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Amplify-and-Forward (AF) Relay Techniques in Wireless SC-FDE Systems to Enhance Diversity Gains

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ABSTRACT- This paper introduces an amplify-and-forward (AF) relaying technique that employs phase dithering and intentional delay within single carrier-frequency domain equalizer (SC-FDE) systems. The proposed relaying technique aims to increase the gain of both frequency diversity and time diversity in slow fading channels. To achieve this, the proposed technique introduces random phase rotation and random intentional delay. The relaying scenario assumes two-hop communication with relaying between the source and destination. It is assumed that many nodes are densely distributed, allowing for many relay nodes to participate in relaying. To verify the performance through computer simulation, the number of relays is 1, 2, 3, 5, 15, and 25, and three modulation coding schemes (MCSs) are considered: QPSK with R=1/3, 16QAM with R=3/4, and 8PSK with R=7/8. The simulation results demonstrate that the proposed relaying technique improves the bit error ratio (BER) performance. The performance improves as the number of relays increases.

Keywords: SC-FDE, AF Relaying, Phase Dithering, Intentional Delay, Time Diversity, Frequency Diversity, Two-hop Relay

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1. INTRODUCTION

Device-to-device communication without a base station is common in terrestrial tactical communications environments. However, in such environments, the distance between the source and destination is often too large for reliable 1:1 communication. One solution is to use a relay for communication [1–4].

There are two different relay communication technologies that differ in how the relay nodes process the signals they receive: amplify-and-forward (AF) relay and decode-and-forward (DF) relay. In AF relay, the relay node amplifies the received signal and forwards it to the destination, while in DF relay, the relay node decodes the received signal, re-encodes it, and forwards it to the destination. AF relay has lower implementation complexity than DF relay because the relay node does not need to decode the signal [5, 6]. However, AF relay has the disadvantage of noise amplification and does not always guarantee a better signal-to-noise ratio (SNR) at the destination. For example, if multiple relays are involved in the relay, the combined signal that arrives at its destination may be significantly weakened by the destructive combining of the multiple signals, the same phenomenon in multi-path fading channels.

This paper presents a multiple relay AF relaying technique in single carrier-frequency domain equalizer (SC-FDE) systems. SC-FDE is designed for frequency-selective channels and, similar to orthogonal frequency division multiplexing (OFDM), has simple computation in equalization and is widely used in broadband 1:1 communication. The main advantage of SC-FDE is that it requires less power to transmit the same amount of data as OFDM, making it particularly suitable for battery-powered mobile communication systems [7]. In the proposed technique, one communication packet is divided into several blocks. The relay applies phase dithering and random delay to each block. The phase dithering and random delay create the effect that the effective channel between the relay and the destination changes drastically from block to block. This has the same effect as fast fading, and phase dithering increases time diversity gain while random delay increases frequency diversity gain.

The proposed technique is validated through computer simulations. All inter-link channels use frequency selective channel models, and the 1:1 link channel model uses the ITU-R pedestrian A model. The performance of the proposed technique is evaluated using three different modulation and coding scheme (MCS): QPSK with a code rate of 1/3, 16QAM with a code rate of 3/4, and 8PSK with a code rate of 7/8. The number of relay nodes is varied from 1 to 25 in the simulation to investigate the impact of the number of relays on the performance. Simulation results show that the bit error ratio (BER) performance improves as the number of relay nodes increases, and the proposed relay technique further improves the BER performance.

2. RELATED WORKS

2.1 Barrage Relay Networks

A barrage relay network is a type of communication network used to transmit signals over long distances. It consists of a series of interconnected relay stations placed along the transmission path. Each relay station receives, amplifies, and retransmits the signal to the next station in the network. The term "barrage" refers to the continuous operation of the relay stations, resembling a barrage of signals, to ensure reliable transmission over long distances. Barrage relay networks were widely used in the early 20th century for long-distance telegraphy and telephony. Later, they were used for early forms of radio communication. The technology was especially crucial for military communication during World War I, enabling messages to be transmitted across battlefields and between front lines. While barrage relay networks have largely been replaced by more advanced communication technologies, their legacy can still be seen in modern communication networks that use similar principles, such as satellite communication and cellular networks [8].

2.2 Cooperative Diversity by Phase Rotations

This paper presents a study on cooperative diversity techniques for wireless communication systems. The authors propose a new cooperative diversity scheme based on relay phase rotations in block fading environments. The proposed scheme utilizes phase rotations at the relay node to improve the diversity gain of the system and mitigate the effects of fading. The study investigates the performance of the proposed scheme under different block fading scenarios and compares it with conventional cooperative diversity schemes. The analytical and simulation results demonstrate that the proposed scheme can significantly improve the system's diversity gain and achieve a lower bit error rate compared to conventional schemes. The study concludes that the proposed scheme can provide a promising solution for improving the reliability and performance of wireless communication systems, particularly in block fading environments where conventional cooperative diversity schemes may not be effective. The proposed scheme is also shown to be simple and efficient in terms of computational complexity and overhead, making it a practical solution for real-world applications [9].

3. PROPOSED RELAY TECHNIQUE

3.1 Multi-hop Relay

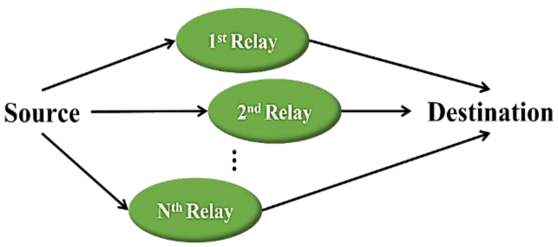

Figure 1: Two-hop Relay Scenario

Figure 1 shows a two-hop relay situation in a multi-hop relay network. Multi-hop relay refers to communication where there are relay nodes between the source and destination, and multiple relay nodes cooperate to transmit signals to the destination [10]. This paper investigates a two-hop relay scenario with a single relay node positioned between the source and the destination. The process between the source and the relay node is assumed to be error-free. The distance from the source to the destination is different for each relay node, and the deviation of the largest and smallest values of this distance is called the maximum distance difference. The maximum distance difference depends on the MCS you use. This is because MCSs with higher data rates are more susceptible to attenuation and interference over longer distances than MCSs with lower data rates.

3.2 Phase Dithering Technique

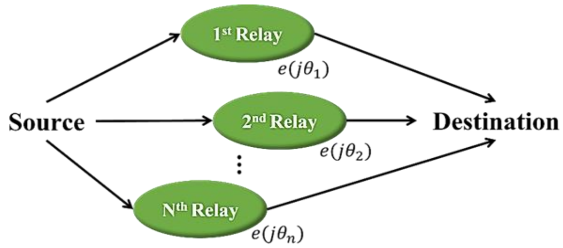

Figure 2: Phase Dithering on Each Relay

The proposed technique involves the use of phase dithering, where a random phase is multiplied into the signal received by a relay to randomly rotate the phase of the signal. Figure 2 illustrates the phases that are multiplied into the signal during phase dithering at each of the relays.

$$h_{effective} = \sum_{n=1}^{N} h_n, \ \left|h_{effective}\right| = \left|\sum_{n=1}^{N} h_n\right| \quad (1)$$

At each relay, the effective channel, which is the signal not multiplied by an arbitrary phase, and its magnitude can be represented by Equation (1). The effective channel is characterized by the fact that it remains constant over time, and its small magnitude makes it difficult to recover the transmitted data.

$$h_{effective} = \sum_{n=1}^{N} h_n e^{j\theta n(m)}, \\ \left|h_{effective}\right| = \left|\sum_{n=1}^{N} h_n e^{j\theta n(m)}\right| \quad (2)$$

The effective channel of the signal multiplied by the random phase at each relay and its magnitude are given by Equation (2), where h_n is the channel between the nth relay and the destination at time slot m, and $e^{j\theta n(m)}$ is the phase multiplied by the nth relay on the signal at time slot m. Multiplying the signal by a random phase causes the magnitude of the signal at the destination to change every time slot.

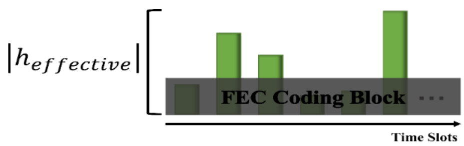

Figure 3: Change in the Effective Channel of a Signal with Phase Dithering

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Figure 3 shows the effective channel size of the signal received at the destination after retransmission with phase dithering at each relay for each time slot when multiple relays participate in the relay. When the signals from the nodes participating in the relay are combined and received, the magnitude of the signal will change from slot to slot due to phase dithering. This has the same effect as fast fading, meaning that the time diversity gain of a fast-fading channel can be achieved in a real slow-fading environment.

3.3 Intentional Delay Techniques

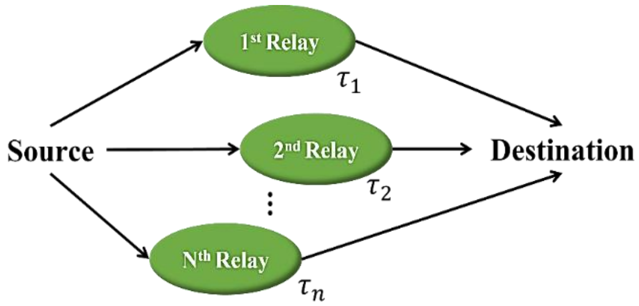

Figure 4: Random Delay on Each Relay

Intentional random delay is a technique in which multiple relays apply random delays to signals received from a source. *Figure 4* illustrates the values and scenarios in which a relay applies a random delay to a signal. The variable τ represents the random delay applied to the signal by the n^{th} relay.

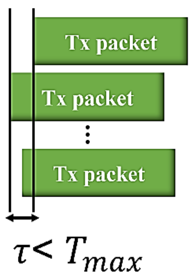

Figure 5: Received Signal at Destination after Applying Random Delay at Each Relay

When the relay retransmits the signal with an intentional delay, each transmitted packet is received at the destination with a time delay, as shown in *figure 5*. Where T_{max} is the maximum time delay that the receiver can tolerate. The receiver of a wideband signal has sufficient resolution in time to utilize all the signals received with a time delay to obtain frequency diversity gain.

4. SYSTEM MODEL

4.1 SC-FDE Transmission Method

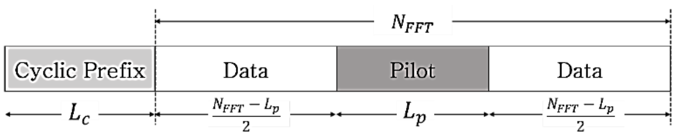

Figure 6: SC-FDE Symbol Structure

Transmission methods used to deal with multipath delay spread in broadband wireless channels include OFDM and SC-FDE. Both methods use cyclic prefix (CP) to avoid inter-block or intra-block interference by setting the length of the CP to be greater than the delay range of the channel [10]. The main advantage of SC-FDE is that it requires less power than OFDM to transmit the same amount of data, making it particularly suitable for mobile communication systems. SC-FDE also has the advantage of lower sensitivity to peak-to-average power ratio (PAPR) and carrier frequency offset (CFO) compared to OFDM [11].

Figure 6 illustrates the symbol structure of the SC-FDE system used in this paper. The distinctive feature of this structure is the placement of the pilot in the middle rather than in front of the data. This arrangement allows for better channel estimation performance and performs well in time-varying fading channels [12]. N_{FFT} refers to the FFT size, L_c is the length of the CP, and L_p is the size of the pilot.

4.2 SC-FDE Transmission Method

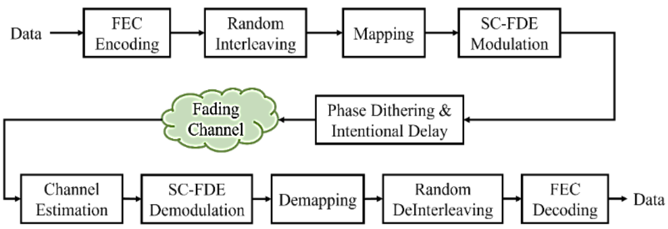

Figure 7: Transmitter and Receiver Structure Block Diagram

Figure 7 illustrates the transmitter structure, receiver structure, and repeater block diagrams used in this paper, as well as the sequence of operations that the system undergoes. The transmitter generates binary data and applies forward error correction (FEC) encoding for error correction. In this case, FEC encoding uses convolutional turbo code (CTC). After that, random interleaving is performed to prevent aggregation errors from occurring. After interleaving, the signal is mapped according to MCS and transmitted after SC-FDE modulation.

The signal transmitted from the transmitter is received by the relay, which applies phase dithering and intentional delay techniques to retransmit the signal. Once the signal passes through the fading channel and is received by the receiver, equalization is performed. The equalization process in this paper uses a pilot to estimate the channel in the time domain and then performs equalization in the frequency domain using the fast Fourier transform (FFT) of the estimated channel and the FFT of the received signal. Once equalization is complete, the data is demodulated and received by reversing the process at the transmitter.

5. SIMULATION

5.1 Simulation Environments

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Table 1. Simulation Parameters

Parameter	Values
Bandwidth	4 MHz
Moving Speed	60 km/h
CP length	64 symbols
Pilot length	256 symbols
FFT size	512
MCS	QPSK, R=1/3
	16QAM, R=3/4
	8PSK, R=7/8
Maximum distance difference	4 km / 2 km
Intentional Delay	[0, 5] clock
Phase dithering range	$[-\pi, \pi]$
Number of relay node	1, 2, 3, 5, 15, 25

The simulations in this paper were performed using MATLAB.

Table 1 shows the names and values of the parameters used in the simulations. The bandwidth is 4 MHz, and the traveling speed is 20km/h. The CP uses 64 symbols, and the pilot uses 256 symbols. The FFT size is 512. There are three MCSs: QPSK, 16QAM, and 8PSK, each with different encoding rates as specified in Table 1. The maximum distance deviation is 4km when using QPSK as the MCS and 2km when using 16QAM or 8PSK. The intentional delays are randomly applied between 0 and 5 clocks, and the phase dithering ranges from -π to π. The simulations are run with different relay counts: 1, 2, 3, 5, 15, and 25.

5.2 Simulation Results

The performance evaluation of the simulation verifies the required SNR when the BER is 10^{-5}. All the performance graphs that follow have a common feature. The number of relays increases in the direction of the black arrow above the BER curve for the entire MCS, with values 1, 2, 3, 5, 15, and 25. The black dashed line represents the performance without phase dithering and intentional delay, which is referred to as the "baseline" in this study. The green solid line shows the performance with phase dithering only, while the blue solid line represents intentional delay only. The pink solid line shows the performance with both phase dithering and intentional delay.

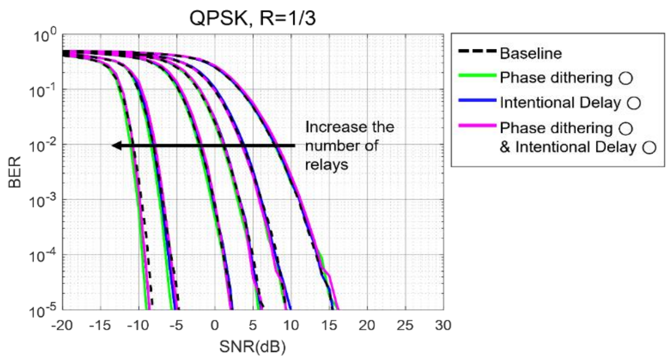

Figure 8: Performance with Relaying Techniques at QPSK, R=1/3

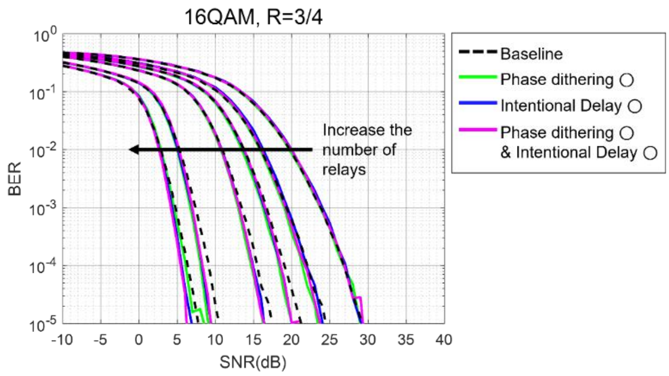

Figure 9: Performance with Relaying Techniques at 16QAM, R=3/4

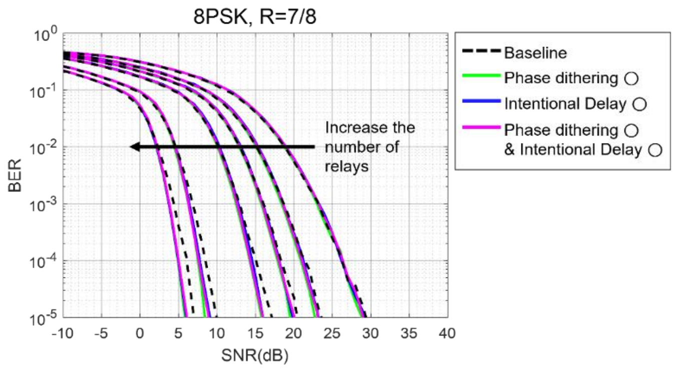

Figure 10: Performance with Relaying Techniques at 8PSK, R=7/8

Figure 8 shows the BER performance with MCS using QPSK, R=1/3. *Figure 9* shows the performance with MCS using 16QAM, R=3/4, and *figure 10* shows the performance with MCS using 8PSK, R=7/8. For all three MCSs, BER performance improves as the number of relay nodes increases. The performance improvement is similar for phase dithering and intentional delay on all nodes in all MCSs. Taking node 15 as an example, the relaying technique improves the performance of QPSK by about 1dB. For 16QAM, the improvement is about 1 to 1.5 dB, and for 8PSK, it is about 1 to 2dB. These results suggest that among the three MCSs, 8PSK, 16QAM, and QPSK are the most affected by relaying.

6. CONCLUSION AND FUTURE WORK

This paper introduces a multiple relay AF relaying technique in SC-FDE systems. Instead of directly retransmitting the signal at the relay, the proposed approach incorporates phase dithering, which introduces random phase rotation, and intentional delay, which introduces random signal delay. Time diversity can be achieved through phase dithering, and frequency diversity can be achieved through intentional delay. The performance was validated through simulations, and the evaluation was conducted for three MCSs and the number of relay nodes 1, 2, 3, 5, 15, and 25. The MCSs used were QPSK with a code rate of 1/3, 16QAM with a code rate of 3/4, and 8PSK with a code rate of 7/8. The simulation results indicate that all MCSs demonstrate performance improvement as the number of relay nodes increases.

The proposed techniques of phase dithering and intentional delay resulted in a performance improvement of about 1~2 dB over the baseline case without these techniques. This suggests that using these techniques for relay communication can significantly enhance the communication reliability. However, the performance improvement achieved by the proposed relaying technique is relatively small, and further research is needed to confirm its effectiveness in different environments. The authors plan to conduct additional studies in the future to further verify the performance improvement achieved by using relaying techniques.

REFERENCES

[1] Bletsas, A., Khisti, A., Reed, D.P., and Lippman, A. 2006. A simple cooperative diversity method based on network path selection. IEEE Journal on selected areas in communications.

[2] Anghel, P.A. and Kaveh, M. 2004. Exact symbol error probability of a cooperative network in a Rayleigh-fading environment. IEEE Transactions on Wireless Communications.

[3] Laneman, J.N., Tse, D.N. and Wornell, G.W. 2004. Cooperative diversity in wireless networks: Efficient protocols and outage behavior. IEEE Transactions on Information theory.

[4] Hasna, M.O. and Alouini, M.S. 2003. End-to-end performance of transmission systems with relays over Rayleigh-fading channels. IEEE transactions on Wireless Communications.

[5] Lee, S., Youn, J. and Jung, B.C. 2021. Hybrid AF/DF cooperative relaying technique with phase steering for industrial IoT networks. Energies.

[6] Patel, C.S. and Stuber, G.L. 2007. Channel estimation for amplify and forward relay based cooperation diversity systems. IEEE Transactions on Wireless Communications.

[7] Hwang, H.S., Park, G.T., Joo, J.H. and Shin, K.C. 2018. A Comparison of Symbol Error Performance for SC-FDE and OFDM Transmission Systems in Modeled Underwater Acoustic Communication Channel. Journal of the Institute of Convergence Signal Processing.

[8] Harford, T.R. and Chugg, K.M. 2010. Barrage relay networks. 2010 Information Theory and Applications Workshop (ITA).

[9] Hammerstrom, I., Kuhn, M. and Wittneben, A. 2004. Cooperative diversity by relay phase rotations in block fading environments. In IEEE 5th Workshop on Signal Processing Advances in Wireless Communications.

[10] Kim, E.C., Cha, J.S., Kim, S.K., Lee, J.J., Kim, J.Y and Kang, J.J. 2009. A Study on the Efficient Interference Cancellation for Multi-hop Relay Systems. The Journal of the Institute of Internet, Broadcasting and Communication.

[11] Hwang, T. and Li, Y. 2004. A bandwidth efficient block transmission with frequency-domain equalization. In Proceedings of the IEEE 6th Circuits and Systems Symposium on Emerging Technologies: Frontiers of Mobile and Wireless Communication.

[12] Joo, S.Y., Choi, J.W., Kim, D.H. and Jeong, E.R. 2019. New SC-FDE Transmission Structure for Coping with Narrow Band Jammers and Reducing Pilot Overhead. Journal of the Korea Institute of Information and Communication Engineering.

[13] Jeong, E.R., Choi, J.W., Lee, J.S. and Lee, S.M. 2022. New SC-FDE Transmission Structure Robust in Mobile Communication Environment. Journal of Next-generation Convergence Technology Association.