

Effects of Cooperative Diversity In Wireless Communication – An Extensive Study

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Abstract:

Cooperative diversity is based on mutual cooperation between mobile stations. The mobile users share each other's antennas for multiple data transmission. Numerous research studies claim that cooperative diversity shows a remarkable performance in wireless communication systems through a reduction in error rates and outage probability. This paper presents a comprehensive study on the performance of cooperative diversity in wireless communication systems.

1. Introduction

Multipath fading is one of the challenges commonly faced in wireless communication. Spatial diversity is an effective option to reduce the adverse effects of fading and increase the reliability of data transmission and reception. However, it is not always feasible to implement spatial diversity at transmitting end due to various constraints [1-2]. One possible solution to this problem could be the use of cooperative diversity to create virtual transmit diversity.

Cooperative diversity is the result of mutual sharing of antennas by a number of mobile nodes. The information of each user can be transmitted as many times as the number of cooperative nodes. Thus, multiple copies of same information reach the receiver, as shown in figure 1. There is a trade-off between cooperative diversity and computational complexity. Therefore, a balance is required for an optimized system performance. The major advantages of implementing cooperative diversity are increased network capacity, good quality of service, and diversity gain [3].

There are different forms of cooperative diversity which can be created at the transmitting end viz. amplify and forward, decode and forward, and coded cooperation. Figure 2 shows the mechanism of different cooperative diversity techniques. AF cooperative diversity is created when cooperative node simply amplifies the overheard signal of other mobile nodes for transmission to destination node. DF cooperative diversity is created when cooperative node decodes the overheard signal of other mobile nodes and re-encodes it for transmission to destination node.

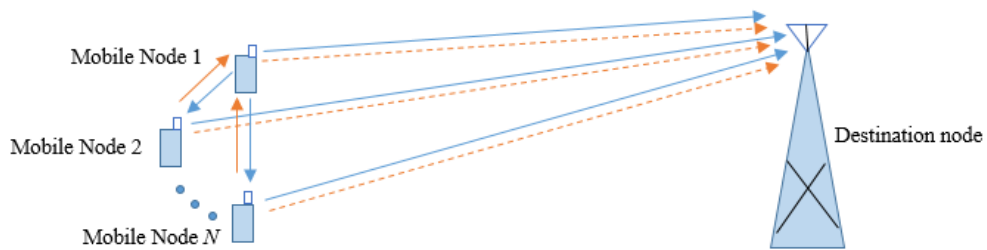
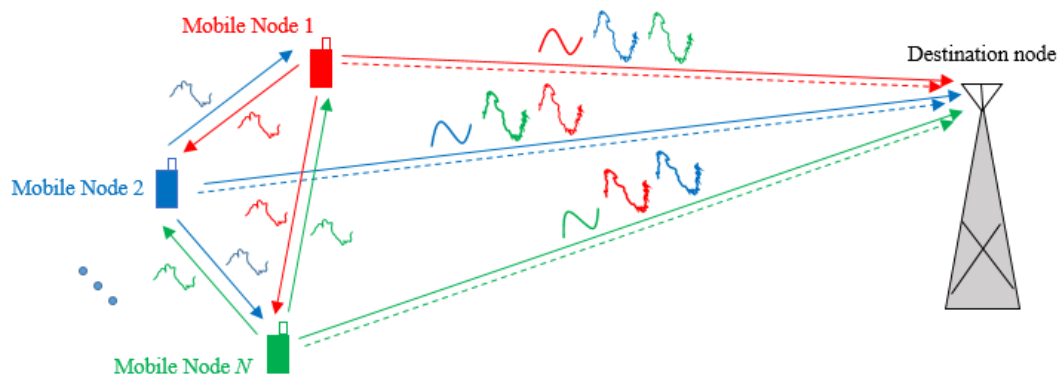
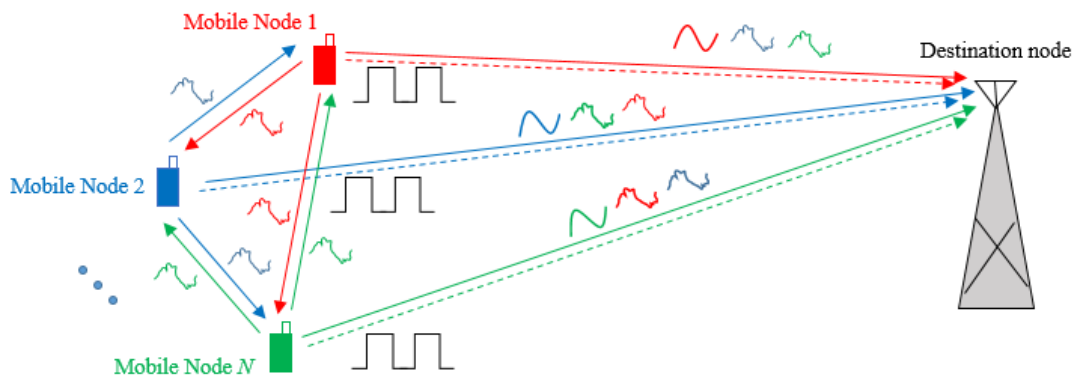


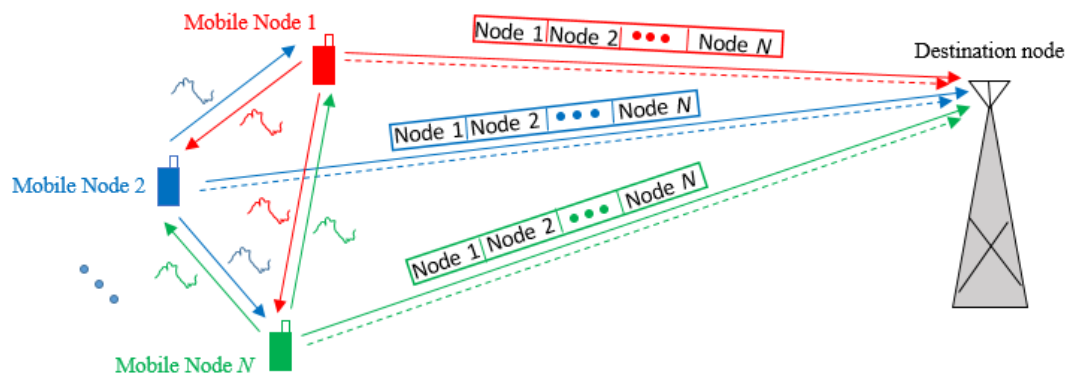
Figure 1: Cooperative diversity



(a)



(b)



(c)

Figure 2: a) Amplify and forward cooperative diversity b) Decode and forward cooperative diversity c) Coded cooperation

2. Performance Analysis of Cooperative Diversity in Wireless Networks

The underlying idea of cooperative diversity lies in the classical relay channel. Cover and Gamel [4] studied the capacity of degraded, reversely degraded and feedback relay channels for a single sender and receiver. Willems [5] introduced the concept of partially cooperating encoders in a multiple access channel for two senders and single receiver. The partial cooperation is due to limited capacities of channels.

Sendonaris et al. [6], [7] proposed a novel user cooperation diversity technique which creates spatial diversity for single-antenna mobile users through cooperation of in-cell users. Every cell has a partner for each user. The partners receive information of each other, detect it and transmit it along with their own information. The system employing user cooperation diversity shows an increased capacity and robustness, even when the channel between users is noisy.

Laneman and Wornell [8], [9] and Laneman et al. [9] designed energy efficient cooperative transmission protocols, namely ‘amplify and forward protocol’ and ‘decode and forward protocol’ to combat multipath fading in wireless networks. In amplify and forward (AF) cooperative transmission technique, the relay estimates fading coefficient between source and relay, and scales the received signal in order to meet its average power constraint prior to transmission. Decode and forward (DF) cooperative transmission technique can be applied when signal-to-noise ratio (SNR) between source and relay is reasonably high. In this case, the relay decodes received signal and re-encodes it before transmitting to the destination.

Barbarossa and Scutari [10] derived a coding strategy that maximizes the sum of rates from cooperating mobile terminals to base station, under total available power constraint. Yuksel and Erkip [11] investigated diversity order effects for a network with single source, single destination and two amplify and forward relays. This network showed lowest error rate in comparison to direct transmission, traditional multi-hop transmission and well-known transmit diversity methods.

Sendonaris et al. [12] analyzed the system based on user cooperation concept in terms of capacity, outage and coverage. The user cooperation concept was implemented to a CDMA system and positive results were obtained. In [13], Sendonaris et al. observed that user cooperation is beneficial in terms of reduced sensitivity to channel variations and enhanced system throughput and coverage.

Mo and Wang [14] analyzed the performance of cooperative diversity system in terms of outage probability and average symbol error probability (SEP) over random fading channels at high SNR. Diversity gain and coding gain parameters were introduced to characterize average SEP and outage probability. Nosratinia et al. [15] presented an overview of the developments in cooperative communication and reported that cooperative diversity has a promising future in wireless networks.

Laneman et al. [16] developed low-complexity protocols for fixed cooperative schemes namely ‘amplify and forward’ and ‘decode and forward’, selection based cooperative schemes that adapt with CSI between cooperating nodes, and incremental relaying that exploits the limited feedback from destination. These protocols resulted

in reduction energy consumption as well as outage probability. Nabar et al. [17] analysed the performance of protocols for a simple fading relay channel where the relay uses AF or DF cooperative scheme. Further, space-time codes were used for AF based relay. It was reported that full spatial diversity order can be achieved in case of appropriate power control. Ribeiro et al. [18] analyzed the performance of AF cooperative diversity protocol in terms of average SEP for a system with multiple cooperating branches and multiple cooperating hops at high SNR. It was observed that error gain of multi-hop systems is due to lower path loss, and error gain of multibranch systems is due to lower path loss and diversity gain.

Larsson and Vojcic [19] proposed a new cooperative diversity technique based on superposition modulation and multi-user detection. With this technique, relay can transmit the received data as well as its own data to destination simultaneously. It outperforms the classical DF cooperative diversity technique by about 1.5-2 dB at same complexity. Bletsas et al. [20] proposed another cooperative transmission technique based on network path selection. It selects the best relay from a group of relays for cooperation between source and destination. Ribeiro et al. [21] developed a general framework for multi-source cooperation protocols that improves diversity and spectral efficiency in comparison to single-source cooperation, with manageable complexity. Xiao et al. [22] proposed a cooperative diversity technique based on network coding in which cooperating partners transmit algebraic superposition of its own information and relayed information to destination.

Han and Sun [23] investigated security problems in traditional cooperative transmission schemes and designed a secure cooperative transmission scheme that can manage channel estimation errors and relays' misbehaviour. This technique outperforms the traditional cooperative transmission technique under various attacks. Ding et al. [24] designed a cooperative secure transmission system that can approach zero outage probability. The relay transmission was exploited using distributed beamforming and precoding.

Ibrahim et al. [25] proposed another cooperative transmission protocol with same diversity order and high spectral efficiency in comparison to conventional cooperative scheme. The system comprises a number of DF based relays from which the optimal relay is selected on the basis of partial CSI at source and relays. Liang et al. [26] performed an analysis and comparison of numerical protocols for selecting the relay. Further, optimal relay assignment and cooperative transmission were also discussed.

Capar et al. [27] investigated the broadcast capability of nodes in a cooperative wireless network. It was observed that the broadcast performance is dependent on path loss exponent of medium. Zhou and Zhuang [28] reported that the link distance affects cooperative communication by studying the spatial diversity gain for the network.

Korn et al. [29] considered a two-dimensional user distribution scenario to investigate the power saving potential of cooperative communication. For the same SNR at base station, the average transmit power of cooperative transmission and conventional communication were compared. It was observed that power savings per user in a cooperative transmission system increases with an increase in path loss exponent and number of users in the circular cell. Ling et al. [30] designed an optimal

power allocation algorithm for cooperative networks that outperforms the conventional techniques in terms of energy saving.

Yu et al. [31] proposed an efficient cooperative transmission technique for two user cooperative systems, that achieves signal space diversity using rotated constellation. This technique performs better than the conventional cooperative scheme based on orthogonal signaling when the inter-user channel quality is low.

3. Future Scope

The cooperative diversity can be incorporated with various coding schemes, partitioning strategies and modulation schemes to enhance the system performance. Other possible area of future research can be to find alternative solutions to exploit the performance of cooperative communication without compromising complexity.

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