Telecommun Syst
DOI 10.1007/s11235-017-0363-7

Channel and queue aware joint relay selection and resource allocation for MISO-OFDMA based user-relay assisted cellular networks

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Abstract User-relay assisted orthogonal frequency division multiple access (OFDMA) networks are cost-effective solutions to meet the growing capacity and coverage demands of the next generation cellular networks. These networks can be used with multiple antennas technology in order to obtain a diversity gain to combat signal fading and to obtain more capacity gain without increasing the bandwidth or transmit power. Efficient relay selection and resource allocation are crucial in such a multi-user, multi-relay and multi-antenna environment to fully exploit the benefits of the combination of user-relaying and multiple antennas technology. Thus, we propose a channel and queue aware joint relay selection and resource allocation algorithm for multiple-input single-output (MISO)-OFDMA based user-relay assisted downlink cellular networks. Since, the proposed algorithm is not only channel but also queue-aware, the system resources are allocated efficiently among the users. The proposed algorithm for the MISO-OFDMA based user-relay assisted scheme is compared to existing MISO-OFDMA based non-relaying and fixed relay assisted schemes and it is also compared with the existing single-input single-output (SISO)-OFDMA based user-relay assisted scheme. Simulation results revealed that the proposed scheme outperforms the existing schemes in terms of cell-edge users' total data rate, average backlog and average delay.

Keywords User relaying · MISO-OFDMA · Relay selection · Resource allocation

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1 Introduction

Nowadays, the number of mobile users and mobile devices are increasing enormously and the mobile users want to get service at higher data rates seamlessly because of the data hungry applications such as video streaming, online gaming etc.. Thus, next-generation wireless communication networks require higher data rates and ubiquitous coverage in order to satisfy the quality of service (QoS) demands of the mobile users. In order to meet these demands, for the current and future wireless networks there are tough technical challenges as transmission channel impairments, limited availability of frequency spectrum and transmission power constraint to overcome.

High data rate transmission over wideband wireless channels are significantly limited by inter-symbol interference (ISI) because of the dispersive fading of the wireless channels. OFDMA is a good technology due to its inherent robustness against frequency-selective fading, its high spectral efficiency and its flexible resource allocation [1]. In OFDMA, the spectrum is divided into a number of subcarriers and then subsets of these subcarriers also called subchannels are allocated to different users by exploiting multiuser diversity. Multiple-input multiple-output (MIMO) technology [2] also offers significant increase in the data throughput without additional bandwidth or transmit power requirements. MIMO systems adopt multi antenna arrays either on the transmitter or the receiver side. Compared to SISO system, MIMO offers a higher diversity which can potentially lead to a multiplicative increase in capacity. Due to the potential of improving performance and enhancing the spectral efficiency, many broadband wireless networks have included the MIMO option in their protocols. In practice, due to the size and cost limitation, it is difficult to deploy multiple antennas in mobile terminals. Thus, there are multiple antennas at the base station (BS) and only one antenna at each mobile station (MS) which is called MISO. Using MISO and OFDMA together gives rise to greater system capacity. Moreover, multiuser diversity can be exploited not only in the frequency domain, but also in the spatial domain.

Although, the throughput in conventional cellular networks can be significantly increased by using multiple antennas technology, this might not be sufficient to provide a required QoS if there are long distances between the users and the BS. In this case, one way to increase the capacity along with the coverage without using more bandwidth is to minimize cell sizes. However, more BSs are required to cover the same area with smaller cells which is a cost prohibitive solution for network service providers. An alternative solution to alleviate this problem is to deploy relay stations (RSs) in each cell since they can forward high data rates in remote areas of the cell while keeping a low cost of infrastructure. RSs can enhance throughput, save power, increase the coverage area or fill some coverage black spots without the need for a wired backhaul connection. The combination of MISO-OFDMA and relaying is one of the key technologies to deliver the promise of the reliable and high-data-rate coverage in the most cost effective manner.

Relay assisted networks can be categorized as fixed and mobile relay networks according to the motion of the relays [3–9]. Fixed relay networks in which the deployment of RSs is an integral part of the network planning, design and deployment process since the RSs are part of the network infrastructure have been extensively studied in the literature, and have already been included in the 4G long term evolution (LTE)-advanced standard [10]. In mobile relay networks, the RSs are not part of the fixed wireless infrastructure and their locations are not deterministic. The utilization of mobile RSs extends coverage and increases throughput [5,11,12]. The mobile RSs can be examined in two different forms such as dedicated mobile RSs that are mounted on moving vehicles or user terminals acting as mobile RSs which are also called as user-relays. User-relaying is foreseen as one of the emerging technologies that will change and define the fifth generation (5G) telecommunication standard [13,14]. The number of fixed RSs in a network is limited thus the relay usability in the network is also limited. User-relays have more degrees of freedom compared to fixed RSs since the number of user-relays scales with the number of mobile users. The lower deployment cost is the main advantage of the user-relays. It is not required to add any costly infrastructure for relaying, since the existing user terminals are used. The user terminals can organize themselves to cover unknown dead spots, which are difficult to predict with the operators planning tool. There are also some challenges of user-relays. It is obvious that the users' density is a critical parameter for the relaying opportunity and the battery life of the user-relay is important since forwarding the other users' data can considerably decrease the battery life.

In OFDMA-based relay assisted networks, potential gain in capacity and coverage is highly dependent on the radio resource management (RRM) strategy [15,16]. Thus, it is necessary to develop efficient RRM algorithms such as relay selection and resource allocation in order to reveal the advantages of these combined technologies. There are many works studied on the RRM problem for OFDMA-based fixed relay networks [17–26] and mobile relay networks [27–36]. These works use the common assumption that users have infinitely backlogged buffers in BS. However, this assumption might not be true and users have random and bursty traffic arrival of packets in practical. Therefore, the channel aware scheduling without considering the buffer status, would lead into inefficient use of resources.

Queue-aware resource allocation is of great research interest in order to cope with wasting resources. One of the way to integrate queue awareness into resource allocation schemes is involving the queue lengths in the formulation. In this case, the optimization problem can be worked out as sum-utility or sum-demand maximization. The demand metric can be proportional to both the queue length at the source node and the quality of the link to the destination. Such a scheduling policy belongs to the class of throughput-optimal scheduling developed in [37] for multihop packet radio networks. The users are not always scheduled according to their channel conditions in this policy since it is not only channel aware but also queue-aware. When a user's queue is becoming too long, this user has to be scheduled even if its channel gain is not favorable. In other words, the user with bad channel gain has opportunity to receive the data when the queue length of this user is large. Since the user with good channel condition is not always backlogged, the system resources are not wasted. The throughput-optimal policy achieves fairness among users by stabilizing the user queues at all nodes. Several throughput-optimal RRM algorithms have been examined for different network types such as ad-hoc networks and cellular networks with/without relaying by using different optimization problems. In [38] and [39], modified versions of the demand metric have been used in conventional cellular Space Division Multiple Access (SDMA)/Time Division Multiple Access (TDMA) and OFDMA networks, respectively. It has been applied to OFDMA based fixed relay networks in [40–43]. A fair queue-aware resource allocation scheme which can significantly reduce the co-channel interference and improve spectrum utilization in OFDMA-based multicellular networks assisted by fixed RSs has been presented in [40] and [41]. In [40], the optimization problem has been defined for the quasi full-duplex relaying protocol and a centralized joint relay selection and fair resource allocation algorithm has been given for this problem. Despite the significant performance of this joint algorithm, it suffers from a performance limiting bottleneck since the traffic load increases which cause some practical limitations in hardware technology. Thus, in [41], the same problem is defined for the half-duplex relaying scheme that has been considered more realistic for practical implementation. They have presented low complexity iterative algorithms to solve the formulated optimization problem. In [42], with the throughput-optimal scheduling, a low-complexity iterative algorithm has been devised to solve the resource allocation using the queue length and the achievable rates for the OFDMA based fixed relay assisted networks. Contrary to [40] and [41], in [42] relay selection and resource allocation algorithms have been studied disjointly and the resource allocation algorithm is semi-distributed where RSs could also perform resource allocation. In [43], a novel framework is presented for formulating and solving QoS-aware routing and subchannel allocation in OFDMA networks enhanced with buffering fixed relays, with the objective of guaranteeing throughput and stringent packet delays, respectively, for delay-tolerant and delay-sensitive users. We have proposed a heuristic resource allocation algorithm based on the queue and channel state information of the users for user-relay assisted OFDMA networks in [44]. The existing queue-aware relay selection and resource allocation algorithms for relay assisted OFDMA cellular networks in [40–44] are all studied for SISO-OFDMA systems. To the best of our knowledge, there is a gap about the queue-aware RRM problem for relay assisted MISO-OFDMA based cellular networks.

In this paper, we combine multiple antenna technology with user relaying concept and develop a new RRM formulation for MISO-OFDMA based user-relay assisted downlink cellular networks in order to fill this gap. We prefer user-relaying in our study, since relaying through other users' terminal provides more flexibility to the cellular network by increasing the number of relay candidates and reducing the infrastructure cost. While fixed terminal relaying brings improvements in cellular systems, the implementation of user relaying will bring a huge gain to 5G based wireless networks with employing different scenarios [13]. One of the scenarios that will be examined in 5G based systems is device relaying with operator controlled link establishment corresponds to the framework that we present in this manuscript. The contribution of the paper and the features of the proposed scheme are summarized as follows:

- RRM optimization problem is defined for MISO-OFDMA based user-relay assisted cellular networks.
- A novel channel and queue aware sub-optimum joint relay selection and resource allocation algorithm is proposed to solve the formulated RRM optimization problem since the existing queue-aware algorithms presented for SISO-OFDMA systems [40–44] can not be directly applied to the MISO-OFDMA systems in which more than one user is supported per subchannel.
- The proposed algorithm is suitable for the realistic scenarios and use system resources efficiently because of the queue-awareness contrary to [27–36] where queue information is ignored with the assumption that users have infinitely backlogged buffers in BS.
- Relay selection and resource allocation is performed jointly in the proposed scheme contrary to many works in the literature [19,34,42], since separated relay selection and resource allocation can limit the system performance.
- In most of the existing works in the literature, it is assumed that the same subchannel is used for the BS to relay and for the relay to users links at different time slots [27,29,34–36]. However, the performance of the system is limited due to this assumption, despite the fact that the complexity of the problem is reduced. In the proposed scheme, the system is flexible to use different subchannels at different time slots between the BS-relay and relay-user links.

The rest of this article is organized as follows. In Sect. 2, we give the system model and problem definition. In Sect. 3, we present the proposed algorithm. In Sect. 4, performance results are examined and finally, the conclusions are given in Sect. 5.

2 System model and problem definition

As shown in Fig. 1, a single cell MISO-OFDMA based user-relay assisted downlink network topology is used. The BS with N_t transmit antennas is located in the centre of the cell and K users equipped with single receive antenna are distributed randomly around it. The cell area is divided into two ring shaped boundary zones such as inner zone between 0 and R_1 and outer zone between R_1 and R where R is the radius of the cell. M users located inside the inner zone do not require relays in most cases due to good channel condition since they are closer to the BS. Thus, these users are allowed to communicate to the BS directly. L users located inside the outer zone (cell-edge users) may require relays in most cases due to heavy blockage and long distance transmission [20,23]. Thus, these users are allowed to communicate with the BS either directly or with the help of user-relay in two hops. Inner users may act as relays for outer users that are far from the BS to enhance end-to-end link quality of them in terms of capacity and coverage. In the proposed system model, only cell-edge users can utilize user-relays and inner users are the user-relay candidates of these users. If all available inner users are utilized as user-relay candidates of a cell-edge user, this will increase the feedback load and the computational complexity. The number of relay candidates,

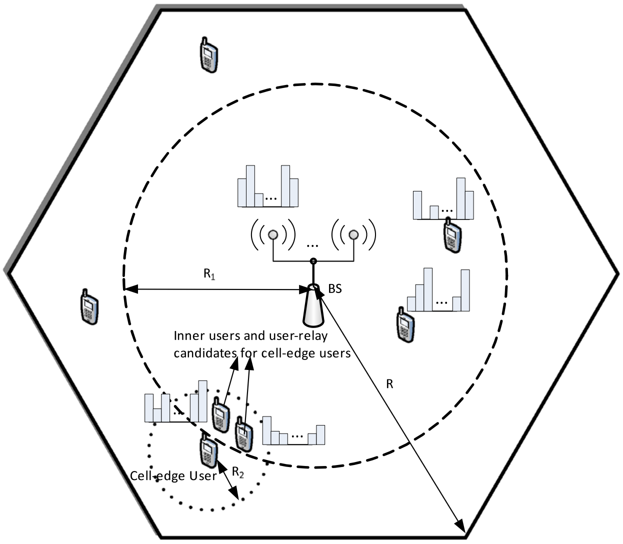

Fig. 1 MISO-OFDMA based user-relay assisted downlink network topology

and thus feedback load and the computational complexity can be significantly reduced by selecting the user-relays in a limited area around for each cell-edge user [31,32,34,44]. Thus, the cell edge users' relay candidates can be determined by using the area whose radius is R_2 as illustrated in Fig. 1. The inner users, which remain in the coverage area of a cell-edge user, are the user-relay candidates of this cell-edge user. The BS has K separate data queues and M inner users have L separate data queues as a relay illustrated in Fig. 2. The user packets are generated according to suitable traffic model. All of the available bandwidth B, is divided into N subchannels, and each subchannel consists of a set of adjacent orthogonal frequency division multiplexing (OFDM) subcarriers. We assume that the total transmission power is equally shared among all subchannels. Besides, the transmission power belonging to each subcahnnel is also equally shared among all assigned users to this subchannel. We assume that all required channel gains among BS and all MSs, and among MSs and user-relays are available perfectly at the BS.

A generic frame structure in which the downlink frame is partitioned into two consecutive subframes is used as shown in Fig. 3. The subframes are divided in time with durations T_1 and T_2 and these durations are selected equally as $T_1 = T_2 = T$ in this work. The subframe durations may not necessarily be equal length since this is an optimization problem, which is not the focus of this paper. In the first subframe, BS transmits data to MSs and RSs and these are indicated as BS → MS and BS → RS. In the second subframe, MSs receive data from BS and RSs and these are labeled as BS → MS and RS → MS. The communication links BS → RS and RS → MS may use the same or different frequency bands at different time slots.

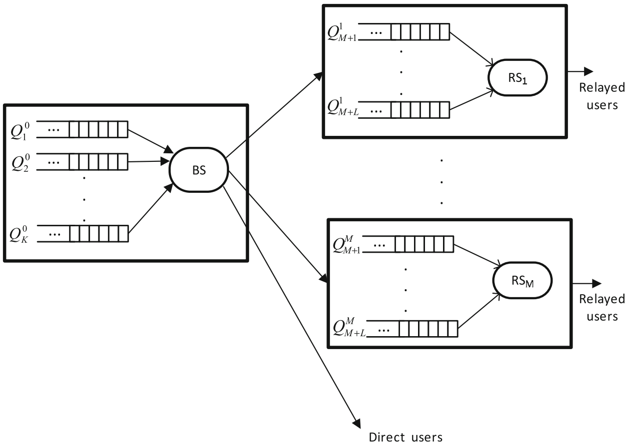

Fig. 2 Resource allocation architecture for relay-assisted networks

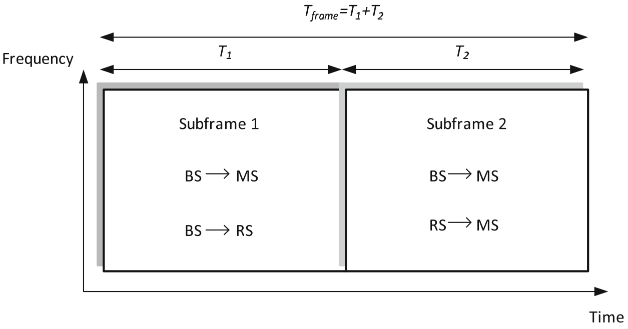

Fig. 3 Generic relaying frame structure

Two separate optimization problems are formulated for the two consecutive subframes before the BS starts transmitting the data in the first subframe. These are explained in detail in the following subsections.

2.1 Problem definition for subframe 1

BS transmits data to all MSs that can be a user or a user-relay in this subframe. An inner user can receive data from the BS either a direct user or a user-relay candidate on each subchannel. The total number of nodes that BS will serve is counted as $K + M$, because of the two different roles of the inner user. In our model, the BS can transmit to multiple nodes simultaneously at each subchannel since it has N_t transmit antennas. Total number of nodes that BS will serve is larger than the number of transmit antennas, $K + M > N_t$ as in the practical scenarios. Thus, it is required to select $a \leq N_t$ links for each subchannel. The number of simultaneously served links on each subchannel is limited by the number of transmit antennas. There are, $\Pi^{(1)} = \sum_{a=1}^{N_t} \binom{K+M}{a}$ possible combinations of links in the same subchannel. The scheduled users' and/or user-relays' set on subchannel n is denoted as $S_{\pi,n}$ whose cardinality is given as $0 < |S_{\pi,n}| \leq N_t$ where

$\pi = 1, 2, \ldots, \Pi^{(1)}$. Let assume a set of users and/or user-relays, $S_{\pi,n} = \{s_1, s_2, \cdots, s_a\}$, that produces the channel matrix which consists of a channel vectors belonging to these selected nodes for subchannel n;

$$\mathbf{H}_n(S_{\pi,n}) = [\mathbf{h}_{0,s_1,n}^T \cdots \mathbf{h}_{0,s_a,n}^T]^T \tag{1}$$

where $\mathbf{h}_{0,s_a,n}$ is $1 \times N_t$ channel vector between the BS and node s_a on subchannel n.

When multiple nodes are served simultaneously on the same subchannel, it causes interference among the nodes. In order to alleviate this problem, zero forcing beamforming (ZF-BF) technique in which weight vectors are chosen to avoid interference among users is used. Thus, the ZF-BF matrix belonging to each node on subchannel n is calculated as follows,

$$\mathbf{W}_n(S_{\pi,n}) = \beta(\mathbf{H}_n(S_{\pi,n}))^H [(\mathbf{H}_n(S_{\pi,n}))(\mathbf{H}_n(S_{\pi,n}))^H]^{-1} \tag{2}$$

where $\mathbf{W}_n(S_{\pi,n}) = [\mathbf{w}_{0,s_1,n} \cdots \mathbf{w}_{0,s_a,n}]$ that contains $N_t \times 1$ beamforming vectors belonging to each node on subchannel n.

In order to keep the short term power constraint, we determine β as,

$$\beta = \frac{1}{\sqrt{\mathrm{tr}[((\mathbf{H}_n(S_{\pi,n}))(\mathbf{H}_n(S_{\pi,n}))^H)^{-1}]}} \tag{3}$$

The data rate between the BS and any user or user-relay node $j \in S_{\pi,n}$ on subchannel n is calculated as;

$$R_{0,j,n,\pi} = \frac{B}{N} \log_2(1 + \gamma_{0,j,n,\pi}) \tag{4}$$

where $\gamma_{0,j,n,\pi} = \dfrac{P_{0,n,\pi} |\mathbf{h}_{0,j,n} \mathbf{w}_{0,j,n}|^2}{N_0(B/N)}$ is the Signal to Noise Ratio (SNR) value between the BS and receiver node j on subchannel n. $P_{0,n,\pi}$ is the transmitted power per subchannel per node, $\mathbf{h}_{0,j,n}$ is the channel coefficient vector between BS and node j that includes pathloss, shadowing and multipath and N_0 is the noise spectral density.

In this subframe, a MS is getting data from the BS as a user or user-relay so different demand metrics are calculated for both cases. The demand metric belongs to any BS → MS link on subchannel n is calculated as:

$$W_{0,k,n,\pi} = R_{0,k,n,\pi} Q_k^0, \quad \forall k \in \mathbb{K}, \forall \pi \tag{5}$$

where $\mathbb{K} = \{1, 2, \ldots, K\}$ is the set of the total users and Q_k^0 is the queue length, expressed in bits or bytes, of user k at BS. According to this metric, the subchannels are allocated to the users not only using the data rates but also using the queue lengths.

The demand metric of any BS → RS link on subchannel n which incorporates the maximum differential backlog of the queues of the BS and those at the relay candidate m [45,46] can be expressed as:

$$W'_{0,m,n,\pi} = R_{0,m,n,\pi} \max_{c \in \mathbb{S}_m} \{(Q_c^0 - Q_c^m)^+\}, \quad \forall m \in \mathbb{M}, \forall \pi \tag{6}$$

where $\mathbb{M} = \{1, 2, \ldots, M\}$ is the set of the user-relays and $\mathbb{S}_m$ is the set of outer users served through relay m. Q_c^m is the queue length of outer user c at node m which is not only the inner user but also the user-relay candidate. The function $(\cdot)^+$ is used to set negative values to zero. This metric provides to perform relay selection and resource allocation jointly. If the link between BS and user-relay m is assigned to subchannel n, then the data nominated by this maximum differential backlog is scheduled. The maximum differential backlog takes advantage of not only the first hop link but also the second hop link quality. For example, assume that the link between user-relay m and the user c is poor but BS has sent data to user-relay m belonging to user c because of the quality of the first link. In this case, this data will not be forwarded to user c. This will increase the queue length of user c at relay m which means the user c may no longer achieve the maximum difference $Q_c^0 - Q_c^m$. The algorithm therefore, learns that the relay m can not serve the user c for the next iterations so the data of user c is forwarded to another possible relay candidates.

The sum demand maximization problem for this subframe is given in detail below:

$$\begin{aligned} \max_{\rho_{0,k,n,\pi}^{(1)}, \sigma_{0,m,n,\pi}^{(1)}} & \sum_{n=1}^{N} \sum_{k=1}^{K} \sum_{\pi=1}^{\Pi^{(1)}} \rho_{0,k,n,\pi}^{(1)} W_{0,k,n,\pi} \\ & + \sum_{n=1}^{N} \sum_{m=1}^{M} \sum_{\pi=1}^{\Pi^{(1)}} \sigma_{0,m,n,\pi}^{(1)} W'_{0,m,n,\pi} \end{aligned} \tag{7}$$

subject to

$$\rho_{0,k,n,\pi}^{(1)} \in \{0, 1\}, \quad \forall k, \forall n, \forall \pi \tag{8}$$

$$\sigma_{0,m,n,\pi}^{(1)} \in \{0, 1\}, \quad \forall m, \forall n, \forall \pi \tag{9}$$

$$\sum_{k=1}^{K} \rho_{0,k,n,\pi}^{(1)} + \sum_{m=1}^{M} \sigma_{0,m,n,\pi}^{(1)} \leq N_t, k \neq m, \quad \forall n, \forall \pi \tag{10}$$

$$\sum_{n=1}^{N} \sum_{\pi=1}^{\Pi^{(1)}} \rho_{0,d,n,\pi}^{(1)} R_{0,d,n,\pi} T_1 \leq Q_d^0, d = 1, 2, \ldots, M \tag{11}$$

$$\sum_{n=1}^{N}\sum_{\pi=1}^{\Pi^{(1)}} \rho^{(1)}_{0,l,n,\pi} R_{0,l,n,\pi} T_1 + \sum_{n=1}^{N}\sum_{m=1}^{M}\sum_{\pi=1}^{\Pi^{(1)}} \sigma^{(1)}_{0,m,n,\pi} R_{0,m,n,\pi} T_1 \mu_l^m \le Q_l^0, \quad \forall l \in \mathbb{L} \tag{12}$$

where $d = 1, 2, \ldots, M$ represents inner users when they receive data from the BS for themselves and $\mathbb{L} = \{M+1, M+2, \ldots, M+L\}$ is the outer users set in which $M+L = K$.

In Eqs. (7)–(12), $\rho^{(1)}_{0,k,n,\pi}$ and $\sigma^{(1)}_{0,m,n,\pi}$ are the binary assignment variables such that $\rho^{(1)}_{0,k,n,\pi} = 1$ if user $k \in S_{\pi,n}$ and $\sigma^{(1)}_{0,m,n,\pi} = 1$ if user-relay $m \in S_{\pi,n}$ and $S_{\pi,n}$ is selected on the nth subchannel during the subframe 1. The constraint in Eq. (10) guarantees that the number of supportable users and/or user-relays can not exceed the number of transmit antennas for each subchannel and an inner user can not be used as a user and user-relay simultaneously on the same subchannel. The constraints in Eqs. (11) and (12) provide not giving resources more than queue lenghts to any inner and outer user, respectively. The μ_l^m which is used in Eq. (12) is also a binary variable. It indicates that outer user l will be served by relay m at subchannel n and it can be defined as follows:

$$\mu_l^m = \begin{cases} 1, & l = \arg\max\limits_{c\in\mathbb{S}_m}\{(Q_c^0 - Q_c^m)^+\} \\ 0, & o.w. \end{cases} \tag{13}$$

The queue lengths at each node could vary according to the allocation results at the end of the first subframe. Thus, the new queue lenghts at BS for inner and outer users are given below, respectively:

$$\tilde{Q}_d^0 = Q_d^0 - \sum_{n=1}^{N}\sum_{\pi=1}^{\Pi^{(1)}} \rho^{(1)}_{0,d,n,\pi} R_{0,d,n,\pi} T_1, \quad d = 1, 2, \ldots, M \tag{14}$$

$$\tilde{Q}_l^0 = Q_l^0 - \sum_{n=1}^{N}\sum_{\pi=1}^{\Pi^{(1)}} \rho^{(1)}_{0,l,n,\pi} R_{0,l,n,\pi} T_1 - \sum_{n=1}^{N}\sum_{m=1}^{M}\sum_{\pi=1}^{\Pi^{(1)}} \sigma^{(1)}_{0,m,n,\pi} R_{0,m,n,\pi} T_1 \mu_l^m, \quad \forall l \in \mathbb{L} \tag{15}$$

The new queue lenght at each RS is denoted by,

$$\tilde{Q}_l^m = Q_l^m + \sum_{n=1}^{N}\sum_{\pi=1}^{\Pi^{(1)}} \sigma^{(1)}_{0,m,n,\pi} R_{0,m,n,\pi} T_1 \mu_l^m, \quad \forall m \in \mathbb{M} \tag{16}$$

2.2 Problem definition for subframe 2

In this subframe, the BS shares the system resources, i.e., subchannels, with the RSs. BS continues to transmit data to direct users and the inner users that are used as user-relays transmit data to the cell-edge users.

On each subchannel, the serving node can be the BS or any user-relay. If the BS is serving node, it can transmit data to more than one user since the BS has N_t transmit antennas as explained in detail in the former subsection. In this subframe, possible combinations of users that will be supported on each subchannel is $\Pi^{(2)} = \sum_{a=1}^{N_t} \binom{K}{a}$ and $\pi = 1, 2, \ldots, \Pi^{(2)}$ since the BS can only transmit data to K direct users. If the serving node is a user-relay, only one user is supported for each subchannel since the RSs have only one tranmit antenna.

If any relay node m transmits data to a cell-edge user $c \in \mathbb{S}_m$, the data rate between any two nodes can be calculated as,

$$R_{m,c,n} = \frac{B}{N}\log_2(1 + \gamma_{m,c,n}) \tag{17}$$

where $\gamma_{m,c,n} = \dfrac{P_{m,n}|h_{m,c,n}|^2}{N_0(B/N)}$ is the SNR between a transmitter node m and receiver node c on subchannel n. $P_{m,n}$ is the transmitted power per subchannel, $h_{m,c,n}$ is the channel coefficient between two nodes (m and c) that includes pathloss, shadowing and multipath.

The demand metrics for any BS → MS and RS → MS links are expressed below, respectively.

$$\tilde{W}_{0,k,n,\pi} = R_{0,k,n,\pi}\tilde{Q}_k^0, \quad \forall k \in \mathbb{K}, \quad \forall \pi \tag{18}$$

$$\tilde{W}_{m,c,n} = R_{m,c,n}\tilde{Q}_c^m, \quad \forall m \in \mathbb{M}, \quad \forall c \in \mathbb{S}_m, \tag{19}$$

where $\tilde{Q}_k^0$ is the new queue length of mobile user k at BS and $\tilde{Q}_c^m$ is the new queue length of cell-edge user c at user-relay m, after the resource allocation of subframe 1. By using these demand metrics, the subframe 2 optimization problem can be given in detail as follows:

$$\max_{\rho^{(2)}_{0,k,n,\pi},\sigma^{(2)}_{m,c,n}} \sum_{n=1}^{N}\sum_{k=1}^{K}\sum_{\pi=1}^{\Pi^{(2)}} \rho^{(2)}_{0,k,n,\pi}\tilde{W}_{0,k,n,\pi} + \sum_{n=1}^{N}\sum_{m=1}^{M}\sum_{c\in\mathbb{S}_m} \sigma^{(2)}_{m,c,n}\tilde{W}_{m,c,n} \tag{20}$$

subject to

$$\rho^{(2)}_{0,k,n,\pi} \in \{0, 1\}, \quad \forall k, \forall n, \forall \pi \tag{21}$$

$$\sigma^{(2)}_{m,c,n} \in \{0, 1\}, \quad \forall m, \forall c \in \mathbb{S}_m, \quad \forall n \tag{22}$$

$$\sum_{k=1}^{K}\rho^{(2)}_{0,k,n,\pi}(1-\varrho)+\sum_{m=1}^{M}\sum_{c\in\mathbb{S}_m}\sigma^{(2)}_{m,c,n}\varrho\le N_t,\quad \forall n,\forall\pi \tag{23}$$

$$\sum_{n=1}^{N}\sum_{\pi=1}^{\Pi^{(2)}}\rho^{(2)}_{0,k,n,\pi}R_{0,k,n,\pi}T_2\le\tilde{Q}^0_k,\quad\forall k \tag{24}$$

$$\sum_{n=1}^{N}\sigma^{(2)}_{m,c,n}R_{m,c,n}T_2\le\tilde{Q}^m_c,\quad\forall m,\forall c\in\mathbb{S}_m \tag{25}$$

The $\rho^{(2)}_{0,k,n,\pi}$ is the binary assignment variable such that $\rho^{(2)}_{0,k,n,\pi}=1$ if user $k\in S_{\pi,n}$ and $S_{\pi,n}$ is selected on the nth subchannel; otherwise $\rho^{(2)}_{0,k,n,\pi}=0$ during the subframe 2. The variable $\sigma^{(2)}_{m,c,n}$ is the mth relay binary indicator that assigns subchannel n to the cell-edge user c at RS m during the subframe 2. The constraint given in Eq. (23) tells us that maximum N_t users can be supported for the subchannel n. In this constraint, we define a binary indicator ϱ given in Eq. (26) to ensure that one link will be active at subchannel n, if the serving node is an user-relay.

$$\varrho=\begin{cases}1, & \sum_{m=1}^{M}\sum_{c\in\mathbb{S}_m}\sigma^{(2)}_{m,c,n}=1,\quad\forall n\\ 0, & o.w.\end{cases} \tag{26}$$

Moreover, the constraints given in Eqs. (24) and (25) guarantee to transmit data from BS to any mobile user k not more than $\tilde{Q}^0_k$ and from RS m to cell-edge user c not more than $\tilde{Q}^m_c$, respectively.

At the end of this subframe, an allocation frame is completed and the queue lengths at BS and each RS are updated, respectively as follows:

$$Q^0_k=\tilde{Q}^0_k-\sum_{n=1}^{N}\sum_{\pi=1}^{\Pi^{(2)}}\rho^{(2)}_{0,k,n,\pi}R_{0,k,n,\pi}T_2,\quad\forall k\in\mathbb{K} \tag{27}$$

$$Q^m_c=\tilde{Q}^m_c-\sum_{n=1}^{N}\sigma^{(2)}_{m,c,n}R_{m,c,n}T_2,\quad\forall m,\quad\forall c\in\mathbb{S}_m \tag{28}$$

The new traffic arrivals, X_k are added to the users' buffer at BS before the following downlink allocation frame. Thus, the updated queue lenghts at BS is expressed:

$$Q^0_k=Q^0_k+X_k,\quad\forall k\in\mathbb{K} \tag{29}$$

3 The proposed joint relay selection and resource allocation algorithm for MISO-OFDMA

To find an optimum solution for the defined problems in the former section is very difficult and time-consuming in such a complex environment that contains multiple users, multiple relays, multiple antennas and multiple subchannels. Thus, we propose two steps sub-optimal algorithm in order to solve the problems for subframes 1 and 2. The proposed algorithm is given in detail below. In the following proposed algorithm notice that index π is omitted for the rate and demand metric calculations because they refer to specific set of users. Moreover, T is used instead of the transmission durations of the first and second subframes T_1 and T_2, since they are assumed to be equal $T_1=T_2=T$, as mentioned earlier

Step 1 - Solution for Subrame 1

```
• Update the queue lenghts of each user at BS, $\mathbb{Q}^0=[Q^0_1,\ldots,Q^0_K]$ by new arrivals and update the affected queues of the users at relay $m$, $\mathbb{Q}^m=[Q^m_{M+1},\ldots,Q^m_{M+L}]$.
• Initially, $n=1$,
while $\sum_{k=1}^{K}Q^0_k\neq 0$ and $n\le N$ do
  ∗ Set $|S_n|=\emptyset$ and $\mathbb{U}=\mathbb{K}$
  ∗ Calculate the demand metrics for all users by using
    Eq. (5). As mentioned before, index $\pi$ is
    omitted for the remaining calculations. Thus,
    Eq. (5) can be rewritten as follows;
        $W_{0,k,n}=R_{0,k,n}Q^0_k,\quad\forall k\in\mathbb{K}$
  ∗ Calculate the demand metrics for user-relay
    candidates by using Eq. (6). After omitting $\pi$,
    this equation can also be rewritten as follows;
        $W'_{0,m,n}=R_{0,m,n}\max_{c\in\mathbb{S}_m}\{(Q^0_c-Q^m_c)^+\},\forall m\in\mathbb{M}$
        $\ell^m=\arg\max_{c\in\mathbb{S}_m}\{(Q^0_c-Q^m_c)^+\}$
    where $\ell^m$ is the cell-edge user that will be served
    through relay $m$.
  ∗ Decide the best link at subchannel $n$ and set $a=1$.
        $k^*=\arg\max_k\{W_{0,k,n}\},\quad m^*=\arg\max_m\{W'_{0,m,n}\}$
    if $W'_{0,m^*,n}>W_{0,k^*,n}$ do
      ⋆ BS transmits data to user-relay node $m^*$.
      ⋆ $S_n(a)=\{m^*\}$ where $S_n(a)$ shows the allocation
        result of the step $a$ and $\mathbf{H}(S_n(a))=\mathbf{h}_{0,m^*,n}$.
      ⋆ $\mathbb{U}\leftarrow\mathbb{U}\setminus\{m^*\}$.
    else do
      ⋆ BS transmits data to direct user $k^*$.
      ⋆ $S_n(a)=\{k^*\}$ and $\mathbf{H}(S_n(a))=\mathbf{h}_{0,k^*,n}$
      ⋆ $\mathbb{U}\leftarrow\mathbb{U}\setminus\{k^*\}$.
    end if
  ∗ Compute the achievable rate $\mathcal{R}(S_n(a))$ for $n$.
      $\mathcal{R}(S_n(a))=\sum_{j\in S_n(a)}r_j$
```

```
  $r_j = \begin{cases} \min\{Q^0_{\ell j}, R_{0,j,n}T\}, & \text{if } j \text{ is a user-relay} \\ \min\{Q^0_j, R_{0,j,n}T\}, & \text{if } j \text{ is a direct user} \end{cases}$
∗ Add new users and/or user-relays to subchannel $n$.
  while $a \leq N_t$ do
    ∘ Increase $a$ by 1,
    ∘ Find as much as orthogonal users to the already
      selected ones in $S_n(a-1)$ by using the projector
      matrix, $\mathbf{P}^{\perp}_a$.
        · $\mathbf{P}^{\perp}_a = \mathbf{I}_{N_t} - \tilde{\mathbf{H}}^H(\tilde{\mathbf{H}}\tilde{\mathbf{H}}^H)^{-1}\tilde{\mathbf{H}}$,
          where $\tilde{\mathbf{H}} = \mathbf{H}_n(S_n(a-1))$.
        · $q_\kappa = \mathbf{h}_{0,\kappa,n}\mathbf{P}^{\perp}_a\mathbf{h}^H_{0,\kappa,n}, \forall \kappa \in \mathbb{U}$
        · Form a group, $\zeta$, that contains the first $\mathcal{V}$ users
          that have the largest values of $q_\kappa$
    ∘ Calculate new demand metrics of each link $\phi \in \zeta$
      by using Eq. (5) for direct users. If $\phi$ is
      not only direct user but also user-relay candidate,
      use Eq. (6) for relaying case.
    ∘ Find the node $z \in \zeta$ that has the maximum
      demand metric.
    ∘ Decide admitting this node to subchannel $n$.
      if $\mathcal{R}(S_n(a-1) \cup \{z\}) \geq \mathcal{R}(S_n(a-1))$ do
        ⋆ $S_n(a) = S_n(a-1) \cup \{z\}$,
          $\mathcal{R}(S_n(a)) = \mathcal{R}(S_n(a-1) \cup \{z\})$
        ⋆ $\mathbb{U} \leftarrow \mathbb{U} \setminus \{z\}$.
        ⋆ $\mathbf{H}(S_n(a)) = [\mathbf{H}(S_n(a-1))^T \ \mathbf{h}^T_{0,z,n}]^T$.
      else do
        ⋆ Terminate the allocation loop in $n$.
      end if
  end while
∗ Update the queues for each node $j \in S_n(a)$
  if $j$ is a relay node do
    . Decrease the queue length of served user by relay
      $j$ at BS.
          $Q^0_{\ell j} = Q^0_{\ell j} - \min\{Q^0_{\ell j}, R_{0,j,n}T\}$
    . Increase the queue length of this user at relay $j$.
          $Q^j_{\ell j} = Q^j_{\ell j} + \min\{Q^0_{\ell j}, R_{0,j,n}T\}$
  else do
    . Decrease the queue length of the direct user at
      BS.
          $Q^0_j = Q^0_j - \min\{Q^0_j, R_{0,j,n}T\}$
  end if
∗ Increase $n$ by 1.
end while
```

In the first step, the algorithm allocates the resources to the direct users and user-relay candidates. Multiple users and/or user-relays can be allocated to each subchannel since the BS has N_t transmit antennas. In this step, demand metrics are calculated for all users and user-relay candidates on subchannel n as given in Eqs. (5) and (6), respectively. Then, the best BS link that has the maximum demand metric out of all potential links is determined. Thereafter, new users and/or user-relays are admitted to subchannel n according to the following two criterias: (1) additional node should be as much as orthogonal to the already selected users and/or user-relay candidates, (2) it should increase the sum data rate in this subchannel. In order to determine an orthogonal user set for the already selected nodes, a projector matrix, $\mathbf{P}^{\perp}$ is calculated [47] and each remaining channel vectors belonging to users not selected yet are projected onto the orthogonal complement of the subspace spanned by the channels of the selected nodes. Then, through these orthogonal users, we select the largest valued $\mathcal{V}$ users and form a group, ζ. The value of $\mathcal{V}$ is decided heuristically as $min\{|\mathbb{U}|, N_t\}$. The demand metrics of each link in ζ are calculated by using Eq. (5) for direct users and Eq. (6) for user-relays. Thereafter, the node whose demand metric is maximum is selected. After selecting the node, it is controlled that if it increases the sum rate of this subchannel in order to admit this user to subchannel n. After allocating all selected nodes on subchannel n, the queue lenghts at BS and user-relays are updated. This step is repeated until all subchannels are exhausted or the queue lenghts at BS is zero.

Step 2- Solution for Subframe 2

```
• Let $\tilde{\mathbb{Q}}^m$ is the updated queue of node $m$ after first subframe
  where $m = 0, 1, 2, \ldots, M$ and the case $m = 0$ represents
  BS node.
• Initially, $n = 1$
while $\left( \sum_{k=1}^{K} \tilde{Q}^0_k \neq 0 \text{ or } \sum_{m=1}^{M} \sum_{c \in \mathbb{S}_m} \tilde{Q}^m_c \neq 0 \right)$ and
 $n \leq N$ do
 ∗ Set $|S_n| = \emptyset$, $\mathbb{U} = \mathbb{K}$ and $a = 1$
 ∗ Find the best demand metric for each node by using
   Eqs. (18) and (19), respectively. Index $\pi$ is also
   omitted from these equations.
       for $m = 0$ to $M$ do
           $u_{m,n} = \begin{cases} \arg\max_{k \in \mathbb{K}}\{\tilde{W}_{0,k,n}\}, & \text{if } m = 0 \\ \arg\max_{c \in \mathbb{S}_m}\{\tilde{W}_{m,c,n}\}, & o.w \end{cases}$
           $\tilde{W}_{m,n} = \tilde{W}_{m,u_{m,n},n}$
       end for
 ∗ Decide the transmitting node $\hat{m}$ and related serviced
   user $\kappa$,
           $\hat{m} = \arg\max_m\{\tilde{W}_{m,n}\}, \qquad \kappa = u_{\hat{m},n}$
     if $\hat{m} = 0$ do
       ⋆ BS transmits data to direct users. Since the
         BS has multiple transmit antennas, more
         direct users can be allocated to subchannel $n$.
```

```
        ⋆ $S_n(a) = \{\kappa\}, \mathbf{H}_n(S_n(a)) = \mathbf{h}_{0,\kappa,n}$,
          $\mathbb{U} \leftarrow \mathbb{U} \setminus \{\kappa\}$,
        ⋆ Compute the achievable rate for subchannel
          $n, \mathcal{R}(S_n(a))$.
        ⋆ Add new users to subchannel $n$.
        while $a \le N_t$ do
          ∘ Increase $a$ by 1,
          ∘ Find as much as orthogonal users to the
            already selected ones in $S_n(a-1)$ by using
            the projector matrix, $\mathbf{P}_a^{\perp}$.
              · $\mathbf{P}_a^{\perp} = \mathbf{I}_{N_t} - \tilde{\mathbf{H}}^H(\tilde{\mathbf{H}}\tilde{\mathbf{H}}^H)^{-1}\tilde{\mathbf{H}}$,
                where $\tilde{\mathbf{H}} = \mathbf{H}_n(S_n(a-1))$.
              · $q_u = \mathbf{h}_{0,u,n}\mathbf{P}_a^{\perp}\mathbf{h}_{0,u,n}^H, \forall u \in \mathbb{U}$
              · Form a group, $\Lambda$, of candidates that
                contains the first $\mathcal{V}$ users that have the
                largest values of $q_u$
          ∘ Calculate demand metrics of each link in $\Lambda$
            by using Eq. (18).
          ∘ Find the user $\lambda \in \Lambda$ that has the maximum
            demand metric.
          ∘ Decide admitting this user to $n$.
          if $\mathcal{R}(S_n(a-1) \cup \{\lambda\}) \ge \mathcal{R}(S_n(a-1))$ do
              ▪ $S_n(a) = S_n(a-1) \cup \{\lambda\}$,
                $\mathcal{R}(S_n(a)) = \mathcal{R}(S_n(a-1) \cup \{\lambda\})$,
              ▪ $\mathbf{H}_n(S_n(a)) = [\mathbf{H}_n(S_n(a-1))^T \; \mathbf{h}_{0,\lambda,n}^T]^T$,
                $\mathbb{U} \leftarrow \mathbb{U} \setminus \{\lambda\}$
          else do
              ▪ Terminate the allocation loop in $n$.
          end if
        end while
        ⋆ Update the queues for direct users $j \in S_n(a)$
              $\tilde{Q}_j^0 = \tilde{Q}_j^0 - \min\{\tilde{Q}_j^0, R_{0,j,n}T\}$
    elseif $\hat{m} \neq 0$ do
        ⋆ RS transmits data to cell-edge users. Do not
          add any more node on this subchannel
          since RS has single transmit antenna.
        ⋆ $S_n(a) = \{\kappa\}$.
        ⋆ Update the queue values for relay nodes
              $\tilde{Q}_\kappa^{\hat{m}} = \tilde{Q}_\kappa^{\hat{m}} - \min\{\tilde{Q}_\kappa^{\hat{m}}, R_{\hat{m},\kappa,n}T\}$
    end if
  ∗ Increase $n$ by 1.
end while
```

In the second step of the algorithm, BS shares the resources with user-relays to transmit to the selected users. The link which has the maximum demand metric belonging to each node (BS and RSs) are determined and then the best link is selected among these links on subchannel n. If the best link is BS link, new users are admitted to the subchannel n according to the two criterias explained above. If the best link is RS link, only one link is active for this subchannel. According to the selected node and serviced user, the queue values are updated. This step is terminated when the queue values at each node reach to zero or the available subchannels are finished.

4 Performance evaluations

We obtain the performance results to illustrate the benefits of the proposed channel and queue-aware joint relay selection and resource allocation algorithm in a single cell MISO-OFDMA system in which the BS has $N_t = 4$ transmit antennas and all users have single receive antenna. We consider a downlink network topology with a BS located in the center and surrounded by MSs as shown in Fig. 4. R_1 distance is selected as 0.6 of the cell radius and the users which are far from R_1 in the cell is labeled as the cell-edge users [48,49]. Cellular network users are generally assumed to be uniformly distributed however in practice they are not always uniformly distributed because of the hot-spot regions and capacity centric deployment of BSs. BSs can be mounted to the areas where user density is high. In this case, it can be thought that the user density is reduced as moving away from the BS. Thus, in this study, the percentage of cell-edge users is chosen as 10%. The evaluation of relay candidate selection coverage area radius R_2 is performed in [32] and it is shown that the maximum performance is achieved when coverage area radius is almost 0.5 of the cell-radius. It is shown that the performance saturates for higher values of coverage area radius and good relay candidates for a cell-edge user are not likely to be found any further than $R/2$ from this cell-edge user. Thus, we select the relay candidate selection coverage

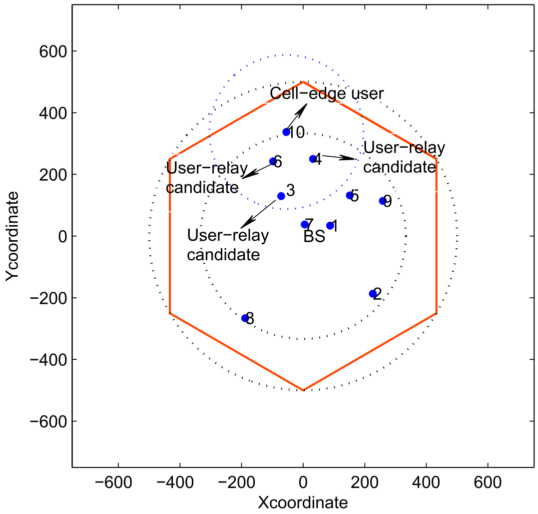

Fig. 4 User-relay assisted network topology

Table 1 Simulation parameters

Parameter	Value
Frequency	2 GHz
Bandwidth	20 MHz
Thermal noise density	−134.89 dBm/Hz
$N_t \times N_r$ antennas	4 × 1
BS transmit power	46 dBm
Fixed relay transmit power	37 dBm
User-relay transmit power	24 dBm
Cell radius	500 m
MS min. close-in distance to BS	35 m
Frame duration (T_{frame})	10 ms
Simulation duration	1 s
Pathloss model	BS → MS, BS → RS and RS → MS $128.1 + 37.6 \log_{10} \mathrm{d(km)}$
Shadowing model	Lognormal distribution, $\mu = 0, \sigma = 10\,\mathrm{dB}$
Multipath model	Extended pedesterian A

area radius $R_2 = R/2$. Independent Poisson packet arrival process is assumed at BS queues with an average arrival rate 336 kbps per user. All users have the same traffic pattern. In the simulations, we use the parameters as summarized in Table 1. Simulation results are performed for 1000 Monte-Carlo trials.

We compare the proposed user-relay assisted scheme with the two different MISO-OFDMA based schemes in which queue-aware schedulers are used. The first scheme that is called *w/o relay*, there is no relay in the system and all users communicate to the BS directly during the whole transmission frame. In this scheme, the resource allocation is performed at BS by using a greedy algorithm that assigns the available resources to the users sequentially based on their rate and queue values. Each subchannel is allocated to the link with the user having maximum product of rate and queue values. The second one is the fixed relay assisted scheme in which we locate 3 fixed relays at equal angles and equal distances to the BS as seen in Fig. 5. The distance of each fixed RSs from the BS is selected as 0.6 of the cell radius. The path loss, shadowing and multipath channel parameters for all links except the BS → RS link, which has 4 dB lognormal shadowing and experience Rician fading with a Rician factor of 10 dB, is the same with user-relay assisted scheme and given in Table 1.

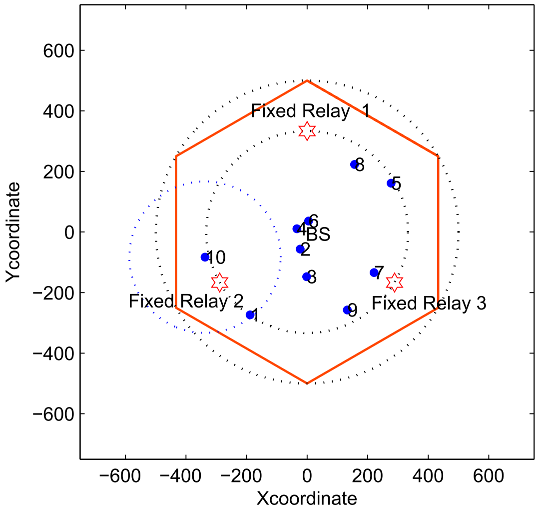

Fig. 5 Fixed relay assisted network topology

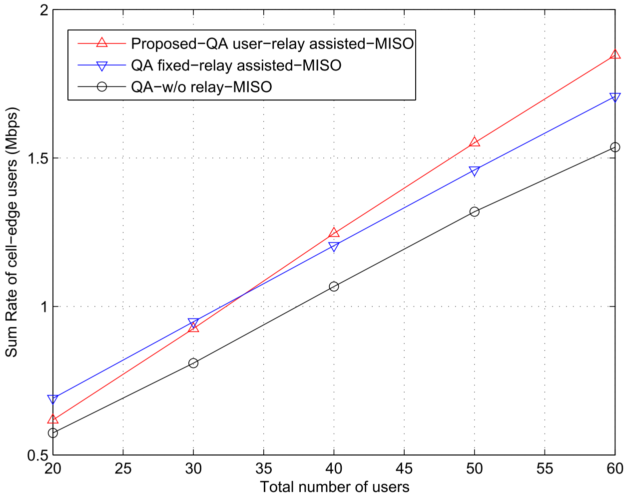

Fig. 6 Sum rate of cell edge users versus number of users

In the simulations, we let only cell-edge users to use relays for the user-relay and fixed relay assisted schemes in order to increase the data rate of these users. In Fig. 6, the cell-edge users' data rate as a function of total number of users is illustrated. As expected, relay assisted schemes outperform the *w/o relay* scheme, since they have a chance to communicate with the help of a relay when the direct link of the cell-edge users is not good enough to communicate. Among all schemes, the cell-edge users' data rate of the *w/o relay* scheme is the lowest and the proposed user-relay assisted scheme outperforms the fixed relay assisted scheme over 35 users and the difference is getting higher when the number of users increases. The reason is that in user relay assisted networks, the users' density has an impact on the relaying opportunity. Depending on this, the system performance is affected. In lower user density case, the number of relay candidates is limited so the cell-edge users may not find suitable relay candidates that decrease the system performance. However, in higher user density case not only the number of users but also the user-relays is increasing in the cell since there are more choice to select a user relay to optimize the system performance. The results show that the cell edge users' data rates are increased by using user-relay assisted networks therefore

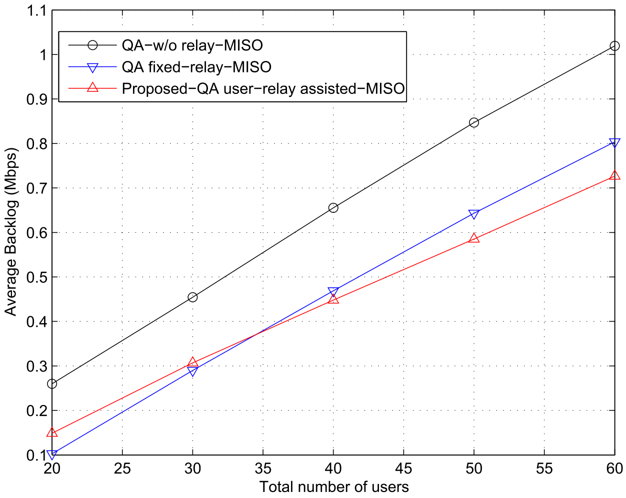

Fig. 7 Backlog of the queues versus number of users

these users are not victimized because of their locations to the BS.

In Fig. 7, the average backlog of the queues, which is averaged over the simulation duration, versus total number of users is given. It is illustrated from this figure that the fixed relay assisted scheme and the proposed user-relay assisted scheme have lower backlog value than *w/o relay* scheme. Moreover, the proposed user-relay assisted scheme outperforms the fixed relay assisted scheme when the number of users is getting higher. Since the remaining data at the end of the simulation time is the lowest in the proposed scheme, it can be interpreted as the overall performance is not deteriorated although the cell-edge users' data rate is increased.

In queue-aware communication schemes, not only the data rate but also the waiting time in the queue is important. Therefore, the delay information is measured as the time a data unit enters the BS till the time it is delivered in the intended user. The average delay of different schemes is compared in Fig. 8. It is seen from this figure that the proposed user-relay assisted scheme has lower delay value compared to *w/o relay* scheme for all users and it outperforms the fixed relay assisted scheme for the higher number of users.

Finally, we compare the proposed queue aware relay selection and resource allocation algorithm for MISO-OFDMA with the SISO-OFDMA scheme [44] in order to show the effect of multiple antennas over OFDMA based relaying technology. Firstly, in Fig. 9, the sum data rate of the cell-edge users are compared for different number of users. It is observed that the cell-edge users' sum data rate is increased by using multiple antennas at the BS. Secondly, average backlog of the queues are compared in Fig. 10 in order to examine

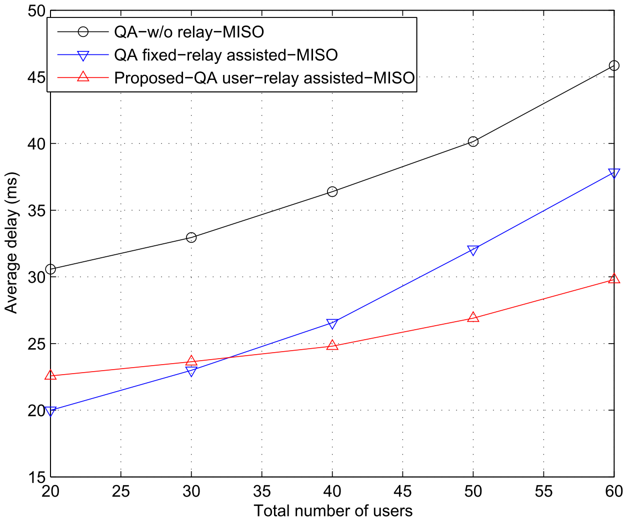

Fig. 8 Average delay versus number of users

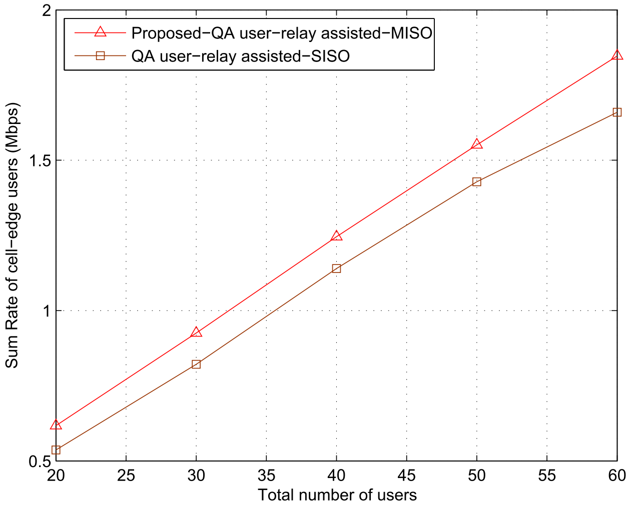

Fig. 9 Proposed MISO versus SISO case-cell-edge data rate comparion

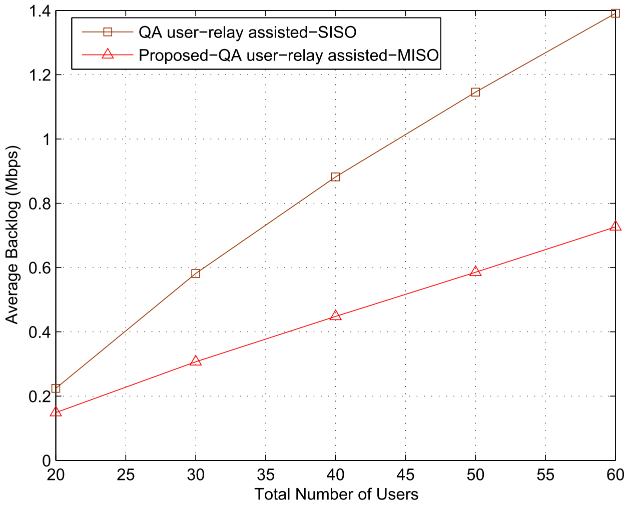

Fig. 10 Proposed MISO versus SISO case-backlog of the queues comparison

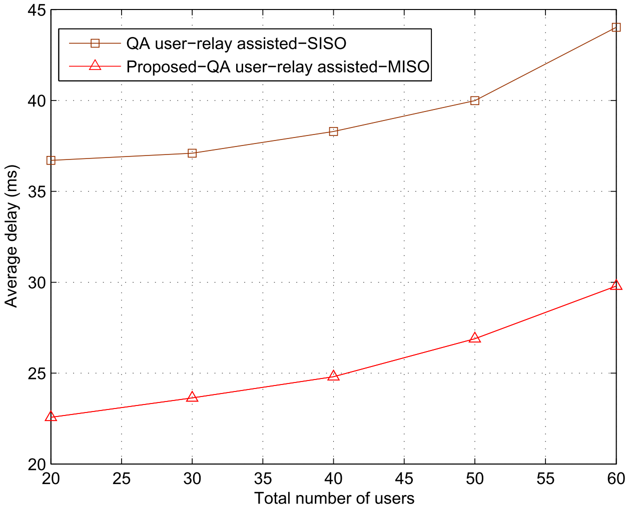

Fig. 11 Proposed MISO versus SISO case-average delay comparison

the effect of multiple antennas on the overall system performance. It is seen that the average backlog is reduced by using the proposed MISO scheme. This result is important since it shows that not only cell-edge users' data rate is increased but also the overall systems' backlog is decreased by using multiple antennas. Lastly, the delay comparison results are given in Fig. 11 and it is observed that the proposed MISO scheme has a lower delay time compared to SISO scheme for all number of users. According to these results, MISO-OFDMA scheme has higher cell-edge users' data rate, lower backlog and delay values than SISO-OFDMA case since more than one link is supported on each subchannel in MISO-OFDMA case.

All users are assumed to utilize the same service and thus have the same traffic arrival statistics throughout the previous simulation results. To examine the effect of different traffic types on the proposed scheme, the MISO-OFDMA and SISO-OFDMA schemes are also compared by using a different scenario in which the users are assumed to utilize different data rates. Thus, half of the users are assumed to have average arrival rate of 336 kbps per user and half of them are assumed to have 168 kbps per user. Figures 12,13 and 14 show us the cell-edge users' data rate, backlog and delay comparison results, respectively. It is seen that the proposed algorithm also outperforms the existing schemes in the case of different data rates are assigned for the users. Thus, different data rates can also be supported with the proposed scheme.

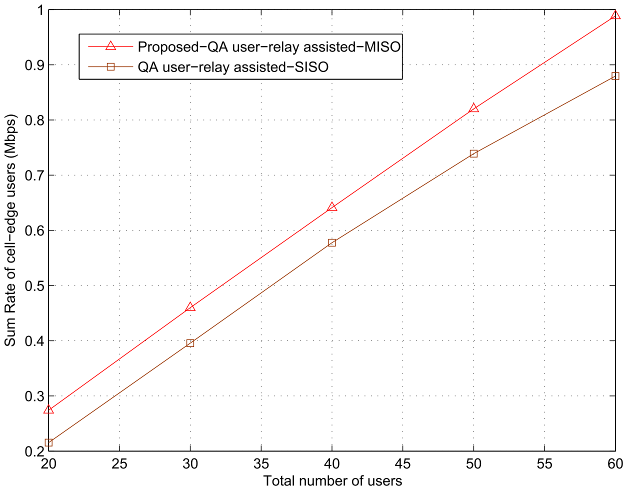

Fig. 12 Cell-edge data rate comparison for different data rates scenario

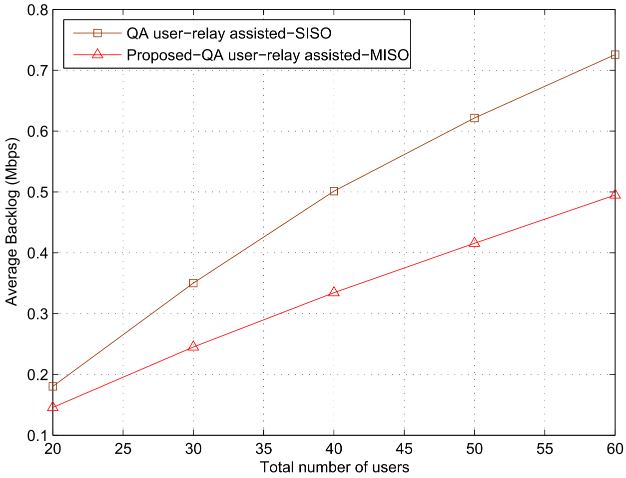

Fig. 13 Backlog of the queues comparison for different data rates scenario

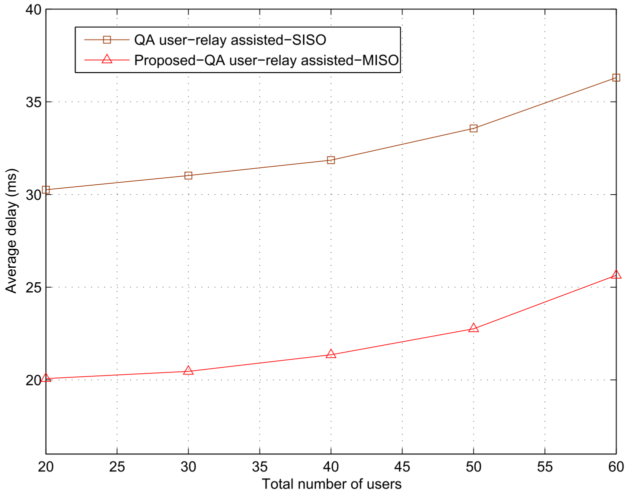

Fig. 14 Average delay comparison for different data rates scenario

5 Conclusion

In this paper, we have defined RRM optimization problem for MISO-OFDMA based user-relay assisted downlink cellular networks. We have proposed efficient suboptimal channel and queue-aware joint relay selection and resource allocation algorithm for this multi-user, multi-relay and multi-antenna environment. When the relay selection and resource allocation have been performed disjointly, the system performance can be limited. Thus, the proposed algorithm performs joint relay selection and resource allocation to overcome this limitation. In the proposed algorithm, the system resources have been allocated by using not only the channel gain of the users but also the queue lengths of the users. Therefore, the system resources have not been wasted and they have been used efficiently that when some users have no data to send at an allocation instant, more resources have been allocated to the other users to provide a better and fairer service to them. The simulation results showed us that the proposed user-relay assisted MISO-OFDMA scheme increased the data rate of the cell-edge users, decreased the average backlog data of the queues and minimized the queuing delays when compared to existing non-relaying and fixed relay assisted MISO-OFDMA schemes. Moreover, the proposed solutions for the multiple antenna scheme are compared with the existing single antenna scheme. It was shown that the MISO-OFDMA scheme increased the cell-edge users' data rate, decreased the average data rate waiting in the queues and the delay time because of the queues when compared to SISO-OFDMA scheme without additional transmit power or bandwidth.

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