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Radio resource management for user-relay assisted OFDMA-based wireless networks

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ABSTRACT

Orthogonal frequency division multiple access (OFDMA) based relay assisted networks are important for current and next-generation wireless networks since they have great potential to provide high data rate to users at anywhere, anytime. Towards that end, fixed relay assisted OFDMA networks are commonly utilized by the operators. However, they require supplementary costly infrastructure. User-relay assisted OFDMA-based networks are promising candidates to fulfill the demanding coverage and capacity requirements of future wireless networks in a cost efficient way. Thus, they have become popular as a complementary solution to fixed relay networks. Generic frame structure that divides the resource allocation frame into two subframes is mostly used in the literature for fixed and user-relay assisted networks in which it is assumed that a user can act as a destination and a relay simultaneously. However, it may be difficult to apply this assumption to practical systems because of the limitations of the current transceiver design. Thus, we propose a novel frame structure for user-relay assisted OFDMA-based wireless networks in order to cope with these drawbacks. The efficient radio resource management algorithms including relay selection and resource allocation are developed in order to exploit the opportunities of the proposed frame structure.

1. Introduction

One of the expectations for the next-generation wireless communication networks is to provide ubiquitous high data rate coverage. OFDMA is one of the key technologies to achieve this objective due to its inherent robustness against frequency-selective fading and its capacity for achieving high spectral efficiency [1]. Conventional cellular networks are limited in their coverage and capacity. One of the solutions is to deploy more base stations (BSs) in order to overcome these limitations. However, this solution is not cost efficient for the service providers. An alternative cost efficient solution is the usage of a relay station (RS) as a third type of stations in a cellular network to construct a relay network consisting of BSs, RSs and Mobile Stations (MSs). The combination of 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.

Relaying strategies are mainly studied for two different purposes in wireless communication systems. One of them is called cooperative diversity relaying mitigating signal power fluctuation due to multipath fading [2–6], and the other is called multi-hop relaying mitigating signal attenuation due to path-loss [7–10].

Relay assisted network architectures can be classified as fixed relay networks and mobile relay networks according to the movement of the relays [8–13]. In fixed relay networks, the relay stations are part of the network infrastructure, therefore their deployment will be an integral part of the network planning, design and deployment process. Fixed relay networks have been extensively studied in the literature and have already been included in the 4G Long Term Evolution (LTE)-Advanced standard [14]. In mobile relay networks, relay stations are not part of the fixed wireless infrastructure and their locations are not deterministic. The usage of mobile relay networks extends the coverage and increases the throughput [10,15,16]. Different types of mobile relays can be addressed as dedicated mobile relays that are mounted on moving vehicles and user terminals acting as mobile relays 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 [17,18]. As the number of fixed RSs in a network is limited, 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

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of the user-relays since it is not required to add any costly infrastructure for relaying. Users' density which is a critical parameter for the relaying opportunity and the battery life are the challenges of user-relay assisted networks.

In order to fully realize the capacity and coverage benefits in relay assisted networks, efficient radio resource management (RRM) including relay selection and resource allocation (RA) is critical. The problem formulation may differ significantly in optimization objectives (rate maximization, power minimization), optimization constraints (fairness, load balancing), relaying protocols (amplify and forward (AF), decode and forward (DF)), relaying modes (full-duplex, half-duplex), relay types (fixed, mobile), antenna numbers of the source, destination and relay (single antenna/multiple antennas) and system architectures (downlink/uplink, single-cell/multi-cell). The RRM problem has been examined in numerous research works for OFDMA-based fixed relay networks [19–29]. The opportunities and challenges of the OFDMA-based fixed relay networks have been discussed in detail in [19,20]. In [21], RRM problem for sum rate maximization has been examined for single-cell OFDMA system. The problem has been solved optimally by using a continuous relaxation, since the problem belonging to the class of integer programming is very difficult to solve easily in direct forms. In [22], a low complexity heuristic solution has been presented for the same RRM problem. The fairness issue has been considered in [23–25] contrary to given studies earlier and heuristic RRM algorithms have been presented. In [26,27], the joint relay selection and RA problem have been investigated for the uplink single-cell OFDMA-based system. In [28,29], the RRM problem has been adapted for the multi-cell scenario. Moreover, multiple antennas are deployed at sources, relays, and destinations in [30,31] to increase the system capacity. Efficient relay and antenna selection algorithms are developed in this multi-relay and multi-antenna environment to fully exploit the benefits of the combination of fixed-relaying and multiple antennas technology. The works in [32–38] have examined the RRM problem for OFDMA-based mobile relay networks in which users act as relays. In [32], the RA strategy in OFDMA systems using an AF scheme has been considered, the optimal and suboptimal solutions for the power minimization have been presented. The fairness issue has been taken into consideration with subcarrier and power allocation schemes for uplink OFDMA in [33]. In [34], the joint optimization of relay selection, relay-strategy selection as AF or DF and RA have been considered to maximize an utility function for cellular networks. In [35], an optimal cooperation strategy has been developed for two-user uplink OFDMA systems, which have achieved the capacity region upper bound for DF scheme. In [34,35], it has been assumed that nodes are able to transmit and receive simultaneously on adjacent subcarriers. The feasibility of this assumption has been examined in [36] and a performance degradation has been observed since the orthogonality between different subcarriers is lost in practical communication systems. In [37,38], we have proposed suboptimal practical RRM solutions for the user-relay assisted OFDMA networks. In [37], heterogeneous networks which contain both macro BSs and access points have been combined with the mobile relaying technology and the efficient relay selection and the network interface selection have been presented for such a complex environment. In [38], a joint relay selection and RA algorithm has been examined by considering the queue information for each user. All these studies for fixed and mobile relay networks use a generic frame structure in which the downlink frame is partitioned into two consecutive subframes.

In this paper, we focus on the user-relay assisted OFDMA networks since relaying through 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 employing different scenarios [17]. One of the scenarios examined in 5G based systems is device relaying with operator controlled link establishment corresponding to the framework which is considered in this paper. We propose a novel frame structure with effective relay selection and resource allocation for user-relay assisted OFDMA-based wireless networks. The contribution and features of the proposed scheme are summarized as follows:

- While keeping the same transmission time, we propose to divide the whole frame duration into three subframes instead of two subframes in order to classify the users as satisfied and unsatisfied users after an initial direct transmission session.
- The satisfied users are given permission to act as a relay and they are assigned as the user-relay candidates of the unsatisfied users.
- The users are not allowed to act as a destination and a relay simultaneously contrary to [34,35]. This 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 [36].

The rest of this paper is organized as follows. In Section 2, we give the system model and assumptions. In Section 3, we examine the RRM strategy for user-relay assisted OFDMA networks with the proposed frame structure. The extensive performance evaluations are provided in Section 4. Finally, the conclusion is given in Section 5.

2. System model

We consider a single-cell downlink user relay-assisted OFDMA-based network topology as illustrated in Fig. 1. The BS is located in the center of the cell and K users are distributed uniformly in the cell. The BS and each of the user which will be called as User Equipment (UE) in the rest of the paper have single antenna. The UEs can communicate to the BS either directly or through a user-relay.

The achievable performance and the required signalling of an relay selection scheme depend on the number of relay candidates. If all the available users are utilized as user-relay candidates as in [10,32,34,39–43] this will cause maximum signalling overhead. The number of relay candidates, and thus signalling, can be significantly reduced by selecting the user-relays in a limited area around each

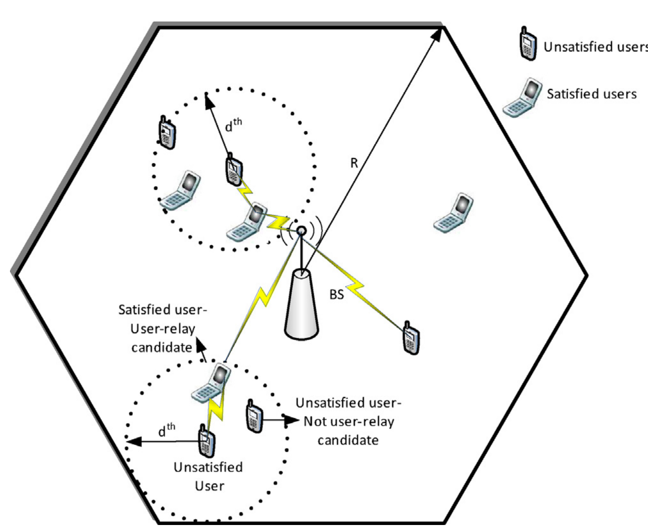

Fig. 1. User-relay assisted OFDMA network topology.