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Investigation of Cooperative Communications with Multiple Relays and High-order Modulation Schemes

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Abstract:
In wireless networks, this article investigates the use of numerous relays, cooperative communications, and high-order modulation methods. Cooperative communication involves relays assisting the source node in transmitting data to the destination, while multiple relay systems offer spatial diversity and cooperative diversity. High-order modulation schemes enable higher data rates by transmitting multiple bits per symbol. The benefits of this combination include increased data rates, enhanced spectral efficiency, and improved reliability. Efficient relay selection algorithms, cooperation strategies, power allocation, and resource management are needed for optimal system performance. Comprehensive performance analysis is also necessary to evaluate the benefits in various scenarios.

Keywords: Cooperative communications, Multiple relays, Improved reliability, Algorithms.

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دراسة الاتصالات التعاونية ذات المرحلات المتعددة وأنظمة التعديل عالية الترتيب

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الملخص
تستكشف هذه المقالة مجموعة الاتصالات التعاونية والمرحلات المتعددة وأنظمة التعديل عالية الترتيب في الشبكات اللاسلكية. يتضمن الاتصال التعاوني مرحلات تساعد العقدة المصدر في نقل البيانات إلى الوجهة، في حين توفر أنظمة الترحيل المتعددة التنوع المكاني والتنوع التعاوني. تتيح أنظمة التعديل عالية الترتيب معدلات بيانات أعلى عن طريق إرسال بتات متعددة لكل رمز. وتشمل فوائد هذا المزيج زيادة معدلات البيانات، وتعزيز الكفاءة الطيفية، وتحسين الموثوقية. هناك حاجة إلى خوارزميات اختيار التتابع الفعالة واستراتيجيات التعاون وتخصيص الطاقة وإدارة الموارد لتحقيق الأداء الأمثل للنظام. يعد التحليل الشامل للأداء ضروريًا أيضًا لتقييم الفوائد في السيناريوهات المختلفة.

الكلمات المفتاحية: الاتصالات التعاونية، المرحلات المتعددة، تحسين الموثوقية، الخوارزميات.

Introduction

In terms of dependability, device size, signal quality, and battery life, wireless communications technology has advanced significantly during the past few years. However, significant fading and path loss from multipath propagation poses one of the biggest obstacles to the next generation of wireless communication [1].

Diversity in terms of frequency, duration, and space is created to lessen the impact of fading [2]. Spatial diversity is the only one of the three types of diversity approaches that do not cause the system to delay or lose bandwidth efficiency [3]. Nonetheless, the several-input (MIMO) approach, which makes use of several antennas at the transmitter and/or receiver, can produce spatial diversity [4]. Without more bandwidth or transmit power, the MIMO approach can offer significant gains in data speed, diversity, and network dependability. However, because of the hardware limits, size, cost, and power consumption, this technique might not be feasible. As a result, this approach is viewed as impractical and challenging to widely adopt [5]. As a result, a novel method known as cooperative communication was developed, which enables the signal wireless device antenna to get some of the benefits of MIMO without any of its drawbacks [6].

This method's primary principle is to let two or more signal mobile antennas (nodes) assist one another in transmitting information to the destination node by sharing their antenna. As a result, there is an improvement in speed, throughput, communication capacity, and network and battery longevity [7]. Nonetheless, cooperative communications can be divided into three categories: coded cooperation, decode and forward, and amplified and forward.

In wireless communication systems, cooperative communication is a new field that seeks to increase system performance by taking advantage of numerous nodes' or relays' cooperation [8].In recent years, the combination of cooperative communication and high-order modulation schemes has received significant attention due to their potential to enhance the data rate, spectral efficiency, and overall reliability of wireless networks [9]. This article investigates the application of cooperative communications with multiple relays and high-order modulation schemes, highlighting their benefits and challenges.

The main contribution of the paper is analyzing the cooperative communications with multiple relays and high-order modulation schemes. The remaining sections are structured as follows: the main aim and objectives of this study are discussed in Section 2. The general concepts of the relay channel are expressed in Section 3. Section 4 represented cooperative communication followed by the multiple relay systems definition in Section 5. In Section 6, the high-order modulation schemes have been explained and extensively discussed. Section 7 tabulated the main benefits of combining cooperative communications. The challenges results and discussion are closing the article along with the conclusion and list of recent cited references.

Aims and Objective

- High order modulation (PBSK, QPSK, 8PSK, and 16QAM) transmitted across AWGN and fading channel to demonstrate the serious impact of the latter in comparison to the former and the potential for cooperative technique to address this issue.
- In a baseband signal transmission domain, putting into practice two cooperative strategies: coded decode-and-forward (DF) and coded amplifier-and-forward (AF).
- Drawing comparisons between cooperative and direct transmission to highlight the advantages of the former.
- Enhancing the quality of the Coded Amplify-and-Forward and Coded Decode-and-Forward inter-user channels, evaluating their efficacy, and contrasting the two protocols via direct transmission.
- Using high order modulation schemes such as QPSK, 8-PSK, and 16QAM to make up for the loss of bandwidth efficiency in multi-relay networks.
- The primary goal of this research is to examine how well many relays and high-order modulation methods function in cooperative communication systems.

Relay channel

Using a relay in the direct path between the transmitter and the receiver creates a relay channel in cooperative communication as opposed to simply sending the signal from the emitter to the receiver as in direct transmission [9]. The relay channel functions as an assistance or support for the source node and the destination node's direct channel. In this channel, the relay is used to receive the signal from the source and then retransmit it to the destination after processing [1]. The various relay processing algorithms affect the cooperative communication protocol. Fixed and adaptive relaying methods are the two main categories into which cooperative communication techniques fall. The relay and the source receive a fixed share of the channel's resources under the first approach [10]. The relay only amplifies the received signal from the source and retransmits it to the destination in the first protocol, Amplify-and-Forward; in the Decode-and-Forward protocol, the relay decodes and re-encodes the received signal from the source and retransmits it to the destination [11]. These two systems are simple to set up, but they have the drawback of decreasing bandwidth efficiency because the relay is allotted half of the channel resources for retransmission. This deficiency lowers the overall rate, especially when there is a good channel between the source and the destination. In this instance, the relay retransmission is wasted because the majority of the sent packets are received at the destination.

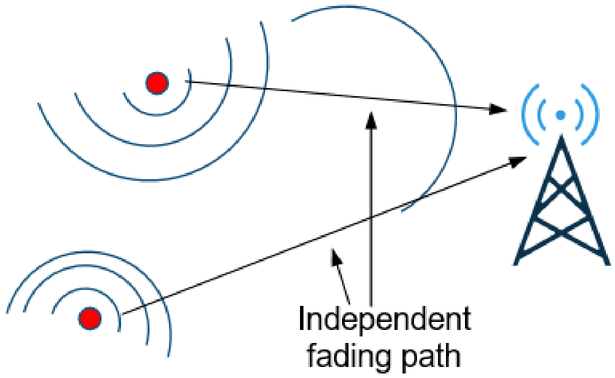

Figure 1: Relay channel.

Cooperative Communications

Cooperative communication involves multiple nodes working together to transmit and receive data, thereby improving the quality of service. In a cooperative communication system, the relays assist the source node in forwarding the information to the destination. By doing so, cooperative communications can mitigate issues such as fading, and interference, and improve signal strength, reliability, and coverage.

Multiple Relay Systems

Multiple relay systems refer to scenarios where more than one relay node is involved in the transmission process. Each relay can amplify, decode, and retransmit the received signal to enhance the overall performance. The cooperative diversity gained from multiple relays helps combat fading and offers spatial diversity, enabling better signal reception at the destination.

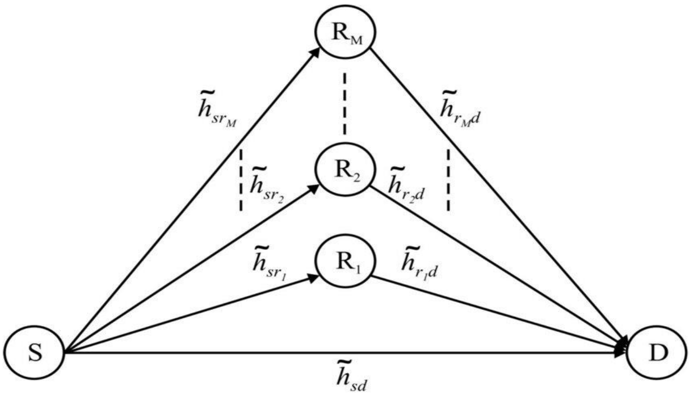

Figure 2: Multiple-relay wireless network with source terminal.

High Order Modulation Schemes

High-order modulation schemes refer to the use of modulation techniques that can transmit multiple bits per symbol, resulting in higher data rates. Examples of high-order modulation schemes include quadrature amplitude modulation (QAM) and orthogonal frequency division multiplexing (OFDM) [8]. These schemes offer increased spectral efficiency and can better utilize the available bandwidth, enabling higher data transmission rates.

Benefits of Combining Cooperative Communications

The main benefits of Combining Cooperative Communications with High Order Modulation Schemes are tabulated in Table 1.

Table 1: Benefits of Combining Cooperative Communications [12].

Benefits	Features
Increased Data Rates	• High-order modulation schemes allow for the transmission of more information per symbol, enabling higher data rates. When combined with cooperative communications, the relay nodes can enhance the signal quality and extend the coverage area, leading to improved overall data rates
Enhanced Spectral Efficiency	• Cooperative communication systems with multiple relays and high-order modulation schemes can achieve higher spectral efficiency by efficiently utilizing the available bandwidth. This is especially beneficial in scenarios where the spectrum is limited.
Improved Reliability	• By employing multiple relays, cooperative communication systems can provide better link reliability. Relays can overcome fading and interference by improving signal strength and reducing error rates, resulting in increased overall system reliability.

Challenges and Research Directions

The main challenges and the future direction research are tabulated in Table 2.

Table 2: Challenges of Combining Cooperative Communications and Research Direction [8], [9], [13].

Challenges	Remarks
Relay Selection and Cooperation Strategies	• Efficient relay selection algorithms and cooperation strategies need to be developed to maximize the benefits of cooperative communications. • These algorithms should consider factors such as channel conditions, relay locations, and transmission power optimization.
Power Allocation and Resource Management	• Optimal power allocation among source, relay, and destination nodes is crucial to achieve the desired performance gains. • Efficient resource management techniques are needed to allocate bandwidth, power, and time slots among multiple relays and users.
System Performance Analysis	• Thorough performance analysis, including bit error rate (BER), outage probability, and capacity analysis, is necessary to evaluate the benefits of cooperative systems with high-order modulation schemes. • Analytical models and simulations can provide insights into the system's performance under different scenarios.

Results and discussion

Based on the explanation given introduction section, this section will demonstrate how the AWGN and slow fading channels differ in their effects or attenuation on the PBSK, QPSK, 8-PSK, and 16-QAM modulation schemes, based on the description provided in the introductory section. The bit error rate (BER) vs signal to noise ratio (SNR) performance over the slow fading channel and the AWGN is shown in Figure 3.

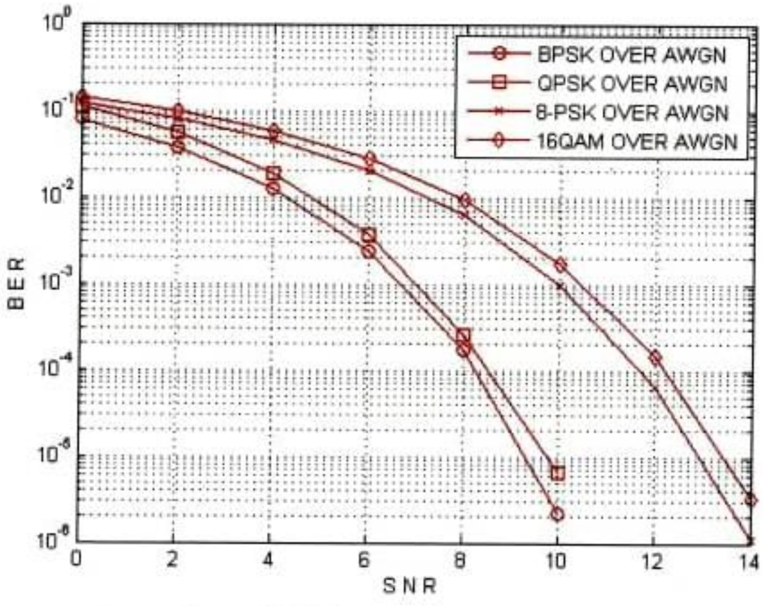

Figure 3: Transmission of high-order modulation over AWGN.

The simulation result shown in Figure 4 shows that the worst BER is obtained for both channels when the higher order modulation is employed. Put otherwise, a higher order M for M-PSK or M-QAM will result in a higher BER. Additionally, it is evident from comparing the two numbers that the slow-fading channel's effect is far worse than the AWGN channel's attenuation. The SNR vs. BER in the fading channel is nearly linear. Cooperative communication, which is covered in the next section, can be used to lessen the impact of the quasi-static Rayleigh fading channel.

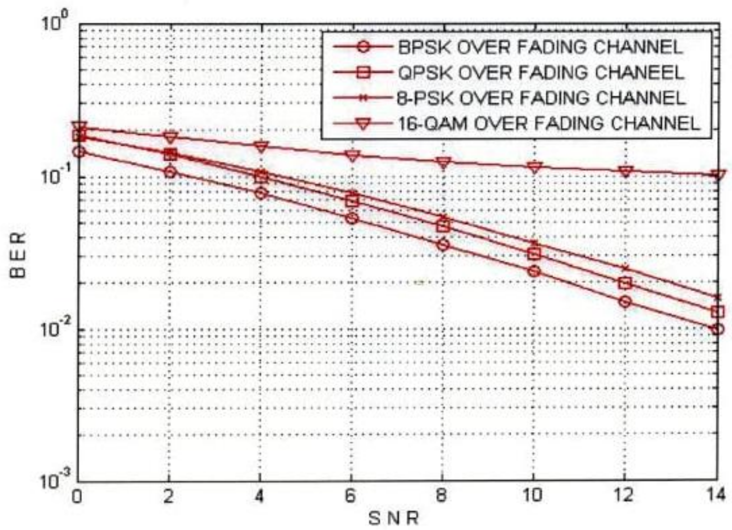

Figure 4: Transmission of high order modulation scheme over Quasi-static fading channel.

In addition to comparing the two cooperative protocols—coded Amplify and Forward and coded Decode and Forward—in this section of the results, we'll also look at how well they work when sent directly using Figure 5. The information bits are encoded using convolution codes in both protocols and direct transmission; the generator polynomials of the rate ½ mother convolution code are (5.7), which correspond to distinct codes with constraint length K=3. A decline in bandwidth efficiency is observed when the number of relays increases. For a fair comparison (1 bit/channel), we therefore utilized QPSK for Coded AF and PBSK modulation for direct transmission.

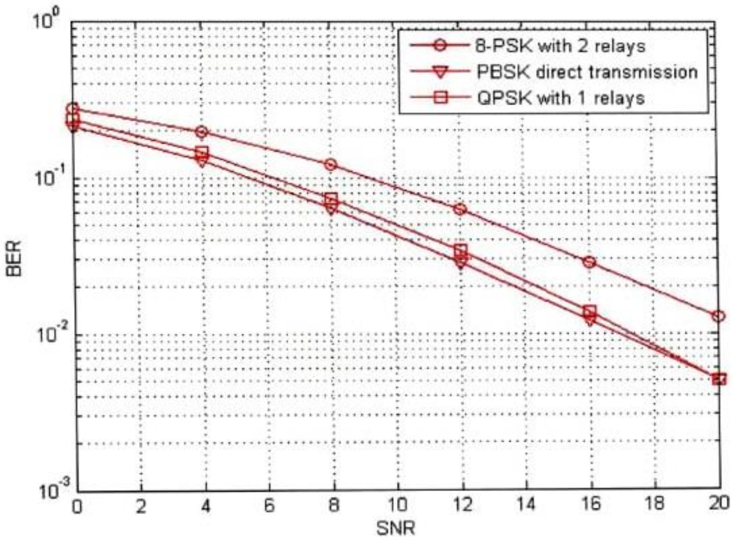

Figure 5: Shows the implementation of high-order modulation with an increase in the number of relays.

The contrast of direct transmission and coded AF is shown in Figure 6. The outcome demonstrates that coded amplify and forward gain outperforms direct transmission in terms of bit error rate. The performance gain of the Coded AF increases significantly over direct transmission, as expected, by boosting the SNR of the uplink channels and the inter-user channel quality ((y_(l ̇J)) ̅=5dB,10dB,15dB, and 20dB) ̅), as shown in the figure below. On the other hand, better inter-user channel quality indicates either a relay close to the source or a high signal-to-noise ratio (SNR) channel, which results in less channel impairment.

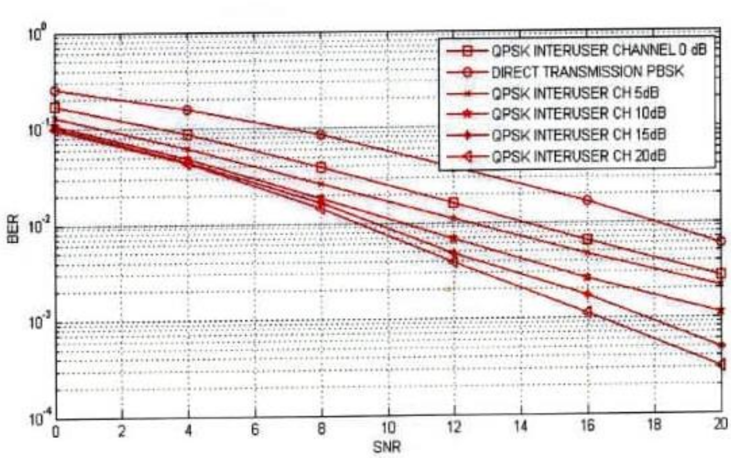

Figure 6: Shows Amplify-and-Forward (Quasi-static Rayleigh fading, QPSK, symmetric uplink) and direct.

Figure 6 illustrates both direct transmission and Amplify-and-Forward (QPSK, symmetric uplink, quasi-static Rayleigh fading). Figure 5 shows that the Coded Decoded-and-Forward method offers a greater BER performance gain than direct transmission. Additionally, the performance benefit of the Coded DF over direct transmission grows significantly by improving the quality of the reciprocal inter-user channel (y_(l ̇J)) ̅> 0).

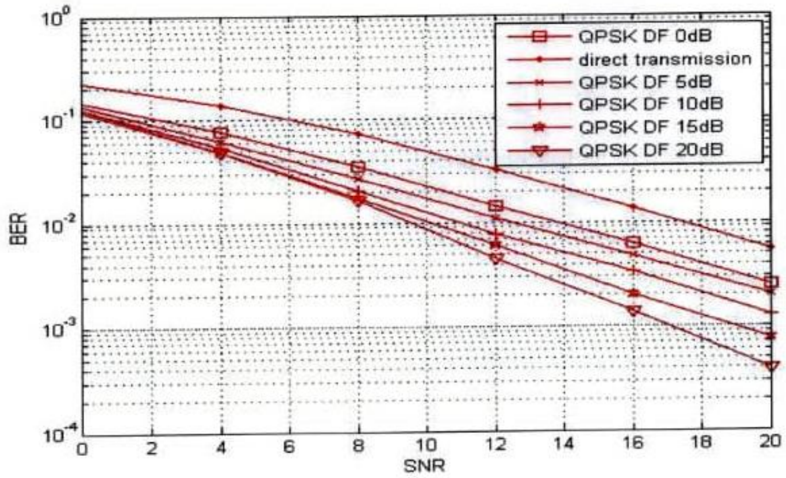

Figure 7: Shows coded decoded-and-forward (Quasi-static Rayleigh fading, QPSK, symmetric uplink) and direct transmission.

When comparing the two cooperative protocols, Figures 6 and 7, it is clear that the Coded Amplify-and-Forward performs better than the Coded Decode-and-Forward when there are issues with the uplink and inter-user channels. Additionally, by enhancing the quality of the inter-user channel for both protocols and contrasting the BER performance in the same quality, say at SNR = 5dB or 20dB. Unfortunately, the Code Amplify-and-Forward performs worse than the Coded Decoded-and-Forward. This is because Coded AF has only been amplifying and retransmitting the version that it received from the source to the destination. Conversely, in selectively coded DF, the relay only retransmits the signal from the source if it can accurately recover the received signal.

Conclusion

The investigation of cooperative communications with multiple relays and high-order modulation schemes holds significant potential to enhance the overall performance of wireless communication systems. By leveraging the cooperation of relays and the increased data rates offered by high-order modulation schemes, these systems can improve spectral efficiency, reliability, and data rates. However, further research is required to address challenges such as relay selection, power allocation, and system performance analysis to fully exploit the benefits of this combined approach. With continued advancements in this field, cooperative communication systems with high order modulation schemes are expected to play a vital role in future wireless networks.

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