

The AF protocol of cooperative communication system

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Abstract. Wireless communication system using cooperative transmission technology, at the receiving node by combining data samples from multiple independent fading channel, can effectively resist the influence of channel fading, obtain diversity gain, and improve the transmission reliability of the system. The purpose of cooperative communication technology is to solve the problem of communication effectiveness. This article expounds the amplify-and-forward(AF) protocol of the cooperative relay technology that is one of the key technology in cooperative communication technology, and discusses its ergodic capacity(EC). Theory proves that two-way relay can greatly improve the rate of information transmission

1. Introduction

Cooperative communication technology is one of the most important research focus in the field of wireless communication nowadays. When to design a wireless communication system, it needs to consider overcoming the characteristics of wireless channel fading, expanding channel capacity and improving the channel quality, while cooperative relay technology can overcome the above problems[1]. Cooperative relay technology can greatly improve the quality of communication, resist the influence of wireless channel fading, shadow effect and multi-path effect, expand the scope of communication, and reduce the mobile terminals, etc. Cooperative relay technology can greatly improve the quality of communication, resist the influence of wireless channel fading, shadow effect and multi-path effect, expand the scope of communication, and reduce the mobile terminals, etc. However, due to the limitation of practical half-duplex relay communication system, the relay technology also brings the loss of spectrum efficiency at the same time in improving the performance of wireless communication. In this case, two-way relay arises at the historic moment. Two-way relay can receive and forward signals of two end users to greatly improve the rate of information throughput(RIT).

The rest of this paper is organized as follows. Section 2 expounds the principle of two-way relay system, analyzes in detail two relay protocols-AF protocol. Section 3 analyzes in detail the AF protocol of two relay protocol and deduces its ergodic capacity(EC) under the condition of Rayleigh fading channel for two-way relay system. Section 4 concludes the paper and proposes future work.

2. The protocol of two-way relay system

Considering a two-way relay communication system, the user nodes-A and B exchange information each other. But because there is no direct link between A and B, and needs to forward information through the relay node-R, as shown in Fig. 1[3]. Supposing the system goes through flat fading, and adopts time-division duplex mode, then the channels are reciprocity. Take the system as shown in Fig. 1 as an example to discuss the different protocols two-way relay system.

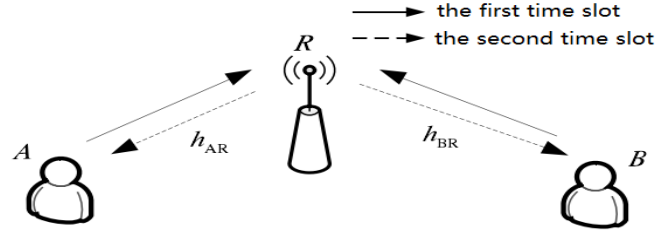


Fig.1 The model of two-way relay system

In the first time slot, A and B simultaneously send their own signals to R. In this way, the received signals at R can be expressed as (1).

$$y_R = h_{AR}x_A + h_{BR}x_B + n_R \quad (1)$$

Among it, x_A and x_B is the sent signal of A and B respectively. h_{AR} is the fading channel coefficient between A and R, h_{BR} is the fading channel coefficient between B and R, and n_R is AWGN with the power- σ^2 at the R.

In the second time slot, R firstly processes the received signals, and then transmits information to A and B. Therefore R amplifies the received signals and then forwards them, while during the amplification process, the following amplification factor is used:

$$\alpha = \sqrt{\frac{P_R}{P_A|h_{AR}|^2 + P_B|h_{BR}|^2 + \sigma^2}} \quad (2)$$

Among it, P_R , P_A and P_B present the sent power of R, A and B respectively. Thus the received signals of A and B can be expressed in the following formulations separately.

$$y_A = h_{AR}\alpha y_R + n_A = h_{AR}\alpha(h_{AR}x_A + h_{BR}x_B + n_R) + n_A \quad (3)$$

$$y_B = h_{BR}\alpha y_R + n_B = h_{BR}\alpha(h_{AR}x_A + h_{BR}x_B + n_R) + n_B \quad (4)$$

Among them, n_A and n_B are AWGN with the variance- σ^2 at A and B. Because A and B are both known their own sent signals, their own self-interference of the formulations-(3) and (4) can be completely eliminated[3]. And the instantaneous received SNR of two one-way channel- $A \rightarrow R \rightarrow B$ and $B \rightarrow R \rightarrow A$ in this two-way relay communication system can be obtained respectively as:

$$\Gamma_B^{AF} = \frac{|h_{AR}|^2|h_{BR}|^2\gamma_A\gamma_R}{\gamma_A|h_{AR}|^2 + (\gamma_R + \gamma_B)|h_{BR}|^2 + 1} \quad (5)$$

$$\Gamma_A^{AF} = \frac{|h_{AR}|^2|h_{BR}|^2\gamma_B\gamma_R}{(\gamma_A + \gamma_R)|h_{AR}|^2 + \gamma_B|h_{BR}|^2 + 1} \quad (6)$$

Among it, $\gamma_A \triangleq P_A/\sigma^2$, $\gamma_B \triangleq P_B/\sigma^2$, and $\gamma_R \triangleq P_R/\sigma^2$. Therefore, the instantaneous information rate of two one-way channel- $A \rightarrow R \rightarrow B$ and $B \rightarrow R \rightarrow A$ can be expressed respectively as

$$I_B^{AF} = \frac{1}{2} \log_2(1 + \Gamma_B^{AF}) \quad (7)$$

$$I_A^{AF} = \frac{1}{2} \log_2(1 + \Gamma_A^{AF}) \quad (8)$$

Note that to estimate the signal-to-noise ratio of two-way relay systems, there still needs to further estimate noise power of nodes. In the actual relay system, it can be sent pilot information to estimate the noise power. Under the condition of known pilot information and channel state information, use the received pilot signals to estimate the noise power[4-5].

3. An analysis of two-way AF relay system for its ergodic capacity(EC)

The EC of two-way AF relay system[7,10] is the sum of two one-way channel for their EC, which can be expressed as:

$$C_T^{AF} \stackrel{\Delta}{=} C_A + C_B \quad (9)$$

Among it, $C_A \stackrel{\Delta}{=} E_{h_{AR}, h_{BR}}(I_A^{AF})$ and $C_B \stackrel{\Delta}{=} E_{h_{AR}, h_{BR}}(I_B^{AF})$, respectively expressed as:

$$C_A = E_{h_{AR}, h_{BR}} \left[\frac{1}{2} \log_2 (1 + \Gamma_A^{AF}) \right] = E_{h_{AR}, h_{BR}} \left[\frac{1}{2} \log_2 \left(1 + \frac{\gamma_B \gamma_R |h_{AR}|^2 |h_{BR}|^2}{(\gamma_A + \gamma_R) |h_{AR}|^2 + \gamma_B |h_{BR}|^2 + 1} \right) \right] \quad (10)$$

$$C_B = E_{h_{AR}, h_{BR}} \left[\frac{1}{2} \log_2 (1 + \Gamma_B^{AF}) \right] = E_{h_{AR}, h_{BR}} \left[\frac{1}{2} \log_2 \left(1 + \frac{\gamma_A \gamma_R |h_{AR}|^2 |h_{BR}|^2}{\gamma_A |h_{AR}|^2 + (\gamma_B + \gamma_R) |h_{BR}|^2 + 1} \right) \right] \quad (11)$$

While the exact resolution calculation of C_A and C_B is very complex, at present there is no literature to give exact solution. This section will give the upper bound of C_A and C_B . According to the in-equation- $xy/(x+y+1) \leq \min(x, y)$, the upper bound of C_A can be expressed as:

$$\begin{aligned} C_A &= E_{h_{AR}, h_{BR}} \left[\frac{1}{2} \log_2 \left(1 + \frac{\gamma_R}{\gamma_A + \gamma_R} \frac{(\gamma_A + \gamma_R) |h_{AR}|^2 |h_{BR}|^2 \gamma_B}{(\gamma_A + \gamma_R) |h_{AR}|^2 + |h_{BR}|^2 \gamma_B + 1} \right) \right] \\ &\leq E_{h_{AR}, h_{BR}} \left[\frac{1}{2} \log_2 \left(1 + \frac{\gamma_R}{\gamma_A + \gamma_R} \min(|h_{AR}|^2 (\gamma_A + \gamma_R), |h_{BR}|^2 \gamma_B) \right) \right] \stackrel{\Delta}{=} C_A^{upper} \end{aligned} \quad (12)$$

According to the assumption: $|h_{AR}|^2, |h_{BR}|^2$ separately subject to the exponential distribution of Ω_{AR}, Ω_{BR} , so the PDF of $Y \stackrel{\Delta}{=} \min(|h_{AR}|^2 (r_A + r_R), |h_{BR}|^2 r_R)$ can be expressed as:

$$f_Y(y) = \left(\frac{1}{(\gamma_A + \gamma_R) \Omega_{AR}} + \frac{1}{\gamma_R \Omega_{BR}} \right) \exp \left[- \left(\frac{1}{(\gamma_A + \gamma_R) \Omega_{AR}} + \frac{1}{\gamma_R \Omega_{BR}} \right) y \right] \quad (13)$$

So C_A^{upper} can be expressed as:

$$\begin{aligned} C_A^{upper} &= \frac{1}{2} \left(\frac{1}{(\gamma_A + \gamma_R) \Omega_{AR}} + \frac{1}{\gamma_R \Omega_{BR}} \right) \times \int_0^\infty \log_2 \left(1 + \frac{\gamma_R y}{\gamma_A + \gamma_R} \right) \exp \left[- \left(\frac{1}{(\gamma_A + \gamma_R) \Omega_{AR}} + \frac{1}{\gamma_R \Omega_{BR}} \right) y \right] dy \\ &= \frac{1}{2 \ln 2} \exp \left(\frac{1}{\gamma_R \Omega_{AR}} + \frac{\gamma_A + \gamma_R}{\gamma_B \gamma_R \Omega_{BR}} \right) E_1 \left(\frac{1}{\gamma_R \Omega_{AR}} + \frac{\gamma_A + \gamma_R}{\gamma_B \gamma_R \Omega_{BR}} \right) \end{aligned} \quad (14)$$

According to the in-equation- $xy/(x+y+1) \leq \min(x, y)$, the upper bound of C_B can be expressed as:

$$C_B \leq E_{h_{AR}, h_{BR}} \left[\frac{1}{2} \log_2 \left(1 + \frac{\gamma_R}{\gamma_B + \gamma_R} \min(|h_{AR}|^2 \gamma_A, |h_{BR}|^2 (\gamma_B + \gamma_R)) \right) \right] \stackrel{\Delta}{=} C_B^{upper} \quad (15)$$

Let $Y \stackrel{\Delta}{=} \min(|h_{AR}|^2 r_A, |h_{BR}|^2 (r_B + r_R))$, so the PDF of Y can be expressed as:

$$f_Y(y) = \left(\frac{1}{(\gamma_B + \gamma_R) \Omega_{BR}} + \frac{1}{\gamma_A \Omega_{AR}} \right) \exp \left[- \left(\frac{1}{(\gamma_B + \gamma_R) \Omega_{BR}} + \frac{1}{\gamma_A \Omega_{AR}} \right) y \right] \quad (16)$$

And C_B^{upper} can be expressed as:

$$C_B^{upper} = \frac{1}{2} \left(\frac{1}{(\gamma_B + \gamma_R)\Omega_{BR}} + \frac{1}{\gamma_A\Omega_{AR}} \right) \times \int_0^\infty \log_2 \left(1 + \frac{\gamma_R y}{\gamma_B + \gamma_R} \right) \exp \left[- \left(\frac{1}{(\gamma_B + \gamma_R)} + \frac{1}{\gamma_A\Omega_{AR}} \right) y \right] dy \quad (17)$$

$$= \frac{1}{2 \ln 2} \exp \left(\frac{1}{\gamma_R\Omega_{BR}} + \frac{\gamma_B + \gamma_R}{\gamma_A\gamma_R\Omega_{AR}} \right) E_1 \left(\frac{1}{\gamma_R\Omega_{BR}} + \frac{\gamma_B + \gamma_R}{\gamma_A\gamma_R\Omega_{AR}} \right)$$

Substitute (14) and (17) into (19), C^{upper} can be expressed as

$$C^{upper} = \frac{1}{2 \ln 2} \left\{ \exp \left(\frac{1}{\gamma_R\Omega_{AR}} + \frac{\gamma_A + \gamma_R}{\gamma_B\gamma_R\Omega_{BR}} \right) E_1 \left(\frac{1}{\gamma_R\Omega_{AR}} + \frac{\gamma_A + \gamma_R}{\gamma_B\gamma_R\Omega_{BR}} \right) \right. \quad (18)$$

$$\left. + \exp \left(\frac{1}{\gamma_R\Omega_{BR}} + \frac{\gamma_B + \gamma_R}{\gamma_A\gamma_R\Omega_{AR}} \right) E_1 \left(\frac{1}{\gamma_R\Omega_{BR}} + \frac{\gamma_B + \gamma_R}{\gamma_A\gamma_R\Omega_{AR}} \right) \right\}$$

4. Conclusion and future work

This paper mainly gives a detailed analysis of one kind of relay protocol, that is, amplify and forward(AF) protocol, and derives their ergodic capacity(EC) under the condition of Rayleigh fading channel. Our future work will compare the EC of AF protocol with DF protocol by simulation and seek whose implementation complexity is low and which is more suitable for application in actual two-way relay system. When to send information, and how to select the relay node, keep synchronization and assign the power is further worth researching.

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