Reduced feedback link design for device-relaying enhanced multiple-input single-output orthogonal frequency-division multiple access wireless systems

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Device-relaying enhanced multiple-input single-output (MISO) orthogonal frequency-division multiple access (OFDMA) systems are one of the promising and cost-effective methods to satisfy data rate requirements of future wireless networks. To implement device relaying in MISO-OFDMA systems efficiently, the channel state information belonging to all links is required at the base station. However, the feedback load increases with the number of users, device-relay candidates, antennas and subcarriers. A novel scheduling and a joint feedback link design and relay selection algorithm in device-relaying enhanced downlink MISO-OFDMA systems are proposed, while reducing the feedback load significantly without sacrificing the system performance.

Introduction: Future networks promise higher data rates, larger network coverage and higher energy efficiency by developing novel radio concepts in the fifth generation (5G) wireless communication systems [1]. To improve overall performance, various technologies are presented for 5G wireless systems including relay-aided techniques through fixed, mobile, multi-hop and device equipment with the benefits of device-to-device (D2D) communications [2]. Device-relaying-based transmission provides more flexibility than fixed relaying in expanding the base station (BS) coverage into larger areas. The combination of multiple-input single-output (MISO) orthogonal frequency division multiple access (OFDMA) and device-equipment-based relaying will be one of the promising solution to achieve the requirements of 5G wireless systems. Relay selection and scheduling are very important aspects for designing efficient relay-assisted wireless systems. In [3], the investigation of learning the optimal cooperation policy including the usage of downlink device relaying has been examined by employing a supervised learning algorithm. In [4], an relay allocation mechanism for user-centric relay-assisted D2D communications has been presented by considering the different demands of users. In [5], a low-complexity joint scheme which simultaneously selects multiple relays and users for cooperation in uplink has been studied by utilising only the channel gains between the nodes. The device-relay-based transmission schemes in the literature assume that all required channel state information (CSI) are available at the transmitter since the system performance are highly sensitive to the quantity of feedback information. However, this feedback load increases with the number of users, device-relay candidates, antennas and subcarriers. In this Letter, we propose a novel scheduling and joint feedback link design and relay selection algorithm to reduce the feedback load while achieving the potential gains of device-relaying schemes in downlink MISO-OFDMA systems.

System model: In this Letter, we consider a device-relay enhanced MISO-OFDMA system where the BS is located in the centre of the cell. The K users with one receive antenna are selected from the set $\mathcal{K} = \{1, 2, \ldots, K\}$. The uth transmitter node has N_u^{t} transmit antennas. The cell area of radius R is divided into two regions: the inner region with radius $2R/3$ and the outer region otherwise. The users which are in the inner region are called cell-centre users. The users which are in the outer region are called cell-edge users. The cell-centre users are selected from the set $\mathcal{M} = \{1, 2, \ldots, M\}$ and they can act as device-relay candidates for the cell-edge users. The cell-edge users are selected from the set $\mathcal{L} = \{M+1, M+2, \ldots, K\}$ and they can use device-relaying assisted transmission. In the system model, the set of cell-centre users and the set of cell-edge users construct the whole set of users as $\mathcal{K} = \mathcal{L} \cup \mathcal{M}$. The total available bandwidth B is divided into Q clusters and each cluster consists of a set of adjacent OFDM subcarriers [6].

In this Letter, our aim is to satisfy users' data rate requirements during a whole transmission frame while maximising the total capacity. To provide an efficient solution, we use a device-relaying-based MISO-OFDMA transmission with decode and forward strategy and a half-duplex operation which divides the whole transmission frame into two equal subframes. In the first subframe, the BS can transmit data to all the users and the device relays. In the second subframe, all the users can receive data from the BS. Besides that, the cell-edge users can also receive data from their device relays.

The optimisation problem is defined as in the following

$$\max_{a_{u,k,q,b}} \sum_{u=1}^{U} \sum_{k=1}^{K} \sum_{q=1}^{Q} \sum_{b=1}^{N_u^{\mathrm{t}}} a_{u,k,q,b} R_{u,k,q,b} \tag{1}$$

subject to

$$R_k \geq T_k \quad \forall k \quad (C_1) \tag{2}$$

$$\sum_{k=1}^{K} a_{u,k,q,b} \leq 1 \quad \forall u, \forall q, \forall b \quad (C_2) \tag{3}$$

$$a_{u,k,q,b} \in \{0, 1\} \quad \forall u, \forall k, \forall q, \forall b \quad (C_3) \tag{4}$$

where (C_1) defines the constraint for the data rate requirement which has to be satisfied at the end of the whole transmission frame with T_k is the threshold data rate, (C_2) and (C_3) indicate the constraints for cluster allocation with $a_{u,k,q,b}$; $b \in \{1, 2, \ldots, N_u^{\mathrm{t}}\}$ indicates that cluster q is allocated to user k for beam b at transmitter node u if $a_{u,k,q,b} = 1$. The value of $u = 1, 2, \ldots, U$ indicates the device-relaying-based communications with $U \leq M$, while u is labelled as 0 to represent direct transmission between BS and the users. The data rate of user is determined by

$$R_k = \sum_{u=1}^{U} \sum_{q=1}^{Q} \sum_{b=1}^{N_u^{\mathrm{t}}} a_{u,k,q,b} R_{u,k,q,b} \tag{5}$$

The data rate of direct transmission is given by $R_{0,k,q,b} = \frac{B}{Q}\log_2\left(1 + \frac{P_0|\boldsymbol{h}_{0,k,q}^{\mathrm{H}}\boldsymbol{w}_{q,b}|^2}{N_0 B}\right)$ where P_0 is the transmitted power of BS, N_0 is the noise spectral density, $\boldsymbol{h}_{0,k,q} = [h_{0,k,q,1}, \ldots, h_{0,k,q,N_0^{\mathrm{t}}}]^{\mathrm{T}}$ is the channel vector between the BS and the receiver k for cluster q including path loss, shadowing and multipath fading, $\boldsymbol{w}_{q,b}$ is the precoding vector based on the scheduled users and/or device-relays obtained by zero-forcing beamforming [6]. The data rate of uth device-relaying node is determined by $R_{u,k,q,1} = \frac{B}{Q}\log_2\left(1 + \frac{P_u|h_{u,k,q,1}|^2}{N_0 B}\right)$ where P_u is the transmitted power of device-relay having one transmit antenna, $h_{u,k,q,1}$ is the channel coefficient between the device relaying u and the receiver k for cluster q including path loss, shadowing and multipath fading.

The problem defined in (1) with the given constraints belongs to class of discrete optimisation with the complexity of $O(Q^{KUN_t})$. Since the optimal solution is very complex to implement, we perform a sub-optimal solution that perform the scheduling at each cluster separately with the complexity of $O(Q(K+U)^{N_t})$.

Proposed algorithm: To perform resource allocation including relay selection, scheduling and precoding for MISO-OFDMA systems efficiently, the CSI between the BS and all users and between all device-relay candidates and the cell-edge users are required at the BS. This feedback load is increased with the number of users, clusters, antennas and device-relay candidates. To reduce the feedback load, we propose a feedback link to select the best clusters as well as device relays at the user side. In the proposed algorithm, the cell-centre users select their best clusters considering the CSI belonging to BS, while the cell-edge users perform cluster selection by taking into account the CSI belonging to BS and their selected device relays. Then, we propose a novel scheduling algorithm to implement device-relaying enhanced MISO-OFDMA systems to improve the performance of cell-edge users while having the same performance for cell-centre users.

Algorithm 1: The proposed joint relay selection and feedback link design:

- *Step 1.1:* The set of channel gains between the user k and the BS is constructed as $\mathcal{C}_{0,k} = \{\|\boldsymbol{h}_{0,k,q}\|, \ldots, \|\boldsymbol{h}_{0,k,Q}\|\}, \forall k \in \mathcal{K}$.
- *Step 1.2:* The cell-edge user selects its device-relay according to average channel gain as, $u_\ell = \arg\max_{\forall m \in \mathcal{M}} \bar{g}_{m,\ell}; \forall \ell \in \mathcal{L}$ where $\bar{g}_{m,\ell} = (1/Q)\sum_{q=1}^{Q} |h_{m,\ell,q,1}|^2, \forall \ell \in \mathcal{L}, \forall m \in \mathcal{M}$. Then, the set of channel gains between ℓth cell-edge user and its device relay is constructed as $\mathcal{C}_{u_\ell,\ell} = \{|h_{u_\ell,\ell,1}|, \ldots, |h_{u_\ell,\ell,Q}|\}, \forall \ell \in \mathcal{L}$. Each device-relay has a set $\mathcal{H}_u$ that includes its serving cell-edge users.
- *Step 1.3a:* Each user constructs independently a set $\mathcal{S}_k; \forall k \in \mathcal{K}$ composed of the $S \leq Q$ clusters which have the highest channel gains from the set $\mathcal{C}_{0,k}$.

- *Step 1.3b:* Each cell-edge user constructs independently a set $\mathcal{S}_\ell^r; \forall \ell \in \mathcal{L}$ composed of the $S \leq Q$ clusters which have the highest channel gains from the set $\mathcal{C}_{u_\ell,\ell}$.

For the first subframe, let $\mathcal{T}_q^{(1)}$ be the set of users and device relays that fed back their CSI associated to the cluster q as

$$\mathcal{T}_q^{(1)} = \{k \in \{1, \ldots, K\}:q \in \mathcal{S}_k\} \cup \{\ell \in \{M+1, \ldots, K\}:q \in \mathcal{S}_\ell^r\}$$

For the second subframe, let $\mathcal{T}_q^{(2)}$ be the set of users that fed back their CSI associated to the cluster q as $\mathcal{T}_q^{(2)} = \{k \in \{1, \ldots, K\}:q \in \mathcal{S}_k\}$. On the basis of the available CSI at the BS belonging to the sets $\mathcal{T}_q^{(1)}$ and $\mathcal{T}_q^{(2)}$, $q = 1, \ldots, Q$, obtained through the proposed feedback link, the scheduling and precoding algorithm are performed for first and second subframes to maximise the sum capacity while satisfying the constraints.
Algorithm 2: The proposed scheduling algorithm:
Step 2.1: Initialisation: Let $\dot{\mathcal{Q}} = \{1, \ldots, Q\}$, $\dot{\mathcal{Q}} = \{1, \ldots, Q\}$ be the set of clusters at first and second subframes, respectively, and $R_k = 0$, $\forall k \in \mathcal{K}$.
Step 2.2: For $\forall q \in \mathcal{Q}$ at the first subframe:

- Construct the set $\mathcal{Z}_q^s$; $\quad s = 1, , \ldots, \left|\binom{|\mathcal{T}_q^{(1)}|}{N_t}\right|$ that includes all possible pairs with combination of users and device relays to be scheduled.
- Choose the best pair $s^* = \arg\max_s \sum_{b=1}^{N_t} R_{0,k,q,b}(\mathcal{Z}_q^s)$
- For $\forall a^* \in \mathcal{Z}_q^{s^*}$:

- If a^* is cell-centre user and also acts as device relay, we propose to give priority to device-relaying transmission than direct one:
Select the best cell-edge user that uses a^* as device relay

$$c^* = \arg \max_{c \in \mathcal{H}_{a^*}} R_{a^*,c} \tag{6}$$

where $R_{a^*,c} = \min\{R_{0,a^*,q,b}, R_{a^*,c,q,1}\}$.
Update the data rate of cell-edge user by $R_{c^*} = R_{c^*} + R_{a^*,c}$.
Remove the cluster q from the second subframe cluster set, $\dot{\mathcal{Q}} \leftarrow \dot{\mathcal{Q}} \backslash \{q\}$.
- Else, $R_{a^*} = R_{a^*} + R_{0,a^*,q,b}$.

- If the scheduled users reach their threshold data rate, then remove all their CSI from the sets $\mathcal{T}_q^{(1)}$ and $\mathcal{T}_q^{(2)}$; $\forall q$.

Step 2.3: For $\forall \dot{q} \in \dot{\mathcal{Q}}$ at the second subframe:

- Construct the set $\dot{\mathcal{Z}}_q^s$; $\quad s = 1, \ldots, \left|\binom{|\mathcal{T}_q^{(2)}|}{N_t}\right|$ that includes all possible combination of users to be scheduled.
- Choose the best pair $\dot{s} = \arg\max_s \sum_{b=1}^{N_t} R_{0,k,q,b}(\dot{\mathcal{Z}}_q^s)$
- For $\forall \dot{a} \in \dot{\mathcal{Z}}_q^{\dot{s}}$:

Update the data rate by, $R_{\dot{a}} = R_{\dot{a}} + R_{0,\dot{a},q,b}$.

- If $R_{\dot{a}} \geq T_{\dot{a}}$, the user $\dot{a}$ is satisfied, then remove all its CSI from the set $\mathcal{T}_q^{(2)}$; $\forall q$.

Performance results: We give the performance results to illustrate the benefits of the proposed reduced feedback links design through wireless channels. The users are uniformly distributed in the cell-centre and cell-edge regions in a cell with a diameter of 500 m. The 20% of users are outer region while the remaining ones are in the inner region. The number of transmit antennas at the BS is $N_0^t = 2$ while all the users and device relays have only one antenna. The transmit power of the BS and the users that act device relays are set at 43.10 and 23 dBm, respectively. The noise power density is -174 dBm/Hz. The path loss between the BS and the users is modelled by $L_p = 128.1 + 37.6 \log_{10}(d(\text{km}))$dB and between the device-relays and the users is given as $L_r = 97.9 + 43.7 \log_{10}(d(\text{km}))$. The wireless channel is modelled using typical urban with a velocity of 10 km/h. The shadowing variance is chosen as 9 dB for the link between the BS and the users and 4 dB for the link between the device relays and the users. The bandwidth, the carrier frequency and the number of clusters are selected as 10 MHz, 2.4 GHz and $Q = 40$, respectively. The clusters are grouped into 12 subcarriers. The threshold data rate for all users is set to 600 kbps. The whole frame duration for relay-assisted transmission is 10 ms and the feedback information is provided every 1 ms. Note that the feedback load is also changing in one frame since the satisfied users do not continue to feed back any information to the BSs.

The performance evaluations in terms of percentage of the users which reaches to their threshold data rate and labelled as satisfied user are illustrated in Fig. 1. According to the results, the proposed device-relaying-based MISO-OFDMA system achieves the same performance than full feedback case while reducing the feedback load upto 25% as given in Table 1. In addition to that the performance of cell-edge users are improved by 3–20% with the proposed algorithm compared with MISO-OFDMA case while requiring 22–7% less feedback depending on the number of users in the system.

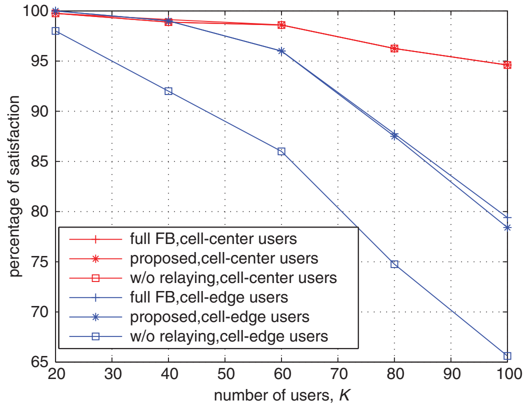

Fig. 1 *Percentage of users' satisfaction ratio*

Table 1: Average feedback load per cluster at each frame

K	20	40	60	80	100
Full FB	39	111	224	364	530
Proposed, $S = 30$	29	85	170	276	403
w/o relaying	37	102	195	307	433

Conclusion: In this Letter, we have proposed an efficient scheduling and joint reduced feedback link design and relay selection for device-relaying-based MISO-OFDMA systems. We have achieved all the gain of device-relaying strategies in MISO-OFDMA systems while reducing to feedback load significantly. Besides, the proposed device-relaying-based MISO-OFDMA system outperforms to MISO-OFDMA systems with having less feedback load.

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One or more of the Figures in this Letter are available in colour online.

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