Relay Technology with Unequal Emission Power: Multi-mode Relay

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Abstract. Relay technology can enlarge the coverage of cellular network, improve the spectral efficiency, and enhance the robustness of communication system. It has been one of the most striking areas in recent years. In this paper we discussed the relay technology with one-way relay and two-way relay, introduced two kinds of relay techniques: amplify-and-forward (AF), and Decode-and-Forward (DF). Then based on two-way amplify-and-forward relay, we derived the amplify factors of unequal emission power relay.

Introduction

The improvement and evolution of future communication will be to increase the throughput rate and the coverage rate. With the improvement of traditional communication system, technique in physical layer has been greatly advanced than before, but the network structure mostly does not change. Also, in traditional cellular networks, the network planning scheme is imperative for satisfying the coverage and traffic requirement. The rapidly growing number of users in today’s cellular networks demands more base stations (BSs) to accommodate the increasing traffic load. The network structure becomes the key factor to enhance the throughput rate and the coverage rate.

The relay technique has been one of the research hotspots. The idea of relay was first presented by the Danish mathematician Erlang in 19th century, and the relay route traffic unit was also named by Erlang. Relay technique aims to enhance the spectral efficiency of the edge of cell, to improve the coverage of cell and to decrease the coverage shadow area.

The study focused on one-way relay system [1][2], but the half-duplex working mode of one-way relay greatly decreased the spectral efficiency and wasted the system resources. Shannon analyzed the two-way system with full duplex working mode [3]. Research shows that the two-way relay system can increase the spectral efficiency on the basis of one-way relay system.

Literature [4] compared a two-way DF relaying system in IEEE 802.11n WLANs. Comparing to the conventional DF relaying system, the two-way DF relaying was able to increase the spectral efficiency and to reduce the delay of a two hop link in an 802.11n WLAN. Some researchers [5] propose a new idea to control the multiple access efficiency of a two-way relay. The idea is to combine the randomized cooperative coding with the two-way relay. In literature [6], writer considers the two-way AF relaying network with unequal power co-channel interferers and channel estimation error. [6] also derives the approximate signal-to-interference plus noise ratio expressions.

In this paper, we mainly discuss the two form of relay, show the; based on two-way AF relay, we simply derive the amplify factors of unequal relay emission powers. Finally, we conclude the problems that future works need to figure out.
Relay Technology

One-way relay

One-way relay system model is shown in Fig.1, which is widely used in many literatures. This is a classical three nodes relay model. Source S broadcasts the signal to relay node R and destination D at the first slot. Then relay node R process the signal and sent it to destination D at second slot. The processing in relay has two ways: Amplify-and-Forward (AF), and Decode-and-Forward (DF).

![Figure 1. One-way Relay System Model.](image)

AF relay protocol means the relay node just simply amplifies the signal and then sends to the destination D. Although the noise in the signal is also amplified, which has influence on SNR, but the destination D receives two independent fading signals, which means D can test the correlation of two signals from S and R. Then D can make more accurate judgments and decrease the influence of the noise.

DF relay protocol means relay node demodulates and decodes the received signal, and get the original information. Then relay codes and modulates the signal, and sends to the destination D. D can also choose to receive just one signal or two signals.

Two-way Relay

The two-way relay system model is shown in Fig.2. Node A and B transmits the signal to relay node with power $p_a$ in the first time slot, and the received signal at relay node is $y_r$. Then relay node broadcast the signal back to A and B after processing (AF or DF, in this paper, we mainly focus on AF relay) in the second time slot. It should be noticed that the relay powers to source A and B are equal ($p_{ra} = p_{rb}$) in these literatures. In this condition, received signal at relay can be expressed as

$$y_r = \sqrt{p_s} x_A H_A + \sqrt{p_s} x_B H_B$$

(1)

Where $H_A$ and $H_B$ are the channel fading which can be assumed as complex Gaussian random distribution with zero mean and unit variance; $x_A$ and $x_B$ are signals from node A and B.

![Figure 2. Two-way Relay System.](image)
Multi-mode Relay and Outage Performance

In [7], researchers introduced a multi-mode relaying system, in which Primary User (PU) can act as both a common UE or as an 802.11g-relay to let Secondary User (SU) to connect to the base station via PU. And then in [8], researchers introduced a realistic energy model to evaluate the energy consumption of multi-mode relay.

So we considers that the multi-mode is expressed as the relay emission powers should be $p_{ra} \neq p_{rb}$. Because of the difference of emission power, the amplify-and-forward (AF) factor $\beta$ from relay to nodes (A and B) should not be the same. Then the $\beta$ should be rewritten as

$$
\beta_1 = \sqrt{p_{ra} \left[ p_s \left( |\tilde{H}_a|^2 + |\tilde{H}_b|^2 \right) + 2p_s \sigma^2_E + \sum_{n=1}^{N} p_{r,n} |H_{1,n}|^2 \right]}
$$

$$
\beta_2 = \sqrt{p_{rb} \left[ p_s \left( |\tilde{H}_a|^2 + |\tilde{H}_b|^2 \right) + 2p_s \sigma^2_E + \sum_{n=1}^{N} p_{r,n} |H_{1,n}|^2 \right]}
$$

Where $\tilde{H}_i$ (i=A, B, I) means the perfect channel state information (CSI); and the variance is $\rho^2 = 1 - \sigma^2_E$; $\sigma^2_E$ denotes the secondary moment of channel estimation errors. According to these we can achieve the system performance of the two-way relay system with unequal relay emission powers.

The outage events in communication system can be denoted as: if the data rate falls below the threshold rate, the outage of communication happens. Then the system outage probability can be written as

$$
P_{out} = 1 - \Pr(r_{BA} > r_{th} \mid r_{BA} < r_{AB}) - \Pr(r_{AB} > r_{th} \mid r_{BA} > r_{AB})
$$

$$
= 1 - \Pr_1 - \Pr_2
$$

where $r_{th}$ represents the target SINR, respectively; the data SINR from B to A are defined as $r_{BA}$, vice versa. Then we can achieve the outage probability expression by using complex mathematical method

$$
R_1 = \frac{d_1 \omega_1 (\Omega \mathbf{1})^j}{\mathbf{1}^j} \cdot \exp \left( -\frac{1}{2t} \left( \Omega \mathbf{1} - \frac{1}{p_{r_2}} \mathbf{1} + \frac{2\Sigma}{p_{r_2}} \right) \right)
$$

$$
\left( \sum_{m=1}^{m} \mathbf{m}^T \right) \cdot \left( \frac{1}{2} \cdot \frac{\frac{1}{p_{r_2}} \mathbf{1}}{2} \cdot \frac{\mathbf{1}}{m} \right) \cdot \exp \left( -\frac{1}{2t} \frac{\Omega \mathbf{1} - \frac{1}{p_{r_2}} \mathbf{1} + \frac{2\Sigma}{p_{r_2}}}{m} \right)
$$

where $\Omega$ is interferences matrix from other nodes and the $\nu$ is the expectation of $\Omega$. The simulation result is shown in Fig.3.
Conclusion

The multi-mode relay not only play a mobile role at the SU-PU-BS system 0, but also can be a fixed multi-mode relay at the heterogeneous hierarchical wireless networks (HHWN). HHWN introduces many low power BSs, like picocells, femtocells, distributed antenna systems, and the standard of these BSs has been set up from 3GPP Release 8 to Release 10. Multi-mode relay could act as both picocell and femtocell at the edge of the cellular network, which is good for reducing the complexity of network and controlling the power consumption.

There are still a lot problems to be considered, like the inner-interference when different modes are running at the same time. We can deal with this problem by protect frequency band, special isolation, or other ways. But the particular system performance still needs to be analyzed.

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Reference

