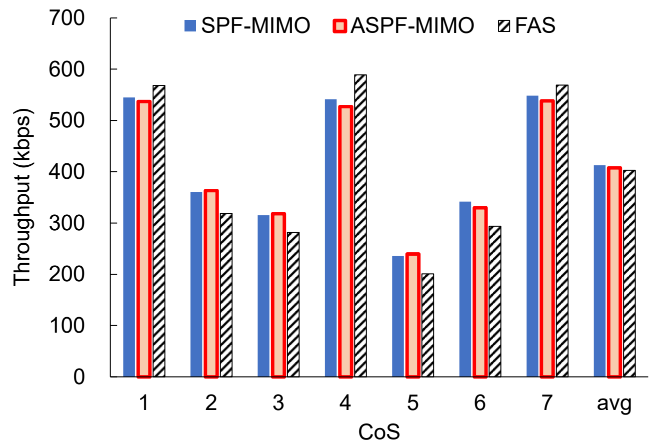
Each BS has a bandwidth of 10 MHz and provides 50 RBs in every TTI (i.e., 1 ms). The radius of a cell is set to 500 m. Here, we adopt a 3-sector cell configuration. More specifically, every cell is divided into 3-sector sites, each with 120-degree coverage. The carrier frequency is set to 2.14 GHz. In addition, a BS's transmission power is set to 46 dBm (around 40 W). The configuration for its antennas is 4×2 (i.e., transmission: 4, reception: 2).

UEs are not uniformly distributed in the network. Instead, some UEs concentrate in a hotspot (i.e., parts of cells of CoSs 2, 3, and 6 and all cells in CoS 5). One normal cell contains about 30 UEs. On the other hand, the average number of UEs in a cell within the hotspot is set to 150. Each UE moves at an average speed of 3 km/h, which follows the random waypoint mobility model [23]. This is used to simulate the way people walk. Regarding the traffic model, we use the full-buffer traffic model [24]. More concretely, each UE always has data to be received from its TP.

As for the channel model, we take path loss and shadowing fading into consideration. According to the 3GPP specification [25], the amount of path loss from a BS b_k to a UE u_i can be estimated by $128.1 + 37.6 \log_{10} D(b_k, u_i)$, where $D(b_k, u_i)$ is the distance (in kilometers) between b_k and u_i. For shadowing fading, we employ the Claussen model [26].



(a) JFI



(b) throughput

Fig. 4. Comparison of JFI and throughput by different methods.

We compare our FAS scheme with SPF-MIMO and ASPF-MIMO [14] discussed in Section II. Both of them calculate a PF-MIMO value for each UE in terms of an RB and pick out UEs with the 1st and 2nd largest PF-MIMO values to compete for that RB. However, SPF-MIMO and ASPF-MIMO consider that UEs are randomly distributed in the network.

Fig. 4(a) shows JFI of each CoS and their average value, which can be calculated by Eq. (1). According to the topology in Fig. 2, all CoSs can be divided into three categories:

1. Not covered by the hotspot: CoSs 1, 4, and 7 fall in this category. None of their cells are within the hotspot.
2. Partially covered by the hotspot: CoSs 2, 3, and 6 belong to this category. For each of them, only one cell resides in the hotspot.
3. Fully covered by the hotspot: This category contains CoS 5. As can be seen, all of its cells are located in the hotspot.

In general, CoSs in the same category have similar JFI values, since their cells may have similar situations. When comparing different categories of CoSs, we observe that the 1st category of CoSs usually has the highest JFI value. The main reason is that their BSs have enough RBs to serve UEs. In most cases, each UE can acquire RB(s) to receive data, thereby increasing the fairness. On the contrary, the 3rd category of CoSs (e.g., CoS 5) has the lowest JFI value, as their cells are all covered by the hotspot. As a result, some UEs may not get any RB (i.e., starvation), which decreases the fairness.

Then, we compare each method for their JFI values. ASPF-MIMO is an advanced version of SPF-MIMO, mainly to reduce the amount of calculation. Hence, the difference between their JFI values is almost negligible. One exception is CoS 5 (i.e., fully covered by the hotspot), where ASPF-MIMO has a slightly higher JFI value than SPF-MIMO. For the 1st category of CoSs (i.e., not covered by the hotspot), FAS will perform similarly to other methods in terms of fairness. However, when some cells are within in the hotspot (i.e., CoSs 2, 3, 5, and 6), our FAS scheme can result in a significantly higher JFI value than both SPF-MIMO and ASPF-MIMO. Such a phenomenon means that the RR mechanism is more suitable than SPF (i.e., the core of SPF-MIMO and ASPF-MIMO) for a BS to allocate RBs when it has insufficient resources (due to many UEs).

Fig. 4(b) presents the amount of throughput in each CoS and their average (which can be treated as network throughput). The 1st category of CoSs has significantly higher throughput due to less competition of UEs. If cells reside in the hotspot, their throughput inevitably reduces drastically. Besides, CoS 5 has the lowest amount of throughput, as none of its BSs has enough RBs to serve all UEs.

Let us examine the throughput of each method. In the 1st category of CoSs (i.e., CoSs 1, 4, and 7), the max-CQI method in the M-SPF allocation procedure helps improve throughput, since it chooses a UE with better channel quality to get each of the first $|\hat{\mathcal{U}}_k|$ RBs in $\hat{\mathcal{R}}_k$. That is why FAS performs better than the other two methods. On the other hand, when some cells are covered the by the hotspot, FAS adopts the RR-based allocation procedure. Because of the RR property, the fairness among UEs can be improved (referring to Fig. 4(a)). However, the expense is that some RBs may be allocated to UEs with poor channel quality. As a result, FAS has lower throughput than SPF-MIMO and ASPF-MIMO in CoSs 2, 3, 5, and 6.

Based on the experimental result in Fig. 4, the FAS scheme improves 13.78% and 10.71% of average JFI as compared to SPF-MIMO and ASPF-MIMO. On the other hand, compared with SPF-MIMO and ASPF-MIMO, FAS merely loses 2.31% and 1.11% of network throughput. This result verifies that our FAS scheme can balance UE fairness and network throughput more efficiently than both SPF-MIMO and ASPF-MIMO.

VI. Conclusion

The CoMP technique enables all BSs in each CoS to share CSI data of UEs for interference mitigation. In CoMP, DPS lets UEs switch between different BSs to act as their TPs, thereby improving flexibility. To solve the fair scheduling problem in DPS, this paper proposes the FAS scheme to select BSs and allocate resources to UEs with the objectives of improving UE fairness and keeping network throughput high. Unlike existing solutions, FAS considers hotspots where UEs gather caused by activities like concerts or sporting events. It regulates the TP-switching period based on network loads and adopts different strategies depending on cell conditions. If a BS has sufficient RBs, a combination of max-CQI and ASPF-MIMO is adopted for the BS to allocate RBs to UEs. When a cell resides in the hotspot, FAS uses the RR-based allocation procedure for RB assignment. Simulation results demonstrate that compared to both SPF-MIMO and ASPF-MIMO, FAS can achieve similar network throughput while significantly improving UE fairness.

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