AMPLIFY, COMPRESS AND FORWARD RELAY ASSIGNMENT IN FULL DUPLEX CELLULAR NETWORK

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ABSTRACT

Efficient utilization of radio resources in wireless networks is crucial and has been investigated extensively. This paper considers a wireless relay network where multiple user pairs conduct bidirectional communications via multiple relays based on orthogonal frequency-division multiplexing (OFDM) transmission. The joint optimization of channel and relay assignment, including subcarrier pairing, subcarrier allocation as well as relay selection, for total throughput maximization is formulated as a combinatorial optimization problem. Using a graph theoretical approach, we solve the problem optimally in polynomial time by transforming it into maximum weighted bipartite matching (MWBM) problem. Simulations are carried out to evaluate the network total throughput versus transmit power per node and the number of relay nodes. In this paper we also develop the performance characterizations of different relaying techniques in terms of outage events i.e. outage probability and signal-to-noise ratio (SNR).

Keywords: OFDM, Relaying, relay nodes, Cooperative, Orthogonal, Full duplex, MWBM.

INTRODUCTION

A relay approach for different analysis is proposed in [1] as the relays were divided into two categories one is fixed relay approach and the second is not fixed. But there is version of direct transmission in wireless protocol networks. The observations were made here on cooperative and orthogonal diversity for half duplex. This relaying channel concept has been extended to a full duplex mode.

The relay channel concept has been extended to a full duplex communication network under two different conceptual modes. One is amplify and forward and the other is non fixed relay channel method in [2]. Fig 1 indicates system model which is extracted from [2] for further communication level of n-relay channel of OFDM system.

In a bi-directional relay channel, two nodes wish to exchange independent messages over a shared wireless half-duplex channel with the help of relays. Recent work has considered information theoretic limits of the bi-directional relay channel with a single relay. In this work we consider bi-directional relaying with multiple relays. We derive achievable rate regions and outer bounds for half-duplex protocols with multiple decode and forward relays and compare these to the same protocols with amplify and forward relays in an additive white Gaussian noise channel [3].

Though the optimal subcarrier pairing has been found for one-way relaying such as [4,5], only heuristic subcarrier pairing methods are available for two-way relaying [6,7]. In addition, the problem is more involved in the multiuser scenario since subcarriers should not only be carefully paired for each two-way link but also be assigned adaptively for different users.

The second challenge lies in the fact that subcarrier pairing and relay selection are tightly coupled, i.e., different relay selections lead to different subcarrier pairing and assignment, and vice versa. For instance, a bad pair of subcarriers in two hops for one relay and one user pair may be good for the same user pair if another relay is selected to them, or good for the same relay if another user pair is selected. It is thus necessary to consider them jointly, which can be referred to as subcarrier-to-relay to-user assignment.
Work by King [27], Carleial [28], and Willems et al. [29–32] examines multiple-access channels with
generalized feedback. Here, the generalized feedback allows the sources to essentially act as relays for one
another. This model relates most closely to the wireless channels we have in mind. The constructions in can be
viewed as two-terminal generalizations of the cooperation scheme in [5]; the construction [27] may be viewed
as a two-terminal generalization of the observation scheme in [5]. Sendonaris et al. introduce multipath fading
into the model of [28–30], calling their approaches for this system model user cooperation diversity [6, 33, 34].
For ergodic fading, they illustrate that the adapted coding scheme of [30] enlarges the achievable rate region.

We formulate the joint optimization problem of subcarrier pairing based subcarrier assignment and relay
selection for multiple two-way users as a combinatorial optimization problem. We then adopt a graph based
approach and establish the equivalence between the proposed problem and a maximum weighted bipartite
matching (MWBM) problem. Then the problem is solved by the corresponding graph based algorithm optimally
in polynomial time.

CHANNEL OPERATIONS

The channel operations are of three modes namely SIMPLEX, HALF DUPLEX, and FULL DUPLEX. This is
mostly accessed in telecommunications. It is a point to point communication system.

- SIMPLEX is one way communication system.
- HALF DUPLEX is two way communication but not at the same time.
- FULL DUPLEX is two way communications at the same time.

To make the communication system most reliable RELAY’s were introduced.

RELAY CHANNELS

Relay channels were accessed in between sources for communication in full duplex or half duplex mode of
communication system. These relay channel posses different relaying schemes which are 1) DECODE and
FORWARD, 2) AMPLIFY AND FORWARD and 3) COMPRESS AND FORWARD. These were separated by
Cut set Upper bound, Degraded Relay Channel, Reversely degraded Relay channel and feedback relay channel.

We consider an OFDM-based wireless network with \(K\) pairs of users and \(M\) relays as shown in Fig. 1, where
each user pair exchange information via the relays. Each node operates in a half-duplex mode. For simplicity,
the amplify and- forward (AF) two-way relay strategy is adopted. We model the wireless fading environment
by large-scale path loss and shadowing, along with small-scale frequency-selective fading. We assume that the
channels between different links experience independent fading and the network operates in slow fading
environment, so that channel estimation is perfect. We also assume that a central controller is available in the
network so that the centralized processing is possible.
Note that in relay-assisted wireless networks such as IEEE 802.16j, the relay nodes are usually fixed and hence the network channel state information can be reliably gathered and utilized at one of the relays for centralized resource allocation. The additive white noises at all nodes are assumed to be independent circular symmetric complex Gaussian random variables. We further assume that the direct communication link between the two users in each pair is neglected due to, for instance, the shadowing effects.

This assumption is commonly used in the literature [6, 8–11]. In this work we do not pursue power allocation for simplicity. It is known that power allocation can bring significant improvement in relay networks when all source and relay nodes are subject to a total power constraint [3].

However, the gain brought by power allocation is very limited in OFDM-based relay networks if each transmitting node is subject to an individual peak power constraint [3, 5, 6]. In the considered system model, all nodes are subject to their own individual peak power constraints and, therefore, the transmit power is assumed to be uniformly distributed across all subcarriers.

To establish baseline performance under direct transmission, the source terminal transmits over the channel [1]. The maximum average mutual information between input and output in this case, achieved by independent and identically distributed (i.i.d.) zero-mean, circularly symmetric complex Gaussian inputs, is given by

$$I_D = \log \left(1 + \frac{\text{SNR}}{|s_{d}|^2}\right)$$  \hspace{1cm} (1)

The amplify-and-forward protocol produces an equivalent one-input, two-output complex Gaussian noise channel with different noise levels in the outputs. The maximum average mutual information between the input and the two outputs, achieved by i.i.d. complex Gaussian inputs, is given by

$$I_AF = \frac{1}{2} \log \left(1 + \frac{\text{SNR}}{|s_{a,d}|^2} + \frac{\text{SNR}}{|s_{a,r}|^2} + \frac{\text{SNR}}{|s_{d}|^2} \right)$$  \hspace{1cm} (2)

To analyze decode-and-forward transmission, we examine a particular decoding structure at the relay. Specifically, we require the relay to fully decode the source message; examination of symbol-by-symbol decoding at the relay becomes involved because it depends upon the particular coding and modulation choices. The maximum average mutual information for repetition-coded decode-and-forward can be readily shown to be

$$I_{DF} = \frac{1}{2} \min \left\{ \log \left(1 + \frac{\text{SNR}}{|s_{d}|^2} \right), \log \left(1 + \frac{\text{SNR}}{|s_{a,d}|^2} + \frac{\text{SNR}}{|s_{d}|^2} \right) \right\}$$  \hspace{1cm} (3)

To overcome the shortcomings of decode-and-forward transmission, we described selection relaying corresponding to adaptive versions of amplify-and-forward and decode-and-forward, both of which fall back to direct transmission if the relay cannot decode.

We cannot conclude whether or not these protocols are optimal, because the capacities of general relay and related channels are long-standing open problems; however, as we will see, selection decode-and-forward enables the cooperating terminals to exploit full spatial diversity and overcome the limitations of fixed decode-and-forward.

$$I_{DF} = \left[ \frac{1}{2} \log \left(1 + \frac{\text{SNR}}{|s_{a,d}|^2} \right) + \log \left(1 + \frac{\text{SNR}}{|s_{d}|^2} \right) \right]$$  \hspace{1cm} (4)

Here degraded relaying takes place for incremental amplify and forward which performs much more transmission between cooperating terminals it is nearly equivalent to prediction of transmission. This brought up to reduce SNR and provide better results than Selective decode and forward method. This noted as

$$I_{AF} = \left[ \frac{1}{2} \frac{1}{\text{SNR}} \log \left(\frac{\text{SNR}}{|s_{a,d}|^2} \right) + \frac{1}{2} \frac{1}{\text{SNR}} \log \left(\frac{\text{SNR}}{|s_{d}|^2} \right) \right]$$  \hspace{1cm} (5)

For a novel strategy here multi relay concept is proposed and the two relays used are AMPLIFY AND FORWARD along with COMPRESS AND DECODE.
In what follows, we show that the simplified P2 is equivalent to a maximum weighted bipartite matching (MWBM) problem. Before we proceed, we review some preliminaries of MWBM in [12]. A bipartite graph is a graph whose vertices are divided into two disjoint sets so that every edge connects a vertex in one set to one in another. If the two sets of vertices have the same cardinality, then the bipartite graph is a balanced bipartite graph. A matching is a set of mutually disjoint edges, i.e., any two edges do not share a common vertex. An example is shown in Fig. 2(a). A perfect matching is a matching that every vertex in the graph is matched, an example of which is shown in Fig. 2(b). Note that perfect matching is the special case of matching.

RESULTS

As a performance benchmark, the fixed subcarrier pairing scheme is considered. Like the previous work [1, 2] we let signals transmitted by the user pair on one subcarrier in the MAC phase is forwarded on the same subcarrier by a relay in the BC phase, i.e., $\pi(n) = n$, rather than seeking the optimal subcarrier pairing. Then the problem reduces to selecting the optimal user pair and relay for each subcarrier for throughput maximization, which can be optimally solved by the greedy algorithm. Namely, each subcarrier $n$ shall be assigned to the user pair and the relay that satisfy $(k, r) = \arg\max_{k \in K, r \in R} \pi(n, k, r)$. The overall complexity of the fixed subcarrier paring scheme is $(\Omega N^2)$. Recall that the complexity of the proposed graph-based scheme is $(\Omega N + N^3)$, which is higher than the benchmark scheme. Fig. 4 illustrates the total throughput when there are $K = 5$ user pairs and $M = 4$ relays in the network. We observe that the proposed optimal channel and relay assignment with adaptive subcarrier pairing achieves $8 \sim 10\%$ improvement.

![Fig 2: Bipartite graph (a) An example of matching, (b) An example perfect matching and (c) Proposed bipartite model](image)

![Fig 3: performance comparison of the proposed algorithm and the benchmark](image)
brought by increasing the number of relays is diminishing when $M$ is large enough. This is due to the fact that the capacity scaling of relay selection.

![Fig 4: Effects of the number of relays](image)

It is interesting that amplify-and-forward and selection decode-and-forward have the same high-SNR performance, especially considering the different shapes of their outage events (cf. (14), (20)), which are shown in the low-spectral-efficiency regime in Fig. 4. When the relay can fully decode the source message and repeat it, i.e., the outage event for selection decode- and-forward is a strict subset of the outage event of amplify-and-forward, with amplify-and-forward approaching that of selection decode-and-forward. On the other hand, when the relay cannot fully decode the source message and the source repeats, i.e., the outage event of amplify-and-forward is neither a subset nor a superset of the outage event for selection decode-and-forward. Apparently, averaging over the Rayleigh-fading coefficients eliminates the differences between amplify-and-forward and selection decode-and-forward. Selection Decode and forward with compress and forward, incremental amplify and forward with compress and forward at least in the high-SNR regime.

![Fig 5: Outage probability under different relaying techniques](image)

For larger spectral efficiencies, fixed and selection relaying lose an additional 3 dB per transmitted bit per second per hertz (bit/s/Hz) with respect to the transmit diversity bound. This additional loss is due to two factors: the full-duplex constraint and the repetition-coded nature of the protocols. As suggested by Fig. 3, of the two, repetition coding appears to be the more significant source of inefficiency in our protocols. In Fig. 3, the SNR loss of orthogonal transmit diversity with respect to unconstrained transmit diversity is intended to indicate the cost of the full-duplex constraint, and the loss of our cooperative diversity protocols with respect to the transmit diversity bound indicates the cost of both imposing the full-duplex constraint and employing repetition-like codes. The figure suggests that, although the full-duplex constraint contributes, “repetition” in the form of amplification or repetition coding is the major cause of SNR loss for high rates. By contrast, incremental amplify-and-forward plus compress and forward overcomes these additional losses by repeating only when necessary.
CONCLUSION

In this paper, we investigated the joint optimization of subcarrier-pairing based subcarrier assignment and relay selection for multi-relay multi-pair two-way relay OFDM networks. The problem was formulated as a combinatorial optimization problem. We proposed a bipartite matching approach to solve the problem optimally in polynomial time. The work assumed the amplify-and-forward based non regenerative relay strategy. The performance characterizations of different relaying techniques were also developed.

REFERENCES


