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Frequency Diversity Using Random Time Delay in Amplify-And-Forward Relay

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ABSTRACT- In a tactical wireless communication environment, it is common for device-to-device communication to occur without a base station, but this can be problematic when the distance between the source and destination is too far. Relays are often used to improve transmission distance and reliability, but amplification-based relaying can result in lower communication performance compared to other methods. This paper proposes a method for obtaining diversity gain through the application of time delay during relaying. The proposed method is compared to a conventional method that uses phase rotation to obtain diversity gain. Simulation results show that the proposed method has slightly lower or similar performance improvement compared to the conventional relay method.

Keywords: Amplify-and-Forward, Relay, Time Delay, OFDM, Frequency Diversity.

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1. INTRODUCTION

The rapid development of information and communication technology has brought about changes in the form of weapon systems, equipment, and military strategies used in battles. Communication technology is a crucial factor in modern warfare, and stable communication is essential in tactical situations. However, in a tactical wireless communication environment, it may not be possible to establish one-to-one communication between a source and a destination due to attacks such as jamming [1, 2]. In such scenarios, another node can be used to relay information between the source and destination. Cooperative diversity networks technology is an effective solution for extending transmission distance and improving transmission reliability in wireless communications [3-7].

Various methods exist for processing the received signal at the relay node, including amplify-and-forward (AF), decode-and-forward (DF), and compress-and-forward (CF) [8, 9]. Among these methods, AF is the simplest, as it only amplifies and retransmits signals at the relay node, without requiring complex routing and resource allocation like DF. However, AF suffers from lower performance compared to other methods [10]. To address this issue, one approach is to introduce a time delay during retransmission at the relay node, creating a high-energy multipath. This can help mitigate the impact of fading and other disturbances on communication quality by introducing diversity in the received signals, caused by the different paths traversed. The paper proposes a method for obtaining diversity gain in the AF method. In addition to the conventional method of gaining diversity by rotating the phase of the carrier [11-14], the paper introduces a new method for obtaining frequency diversity gain by applying a random time delay to the transmitted signal. The performance of the two methods when communicating in the orthogonal frequency division multiplexing (OFDM) method in a wideband is compared through simulation, and the results showed that the diversity gains due to time delay and the diversity gain due to phase rotation are similar.

2. LITERATURE REVIEW

The performance of cooperative diversity systems can be improved using the incremental-best-relay (IBR) technique [15]. This technique selects the most suitable relay among cooperating relays to optimize performance. The paper experimentally verifies that the IBR technique can reduce the bit error rate and the probability of error events in cooperative diversity systems. However, there are disadvantages in that implementing the IBR technology may increase power consumption in the cooperative diversity system, and additional calculations are required, which may increase processing time.

A barrage relay network (BRN) is a wireless communication network that uses multiple relays to improve communication performance and reliability [12, 13]. When a BRN is applied to an unmanned ground system (UGS), it can greatly improve communication range and reliability in UGS scenarios. However, implementing BRN in real-world UGS applications

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presents challenges, such as the need for high-precision positioning and synchronization of relays and the impact of terrain and environmental conditions on network performance.

There is a paper that focuses on optimizing power splitting in two-way decode-and-forward relay networks [3]. The paper proposes a novel power splitting method that maximizes the achievable rate of the network while ensuring that each node's power constraint is satisfied. The paper derives closed-form expressions for the optimal power splitting ratios and analyzes the impact of various system parameters, such as the signal-to-noise ratio and the number of relay nodes, on network performance. Simulation results show that the proposed power splitting scheme can significantly improve network throughput and energy efficiency compared to other power splitting schemes. However, the paper also notes that the optimal power splitting ratios may be sensitive to channel conditions and may require frequent adaptation in dynamic network environments.

A cooperative automatic repeat request (ARQ) protocol for wireless networks that uses opportunistic AF relaying was proposed [10]. The proposed protocol takes advantage of the best relay available for the retransmission of packets, thus improving the performance of the ARQ system. The paper also proposes a channel quality control mechanism that estimates the channel conditions between nodes and adjusts the transmission power of the relays accordingly. Simulation results show that the proposed protocol outperforms traditional ARQ and fixed relay selection schemes, and the channel quality control mechanism further enhances the performance of the cooperative ARQ system. However, the paper does not consider the effect of mobility on the performance of the proposed protocol, which may be a limitation in practical scenarios where nodes move frequently.

3. CONVENTIONAL METHOD

In a wireless communication system, the effective channel is affected by factors such as fading due to distance and obstacles, interference from other signals, and noise. These factors may cause the relayed signal to be weak or distorted compared to the original signal transmitted by the source. To mitigate this distortion, the BRN, also known as cooperative relaying, can be used.

In BRN, each relay node amplifies and retransmits the signal it receives from the previous relay node with a certain phase shift. The phase shift is used to combine the signals from multiple relays at the destination node, so that they add constructively and reinforce the original signal.

However, in practice, the phase shifts may not be perfectly aligned due to various factors such as clock drift, channel variations, and transmission errors. As a result, there may be interference and signal degradation at the destination node. To overcome this problem, rotating the phases is used to periodically adjust the phase shifts of the relay nodes. This can be done in a coordinated way using a common reference signal, such as a pilot signal, or in a distributed way using local measurements and feedback. By rotating the phases, the interference and signal distortion caused by misaligned phase shifts can be reduced, and the overall signal quality and reliability can be improved.

$$h_{eff} = \sum_{m=1}^{M} h_m \, e^{(j\theta_m(n))} \quad (-\pi \leq \theta < \pi) \tag{1}$$

$$y(n) = \sum_{m=1}^{M} h_m \, e^{(j\theta_m(n))} x(n) \quad (-\pi \leq \theta < \pi) \tag{2}$$

When the random phase is multiplied, the effective channel is equal to *equation 1*, and the signal received through the relay is equal to *equation 2*. The relay node is assumed to perfectly receive the transmission signal (x(n)), and h_m represents the channel between the mth relay node and the destination. By multiplying the random phase ($e^{(j\theta_m(n))}$) at each relay node, the signal received at the destination becomes y(n). By randomly changing the effective channel through phase rotation, time diversity gain can be achieved, which helps create a fast-fading environment and improves the performance of wireless communication networks. However, it requires careful design and optimization of the phase rotation scheme to ensure that the signal quality and reliability are improved.

4. PROPOSED METHOD

Wireless communication involves the transmission of signals, which can reach the receiver through various routes, known as multipath. Each path has its unique characteristics, such as propagation delay, attenuation, and phase shift, resulting from reflection, diffraction, scattering, or other phenomena in the transmission medium. When a path carries a substantial amount of energy, it is known as a high-energy multipath. Such paths play a crucial role in enhancing the quality of communication by offering diversity to the received signal in terms of angle, polarization, frequency, or other parameters. This diversity can help mitigate the effects of fading and other disruptions that may affect the signal.

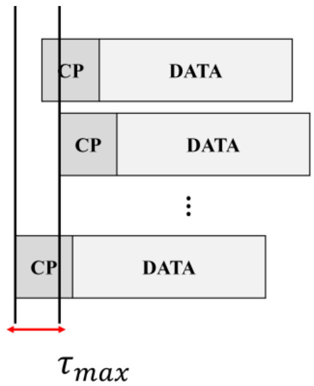

Figure 1. Packet arrival at delay

In this paper, this high-energy multipath is created by applying an artificial delay (τ) when the relay node retransmits the signal to the destination node. When transmitting with a random delay applied, the signals arrive at the destination node with a time difference, as shown in *figure 1*.

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5. SYSTEM MODEL

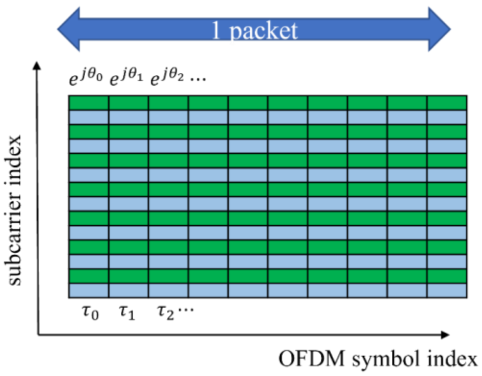

Figure 2. OFDM structure

OFDM works by dividing the data stream into multiple narrowband subcarriers, which are orthogonal to each other and transmitted simultaneously in parallel. These subcarriers are typically modulated with QAM or PSK modulation schemes and have a much smaller bandwidth than the original signal. This allows them to be transmitted over frequency-selective channels with different propagation delays and attenuation without interfering with each other. At the receiver, the received signal is processed using fast Fourier transform (FFT) to recover the original data symbols modulated on each subcarrier. Because the subcarriers are orthogonal, they do not interfere with each other, and their frequencies can be chosen to optimize the spectral efficiency and minimize the inter-symbol interference caused by multipath fading. OFDM can also use error-correction coding techniques to further improve the reliability and robustness of the communication link. Overall, OFDM is a widely used modulation technique due to its robustness to interference and multipath fading, high spectral efficiency, and compatibility with different channel conditions and data rates.

In this paper, we consider a two-hop relaying scenario. It is assumed that error-free communication is achieved between the source and the relay node, and simulations are performed using MATLAB.

Figure 3 shows the system block diagram. At the sender, the message is forward error correction encoded using convolutional turbo code, and zero padding is performed to match the FFT size. Then, random interleaving is performed, and PSK mapping is applied to prevent clustering errors. OFDM modulation is performed on the mapped signals, and cyclic prefix (CP) is inserted before transmission. The transmitted signal travels through the channel and is decoded through the reverse process of the transmitter at the destination node.

Table 1. Simulation parameters

Parameter	Value
Sampling clock	4MHz
Carrier frequency	512MHz
FFT size	512
CP length	64
Channel	ITU vehicular -A
Moving speed	20km/h
Phase rotation angle (θ)	$-\pi \leq \theta < \pi$
Delay (τ)	$0 \leq \tau <$5clock
MCS	QPSK, code rate =1/3
Distance deviation	4km
Number of relay node	1,2,3,5,15,25

Table 2. Vehicular-A channel model

Tap No.	Duration (Sec)	
	Relative delay (ns)	Average power(dB)
1	0	0
2	310	-1
3	710	-9
4	1090	-10
5	1730	-15
6	2510	-20

Simulation parameters for the experiment conducted in the paper are listed in *table 1*. The sampling clock used in the simulation is 4MHz and the bandwidth is 2MHz, with a carrier frequency of 512MHz. Each packet has a CP length of 64symbols and an OFDM FFT size of 512. The ITU vehicular-A model is used as the channel model, and the characteristics of the model are described in Table 2. The speed of the nodes is set to 20km/h, and the phase rotation angle range for the conventional relaying method is -π to π, while the delay range for the proposed method is 0 to 5clocks. The modulation and coding scheme used is QPSK, 1/3, and the deviation between relay distances is set to 4km. The experiment is performed for different numbers of participating nodes in the range of 1, 2, 3, 5, 15, and 25.

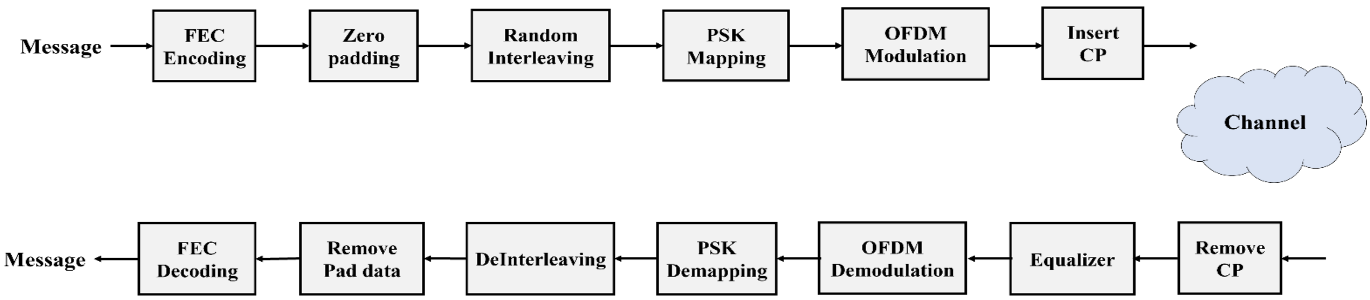

Figure 3. Transmit/receive block diagram

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6. SIMULATION RESULTS

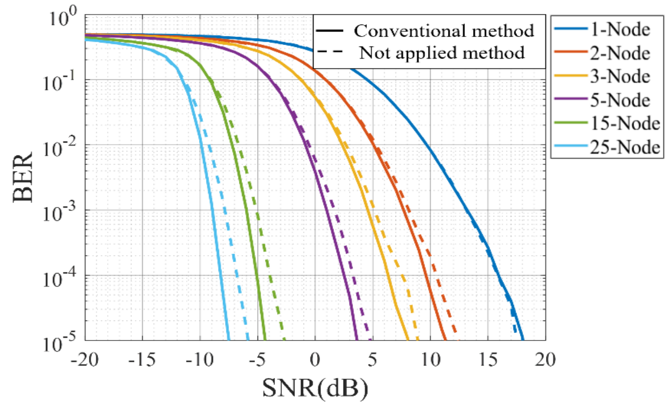

Figure 4. Relay Performance of the conventional method

Figure 4 shows a comparison of the bit error rate (BER) performance of two transmission methods: one with randomly rotated phase in the existing relay node and one without rotation. The dotted line represents the performance when no method is applied, and the solid line represents the performance when the conventional relaying method with phase rotation is applied. The number of nodes participating in relaying is color-coded for each curve, ranging from 1 to 25.

Based on the BER of 10^{-5}, the simulation compares the signal-to-noise ratio (SNR) performances of the two methods for each relay node. The results show that there is no significant gain from the method when only one node is participating in relaying through phase rotation. However, when there are two nodes, the gain is about 1.3dB, when there are three, about 1dB, when there are five, about 1.3dB, when there are 15, 1.5dB, and when there are 25, the gain is about 1.6dB.

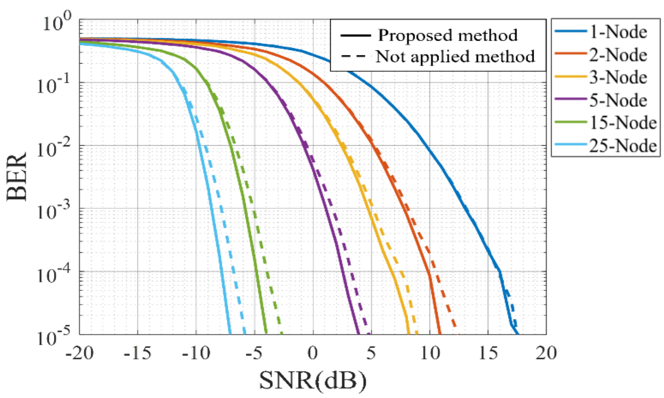

Figure 5. Relay Performance of the proposed method

Figure 5 is a figure comparing the proposed method of applying random delay during relaying and the transmission method without delay through BER performance. The dotted line is the performance when relaying without applying any method, and the solid line is the performance when relaying with random delay applied. The relayed performance without applying any method is the same as *figure 4*. The number of nodes participating in relaying is coded by color. Based on the case where the BER is 10^{-5}, the SNR performances of the method without applying any method and the method transmitting with the application of time delay are compared for each relay node. As a result of the simulation, it is difficult to obtain the gain of the method when there is one node participating in relaying through phase rotation, and it is about 1.5dB when there are two nodes, about 1dB when there are three nodes, about 1dB when there are five nodes, about 1.3dB when there are 15 nodes, and about 1.2dB when there are 25 nodes.

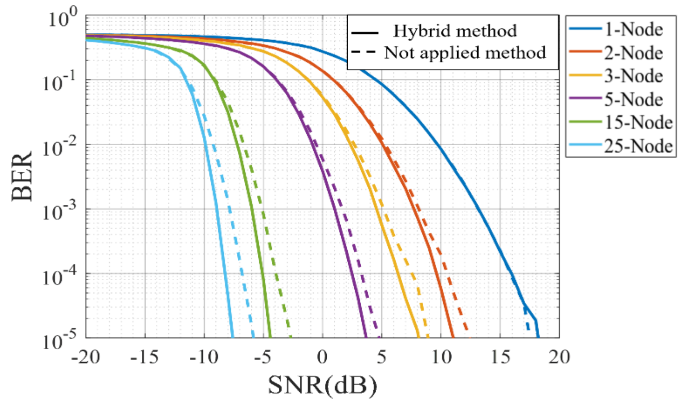

Figure 6. Relay performance of the hybrid method

Figure 6 is a figure comparing the Hybrid method of applying random delay and random phase rotation during relaying and the transmission method using neither method through BER performance. The dotted line is the performance when relaying without applying any method, and the solid line is the performance when relaying with hybrid method. The relayed performance without applying any method is the same as *figure 4*. The number of nodes participating in relaying is coded by color. Based on the case where the BER is 10^{-5}, the SNR performances of the method without applying any method and the method transmitting with the application of time delay and phase rotation are compared for each relay node. The result is similar in performance to Conventional method.

7. CONCLUSION

The paper proposed a novel method to improve the communication performance of the AF method, which is known for its poor performance. The proposed method involves introducing an intentional delay to the transmitted signal, which allows for the exploitation of high-energy multipath in the wireless communication channel to obtain diversity gain. The results of the simulations indicate that the proposed method showed slightly lower or similar performance improvement compared to the conventional method. However, the conventional method is effective in a slow fading environment, and the proposed method is effective in that it is independent of how fast the channel changes. Future studies can potentially increase the degree of improvement by accounting for these factors.

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