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Clustering Based Fractional Frequency Reuse and Fair Resource Allocation in Multi-cell Networks

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***Abstract*—Fractional frequency reuse (FFR), using different frequency reuse factors for cell center and edge regions, is able to effectively improve spectrum efficiency in multi-cell OFDMA networks. However, optimal performance is hard to achieve in practice as the efficiency of resource allocation could drop drastically due to the constraint from the frequency partitions formed by FFR. Since the radio resource is pre-partitioned for cell edge and center, fair resource allocation in a cell is also difficult to implement. Conventional frequency partition adjustment either has high complexity due to global optimization or suffers from heavy performance degradation due to absence of effective control on inter-cell interference (ICI). To solve this issue, we create models for analyzing geographical distribution of interference in multi-cell networks. Based on the observed non-uniform distributed ICI, we redefine the zones for fractional reuse and propose clustering based FFR, which offers resource allocation higher flexibility and better fairness with additional spatial dimension. Extensive simulation has been performed to validate practicality and effectiveness of our proposed scheme.**

I. INTRODUCTION

Frequency reuse is utilized by multi-cell systems to improve system throughput, which inevitably introduces inter-cell interference (ICI) and compromises quality of service. As the frequency resource is spatially reused, mobile stations (MSs) may be interfered by additive signals from multiple neighboring cells operating on the same radio at the same time. To mitigate ICI, frequency reuse in previous multi-cell systems divides frequency band into multiple orthogonal partitions and identical partition is only reused at cells with certain distance away. The number of partitions, defined as frequency reuse factor, can be used to identify the space distribution of frequency resource. Higher frequency reuse factor can reduce ICI significantly; however, it also greatly decreases the spectrum efficiency due to less frequency resource available at each cell.

The emergence of a multi-user version of orthogonal frequency-division multiplexing (OFDM), i.e., OFDMA, facilitates implementation of a more sophisticated technology fractional frequency reuse (FFR) [1][2][3][4]. OFDMA technology, which is widely adopted in most next generation multi-cell cellular systems, such as 3GPP Long Term Evolution (LTE) [5] and IEEE 802.16, enables the use and allocation of resource in both frequency and time domains. The basic allocatable unit is resource block (RB) which consists of subcarries and OFDMA symbols [6][7]. RB allocation follows the constraints of frequency partitions made by FFR on the cell center and the edge area.

Although system performance revenue in utilizing FFR is theoretically observable, challenging problems are also presented in actual practice. The flexibility of resource allocation will be seriously constrained by the pattern of frequency partitions, which may lead to performance degradation in the distinction of traffic load, service requirement, number of MSs, etc. The problem also presents in performing fair resource allocation in multi-cell networks. Conventional FFR is not scalable in solving differentiated frequency partitions and resource allocation. The adjustment of frequency partition in a cell greatly affect its neighboring cells. As cells are back to back to provide a seamless coverage, the effect of frequency partitions in a cell can be observed on other cells. Although global optimization has been proposed for FFR to adjust the partitioned amount and frequency reuse factors, to give higher spectrum efficiency, it is rather hard to implement. Firstly, the global optimization is not easily scalable. When the network size increases, the information exchange overhead will exponentially increase and become too large to be acceptable by the backhual network. Secondly, computation complexity will also increase quickly with the network size. In addition, per frame allocation requires very low latency in exchanging control and information messages, which cannot be guaranteed between the resource allocation center and the base stations (BSs) when the network size is relatively large. Therefore, potential system gain of FFR is lost in a practical system, unless flexible resource allocation and distributed optimization are implemented.

In this paper, we analyze the geographical distribution of interference in multi-cell networks. Based on the observed non-uniform distributed ICI, we reform the zones for fractional reuse and propose a clustering based FFR, which offers higher flexibility in resource allocation with additional spatial adjustment. The performance gains are mainly due to the following advantages: Intra-cluster resource allocation jointly mitigates ICI with fractional resource reuse and provides proportional fair scheduling (PFS). Different from a cell based allocation

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Weihuang Fu worked on this study while visiting Mitsubishi Electric Research Lab, Cambridge, MA.

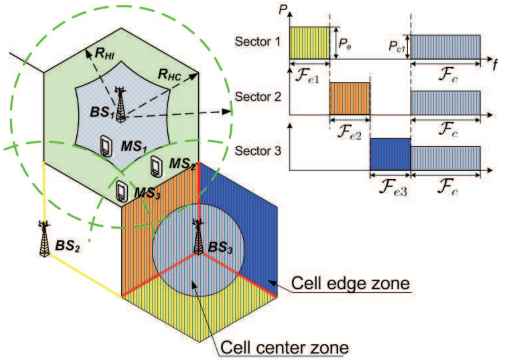

Fig. 1: Multi-cell and FFR

that has a large cell region suffering from ICI, our proposed clustering based allocation has much smaller region having potential inter-cluster interference. Thus, much less information exchange is needed in mitigating inter-cluster interference. A significant performance enhancement from proposed scheme is observed by the simulation results as compared to cell based FFR and cell based FFR-PFS. In addition, automatic modulation and coding (AMC) is also considered to improve the system throughput. Our contributions mainly lie on the following aspects:

- We analytically model the distribution of ICI and signal to interference noise ratio (SINR) in multi-cell systems, considering various frequency reuse and FFR schemes. The problem of global optimization is also discussed.
- From the analytical results, we propose clustering based FFR supporting distributed proportional fair resource allocation. Rather than forming clusters by cells, a generic cluster is formed by combining adjacent sectors from different cells together, where the cluster is formed for sectors mostly interfering with each other.
- A novel proportional fair scheduling scheme is also proposed working in cooperation with clustering based FFR. It also solves the fair allocation problem caused by the "fraction" effect on the frequency band.

II. PROBLEM FORMULATION AND MODELING

We consider an OFDMA network consisting of K BSs and N MSs, where the set of BSs is denoted by $\mathcal{K} = \{1, \ldots, K\}$. The locations of BSs are denoted by $S_1, \ldots, S_K$, respectively. BS provides data service for MSs in the coverage area, usually a circle centered at the coordinates of the BS with radius R_T in a two-dimensional area. This is an area where MS can correctly decode downlink frame preamble if no co-channel interference exists. To cover a large region, multiple BSs are placed as hexagon cells. Inter-BS distance, also called site to site distance, is denoted by D_s. Assume K BSs are connected to each other by the wired backhaul network and form a multi-cell system to provide service for the MSs in the entire coverage area. A non-overlapping coverage of BS is a hexagonal area, where the inradius of hexagonal, denoted by R_{HI}, is $\frac{D_s}{2}$, and circumradius, denoted by R_{HC}, is $\frac{D_s}{\sqrt{3}}$. We consider such a hexagonal area as a cell formed by a BS, and a cell formed by BS u is called cell u. The example for a part of the network is shown in Fig. 1. MS may be covered by multiple BSs. Three situations of the MS locations are illustrated in the figure. MS$_1$ located in the area where it is only in the coverage of BS$_1$. The MS has strong signals from BS$_1$ and weak interference from other neighboring BSs. In the second situation, MS is in the area overlapped by two cell BSs, so it is able to receive the broadcast messages from both BSs and acknowledge both BS identifications (IDs). For example, MS$_2$ in Fig. 1 can receive the messages from BS$_1$ and BS$_3$. MS is only allowed to register at one of the BSs, which is called the serving (or anchor) BS, and the MS only has the data exchange with the serving BS. In general, this is the area for MS to do handover so that MS can migrate the access connection from the serving BS to the adjacent BS. We assume MS in the network takes the BS with the minimum Euclidean distance as the serving BS, and executes the handover process to connect to the target BS when the target BS becomes closer than the serving BS. Similarly, the MS located in the area overlapped by the coverage area of three BSs is able to acknowledge three BS IDs like MS$_3$ in the figure. Every MS will record the BS IDs from which it receives periodic broadcasting messages. The set of BS IDs is called *diversity set*, which will be reported to serving BS by MSs periodically. To improve the spectrum efficiency, BS cell is divided into three sectors with three separated antenna sets. The antenna pattern for each sector refers to [8].

Correct detection of signal depends on the SINR at the receiver [9]. The SINR for MS located at point s in the cell of BS u in RB i can be expressed by:

$$\xi_i^{(u)}(s) = \frac{P_i^{(u)} |S_u - s|^{-\alpha}}{\sum\limits_{v \in U_i - u} P_i^{(v)} |S_v - s|^{-\alpha} + N_o}, \qquad (1)$$

where U_i represents the set of BSs using RB i, $P_i^{(v)}$ denotes the transmit power of BS v over RB i, α ($\alpha \geq 2$) denotes the signal attenuation factor, and N_o shows the thermal noise power. In Eq. (1), if the distance between MS and BS u is fixed, $\xi_i^{(u)}(s)$ is mainly affected by $|S_v - s|$, the distance between the MS and other interfering BSs. If s is on the cell margin, $|S_u - s|$ will be close to $|S_v - s|$. While neighboring cells are using identical RBs, $\xi_i^{(u)}(s)$ in Eq. (1) could be lower than the threshold of correct reception, which means the signals of neighboring cells are strongly interfering to each other. If identical RBs are used by far enough located BSs, the ration of $|S_u - s|$ and $|S_v - s|$ can be large, which indicates weak ICI and $\xi_i^{(u)}(s)$ can be higher than the threshold.

$\xi_i^{(u)}(s)$ becomes larger if $|S_u - s|$ is reduced. FFR takes advantage of non-uniform SINR in a cell and divides a cell into cell center and cell edge zones, using different frequency reuse factors. As shown in Fig. 1, the frequency band is partitioned, where cell center zone can used overlapped frequency sub-band $\mathcal{F}_c$ with transmit power P_{c1}. The rest of frequency band is divided into three partitions for the edge zone of three sectors, which are $\mathcal{F}_{e1}$, $\mathcal{F}_{e2}$, and $\mathcal{F}_{e3}$, respectively. With such a method, the frequency sub-band $\mathcal{F}_c$ has reuse factor one, while the rest frequency partition's reuse factor is three. RBs belonging to different partitions can be assigned to MSs in the corresponding zones. To facilitate MS zone determination, it can utilize MS's diversity set. MS with more than one BS in the diversity set is considered in edge zone; otherwise it is in center zone. Resource allocation for MSs in different zones is subjected to the allocated frequency partition. For example, for MSs located in the edge zone of sector 1 in BS$_3$, the resource allocation is only allowed to be within $\mathcal{F}_{c1}$. The sizes of frequency partitions highly limits the flexibility of resource allocation. It is difficult to adjust the size of frequency partitions as divisions of frequency partition is strongly related. Adjusting the size of one sector could cause overlap of frequency partitions at the neighboring sectors and induce strong ICI. Conventional FFR scheme intends to use global optimization to solve this issue, which is not scalable and involves very high computation complexity. It also leads to heavy exchange of control and information messages at the backhual network and is hard to achieve per frame adjustment due to non-scalable message latency.

OFDMA frames in the system are synchronized and have the same time division duplex (TDD) for downlink (DL) and uplink (UL). TDD frame is called DL frame and UL frame respectively. Although, we discuss the resource allocation for DL frames in this paper, the method is equally applicable to UL frames.

DL frame can be divided into multiple resource blocks (RBs) which are used as the basic units for resource allocation. Each RB is comprised of multiple subcarriers and OFDMA symbols. Logically, the RBs available for data transmission constructs a two-dimensional plane. Let M_f indicate the number of RBs spanning over frequency domain and M_t denote the number of RBs spanning over time domain. RB in a DL frame is identified by frequency and time domain pair (f,t) where $f \in \{1,2,...,M_f\}$ and $t \in \{1,2,...,M_t\}$. RB also can be indicated by index i, where $i = (f-1)M_f + t$.

Resource allocation assigns RBs to MSs with certain scheduling. Different transmission rates can exist in the same OFDMA frame because of different signal to noise ratio (SNR). When RBs are allocated to MSs, the number of transmit bits in each RB may be different. For example, MS can use 64-QAM when SNR is high, and use 4-QAM when SNR is low. Different MSs have different SNRs, following different data rates, but each MS uses same data rate within a DL frame. Data rate of MS u during a DL frame is denoted by r_u.

III. NETWORK CLUSTERING

Our method is based on the cluster formed by adjacent sectors, where most ICI is present. Clustering based FFR reformats the zones to elaborately utilize non-uniform SINR and enable fair resource scheduling. Resource allocation includes two parts: inter-cluster interference mitigation and intra-cluster resource allocation.

For MSs located at the cell edge zone, some are mainly affected by ICI from one BS, and the other will have strong ICI from two neighboring BSs. As shown in Fig. 2, the area around BS$_1$ is the cell center zone where ICI is weak; the light color area at the cell edge of BS$_1$ denotes the area where ICI mainly from one neighboring BS, and the dark color area in BS$_1$ cell denotes the area where ICI mainly from two neighboring BSs. Different from conventional FFR, we further consider the fundamental reasons and utilize non-uniformly distributed ICI.

A general cluster is formed by adjacent sectors of adjacent cells. Cluster on the boundary region of network could be formed by two sectors since only two sectors are adjacent. Some cluster may only have one sector. For a cluster having only one sector, it does not have to exchange sector information through the backhaul, like the cluster having more than one sector. In the rest of the paper, for discussions, we take the cluster having three sectors as a general cluster in the network. The clusters on the boundary are the special case of the typical cluster. The methods and algorithms are also applicable to these clusters.

As shown in Fig. 2, cell edge zones from three adjacent sectors are combined together. The area where ICI is mainly from two BSs, are separated from traditional cell edge zone and is defined as cluster corner zone. The reason behind this cluster formation is that inter-cell interference is most serious in the intersection of three adjacent cells. The BSs that will cause each other's ICI at the cell edge zones (except for the cluster cornor zone) are included in the cluster. By jointly allocating resource in the formed cluster, ICI can be effectively avoided or mitigated.

The resource allocation of MSs are related to their zones. Determination of the zone of an MS depends on its diversity set. If the diversity set only has the Identification (ID) of the serving BS, it indicates that the MS is in the cell center zone. If the diversity set has two BS IDs, it indicates the MS is in the cell edge zone. If the diversity set has three BS IDs and these are included in the same cluster, it indicates the MS in the cell edge zone. More specifically, it is located at the intersection of three sectors. If the diversity set have three BS IDs and any of them is not in the cluster, it indicates that the MS is at the cluster corner zone.

Since a cell is divided into three sectors, the management of resource at BS can be divided into three independent parts for three sectors. For the sectors in a cluster, the BS of the sector leaves the resource management of the sector to the cluster. For a BS involved in three different clusters, the three sectors belong to three different clusters. Every cluster has a cluster head in charge of the resource management and allocation. Clusters are formed at the initiation of the network and are updated when the BS availability changes. For example, when a new BS joins the network, clusters will be formed for the new BS. Or BS leaves the network, clusters also will be reformed again. The reformation is distributed and only happens at the sectors near the place where any BS existing changes.

After performing the resource allocation, this information

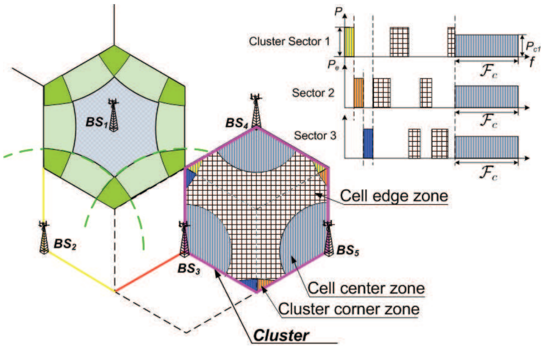

Fig. 2: Proposed clustering based FFR

will be sent to the corresponding BS through the backhaul. The BSs then can perform DL transmissions according to the scheduling. The corresponding transmit power of RB is determined by the zone of MSs, and the data rate are determined by the obtained channel state information (CSI).

As illustrated in Fig. 2, the corner zone frequency can be fixed as similar to conventional FFR, this reduces the overhead in adjusting inter-cluster interference. Since the size of cluster corner zone is very small, the resource for that will not be too much. The resource allocation for cell edge zone can be adjusted within a large region, which offers higher flexible than conventional cell-based FFR. The allowed adjustment in conventional FFR for edge zone is between 0 and $\mathcal{F}_e$. With clustring based FFR, it can be from 0 to $3\mathcal{F}_e - \mathcal{F}_{corner}$.

IV. RESOURCE ALLOCATION

A. *Resource Cuboids*

Our resource allocation is to cooperatively allocate RBs of three DL frames in a cluster, as shown in Fig. 3. Different from RB resource in a square two-dimensional plane, RB is a resource cube in three-dimensional space by adding the dimension of the frame. RB is identified by (f, t, s) in three-dimensional space, where s is the index of DL frame, $s \in \{1, 2, 3\}$. Three resource cubes with the same s construct a resource cuboid, which is identified by (f, t). Similar to previous discussions, a resource cuboid also can be identified by index i, where $i = (f - 1)M_f + t$. So, when we mention the ith resource cuboid latter, we mean the resource cuboid (f, t). The allocation of the three DL frames can be jointly optimized by the cluster head. The allocation is subjected to certain constraints.

B. *Allocation for Cell Center Zone*

When a resource cuboid is used for allocation of MS at the cell center zone, we implement frequency reuse factor one as used by FFR to achieve a higher spectrum reuse factor. Since the SINR are relatively high for MSs in this zone, the system is to take advantage of high reuse factor so as to improve the throughput. So, three RBs in a resource cuboid will be allocated to MSs in the cell center zone of the corresponding sectors as shown in Fig. 3(a). For example, for the kth resource cuboid, RB $(i, 1)$ for the MS is allocated in the cell center zone of sector 1, RB $(i, 2)$ is for the MS in the cell zone of sector 2, and so on. So, a resource cuboid can support up to three MSs in different cell center zones. Let a binary variable $A^{(u)}(i, s)$ denote the allocation of RB i of sector s.

$$\sum_u \sum_s A^{(u)}(i, s) \leq 3, \quad \forall u \in \bigcup_s \mathcal{Z}_c(s), \tag{2}$$

where $\mathcal{Z}_c(s)$ denote the set of MSs in the cell center zone of sector s.

C. *Allocation for Cell Edge Zone*

When a resource cuboid is utilized for allocation of MS at the cell edge zone, the primary purpose is to mitigate inter-cell interference. So, the whole resource cuboid is only allocated for one MS, instead of three MSs, as illustrated in Fig. 3(b). The allocation constraint is:

$$\sum_u \sum_s A^{(u)}(i, s) \leq 1, \quad \forall u \in \bigcup_s \mathcal{Z}_e(s), \tag{3}$$

where $\mathcal{Z}_e(s)$ denote the set of MSs in the cell edge zone of sector s.

Due to RB can only be used once by a sector, an additional constraint is:

$$\sum_u A^{(u)}(i, s) \leq 1, \quad \forall u \in \mathcal{Z}_c(s) \bigcup \mathcal{Z}_e(s). \tag{4}$$

D. *Allocation for Cluster Corner Zone*

The allocation for cluster corner zone is to use the fractional RB reuse to avoid complex inter-cluster information exchange. The resource blocks used for the corner zones are pre-planed for the reuse at different clusters, as illustrated by Fig. 3(c). For example, if the resource cuboid is used by a BS for the cluster corner zones, it will not be used by other BS in the same cluster, but can be reused only by the cluster corner zones of BSs at a reuse distance.

E. *Proportional Fair Scheduling*

Given data RBs of a DL frame, we need an appropriate scheduling scheme to allocate resource cuboids. To fairly perform intra-cluster resource block allocation, our scheme implements proportional fair scheduler (PFS), which means each MS has proportional data rate. To maximize the overall data rate, scheduler enables the MSs having bad channel condition to have more RBs so as to have similar data rate as those having good channel conditions. Also, different from a scheduler considering fair number of RBs, it takes the modulation and coding rate into consideration and provides proportional fairness in terms of data rate.

To allocate RBs for the MSs in the cluster, the scheduler scans the resource cuboids by sequence of $\{1, 2, \ldots, k, \ldots, M_{RB}\}$, where M_{RB} is less than $M_f M_t$. Since certain RBs are reserved for the cluster corner zone, the RBs from $M_{RB} + 1$ to $M_f M_t$ are used for the cluster corner zone.

The scheduler selects MS u with the minimum metric ρ_u from all MSs in the cell center and cell edge zones to allocate the resource and consider two cases: cell center zone MS and

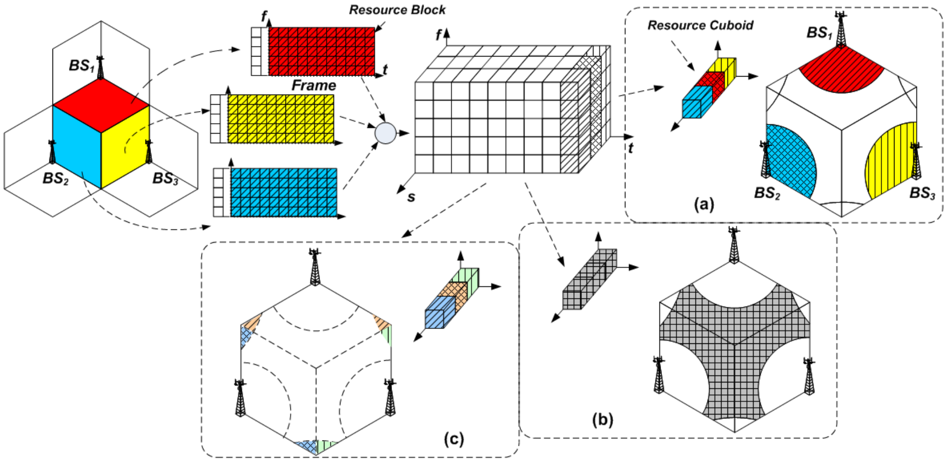

Fig. 3: Resource allocation for zones

TABLE I: Discrete AMC

Modulation	BPSK	4-QAM	16-QAM	64-QAM	256-QAM
r_u **b/sym**	1	2	4	6	8
I_u **(dB)**	2	13.6	20.6	26.8	32.9

cell edge zone MS, which are discussed earlier. Metric ρ_u is computed by:

$$\rho_u = \frac{\sum_i A^{(u)}(i,s) r_u}{R'_u}, \quad u \in \mathcal{Z}(s), \tag{5}$$

where r_u is determined by effective SNR I_u of MS u, $\sum_i A^u(i,s)$ denote the number of RBs allocated to MS u, and R'_u is the data rate of MS u of the last frame. Cluster head gathers CSI information and selects appropriate AMC for MSs. Metric r_u is called proportional fairness parameter and the selection of r_u for MS u follows Tab. I.

On the other side, data rate R_u is updated per DL frame:

$$R_u = \alpha \sum_i A^{(u)}(i,s) r_u + (1-\alpha) R'_u, \tag{6}$$

where R_u is the data rate of current DL frame, R'_u is the data rate of the previous DL frame, and α is the decay factor that controls the influence of the history data rate and currently allocated data rate. The objective is to approach a long-term fairness.

V. PERFORMANCE EVALUATION

In this section, we investigate the performance of the proposed schemes. The configuration of simulation follows the suggestions in the IEEE 802.16m evaluation methodology document [8].

We firstly have a look at the effective SINR of MSs. Because the SINR will be different from the RBs allocated to an MS, we measure the effective SINR for MSs, which is computed from SINR of each allocated RB. Fig. 4 and Fig. 5 show the cumulative distribution function (CDF) of the MS effective SINR in the network with reuse-1 allocation and clustering based allocation. Obviously, the SINR of clustering based allocation is higher than that of reuse-1 allocation. This is because the MS in the edge zone of reuse-1 will suffer from high interference due to the resource reuse of the neighboring cells. Some MSs cannot receive any data due to low SINR. If given a threshold 2dB as the minimum SINR for communication, reuse-1 allocation will have about 7 percent SINR below the threshold. However, in clustering based allocation, the MSs in the edge zone is mitigated by a cooperative allocation between the sectors. The SINR will be higher than the threshold so that all MSs in the network can effectively do the communication. In addition, the span of clustering based allocation is narrower than that of reuse-1, which means the SINR in clustering based allocation has smaller deviation. In reuse-1, the SINR highly relies on the geographical location of MS. MS closer to the BS would have much higher SINR. Clustering based allocation improves SINR of those MSs in the edge zone, so the distribution of SINR is closer to the average SINR. The trends can be investigated both in light traffic load situation of Fig. 4 and heavy traffic load situation of Fig. 5.

Fig. 6 shows the throughput per cell of three allocation methods: cell based FFR, cell based FFR-PFS, and clustering based PFS, where throughput is computed by Shannon capacity equations. Clustering based PFS has higher throughput per cell than these of cell based FFR and cell based FFR-PFS. Due to frequency resource reuse with fixed distance, FFR is not able to fully reuse all resources. With different traffic load, clustering based PFS has almost consistently better throughput as the throughput of cell based FFR and cell based FFR-PFS are changed with traffic load. For light traffic load, clustering based PFS has much higher throughput than that of cell based FFR and cell based FFR-PFS. This is one of the important advantages of clustering based allocation, because it is able to utilize the resource not used by neighboring sectors. When the traffic load is light, the MSs are not distributed so ”uniformly”. The deviation of the number of MSs in a sector and/or the number of MSs in the center and edge zones is large. The resource will be wasted in a cell based FFR and cell based FFR-PFS since they are not able to cooperatively allocate the resources. Clustering based allocation can fully utilize the

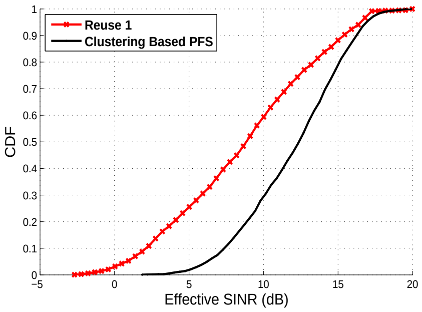

Fig. 4: Effective SINR (light traffic)

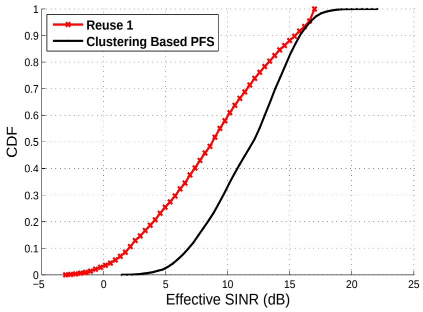

Fig. 5: Effective SINR (heavy traffic)

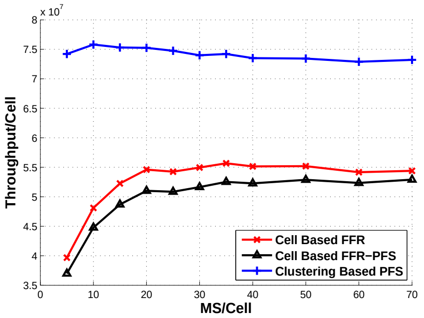

Fig. 6: Throughput per cell

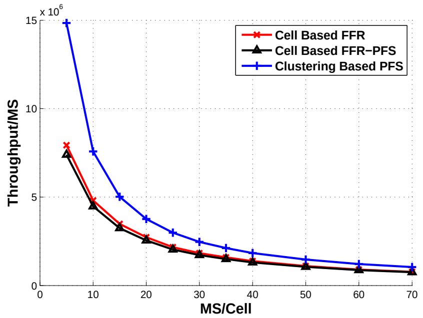

Fig. 7: Throughput per MS

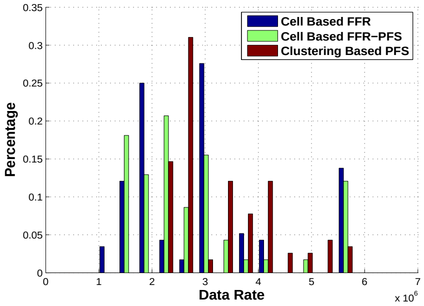

Fig. 8: Data rate (light traffic)

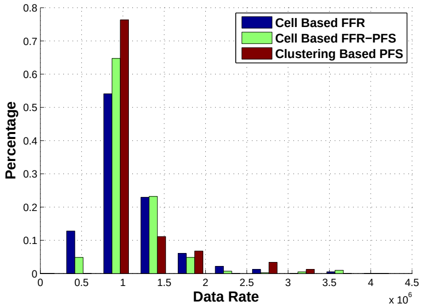

Fig. 9: Data rate (heavy traffic)

”idle” resource of neighboring sectors for heavy loaded sector. From the figure, cell-based FFR has higher throughput than cell-based FFR-PFS. Because cell-based FFR-PFS is to reach the fair rate, the overall throughput is not maximized. Fig. 7 shows the throughput per MS. It indicates a similar trend as in Fig. 6. Clustering based PFS still has the highest throughput and the throughput of cell based FFR is higher than that of cell based FFR-PFS. But, they all approach a limit when the traffic load increases.

Figs. 8 and 9 respectively show the histograms of the data rate with light traffic load and heavy traffic load. In Fig. 9, it is obvious that clustering based FPS fairly concentrates around certain data rate. More than 70 percent of data rate are scaled in a narrow data rate scope in Fig. 9. Cell based FFR and cell based FFR-PFS have a data rate with much wider scope. While the traffic load is light, the data rate is more widely distributed. Since some RBs cannot be used for cell edge zone or other cell center zone in the same cluster, the allocation of resource cuboids for the cell center zone will allocate all the RBs to MSs so as to maximize the throughput. So, some MSs will have higher throughput. When the traffic load is light, deviation of MS geographic location is relatively high, making the effect more obvious.

VI. CONCLUSION

In this paper, we have proposed a novel clustering based FFR for fair resource allocation, which has higher throughput than cell based FFR and cell based FFR-PFS. As mentioned earlier, global optimization is hard to implement due to the complexity and high information exchange overheads. Cell based algorithm cannot provide good performance due to a large cell edge area that suffers from strong interference. While FFR can mitigate inter-cell interference, it is not able to fully utilize the resources. Our scheme is based on clustering of adjacent sectors from different cells. Such clustering makes the most interfered area very small inside the cluster. By implementing different strategies at the cell center zone and cell edge zone, the inter-cell interference can be reduced and the throughput can be enhanced. Considering the advantages in scalability, throughput, and fairness, our scheme can be utilized by current multi-cell OFDMA network standards, such as the IEEE 802.16 or the 3GPP LTE, so that spectrum efficiency and flexibility can be improved.

REFERENCES

[1] “The draft IEEE 802.16m system description document,” in *IEEE 802.16 Broadband Wireless Access Working Group*.
[2] R. Giuliano and C. Monti, “WiMAX fractional frequency reuse for rural environments,” in *Wireless Communications*, June 2008.
[3] Y. Zhou, “Simulation study of fractional frequency reuse for mobile WiMAX,” in *VTC*, 2008.
[4] “Comment for interference mitigation using fractional frequency reuse,” in *IEEE c802.16m-08/1383*.
[5] M. C. Necker, “Local interference coordination in cellular OFDMA networks,” in *VTC*, 2007.
[6] J. Lee, R. V. Sonalkar, and J. M. Cioffi, “A multi-user rate and power control algorithm for VDSL,” in *Globecom*, 2002.
[7] G. Kulkarni and M. Srivastava, “Subcarrier and bit allocation strategies for OFDMA based wireless ad hoc networks,” in *Globecom*, 2002.
[8] “Project 802.16m evaluation methodology document (EMD),” in *IEEE 802.16 Broadband Wireless Access Working Group*.
[9] W. Fu and D. P. Agrawal, “Effective radio partitioning and efficient queue management schemes in a wireless mesh network,” in *Globecom*, 2008.