

Optimizing Performance of Subcarrier Assignment and Power Allocation for OFDMA Systems

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ABSTRACT: Cooperative communication has recently been considered as a key technology for modern wireless standards and next generation wireless networks to improve the quality-of-service (QoS) and extend transmission coverage in a cost-effective manner. For designing the efficient OFDM-based relay communication systems, there are various relaying schemes are used. Among these schemes amplify-and-forward (AF) and decode-and-forward (DF) schemes are considered and adaptive relaying protocol has been proposed to improve the performance of Subcarrier assignment and power profiles with multiple users using orthogonal frequency division multiple access (OFDMA). The objective is to allocate subcarrier for band separation of channel to carry the bits of information at stable power level. We formulate such a problem as a subcarrier based resource allocation that seeks joint optimization of subcarrier pairing, subcarrier-pair-to-relay assignment and power allocation. Simulation result demonstrate the proposed method give better performance when compared with the conventional techniques in terms of SNR and BER.

KEYWORDS: AF/DF cooperative communication, Power allocation, Adaptive Relaying Protocol

I. INTRODUCTION

In wireless relay networks (WRNs) signals are transmitted from one terminal to another through a number of relays. The main advantage of doing so is a reduced signal transmit power. As multiple users come into play, efficient management of relay resources becomes a critical issue for improving the system performance. In [1], the authors developed power allocation schemes for AF multi-user system using different objectives such as maximizing the minimum rate, maximizing the sum rate, and minimizing the total power consumption with a constrained minimum transmission rate. In [2], the authors studied relay assignment and power allocation for AF relay system to maximize the sum-rate of all users subject to individual and total power constraints.

Resource allocation in OFDMA systems is a complex problem, especially in the uplink communication due to the following reasons: the discrete nature of the subchannel assignment, the heterogeneity of the users' subchannel conditions, and individual resource constraints. Compared to conventional OFDMA transmission, relay-aided (cooperative) OFDMA transmission raises more complicated resource allocation problems as it introduces extra tasks. Such tasks are: deciding the transmission mode of each subcarrier, and determining the assisting relays and power assignment for each subcarrier at the source and relay nodes under individual and total power constraints [16]-[19].

Subcarrier allocation in OFDMA systems was investigated in many works to achieve different objective criteria [13]-[15]. In [13], the objective is to minimize the total transmit power under minimum rate constraint. In [14], the objective is to maximize the weighted sum rate subject to individual power constraint. Maximizing the overall system rate subject to individual power constraint while considering proportional fairness based on Nash bargaining is considered in [15].

Time sharing principle is one of the approaches which is used to solve mixed-integer resource allocation problems in OFDM and OFDMA systems [20]. In practical OFDMA systems, the duality gap goes asymptotically to zero for small number of subcarriers as shown in [17]-[22]. Sub-optimally approaches for resource allocation in OFDMA systems are investigated as in [23], where a two-phase approach is proposed; the subcarriers are assigned in the first phase using a genetic algorithm based on equal power allocation, then optimal power allocation is performed in the second phase. Resource allocation for OFDMA with cooperative communication was investigated in many works such as [24]-[26].

An adaptive relaying protocol (ARP) is proposed here, which takes advantages of both DF and AF protocols and minimize their disadvantages. For the proposed scheme, all relays are included into one of two relay schemes, which we called a DF relay scheme, and an AF relay scheme. All relays, which can correctly decode the signals transmitted from the source, are included in the DF relay scheme and the rest of relays, which fail to make a correct decoding, are included in the AF relay scheme.

All the relays in the AF relay scheme amplify the received signals from the source and forward it to the destination, while the relays in the DF relay scheme decode the received signals, re-encode and forward them to the destination. Another important feature is that the processing at relays and destination for the ARP scheme in a practical application is that the relay can automatically adapt to the channel quality by simply switching between the AF and the DF without any need for the channel state information (CSI) to be fed back from the destination to the relays or the source. The processing at the destination for the ARP is the same as for the AF and DF.

All signals received at the destination, forwarded from the relays in both the AF and DF schemes are combined together into one signal. The performance of the proposed ARP is analyzed and compared with other relaying protocols. It is shown that the proposed ARP scheme considerably outperforms the AF scheme and circumvents the error propagation due to the imperfect decoding at relays in a DF protocol, thus considerably outperforming both the AF and the DF protocols. This performance gain grows as the number of relays increases and it approaches the perfect DF at the high signal to noise ratios (SNR). The above analytical results are also validated by simulation results.

Rest of the paper is structured as follows. Section II describes the system model. Section III-V describes different relaying protocols. The Performance analysis is presented in Section VI. Numerical results are presented and discussed in Section VI. Section VIII concludes this paper.

II. SYSTEM MODEL

A simple cooperative communication system is considered in this work and simulated in Matlab. Fig. 1 gives a block diagram of a 2-hop relay system consisting of one source, relay and one destination with a direct link from the source to the destination. We assume that the source and relays transmit data through orthogonal channels. In the separate time slots, the source and relays transmits the information to the destination. The source first broadcasts the information to both the destination and relays. The source node and destination node are fixed so distance between them is constant, while relay node is moved over various points between source node and destination node, starting from near to source node to near to destination node. Signal is sent by transmitting node to destination node and relay node. The relay node performs operation of amplify and forward and decode and forward on the received signal, separately. Then operated signal at relay node is forwarded to destination, so destination will have two copies of the same signal, one direct signal (from transmitting node) and another operated signal (from relay node). Two signals are combined at the destination to get a stronger signal and then BER (bit error rate) of combined signal is calculated over fixed SNR (signal to noise ratio) value. The performance of each technique AF and DF is analyzed against BER. Different graphs are generated over different SNR values to show location impact of relay node on AF and DF's performance. The received signals at the relay i and destination, at time k , denoted by $y_{sr,i}(k)$ and $y_{sd}(k)$ respectively, can be expressed as

$$y_{sr,i}(k) = \sqrt{P_{sr,i}} h_{sr,i} s(k) + n_{sr,i}(k) \quad (1)$$

$$y_{sd}(k) = \sqrt{P_{sd}} h_{sd} s(k) + n_{sd}(k) \quad (2)$$

where $s(k)$ is the symbol transmitted at time k , $P_{sr,i} = P_s \cdot (G_{sr,i})^2$, $P_{sd} = P_s \cdot (G_{sd})^2$ are the received signal power at the relay i and destination, respectively, P_s is the source transmit power, $G_{sr,i}$ and G_{sd} are the channel gains between the source and relay i and that between the source and destination, respectively. Also $h_{sr,i}$ and h_{sd} are the fading coefficients between the source and the relay i and between the source and destination, respectively [5].

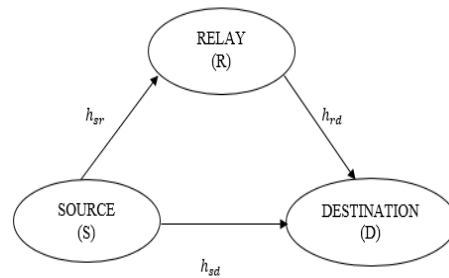


Fig 1. System Model

In this paper, we consider the fading coefficients are constant within one frame and change independently from one frame to another. Furthermore, $n_{sr,i}(k)$ and $n_{sd}(k)$ are zero mean complex Gaussian random variables with power spectral density of $N_0/2$ per dimension. The relays then process the received signals and send them to the destination [5]. Let $x_{sr,i}(k)$ represent the signal transmitted from the relay i at time k . It satisfies the following transmit power constraint,

$$E(|x_{r,i}(k)|^2) \leq P_{r,i} \quad (3)$$

where $P_{r,i}$ is the transmitted power limit at the relay i . The corresponding received signal at the destination at time k , denoted by $y_{rd,i}(k)$, can be written as

$$y_{rd,i}(k) = y_{rd,i} h_{rd,i} x_{r,i}(k) + n_{rd,i}(k) \quad (4)$$

where G_{rd} is the channel gain between the relay i and destination, $h_{rd,i}$ is the fading coefficient between the relay i and destination and $n_{rd,i}(k)$ is a destination noise with power spectral density of $N_0/2$ per dimension.

III. AMPLIFY AND FORWARD (AF)

As the name shows, the Amplify and Forward relaying technique simply amplifies the signal received by the relay and forwards it to the destination [3]. This method is better to use when the relay has only limited computing time and power available, or the time delay caused by the relay to perform operation on the received signal, which has to be minimized [4]. The working principle of amplify and forward relaying protocol is very simple. The signal received by the relay node must be attenuated and needs to be amplified before it can be sent again towards destination. While amplifying the received signal the noise in the signal is also amplified, this is the main drawback of this technique. Another disadvantage of this technique is that it is not able to store any information in a buffer as the processing involved is analogue but not digital.

An AF relaying scheme, denoted by Ω_{AF} , consists of all the relays, which could not decode correctly [5]. Upon receiving signals from the source, each relay in the AF relaying scheme will simply amplify the received signals from the source. Let $x_{r,i}(k)$, $i \in \Omega_{AF}$ represent the signal transmitted from the relay i at time k , then it can be expressed as

$$x_{r,i}(k) = \mu_i y_{sr,i}(k), i \in \Omega_{AF} \quad (5)$$

where μ_i is an amplification factor such that $x_{r,i}(k)$ satisfies the power constraint in (3) and it can be calculated as

$$\mu_i = \sqrt{\frac{P_{r,i}}{|h_{sr,i}|^2 P_{sr,i} + N_0}} \quad (6)$$

By substituting (5) and (1) into (4), the received signal at the destination, transmitted from relay i become

$$y_{rd,i}(k) = G_{rd,i} h_{rd,i} \mu_i (\sqrt{P_{sr,i}} h_{sr,i} s(k) + n_{sr,i}(k)) + n_{rd,i}(k), i \in \Omega_{AF} \quad (7)$$

IV. DECODE AND FORWARD (DF)

This is the most preferred technique for processing the signal received by relay node. Working principal of decode and forward relaying protocol is closest to the one of a conventional relay. The working principal behind decode and forward is that the received data in relay node is decoded first and then it is transmitted to destination after reencoding[3]. If an error correcting code is placed with source message, bit errors in received data could be corrected at the relay node. And if no error correcting code is given in source data then a checksum makes relay node capable of detecting if the received data has errors or not. Now it depends on the implementation that a message with errors should be forwarded to destination or not.

The DF relaying scheme, denoted by Ω_{DF} , consists of all the relays, which can make an error-free decoding [5]. Since all the relays in the DF relay scheme can decode correctly, each relay in the DF relay scheme can accordingly recover the binary information stream is then encoded and modulated into S. The relay i in the DF relay scheme will then forward the modulated symbols S with power $P_{r,i}$ to the destination,

$$x_{r,i}(k) = \sqrt{P_{r,i}} s(k), i \in \Omega_{DF} \quad (8)$$

The received signals at the destination, transmitted from the relay i in the DF relay scheme, become

$$y_{rd,i}(k) = G_{rd,i} h_{rd,i} \sqrt{P_{r,i}} s(k) + n_{rd,i}(k), i \in \Omega_{DF} \quad (9)$$

V. ADAPTIVE RELAYING PROTOCOL (ARP)

For the proposed adaptive relaying protocol (ARP), in each transmission, based on whether relays can make correct decoding or not, each relay is included into one of two schemes, an AF relay scheme and a DF relay scheme. All the relays in the AF relay scheme amplify the received signals from the source and forward it to the destination, while all the relays in the DF relay scheme will decode the received signals, re-encode and forward them to the destination. This is a new method given in this work. As relay node moves between source and destination no single relaying strategy can give constant results and at some points cooperation is no more useful, so if two relaying techniques are used together could result in a better performance. According to this method a relay station will be equipped with more than one relaying strategies and relay station will be capable of switching between different relaying techniques, according to its location relative to source and destination. This could mitigate location effects on the performance, while relay is moving all around. When a relay station is loaded with more than one relaying technique and it is enough intelligent to trace its own location, and it can switch between different relaying techniques according to its location.

For example if we consider a relay station which is equipped with AF and DF and it is capable of locating itself and multiplex between two relaying techniques. In such a scenario whenever the information is more it will use DF, once it is less it will switch to AF. In doing so the user (source) can enjoy the benefits of cooperation throughout the whole transmission, even though relay node is moving all around. Below are graphs generated over different SNR values to show this method is useful. All signals received at the destination, forwarded from the source, the AF and DF schemes, are combined as follows,

$$y_{rd-ARP}(k) = w_{sd} y_{sd}(k) + \sum_{i \in \Omega_{AAF}} w_{r,i} y_{rd,i}(k) + \sum_{i \in \Omega_{DAF}} w_{r,i} y_{rd,i}(k) \quad (10)$$

The optimal values of w_{sd} and $w_{r,i}$ are given by

$$w_{sd} = \frac{\sqrt{P_{sd}h_{sd}^*}}{N_0}, w_{r,i} = \frac{\sqrt{P_{rd}h_{rd,i}^*}}{N_0}, i \in \Omega_{DF}, w_{r,i} = \frac{\mu_i G_{rd,i} \sqrt{P_{sr,i} h_{rd,i}^* h_{sr,i}^*}}{(\mu_i^2 |G_{rd,i} h_{rd,i}|^2 + 1) N_0}, i \in \Omega_{AF} \quad (11)$$

By substituting (11) into (10), the destination SNR after combination, denoted by γ_{ARP} , can be approximated as

$$\gamma_{ARP} = \gamma_{AF} + \gamma_{DF} \quad (12)$$

$$\text{where } \gamma_{AF} = \gamma_{sd} |h_{sd}|^2 + \frac{1}{2} \sum_{i \in \Omega_{AF}} H_2^i \quad (13) \quad \gamma_{DF} = \sum_{i \in \Omega_{DF}} \gamma_{rd,i} |h_{rd,i}|^2 \quad (14)$$

where $\gamma_{sd} = \frac{P_{sd}}{N_0}$, $\gamma_{rd,i} = \frac{P_{rd,i}}{N_0}$, $\gamma_{sr,i} = \frac{P_{sr,i}}{N_0}$, H_2^i is called the Harmonic Mean of variables

VI. PERFORMANCE ANALYSIS

In this section, we analyze the performance of the ARP and compare with other relaying protocols. For simplicity of calculation, we assume that $\gamma_{sr,i} = \gamma_{sr}$ and $\gamma_{rd,i} = \gamma_{rd}$ for all $i=1, \dots, n$. Let γ_{AF} and γ_{DF} represent the instantaneous received SNR of the combined signals in the AF and DF relay schemes.

$$\gamma_{AF} = \gamma_{sd} |h_{sd}|^2 + \frac{1}{2} \sum_{i=1}^q H_2^i \quad (15)$$

$$\gamma_{DF} = \gamma_{rd} \sum_{i=q+1}^n |h_{rd,i}|^2$$

Due to the uniform distribution of relays and assumption of $\gamma_{sr,i} = \gamma_{sr}$ for all $i=1, \dots, n$, the average PEP at high SNR, denoted by $P^{ARP}(d)$, can be calculated as

$$P^{ARP}(d) \leq \sum_{q=0}^n \binom{n}{q} E \left[\prod_{i=1}^q P_{F,SR}^i(\gamma_{sr} |h_{sr,i}|) \prod_{i=q+1}^n \left(1 - P_{F,SR}^i(\gamma_{sr} |h_{sr,i}|) \right) Q(\sqrt{2d\gamma_{AF} + 2d\gamma_{DF}}) \right] \quad (17)$$

$$\text{At high SNR, } P^{ARP}(d) \leq \gamma_{sd}^{-1} \gamma_{rd}^{-n} d^{-(n+1)} \left(1 + \frac{\gamma_{rd}}{\gamma_{sr}} \right)^n \quad (18)$$

Similarly, for a perfect DF, in which all relay are assumed to decode correctly, the average PEP of incorrectly decoding to a code word with weight d , denoted by $P^{DF}(d)$, can be calculated as

$$P^{DF}(d) \leq \gamma_{sd}^{-1} \gamma_{rd}^{-n} d^{-(n+1)} \quad (19)$$

$$\text{Eq. (18) can be expressed as, } P^{ARP}(d) \leq \left(1 + \frac{\gamma_{rd}}{\gamma_{sr}} \right)^n P^{DF}(d) = G^{ARP} P^{DF}(d) \quad (20)$$

where $G^{ARP} = \left(1 + \frac{\gamma_{rd}}{\gamma_{sr}} \right)^n > 1$ (21) represents the performance loss of the ARP compared to the DF. Let P_b^{ARP} be the average upper bound on the bit error rate (BER) for the ARP. At high SNR, it can be approximated as

$$P_b^{ARP} \approx \sum_{d=d_{min}}^{4l} \sum_{j=1}^l \frac{j}{l} \binom{l}{j} p(d|j) P^{ARP}(d) \quad (22)$$

where $\binom{l}{j}$ is the number of words with Hamming weight j and $p(d|j)$ is the probability that an input word with Hamming weight j produces a code word with Hamming weight d .

Similarly analysis, the average PEP of the AF of incorrectly decoding to a code word with weight d , denoted by $P^{AF}(d)$, can be similarly calculated as

$$P^{AF}(d) = Q(\sqrt{2d\gamma_{AF,n}}) \leq \gamma_{sd}^{-1} \left(\frac{1}{\gamma_{sr}} + \frac{1}{\gamma_{rd}} \right)^n d^{-(n+1)}$$

Compared to $P^{AF}(d)$, the average PEP of the ARP in Eq. (18) can also be expressed as

$$P^{ARP}(d) \leq G^{ARP/AF} P^{AF}(d) \quad (23)$$

where $G^{ARP/AF} = \left(1 - \frac{1-\phi(d)}{1+\gamma_{sr}\gamma_{rd}^{-1}}\right)^n < 1$ (24) represents the performance gain of the ARP over the AF.

The power allocated to a sub-channel or the transmit power in each sub-channel $P_{j,d}$ having power gains $h_{ij,d}$ with the water level of user i , $\mu_i = \frac{1}{M} \left[P_t + \sum_{d=1}^M \frac{N_0}{h_{ij,d}} \right]$ is

$$P_{j,d} = \frac{1}{MI} \left[P_t + \sum_{i=1}^I \frac{N_0}{h_{ij,d}} \right] - \frac{N_0}{M_d} + \frac{1}{M} \sum_{d=1}^M \frac{N_0}{h_{ij,d}} - \frac{1}{h_{ij,d}} \quad (25)$$

The data is generated randomly and then modulated by 16 bit, 32 bit and 64 bit QAM modulation schemes to obtain BER performance of the OFDM system.

VII. SIMULATION RESULTS AND DISCUSSION

In this section, we provide simulation results comparisons for various relaying schemes. Fig. 2 compare the performance of the AF, the ARP and the DF for different SNR Values over 1000 iteration. It can be noted that the ARP significantly outperforms the AF in all SNR regions, and perform very close to the perfect DF as γ_{sr} increases. It can be noted from Eq. (24) that $G^{ARP/AF}$ is a decreasing function of γ_{sr} , therefore, as either γ_{sr} or n increases, $G^{ARP/AF}$ is exponentially decreasing, and the ARP can achieve considerable performance gain compared to the AF.

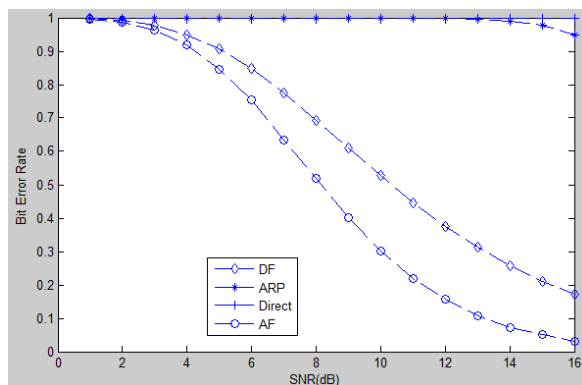


Fig 2. Performance of different relaying protocols

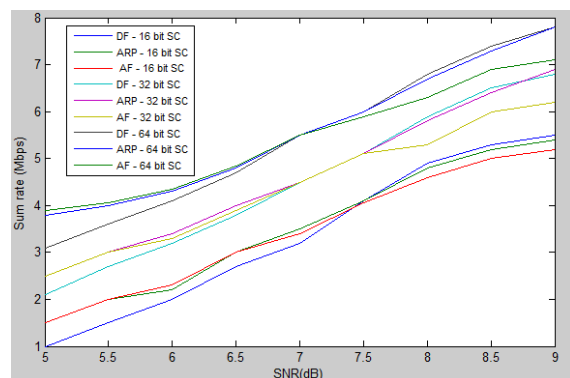


Fig 3. SNR Performance at each subcarrier of three relaying protocols

For low γ_{sr} , values, the channel from the source to the relays are very noisy and probabilities of decoding errors at each relay are very high, so most of relays cannot correctly decode the received signals. For low γ_{rd} values, the relays in the DF relaying scheme can considerably improve the overall channel quality. Fig 3 compares the SNR performance of three relaying protocols at different subcarrier such as 16, 32 and 64 bits. The above simulation results confirm that the ARP can provide a significant coding gain in all SNR regions and perform very closely to the perfect DF as γ_r , increases.

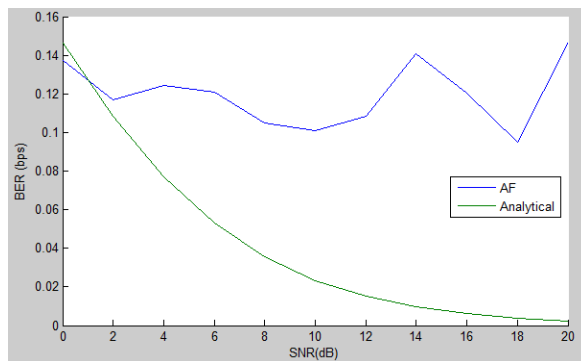


Fig 4. Equal Ratio Combining

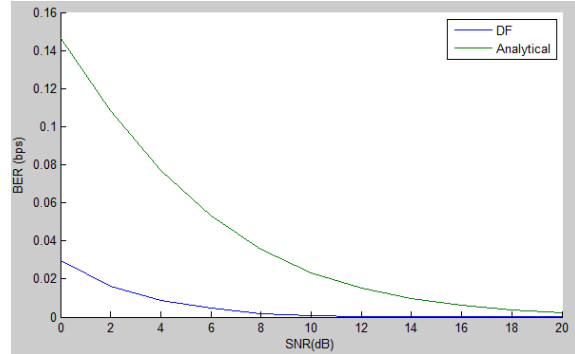


Fig 5. Maximum Ratio Combining

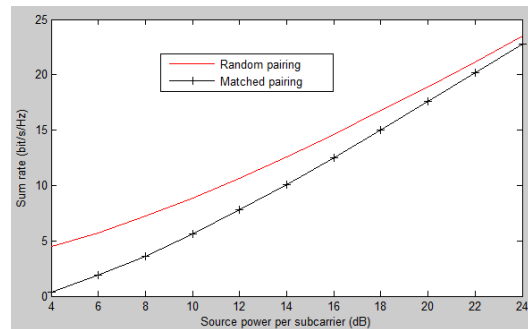


Fig 6. Performance of subcarrier Pairing

Diversity reception schemes, MRC and ERC with OFDM, two types of pairing such as matched and Random pairing are implemented on frequency selective fading channels. The performance plots obtained are shown as in the Fig. 4, 5 and 6. It can be seen that the diversity schemes outperform equalizers and maximize the performance gain. MRC performs marginally better than the ERC scheme at the expense of complexity. It can be concluded that when the constellation size increases the BER also increases and further, the BER performance is almost independent of the number of subcarriers except at very high SNR.

VIII. CONCLUSION

Analytical and theoretical results show that the proposed adaptive protocol can achieve significant power saving or coverage extension compared to the direct transmission. Our results reveal that the proposed scheme can provide a significant SNR gain compared to the AF relay protocols and DF relay scheme. The proposed scheme can also evade the error propagation due to imperfect decoding at relay, which usually occurs in a DF relay protocol, and approach the perfect DF scheme at a high SNR region. Here we have analyzed the performance of diversity schemes under ratio combining model with OFDM technique. We can conclude that by using higher order modulation scheme with OFDM technique we can transmit more data rate.

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