Performance Analysis of Amplify and Forward Protocol in the Asymmetric Channel

Junyi Zhang
College of Information Science and Technology, Engineering Research Center of Digitized Textile & Fashion Technology, Ministry of Education, Donghua University
Shanghai 201620, China

Runhe Qiu
College of Information Science and Technology, Engineering Research Center of Digitized Textile & Fashion Technology, Ministry of Education, Donghua University
Shanghai 201620, China

Abstract—**In the high-speed mobile environment, there exists many problems such as the Doppler effect and body loss. Those problems can make the communication under high-speed rail scene difficult. In this paper, high-speed rail scene is equivalent to asymmetric fading channels. That is to say, the system model consists of Rician and Rayleigh fading channels. On the basis of a single relay installed on the train, its known formulas can derive to the Signal to Noise Ratio (SNR), the Bit Error Rate (BER) and the Outage Probability of multiple relay with the amplify-and-forward protocol (AF). The simulation results show that the BER and the Outage Probability decrease while the SNR increases. Besides, the BER decreases more significant with the growing number of relays. It means that when the SNR is changed from 1 to 20, the decrease of BER is two orders of magnitude while *N* takes 2, and it is about 7 orders of magnitude while *N* takes 6.**

Keywords-high speed railway; mobile relay; Bit Error Rate (BER); Outage Probability; Amplify-and-Forward (AF)

I. INTRODUCTION

With the rapid development of high-speed railway, more and more people choose high-speed railway as their traveling tool. As a result, the demands for the communication under the high-speed railway are becoming higher and higher and passengers hope that their communication needs can be met quickly and smoothly. However, in the high-speed mobile scene, there are some factors that can not be ignored, which affect the users' communication experience, such as the Doppler frequency shift, the Group switching and the body loss. In order to solve the special effects of the high-speed mobile scene, mobile relays can be installed on the train to greatly enhance the users' communication experience as mentioned in many literatures. The common relay forwarding protocols are Amplify-and-Forward (AF) and Decode-and-Forward (DF). At present, there are many researches about mobile relays such as [1], which gives some simple applications and introduces the key technology in the mobile relay system. [2] studies the Handover Mechanism in high-speed LTE-A system with relays. But the studies in relays used in high-speed mobile scenario have defects. In order to mitigate the effect caused by the Doppler frequency shift, a channel estimation scheme based on the speed and the position of the high-speed train is proposed in [3]. In [4], the author uses the AF protocol to analysis the performance of high-speed railway installed some relays by modeling two asymmetric fading channels as a Rician and a Rayleigh channel. At present, the performance of a high-speed railway using the AF or the DF protocol is frequently discussed on a symmetric channel. However, this symmetric channel is not suitable for the high-speed railway scene. Asymmetric channels are discussed in few literatures. The performance of the high-speed railway with only one relay is analyzed in [5]. These studies are far from enough for the high-speed mobile scene.

II. SYSTEM AND CHANNEL MODEL

A. System Model

Assume a dual-hop fixed gain AF relay system operating in an asymmetric fading environment. As illustrated in Figure 1. Both the source, S and the destinations, U_n (n =1,2…) communicate with relays, R_i (i=1,2…N). There is no direct link between S and U_n. Access points AP_m (m=1,2…) are installed at the top of the carriage. The channel between S and R_i is equivalent to the Rician fading channel, while the channel between R_i and U_n is equivalent to the Rayleigh fading channel. The simplified model is shown in Figure 2.

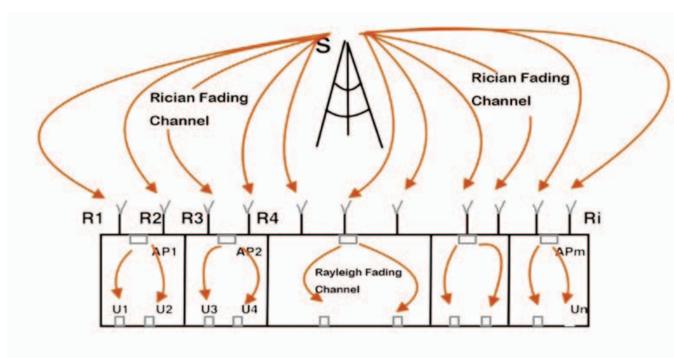

Figure 1. System Model

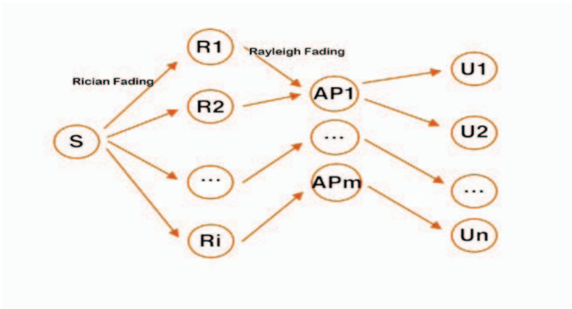

Figure 2. Simplified System Model

III. PERFORMANCE ANALYSIS

In this paper, performance analysis with the AF protocol is carried out in three aspects: SNR, BER and the Outage Probability.

A. SNR

The SNR for the first hop S - R_i satisfies the Rician distribution. Thus its probability density function (PDF) can be expressed as:

$$P_{\gamma_{\alpha_i}}(\gamma) = \frac{(K+1)e^{-K}}{\overline{\gamma_{\alpha_i}}} e^{-\frac{(K+1)\gamma}{\overline{\gamma_{\alpha_i}}}} I_0\left(2\sqrt{\frac{K(K+1)\gamma}{\overline{\gamma_{\alpha_i}}}}\right), i = 1,2,\dots,N \quad (1)$$

where K is the Rician K-factor, it is defined as the ratio of the powers of the line of sight (LoS) component to the scattered components and γ is the end-to-end SNR.

The SNR for the second hop R_i-U_n satisfies the Rayleigh distribution. Thus its probability density function (PDF) can be expressed as:

$$P_{\gamma_{\beta_i}}(\gamma) = \frac{1}{\overline{\gamma_{\beta_i}}} * e^{-\frac{\gamma}{\overline{\gamma_{\beta_i}}}}, i = 1,2,\dots N \quad (2)$$

where:

$$\overline{\gamma_{\alpha_i}} = E_s * \frac{E({\alpha_i}^2)}{N_0}, i = 1,2,\dots N \quad (3)$$

$$\overline{\gamma_{\beta_i}} = E_s * \frac{E({\beta_i}^2)}{N_0 + N_u}, i = 1,2,\dots N \quad (4)$$

where α_i , β_i represent two links S-R_i and R_i-U respectively. γ_{α_i} is the SNR for the first hop of the i-st link, while $\overline{\gamma_{\alpha_i}}$ represents its average SNR. Similarly, γ_{β_i} is the SNR for the second hop of the i-st link, while $\overline{\gamma_{\beta_i}}$ indicates its average SNR. E_s is the received signal energy at S. Therefore, $E({\alpha_i}^2)$ and $E({\beta_i}^2)$ are the received signal energy at the first and the second hop for the i-st link respectively. N_0 is the power of the AWGN at the input of the R_i or U_n. N_u is the power of the interference from the communication users at the destination.

The PDF of the SNR in the Rician and Rayleigh fading channels can be obtained by substituting (3), (4) into (1), (2).

At first, the AF protocol in a single relay is discussed. As shown in Figure 3. Except for considering the AWGN of the value of $n(t)$ on the two links, we also take the interference $n_u(t)$ into account which is caused by the communication of the residual users.

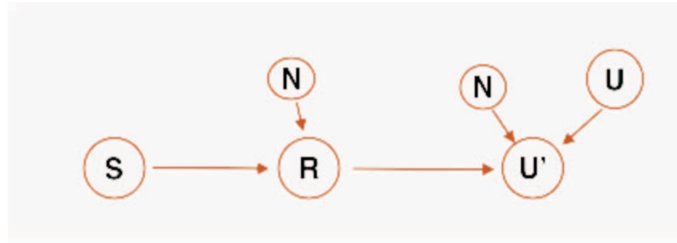

Figure 3. The System Model Under AF Protocol

The signal transmitted at S is $s(t)$, then the received signal at R can be expressed:

$$r(t) = h_\alpha s(t) + n(t) \quad (5)$$

The power amplification factor of the relay is assumed to be G, then the received signal at U' can be expressed:

$$d(t) = h_\beta G r(t) + n(t) + n_u(t) \quad (6)$$

Hence, the end-to-end SNR γ_{AF1} in the single relay scenario with the AF protocol can be deduced as the following formula:

$$\gamma_{AF1} = \frac{\frac{E_s * {h_\alpha}^2 * {h_\beta}^2}{{N_0}^2}}{\frac{{h_\beta}^2}{N_0} + \frac{1}{G^2 * N_0} + \frac{N_u}{{N_0}^2 * G^2}} \quad (7)$$

where the principle of how to determine the value of G is to eliminate the channel effect of the first hop, so that it can be taken as:

$$G^2 = \frac{E_r}{0.5 * E_s * {h_\alpha}^2} \quad (8)$$

where E_r is the received signal energy at R. If:

$$\gamma_{\alpha_i} = \frac{{h\alpha_i}^2 * E_s}{N_0}, i = 1,2,\dots,N \quad (9)$$

$$\gamma_{\beta_i} = \frac{{h_{\beta_i}}^2 * E_r}{N_0 + N_u}, i = 1,2,\dots,N \quad (10)$$

where h_{α_i} and h_{β_i} are the channel gain for the Rician channel (S -R_i) and the Rayleigh channel (R_i-U'). So the end-to-end SNR in the multi-relay scenario can be derived as follows:

$$\gamma_{AF} = \sum_{i=1}^{N} \frac{\gamma_{\alpha_i} * \gamma_{\beta_i}}{0.5\gamma_{\alpha_i} + \gamma_{\beta_i}} \quad (11)$$

Here, $n_u(t)$ is the interference between communication users, which is divided into the co-channel and the adjacent channel interference. In this paper, we just consider the co-channel interference. If the ratio of the co-channel interference is less than 12dB, the drop call rate will rise. The quality of the