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Enhanced cooperative communication MAC for mobile wireless networks

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ABSTRACT

In this paper, we propose a new MAC (medium access control) protocol called enhanced cooperative communication MAC (ECCMAC) based on IEEE 802.11. The major objective of ECCMAC is to maximize the benefits of cooperative communication. We first propose a scheme for selecting and maintaining the best relay node. Second, since both cooperative communication and network coding rely on the selection of a relay node, we consider exploiting a network coding technique for additional throughput improvement. Third, to accommodate asymmetric link rates between a sender and a relay node, we employ ECCMAC to measure forward and reverse link rates, whereas prior works have simply assumed symmetric rates. ECCMAC is evaluated in this paper through theoretical analysis, extensive simulation, and simulation with measured data, and the results show that ECCMAC effectively improves wireless network performance.

1. Introduction

Due to the rapid growth of mobile devices such as laptops and smartphones, wireless data traffic has significantly increased, driving the many efforts to increase wireless bandwidth. Recently, wide attention has focused on a novel paradigm called cooperative communication to maximize the link utilization of a given wireless bandwidth. Cooperative communication is based on active participation of neighboring nodes to assist the transmission of information. Two research areas are exploring this approach: cooperative diversity and packet relay by a neighbor node.

Cooperative diversity works to mitigate the multipath fading effect of wireless channels [1–10]. It uses cooperative multiple antennas to maximize total network channel capacity by decoding the combination of a relayed signal and a direct signal.

Packet relay by a neighbor node aims to improve the link utilization by exploiting the multi-rate capability of the IEEE 802.11 standard. If it is beneficial, packets are relayed by cooperative neighboring nodes instead of being directly transmitted to destinations. Several studies have been proposed to investigate cooperation with regards to fairness [11], coverage [12], reliability [13,14], and throughput improvement [15–23].

In this paper, we focus on cooperative communication via packet relay, and we propose a new MAC (medium access control) protocol called enhanced cooperative communication MAC (ECCMAC) based on the IEEE 802.11 distributed coordination function (DCF). Our first contribution is a relay node selection scheme to select the best relay node. In cooperative communication, the performance gain depends on the relay node, so it is important to select and maintain the best relay node. In existing schemes, a relay node is selected randomly [17,28] or via passive listening [18,19], and it may not be the optimal selection. The proposed scheme actively searches for the best relay node for each transmission. We demonstrate through a mathematical model that our proposed scheme can determine an optimal relay node within a few contention rounds.

The second contribution of this paper is that it actively utilizes network coding for additional throughput

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improvement. Network coding is another technique that employs the broadcasting capacity of relay nodes to achieve efficient resource utilization in wireless networks. In the process of packet exchanges, the relay nodes broadcast a coded collection of forward and reverse packets to reduce the number of transmissions. From an architectural point of view, cooperative communication and network coding are similar approaches in the sense that they both rely on relay nodes. In [28], the simultaneous use of cooperative communication and network coding was investigated. However, network coding was considered as a secondary tool for additional benefits. In ECCMAC, we consider the aggregate benefits of both cooperative communication and network coding to maximize the throughput gain by optimizing the relay node selection process.

Third, we propose a scheme to address asymmetric link conditions in wireless communication. In prior works on cooperative communication, it was assumed that the wireless channel was symmetric [16–28]. However, many experimental studies have shown that wireless links are usually asymmetric, so that assumption can be a source of performance degradation. In ECCMAC, forward and reverse data rates are separately measured to cope with asymmetric data rates.

Finally, we analyzed the proposed scheme for a single-hop environment and we evaluated it through extensive simulations. We found that our design achieved significant throughput gain in various network scenarios. Additionally, we conducted a set of simulations with the measured data rate in the testbed to investigate the impact of asymmetric link rates, and we observed that the proposed scheme shows improved performance.

The rest of this paper is organized as follows: In Section 2, we present related works along with the motivation of this work. In Section 3, we propose ECCMAC, our scheme for relay node selection, transmission mechanisms with cooperation and network coding, and asymmetric link rates management. In Section 4, we analyze ECCMAC in terms of saturated throughput and overhead for the relay node selection. In Section 5, we evaluate ECCMAC based on extensive simulations. Finally, in Section 6, we provide conclusions for this paper.

2. Related work and motivation

The IEEE 802.11 standard in [29] specifies the multi-rate capability in the physical layer that can be used to improve network performance. In IEEE 802.11b, four data rates (1, 2, 5.5, and 11 Mbps) are available, and eight data rates (6, 9, 12, 18, 24, 36, 48, and 54 Mbps) are available in IEEE 802.11g. However, the standard does not specify the rate adaptation algorithm, and so several protocols have been proposed to efficiently utilize the multi-rate capability. A basic policy for rate adaptation is to send data at a high data rate in good channel conditions, and to decrease the data rate in bad channel conditions. In [30], the Auto Rate Fallback (ARF) protocol was proposed to decide the sending rate based on communication history. In the receiver-based auto rate (RBAR) protocol proposed in [31], receivers measured the signal-to-noise ratio (SNR) of received RTS messages, and decided the data rate based on a predefined SNR threshold. The rate was piggybacked in CTS messages to senders. In [35], the bit error rate (BER) was measured instead of the SNR, and the senders were informed of the BER by ACKs. Then, senders decided the data rate for the next transmission based on the BER. Basically, receiver-based rate adaptation shows better performance than sender-based adaptation, since the decodable transmission rate is mainly determined by the received signal strength. In receiver-based rate adaptation, however, an additional cost (CTS or ACK) is required for informing the rate to senders. In this paper, we employ receiver-based rate adaptation since we use RTS–CTS exchange for collision avoidance and cooperation.

In wireless networks, the channel condition is usually location-dependent, so neighbors of a node may each observe different channel conditions. With the multi-rate capability, therefore, cooperative communication is a promising technique for enhancing network performance. Recently, many studies have proposed employing cooperative communication, such as in [13–23]. Among them, rDCF in [17], CoopMAC in [18], RCF-CMAC in [19], CoopMACA in [20], MCoopMAC in [21], 2rcMAC in [22], and PR-MAC in [23] are quite related to our proposed protocol in actively utilizing the multi-rate capability of IEEE 802.11. Their approaches are similar in that packets are delivered to their destinations via a relay node if it can transmit at a higher data rate, but they are different in how they select the relay node. In rDCF, each node monitors transmissions among its neighbors to find the transmission rate for each sender–receiver pair. Then, it broadcasts a list of pairs for which it can relay packets with a higher rate. A sender can select a relay node from this list. In CoopMAC, to avoid the overhead due to the broadcasting in rDCF, each sender (instead of relay nodes) monitors neighboring nodes' transmissions to select a relay node. Since each sender uses its local information to select a relay node, CoopMAC can avoid additional message overhead for cooperation. However, since a relay node is selected based on its previous transmissions, a sender may fail to select the currently best relay node. RCF-CMAC is similar to CoopMAC in that a relay node is selected based on the transmission history, but RCF-CMAC utilizes multiple relay nodes for most robust cooperation. In CoopMACA, packet aggregation is considered to improve throughput when selecting a relay node. If multiple candidate nodes exist for the relay node, a node with a packet to send is selected as the relay node for packet aggregation. MCoopMAC is basically the same as CoopMAC except that a receiver initiates the cooperation. When a receiver receives an RTS from a source, it monitors the channel quality and, when it is not good, asks for cooperation by sending a relay RTS frame. In 2rcMAC, a packet is relayed by two independent nodes to achieve high reliability. Under fast-fading conditions, it was shown that 2rcMAC outperforms CoopMAC. In PR-MAC, a packet is delivered via a stationary infrastructure instead of neighboring nodes to provide greater reliability.

Cooperative communication by itself is very effective for increasing wireless throughput, but it is possible to achieve additional benefits by adding network coding.