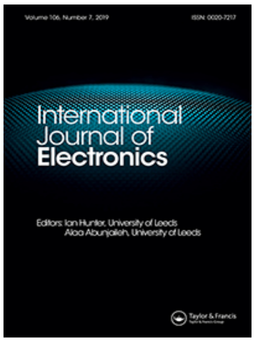

International Journal of Electronics

ISSN: 0020-7217 (Print) 1362-3060 (Online) Journal homepage: https://www.tandfonline.com/loi/tetn20

User-relay assisted cellular networks with multiple antennas

İlhan Baştürk & Berna Özbek

To cite this article: İlhan Baştürk & Berna Özbek (2019) User-relay assisted cellular networks with multiple antennas, International Journal of Electronics, 106:7, 1029-1040, DOI: 10.1080/00207217.2019.1579368

To link to this article: https://doi.org/10.1080/00207217.2019.1579368

Published online: 27 Feb 2019.

INTERNATIONAL JOURNAL OF ELECTRONICS
2019, VOL. 106, NO. 7, 1029–1040
https://doi.org/10.1080/00207217.2019.1579368

User-relay assisted cellular networks with multiple antennas

İlhan Baştürk[a] and Berna Özbek[b]

[a]Department of Electrical and Electronics Engineering, Aydın Adnan Menderes University, Aydın, Turkey;
[b]Department of Electrical and Electronics Engineering, İzmir Institute of Technology, İzmir, Turkey

ABSTRACT
User-relay assisted OFDMA-based cellular networks have gained great importance recently since these networks are indicated as one of the powerful technologies that will contribute the 5G standard. These networks can be used with novel three-phase frame structure unlike classical two-phase frame structure and can be enhanced with multiple antennas to utilise the advantages of them. The main advantage of the three-phase frame structure is taking care of the limitations of the current transceiver design in practical systems and not allowing users to be relay and user simultaneously. Diversity and capacity gains are also the advantages of extending the network with multiple antennas. In this paper, we will use the novel three-phase frame structure for downlink MISO-OFDMA cellular networks and develop resource management algorithms as relay selection and resource allocation to observe the benefits of this system.

ARTICLE HISTORY
Received 9 August 2017
Accepted 12 January 2019

KEYWORDS
User-relaying; OFDMA; multiple antenna networks; downlink; resource management

1. Introduction

Developments in the wireless communication technologies increase the number of mobile devices, such as smartphones, tablets, etc. so the wireless services and applications as social networking, online gaming and video platforms are being a part of our daily lives every day. Thus, users want to obtain ubiquitous seamless service at higher data rates. However, there are many environmental challenges as transmission channel impairments, limited availability of frequency spectrum and transmission power constraint to overcome to meet these demands of the users. There are some well-known strategies to eliminate these drawbacks as the orthogonal frequency division multiple access (OFDMA), relaying and multiple antenna technologies.

OFDMA is a very popular transmission technology for high data rate communication systems because of the robustness against frequency-selective fading and high spectral efficiency. Using multiple antennas technologies such as multiple-input multiple-output (MIMO) or multiple-input single-output (MISO) also provides a capacity gain without increasing the bandwidth or transmit power in rich scattering environments and diversity gain to combat signal fading compared to classical single-input single-output (SISO) systems. However, if there are long distances between the users and the base station (BS), it may be difficult to reach the required capacity values by using only multiple antennas in conventional cellular networks. Moreover, it is difficult to cover areas suffering from bad channel conditions. Additional BSs can be established on these networks as a solution but the new BSs increase the cost of mobile operators. Using low-cost relay stations (RSs) in cellular networks without deploying new BSs can be an alternative cost-effective solution for this problem. In relaying operation, path loss and shadowing effects become less dominant so

CONTACT İlhan Baştürk ilhan.basturk@adu.edu.tr Department of Electrical and Electronics Engineering, Aydın Adnan Menderes University, Aydın, Turkey

the low power communication is possible since the direct path is divided into shorter links (Laneman, Tse, & Wornell, 2004; Pabst et al., 2004).

The RSs can be fixed or mobile according to the ability to move (Nourizadeh, Nourizadeh, & Tafazolli, 2006; Taki & Heshmati, 2017; Yanikomeroglu, 2002). Most of the recent works studied on fixed RSs whose architecture has already been optimised in the standard of 4G long term evolution (LTE)-Advanced (Hoymann et al., 2012). However, the deployment of the fixed RSs causes high infrastructure, operational and maintenance costs for the mobile operators. Therefore, mobile relays whose location changes dynamically have recently attracted interest. Mobile relays are used in two different scenarios. In the first case, they are mounted on moving vehicles such as buses or trains and in the second case simple user terminals are used as mobile relays which are also called as user-relays. User-relaying has an advantage that it can increase the system performance without any additional infrastructure cost and it is a serious candidate for the 5G wireless systems (Chin, Fan & Haines, 2014; Tehrani, Uysal, & Yanikomeroglu, 2014).

The combination of MIMO-OFDMA and user-relaying constructs a multi-user, multi-relay and multi-antenna network to deliver the promise of the reliable and high-data-rate coverage in the most cost-effective manner. Once the network has been established, the next task is to develop suitable relay selection and resource allocation (RA) algorithms to guarantee to meet certain demands of users and enhance the performance of this complicated network. Relay selection and RA for user-relay assisted cellular networks have been actively studied in the literature and optimal or suboptimal solutions are proposed. Most of these works are concentrated on the classical two-phase frame structure for SISO systems (Han, Himsoon, Siriwongpairat, & Liu, 2009; Ng & Yu, 2007; Shenghong & Murch, 2013; Shim, Han, & Kim, 2010; Weng & Murch, 2009). In Ng and Yu (2007), an utility function is defined in cellular networks and in order to make this function maximum, a joint relay selection, RA and relaying protocol (amplify-and-forward (AF), decode-and-forward (DF)) selection algorithm is presented. In Weng and Murch (2009), uplink OFDMA system with two users is considered and an optimal relaying strategy has been developed. In Ng and Yu (2007) and Weng and Murch (2009), the algorithms are formed using the assumption that nodes are able to transmit and receive simultaneously on adjacent subcarriers. In Shenghong and Murch (2013), feasibility analysis of this assumption is studied. Power minimisation problem has been presented and optimum/suboptimum solutions have been designed for AF relaying in Han et al. (2009). In Shim et al. (2010), uplink OFDMA-based wireless network is considered and subcarrier–power allocation algorithms are presented by taking care of the fairness constraint. In Basturk and Ozbek (2015), the classical two-phase frame structure is used with multiple antennas and the RA is performed on MISO-OFDMA-based cellular networks. In Basturk and Ozbek (2016a), a novel three-phase frame structure in which the users are not allowed to act as a destination and a relay simultaneously is developed since the assumption in which users are able to transmit and receive at the same time through adjacent subcarriers may have practical limitations with the current transceiver design. Relay selection and RA algorithms are presented for the proposed frame structure by using SISO-OFDMA system model. In Basturk and Ozbek (2016b), the trade-off between the signalling overhead and relay selection distance threshold is examined by using the same system model proposed in Basturk and Ozbek (2016a).

To the best of our knowledge, relay selection and RA problem for the OFDMA-based user-relay assisted cellular networks with multiple antennas has not been well examined in the literature. Motivated by the above literature, multiple antenna technology is combined with user-relaying concept and relay selection and RA algorithms are developed for this MISO-OFDMA-based joint model, since the existed algorithms presented for classical SISO-OFDMA systems cannot be used directly. The contribution of the paper and the features of the proposed scheme are summarised as follows:

- Inspired by Basturk and Ozbek (2016a), in this study, the three-phase frame structure is enriched with multiple antennas to support more users at the same time. In order to reveal the benefits of this structure, an algorithm which selects the user-relay candidates and allocates the subchannels to the users is proposed.

- The proposed scheme has multifold advantages that multiuser diversity can be exploited not only in the frequency domain, but also in the spatial domain contrary to works (Basturk & Ozbek, 2016a, 2016b) in which SISO scheme is used. Moreover, users are prevented to act as a destination and a relay simultaneously contrary to (Basturk & Ozbek, 2015; Ng & Yu, 2007; Weng & Murch, 2009) since only the satisfied users are assigned as the user-relay candidates. Thus, it is more practical with the current transceiver design.

The rest of this paper is organised as follows. In Section 2, system model is described. In Section 3, the proposed relay selection and RA algorithm for user-relay assisted MISO-OFDMA networks which use three-phase frame structure are presented. In Section 4, performance evaluations are examined and finally, the conclusions are given in Section 5.

2. System model

A single cell, OFDMA-based downlink network model is utilised in this paper. The network is enhanced with user-relays as illustrated in Figure 1 so the users (user equipments (UEs)) are given a chance to communicate to the BS either directly or through a user-relay. We have located a BS in the middle of the cell that has a radius R, and distributed K users uniformly around it. BS is equipped with multiple antennas to support more users at the same time and each user and user-relay are equipped with single antenna because of the size limitation of the devices.

The system performance depends on the number of relay candidates in relay-assisted networks. For fixed relay networks the number of relay candidates is limited so the relay usability is also limited. However, this case is not valid for the user-relay assisted networks since the number of relays scales with the number of users. In these networks, signalling overhead may be a problem when all UEs are selected as the possible relay candidates (Han et al., 2009; Kim, Lee, Son, Song, & Chong, 2012; Ng & Yu, 2007). In this work, to overcome this problem and to have lower computational complexity relay candidates are selected using a restricted area which has a radius d^b (Basturk & Ozbek, 2015, 2016a, 2016b; Papadogiannis, Alexandropoulos, Burr, & Grace, 2012), as shown in Figure 1.

In this study, we will use the proposed frame structure in Basturk and Ozbek (2016a) that splits downlink allocation frame into three subframes. In this frame structure, only direct communication between the BS and UEs is allowed through the subframe one. In the second and third subframes, UEs can get data from the BS directly or over user-relay. Two-hop and half-duplex relaying is considered for the relayed communication. If a user communicates with the BS via a user-relay, BS sends the data

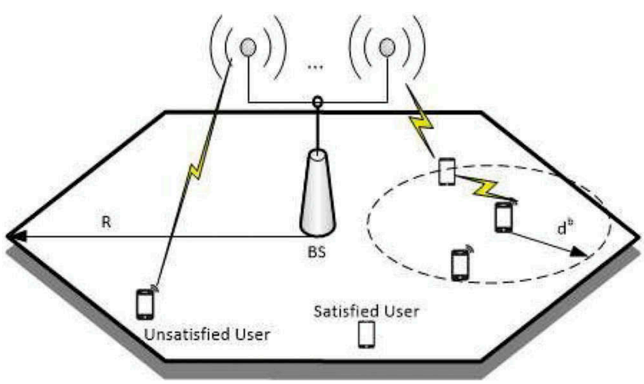

Figure 1. User-relay assisted MISO-OFDMA network topology.

of this user to user-relay at subframe two and user-relay forwards the data in the third subframe. The same subchannels are used at subframe two and three for the links between the BS, relay and relay, UE. Different subchannels can also be used for this operation but this will cause a trade-off between the system performance and computational complexity (Dang, Tao, Mu, & Huang, 2010; Weng & Murch, 2009). We assume that all required channel gains among BS and all UEs, and among UEs and user-relays are available perfectly at the BS as in the previous user-relay assisted OFDMA systems (e.g. Han et al., 2009; Ng & Yu, 2007; Shim et al., 2010; Weng & Murch, 2009).

In our system model, there are two different communication link types to be analyzed as MISO and SISO links. The communication links between the BS and UEs will be MISO links because of the multiple antennas at the BS and the communication links between the UEs and user-relays will be SISO links since all the UEs and so user-relays have single transmit and receive antennas. These links will be examined in detail below.

A-MISO link analysis

In the network model given in Figure 1, N_t^{BS} transmit antennas are mounted on the BS to give service to multiple UEs simultaneously. In this system model, two schemes can be considered according to the number of users in the cellular area. The number of users can be smaller or higher than the number of transmit antennas that latter is more suitable for realistic scenarios. When the number of users is more than the number of transmit antennas, user selection is required since the number of maximum supportable users at each time and/or frequency slot cannot be more than the number of transmit antennas. In this study, we utilise the scenario where $K > N_t^{BS}$ so, we have to select ψ links which can be smaller or equal to the N_t^{BS}. There will be $\Delta = \sum_{\psi=1K}^{N_t^{BS}} C_\psi$ possible combinations on each subchannel to perform this selection procedure.

$\mathbb{V}_{\delta,n} = \{v_1, v_2, \cdots, v_\psi\}$ where $\delta = 1, 2, \ldots, \Delta$ can be assumed as one of the selected user sets that contains direct users and/or user-relays who together form a channel matrix $\mathbf{H}_n(\mathbb{V}_{\delta,n}) = [\mathbf{h}_{0,v_1,n}^T \cdots \mathbf{h}_{0,v_\psi,n}^T]^T$ on subchannel n. Any element of this channel matrix, $\mathbf{h}_{0,v_\psi,n}$ is $1 \times N_t^{BS}$ channel vector between the BS and node v_ψ. Serving to multiple nodes on any subchannel at the same time gives rise to interference problem which decreases the system performance. To cope with this problem and provide spatial multiplexing, we have chosen zero-forcing beamforming (ZF-BF) which is the simple beamforming technique and calculated a ZF-BF matrix on subchannel n by using the channel matrix as $\mathbf{W}_n(\mathbb{V}_{\delta,n}) = \lambda(\mathbf{H}_n(\mathbb{V}_{\delta,n}))^H[(\mathbf{H}_n(\mathbb{V}_{\delta,n}))(\mathbf{H}_n(\mathbb{V}_{\delta,n}))^H]^{-1}$ where $\lambda = \frac{1}{\sqrt{\mathrm{tr}[((\mathbf{H}_n(\mathbb{V}_{\delta,n}))(\mathbf{H}_n(\mathbb{V}_{\delta,n}))^H)^{-1}]}}$. The calculated matrix includes $N_t^{BS} \times 1$ beamforming vectors belonging to each node on subchannel n as $\mathbf{W}_n(\mathbb{V}_{\delta,n}) = [\mathbf{w}_{0,v_1,n} \cdots \mathbf{w}_{0,v_\psi,n}]$. Finally, by using the channel and beamforming vectors, the data rate between the BS and any node (user or user-relay) $j \in \mathbb{V}_{\delta,n}$ on subchannel n are computed as follows:

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

where $\gamma_{0,j,n,\delta} = \frac{P_{0,j,n,\delta}|\mathbf{h}_{0,j,n}\mathbf{w}_{0,j,n}|^2}{N_0(B/N)}$ is the signal to noise ratio (SNR) between the BS and receiver node j on subchannel n. $P_{0,j,n,\delta}$ 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, B is the available bandwidth and N_0 is the noise power density.

B-SISO link analysis

The links between any two users (UE → user-relay) will be SISO links since all the users will have only one transmit and receive antennas, $N_t^{UE} = N_r^{UE} = 1$. Thus, only one user pair can be in connection for each subchannel. The data rate between any two nodes when relayed communication is performed can be given as

$$R_{i,j,n} = \frac{B}{N}\log_2(1 + \gamma_{i,j,n}) \tag{2}$$

In this equation, $\gamma_{i,j,n} = \frac{P_{i,j,n}|h_{i,j,n}|^2}{N_0(B/N)}$ is the SNR between a transmitter user i and receiver user j on subchannel n. $P_{i,j,n}$ is the transmitted power per subchannel, $h_{i,j,n}$ is the channel coefficient between two nodes that includes pathloss, shadowing and multipath.

3. The proposed relay selection and RA for three-phase frame structure with multiple antennas

Solving the relay selection and RA problems optimally is very difficult because of the discrete nature of subchannel assignment. When it is coupled with quality of service (QoS) requirements, the problem becomes even harder to solve. In large systems which consider many users, relays, subchannels and transmitter antennas, it is not practical to search all possible allocation sets. Thus, in this paper, we will propose a suboptimal relay selection and RA algorithm for user-relay assisted OFDMA-based downlink multiple antenna networks that utilise three-phase frame structure. The efficiency of the three-phase frame structure with multiple antennas can be brought into the open by presenting practical relay selection and RA algorithms. This frame structure prevents users to simultaneously act as a destination and a relay. It is also practical with current transceiver design, since any user does not have to receive its own data and to transmit the other users' data at the same time. A user cannot help other users as a relay, before fulfilling its own data rate requirements.

The proposed relay selection and RA algorithm will be performed at the BS and it will be examined in four parts. At the beginning of the algorithm, $\mathbb{N}^1, \mathbb{N}^2$ and $\mathbb{N}^3$ will be defined as subchannels set at subframes 1, 2 and 3, respectively. In our algorithm, each user will try to reach a target rate value, R_k^t which can be thought as a QoS parameter. The users that arrive to this value will be called as satisfied users, otherwise they will be called as unsatisfied users. Thus, in the algorithm $\mathbb{U}$ and $\mathbb{S}$ are the unsatisfied and satisfied users set, respectively. R_k is also be the total data rate of any user k. It is assumed that the BS knows the possible user-relay candidates set of each user, $\mathbb{Z}_k$. In this set, the distance between user k and user-relay r, $d_{k,r}$ must be smaller than a predefined boundary distance, d^b in order to be a relay candidate. The algorithm is given below in detail.

Algorithm

$\mathbb{N}^1 = \mathbb{N}^2 = \mathbb{N}^3 = \{1, 2, ..., N\},\ \mathbb{U} = \{1, 2, ..., K\},\ \mathbb{S} = \{\emptyset\},\ R_k = 0,\ \forall k \in \mathbb{U},\ \mathbb{Z}_k = \{r | d_{k,r} \le d^b;$ $r = 1, 2, ..., K, k = 1, 2, ..., K, r \ne k\}$

Part I

1: Set $n = 1$ where $n \in \mathbb{N}^1$.
2: Set $\mathbb{V}_n = \emptyset$, $\mathbb{K} = \mathbb{U}$, $\psi = 1$
3: Compute $R_{k,n} = R_{0,k,n}$, $\forall k \in \mathbb{K}$, by using Equation (1). Find $k^* = \arg\max_{k \in \mathbb{K}} R_{k,n}$.
4: Update the sets as $\mathbb{V}_n(\psi) = \{k^*\}$, $\mathbb{K} \leftarrow \mathbb{K} \setminus \{k^*\}$ and $\mathbf{H}_n(\mathbb{V}_n(\psi)) = \mathbf{h}_{0,k^*,n}$.
5: Calculate subband achievable rate; $\mathcal{R}(\mathbb{V}_n(\psi)) = \sum_{j \in \mathbb{V}_n(\psi)} R_{0,j,n}$
6: $\psi = \psi + 1$. **If** $\psi \le N_t^{BS}$, add new nodes to n, **else** go to step 7.
  6.1: Use projector matrix to obtain as much as orthogonal nodes to the already selected ones for n. $\mathbf{P}_\psi^\perp = \mathbf{I}_{N_t^{BS}} - \bar{\mathbf{H}}^H(\bar{\mathbf{H}}\bar{\mathbf{H}}^{\mathbf{H}})^{-1}\bar{\mathbf{H}}$, where $\bar{\mathbf{H}} = \mathbf{H}_n(\mathbb{V}_n(\psi - 1))$.
  6.2: Select L orthogonal users who has higher values of $q_k = \mathbf{h}_{0,k,n}\mathbf{P}_\psi^\perp\mathbf{h}_{0,k,n}^H$, $\forall k \in \mathbb{K}$
  6.3: Find the best link Ω that has the maximum rate value among these users.
  6.4: **If** $\mathcal{R}(\mathbb{V}_n(\psi - 1) \cup \{\Omega\}) \ge \mathcal{R}(\mathbb{V}_n(\psi - 1))$ **then** $\mathbb{V}_n(\psi) = \mathbb{V}_n(\psi - 1) \cup \{\Omega\}$,

$\mathbf{H}_n(\mathbb{V}_n(\psi)) = [\mathbf{H}_n(\mathbb{V}_n(\psi-1))^T\ \mathbf{h}_{0,\Omega,n}^T]^T$, $\mathbb{K} \leftarrow \mathbb{K} \setminus \{\Omega\}$ and go to step 6.
Else, terminate to add new nodes and go to step 7.

7: Update user's data rate values; $R_j = R_j + R_{j,n}$, $\forall j \in \mathbb{V}_n(\psi)$ where $R_{j,n} = R_{0,j,n}$.

8: Decide satisfied and unsatisfied users. **If** $R_j \geq R_j^t$ **then** $\mathbb{U} \leftarrow \mathbb{U}\backslash\{j\}$, $\mathbb{S} \leftarrow \mathbb{S} \cup \{j\}$.

9: Set $n = n+1$. **If** $n \leq N$ and $\mathbb{U} \neq \emptyset$ go to step 2, **else** terminate Part I.

Part II

1: **If** $\mathbb{U} \neq \emptyset$, **then** update $\mathbb{Z}_k$, $\forall k \in \mathbb{U}$ by removing the unsatisfied users from this set.

2: **If** $\mathbb{Z}_k \neq \emptyset$, **then** select a user-relay, $r_k = \arg\max_{z\in\mathbb{Z}_k}(\min(\bar{\gamma}_{0,z}, \bar{\gamma}_{z,k}))$, $\forall k \in \mathbb{U}$.

$\bar{\gamma}_{i,j} = \frac{1}{N}\sum_{n=1}^{N}\gamma_{i,j,n}$ is the average SNR value between two nodes.

Part III

1: Set $n = 1$ where $n \in \mathbb{N}^2$.

2: Set $\mathbb{V}_n = \emptyset$, $\mathbb{K} = \mathbb{U}$, $\psi = 1$ and $\varphi = 1$.

3: Compute $R_{k,n}, \forall k \in \mathbb{K}$ and find $k' = \arg\max_{k\in\mathbb{K}} R_{k,n}$.

$$R_{k,n} = \begin{cases} \max\{R_{0,k,n}, \min\{R_{0,r_k,n}, R_{r_k,k,n}\}\}, & r_k \neq \emptyset \\ R_{0,k,n}, & \mathit{otherwise}. \end{cases}$$

4: **If** k' is a direct user **then** $\mathbb{V}_n(\psi) = \{k'\}$, $\mathbb{K} \leftarrow \mathbb{K}\backslash\{k'\}$ and $\mathbf{H}_n(\mathbb{V}_n(\psi)) = \mathbf{h}_{0,k',n}$.
Elseif, k' is a relayed user, **then** $\mathbb{V}_n(\psi) = \{r_{k'}\}$, $\mathbf{H}_n(\mathbb{V}_n(\psi)) = \mathbf{h}_{0,r_{k'},n}$ and set $\varphi = 0$, update $\mathbb{N}^3 \leftarrow \mathbb{N}^3\backslash n$.

5: $\mathcal{R}(\mathbb{V}_n(\psi)) = \sum_{j\in\mathbb{V}_n(\psi)} R_{0,j,n}$

6: $\psi = \psi + 1$. **If** $\psi \leq N_t^{BS}$, add new nodes to n, **else** go to step 7.

6.1: $\mathbf{P}_\psi^\perp = \mathbf{I}_{N_t^{BS}} - \bar{\mathbf{H}}^H(\bar{\mathbf{H}}\bar{\mathbf{H}}^H)^{-1}\bar{\mathbf{H}}$, where $\bar{\mathbf{H}} = \mathbf{H}_n(\mathbb{V}_n(\psi-1))$.

6.2: Select L orthogonal users who has higher values of $q_k, \forall k \in \mathbb{K}$.

$$q_k = \begin{cases} \max\{\mathbf{h}_{0,k,n}\mathbf{P}_\psi^\perp\mathbf{h}_{0,k,n}^H, \mathbf{h}_{0,r_k,n}\mathbf{P}_\psi^\perp\mathbf{h}_{0,r_k,n}^H\}, & \varphi = 1 \text{ and } r_k \neq \emptyset \\ \mathbf{h}_{0,k,n}, \mathbf{P}_\psi^\perp\mathbf{h}_{0,k,n}^H, & \mathit{otherwise}. \end{cases}$$

6.3: Compute the data rates for each node, $l = 1, 2, .., L$ by using Equations (1) and (2) and find the best link ϖ that has the maximum rate value.

6.4: **If** $\mathcal{R}(\mathbb{V}_n(\psi-1) \cup \{j\}) \geq \mathcal{R}(\mathbb{V}_n(\psi-1))$, add j, which is equal to ϖ for direct and r_ϖ for relayed users, to n. **Else** terminate to add new nodes and go to 7.

6.4.1: Set $\mathbb{V}_n(\psi) = \mathbb{V}_n(\psi-1) \cup \{j\}$, $\mathcal{R}(\mathbb{V}_n(\psi)) = \mathcal{R}(\mathbb{V}_n(\psi-1) \cup \{j\})$, and $\mathbf{H}_n(\mathbb{V}_n(\psi)) = [\mathbf{H}_n(\mathbb{V}_n(\psi-1))^T\ \mathbf{h}_{0,j,n}^T]^T$.

6.4.2: **If** j is a direct user, $\mathbb{K} \leftarrow \mathbb{K} \setminus \{\varpi\}$, **else** $\varphi = 0$ and $\mathbb{N}^3 \leftarrow \mathbb{N}^3\backslash n$.
Go back to step 6.

7: Update the rate values of each link $j \in \mathbb{V}_n(\psi)$.
If j is a user-relay, k^j gets data over j, **then** $R_{k^j} = R_{k^j} + R_{k^j,n}$ where $R_{k^j,n} = \min\{R_{0,j,n}, R_{j,k^j,n}\}$. When $R_{k^j} \geq R_{k^j}^t$ then $\mathbb{U} \leftarrow \mathbb{U}\backslash\{k^j\}$, $\mathbb{S} \leftarrow \mathbb{S} \cup \{k^j\}$.
Elseif j is a direct user, **then** $R_j = R_j + R_{j,n}$ where $R_{j,n} = R_{0,j,n}$, and when $R_j \geq R_j^t$ then $\mathbb{U} \leftarrow \mathbb{U}\backslash\{j\}$, $\mathbb{S} \leftarrow \mathbb{S} \cup \{j\}$.

8: Set $n = n+1$. **If** $n \leq N$ and $\mathbb{U} \neq \emptyset$ go back to 2, **else** terminate Part III.

Part IV

1: **While** $\mathbb{U} \neq \emptyset$ and $\mathbb{N}^3 \neq \emptyset$, apply Part I to allocate remaining subchannels in $\mathbb{N}^3$.

In the first part of the algorithm, RA is performed for subframe 1. In this subframe, only direct communication is allowed. Each subchannel can be allocated to more than one user in this part. On subchannel n, first user is selected according to the maximum rate value. The rate values are calculated by using Equation (1), but notice that index δ is omitted in all parts of the algorithm, since it refers to specific set of users. After the first user selection, at most N_t^{BS} users can also be admitted to this subchannel and ψ is used for the allocation index in the algorithm. The new users must be as much as orthogonal to the already selected users on subchannel n. Thus, we calculate a projector matrix, $\mathbf{P}^{\perp}$ and project the new users' channel vectors onto the orthogonal complement of the subspace spanned by the channels of the selected ones. Then, L orthogonal users whose value is found heuristically as $min\{|\mathbb{K}|, N_t^{BS}\}$ are determined and the best user who has maximum rate value is selected among them. If the data rate on this subchannel after appending new user is equal or larger than the previous sum rate value, the new user is admitted to this subchannel. After terminating to allocate new users to subchannel n, rate values are updated. Each user's rate value is compared with the target rate value and users are labeled as satisfied or unsatisfied users. This part is ended when all subchannels are allocated in subframe 1 or all users are satisfied. At the end of subframe 1, relay selection is performed for unsatisfied users by using the average SNR values of the first and second hop links in the second part of the algorithm.

When it comes to the third part of the algorithm, unsatisfied users get data directly or with the help of a satisfied user in this part. RA is performed for subframe 2, but some subchannels belong to subframe 3 are also reserved for the relaying operation. In our frame model, it is assumed that the user-relays receive and transmit the data using the same subchannel in two consecutive subframes. Thus, if a subchannel in subframe 2 is allocated to a relayed user, the same subchannel in subframe 3 is also reserved for this user because of the two-hop relaying. The subchannel in subframe 2 will be used for BS $\rightarrow$ user-relay link and the subchannel in subframe 3 will be used for user-relay $\rightarrow$ UE link. In this part, BS can also support multiple nodes on each subchannel as a direct user and/or user-relay. Only one of the allocated nodes can be a user-relay since the link between the users is SISO as mentioned before. In Part III, φ parameter is used to let maximum one user-relay for each subchannel. The node selection procedure is similar to the first part of the algorithm except the rate calculations of the relayed users. In this part, in steps 3 and 7, the rate values of the relayed users are calculated as the minimum of the first and second hop links since the relaying protocol is selected as DF. This part is repeated until all subchannels in subframe 2 are finished or all users are satisfied. In Part IV, the remaining subchannels in subframe 3 are only allocated to the direct users as in Part I. In Figure 2, a summary of the proposed algorithm is illustrated to make it more understandable.

4. Performance evaluations

In this paper, we aim to contribute to MISO-OFDMA-based user-relay assisted cellular networks which are one of the emerging technologies in the 5G applications. In accordance with this purpose, simulation results are given in this section to illustrate the benefits of the relay selection and RA algorithms presented for the proposed three-phase frame structure in user-relay enhanced downlink MISO-OFDMA wireless networks. We perform our simulations on a single-cell network whose diameter is $R = 750m$. A BS is placed in the middle of the cell with N_t^{BS} transmit antennas and the UEs are randomly distributed in the cellular area. All UEs have single transmit and receive antennas $N_t^{UE} = N_r^{UE} = 1$. The UEs' minimum distance to the BS is set to 35 m. The transmit power of the BS and the users that act as user-relays are set to 46 and 23 dBm, respectively. The noise power density is -134.89 dBm/Hz. The path loss between the BS and the users and between the user-relays and the users are modelled by $L_p = 128.1 + 37.6\log_{10}d(km)$. The wireless channel is modelled using typical urban with a velocity of 10 km/h and the shadowing is modelled using lognormal distribution with $\mu = 0$ and $\sigma = 10dB$. The bandwidth and the carrier frequency are selected as 20 MHz and 2 GHz. The number of subchannels used for the data is $N = 100$. The total duration of the proposed three-phase downlink frame is $T_{frame} = 10$ ms and the duration of subframes is selected as $T_1 = 4$ ms, $T_2 = T_3 = 3$ ms since these durations give the best performance results as explained in Basturk and Ozbek (2016a). The simulation results are obtained for 1000 Monte-Carlo trials.

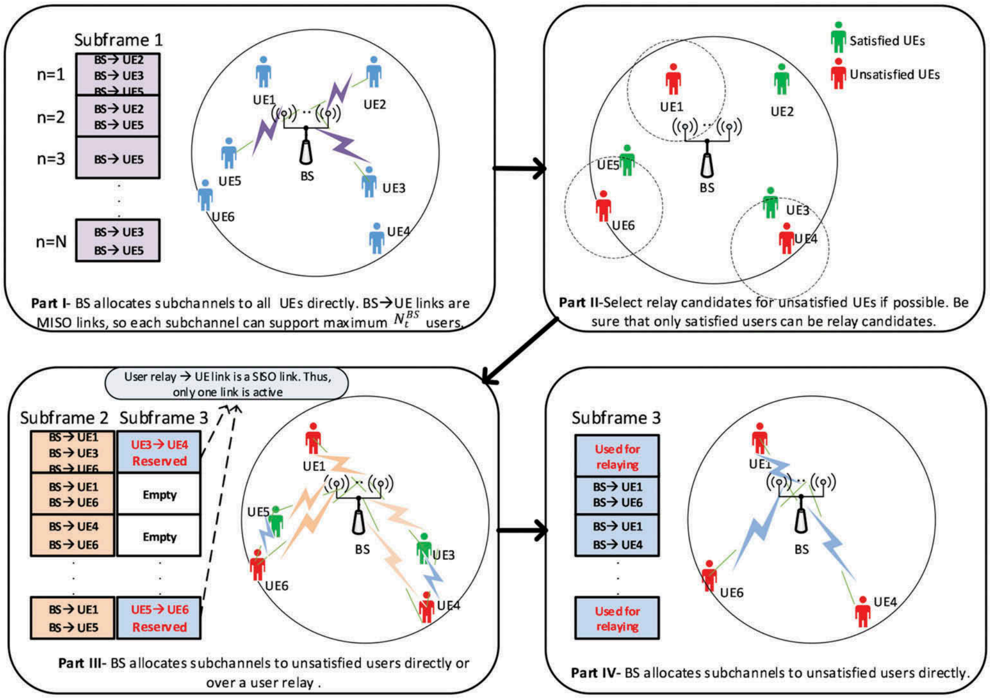

Figure 2. Visual representation of the proposed algorithm ($K = 6, N_t^{BS} = 3$).

Firstly, the proposed scheme is compared with the user-relay assisted classical two-phase frame also known as generic frame (Basturk & Ozbek, 2015; Ng & Yu, 2007; Weng & Murch, 2009) and non-relaying schemes for MISO scenario where $N_t^{BS} = 4$. In the non-relaying scheme, there is no relay in the cellular area and all users get their data from the BS directly. In generic frame scheme, downlink frame is partitioned into two equal subframes. In the first subframe, BS transmits data to the direct users and user relays and in the second subframe, BS goes on sending data to the direct users and user-relays forwards the received data to the relayed users. For the proposed and generic frame user-relaying schemes, the users which have deep fades in direct communication because of the pathloss, shadowing and multipath effects have an alternative way to be satisfied users. If they have suitable user-relays in their neighbourhood, they can communicate with the BS via these user-relays. The boundary distance, d^b is set to 100 m to select user-relays. The comparison of the three schemes is performed in terms of the users' satisfaction percentage and total data rate of the system. In order to measure the satisfaction of the users, the results are obtained for two different target data rate values as 168 and 336 *kbps* in Figure 3. The users' satisfaction percentage is increased compared to non-relaying scheme not only for low target data rate values but also for higher target data rate values by using the user-relaying schemes. The proposed scheme not only has slightly better user satisfaction performance compared to generic frame scheme but also it eliminates the drawbacks of generic frame scheme for user-relay assisted networks in which a user acts as a destination and a relay simultaneously. In order to comment on the overall system performance, we also give the sum data rate of the users in Figure 4(a, b) for 168 and 336 *kbps*, respectively. Again, the proposed scheme is slightly higher sum data rate than generic frame scheme and they both outperform the non-relaying scheme. The simulation results for the proposed scheme show an increase on the sum capacity of non-relaying scheme ranging from 4% to 7% for $R_k^t = 168$ *kbps*, $\forall k$ and 2% to 3% for $R_k^t = 336$ *kbps*, $\forall k$ depending on the number of users.

Secondly, the proposed MISO-OFDMA model is compared with the SISO-OFDMA model presented in Basturk and Ozbek (2016a). Different numbers of BS transmit antenna configurations are

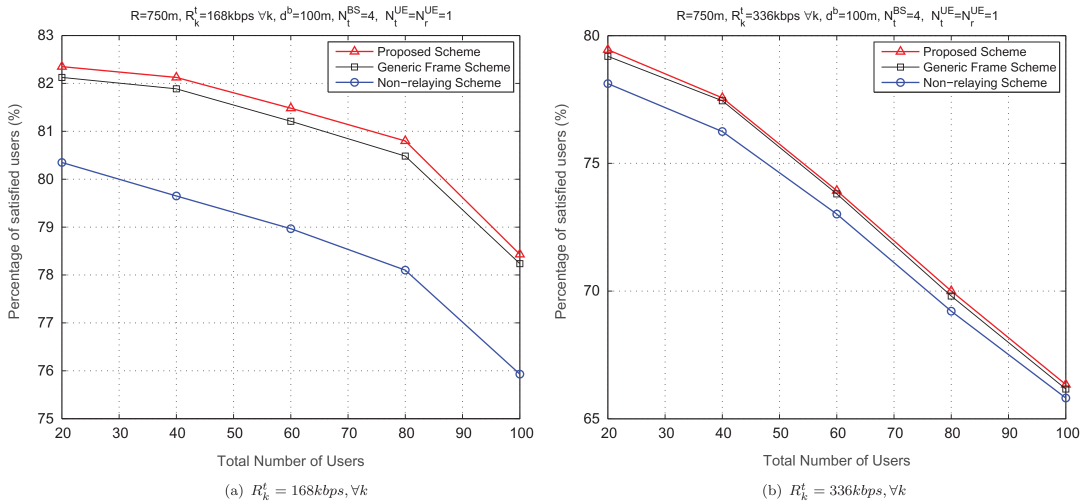

Figure 3. Users' satisfaction percentage for MISO-OFDMA.

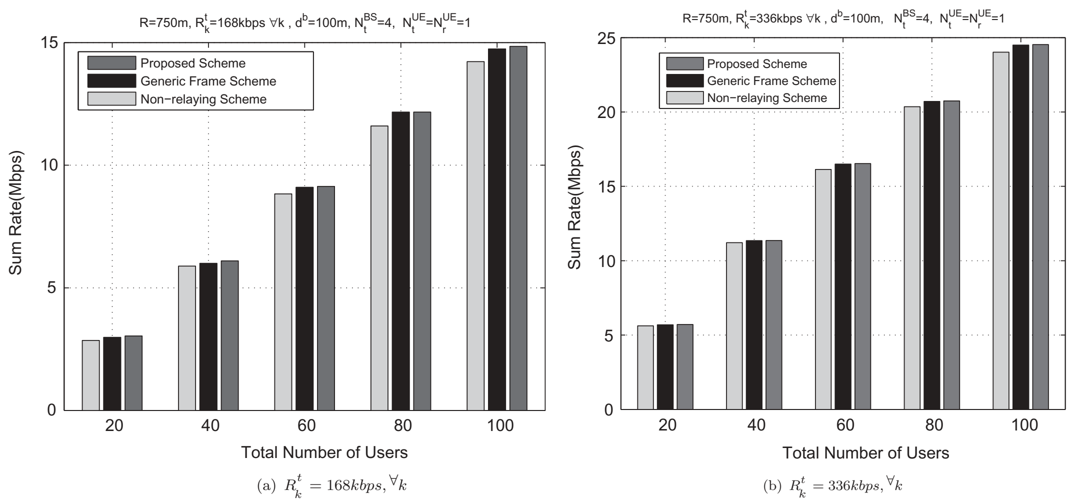

Figure 4. Sum data rate of users for MISO-OFDMA.

used to get an idea about the effect of the multiple antennas. The results are obtained for two different target data rate values again. In Figure 5(a, b), the satisfaction percentages are given for 168 and 336 *kbps*, respectively. From these figures, it is clearly seen that the increment of the transmit antenna numbers in the BS has a positive effect on the satisfied users' percentage for both target rate values. In Table 1, the gain of the MISO-OFDMA system over SISO-OFDMA system in terms of satisfied users' percentage is tabulated for $K = 60$ users. This table also gives us a perspective about the advantage of the multiple antennas in the user-relay assisted networks. The users' satisfaction percentage reaches the maximum gain at $N_t^{BS} = 4$ antennas case. Moreover, in Figure 6, the sum data rates of the proposed scheme are illustrated for two different target data rates. Sum data rate values are also increased by increasing the number of transmit antennas at the BS for both target data rate values. This result is also tabulated for $K = 60$ users in Table 2 and the

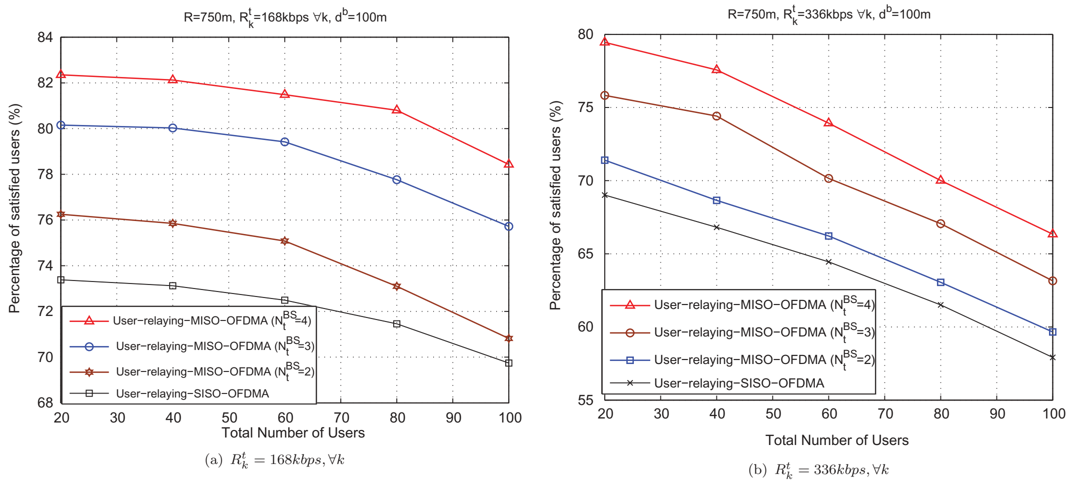

Figure 5. Users' satisfaction percentage for MISO-OFDMA vs SISO-OFDMA.

Table 1. MISO-OFDMA gain over SISO-OFDMA for users' satisfaction percentage.

		N_t^{BS}		
		2	3	4
$R_k^t, \forall k$	168*kbps*	3.6%	9.56%	13.1%
	336*kbps*	2.75%	8.85%	13.9%

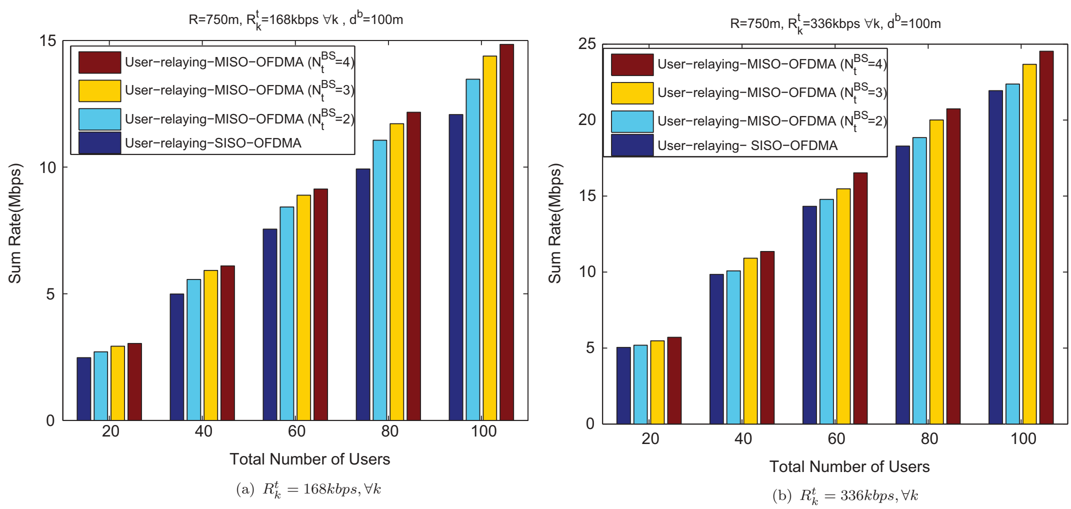

Figure 6. Sum data rate of users-MISO-OFDMA vs. SISO-OFDMA.

Table 2. Sum data rate gain of MISO-OFDMA over SISO-OFDMA.

		N_t^{BS}		
		2	3	4
$R_k^t, \forall k$	168*kbps*	11.6%	17.74%	21%
	336*kbps*	3.5%	8.4%	16%

Table 3. Average execution time (s) under different number of users, $N_t^{BS} = 4$.

Number of users	Proposed scheme	Generic frame scheme	Non-relaying scheme
20	2.27	2.27	1.36
40	3.97	4.01	2.01
60	5.17	5.15	2.85
80	6.30	6.25	3.63
100	7.89	7.83	4.45

Table 4. Average execution time (s) under different number of BS transmit antennas, $K = 60$.

Number of BS transmit antennas	Proposed scheme
2	4.28
3	4.53
4	5.17

data rate increment of multiple antenna system over single antenna system is given as a percentage. Higher N_t^{BS} values provided higher sum data rates.

Finally, the computational complexity of the proposed scheme is obtained by measuring the average execution time of the algorithm for different number of users and different number of antennas. Average execution time measurement is one of the valuable performance metrics that is mostly used to compare the complexity of the algorithms in a simulation environment (Patterson & Hennessy, 2013). The proposed scheme is compared with the generic frame and non-relaying schemes in Table 3 in terms of computational complexity for different number of users. The results are obtained by using MATLAB R2017b on a PC with Core $i7 - 4770$ processor operating with a clock 3.4 GHz. As expected, non-relaying scheme has the lowest computational complexity. The computational complexity of the proposed and generic frame schemes is almost the same and the computational complexity is increasing for all schemes for higher number of users. The measured average execution time of an algorithm may change, if the algorithm is implemented on a real-time system. However, this case is valid for all schemes. Thus, the obtained results by using average execution time in the simulation environment provide meaningful information about the system complexity. The comparison is also fair, since all the algorithms are compared on the same conditions. We have also examined the computational complexity of the proposed scheme for varying BS transmit antenna numbers in Table 4. It is observed that the average execution time of the proposed scheme is increasing slightly with the increment of the BS transmit antennas.

5. Conclusions

In this paper, multiple antenna technology has been applied to the novel three-phase frame structure presented for user-relay assisted OFDMA-based cellular networks. This scheme is more applicable to practical systems since it prevents users to be UE and user-relays at the same time. In order to exhibit the benefits of this new MISO-OFDMA system model, we have proposed resource management algorithms as relay selection and RA. It is shown that the users' satisfaction percentage and total system data rate are increased with the proposed scheme compared to non-relaying scheme by using simulation results. Moreover, it is revealed that the proposed scheme has slightly better performance than the generic frame scheme while it avoids users' to act as a destination and a relay simultaneously.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

Basturk, I., & Ozbek, B. (2015, August). Resource allocation for user-relay assisted MISO-OFDMA networks. *Proc. International Symposium on Wireless Communication Systems* (pp.126–130), Brussels.

Basturk, I., & Ozbek, B. (2016a). Radio resource management for user-relay assisted OFDMA based wireless networks. *International Journal of Electronics and Communications (AEU)*, *70*(5), 643–651.

Basturk, I., & Ozbek, B. (2016b, May). Distance based selection for user-relaying in OFDMA-based wireless networks. *IEEE Signal Processing and Communication Application Conference* (pp.989–992), Zonguldak.

Chin, W. H., Fan, Z., & Haines, R. (2014). Emerging technologies and research challenges for 5G wireless networks. *IEEE Wireless Communications*, *21*(2), 106–112.

Dang, W., Tao, M., Mu, H., & Huang, J. (2010). Subcarrier-pair based resource allocation for cooperative multi-relay OFDM systems. *IEEE Transactions on Wireless Communications*, *9*(5), 1640–1649.

Han, Z., Himsoon, T., Siriwongpairat, W. P., & Liu, K. J. R. (2009). Resource allocation for multiuser cooperative OFDM networks: Who helps whom and how to cooperate. *IEEE Transactions on Vehicular Technology*, *58*(5), 2378–2391.

Hoymann, C., Chen, W., Montojo, J., Golitschek, A., Koutsimanis, C., & Shen, X. (2012). Relaying operation in 3GPP LTE: Challenges and solutions. *IEEE Communications Magazine*, *50*(2), 156–162.

Kim, J., Lee, J., Son, K., Song, S., & Chong, S. (2012). Two-hop opportunistic scheduling in cooperative cellular networks. *IEEE Transactions on Vehicular Technology*, *61*(9), 4194–4199.

Laneman, J., Tse, D. N. C., & Wornell, G. (2004). Cooperative diversity in wireless networks: Efficient protocol and outage behavior. *IEEE Transactions on Information Theory*, *50*(12), 3062–3080.

Ng, T. C. Y., & Yu, W. (2007). Joint optimization of relay strategies and resource allocations in cooperative cellular networks. *IEEE Journal on Selected Areas in Communications*, *25*(2), 328–339.

Nourizadeh, H., Nourizadeh, S., & Tafazolli, R. (2006, September).Performance evaluation of cellular networks with mobile and fixed relay station. *IEEE Vehicular Technology Conference* (pp. 1–5), Montreal.

Pabst, R., Walke, B. H., Schultz, D. C., Herhold, P., Yanikomeroglu, H., Mukherjee, S., & Fettweis, G. P. (2004). Relay-based deployment concepts for wireless and mobile broadband radio. *IEEE Communications Magazine*, *42*(9), 80–89.

Papadogiannis, A., Alexandropoulos, G. C., Burr, A., & Grace, D. (2012). Bringing mobile relays for wireless access networks into practice-learning when to relay. *IET Communications*, *6*(6), 618–627.

Patterson, D. A., . &., & Hennessy, J. L. (2013). *Computer organization and design: The hardware/software interface*. San Francisco, CA: Morgan Kaufmann.

Shenghong, L., & Murch, R. D. (2013). Realizing cooperative multiuser OFDMA systems with subcarrier resource allocation. *IEEE Transactions on Wireless Communications*, *12*(4), 1923–1935.

Shim, W., Han, Y., & Kim, S. (2010). Fairness-aware resource allocation in a cooperative OFDMA uplink system. *IEEE Transactions on Vehicular Technology*, *59*(2), 932–939.

Taki, M., & Heshmati, M. (2017). New transmission scheme to enhance throughput of DF relay network using rate and power adaptation. *International Journal of Electronics*, *104*(9), 1500–1513.

Tehrani, M., Uysal, M., & Yanikomeroglu, H. (2014). Device-to-device communication in 5G cellular networks: Challenges, solutions, and future directions. *IEEE Communications Magazine*, *52*(5), 86–92.

Weng, L., & Murch, R. D. (2009). Cooperation strategies and resource allocations in multiuser OFDMA systems. *IEEE Transactions on Vehicular Technology*, *58*(5), 2331–2342.

Yanikomeroglu, H. (2002, July). Fixed and mobile relaying technologies for cellular networks. *Second Workshop on Applications and Services in Wireless Networks* (pp.75–81), Paris.