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An interference avoidance MAC protocol design in mobile ad hoc networks

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ABSTRACT

The multi-rate IEEE 802.11 DCF MAC protocol can transmit control signals at a basic transmission rate and data signals at various transmission rates. When the transmission rates of the control signals and the data signals differ, the transmission range of the lower transmission rate is larger than the transmission range of the higher transmission rate. Since a lower transmission rate increases the transmission range, it also increases the nodes in the Network Allocation Vector (NAV) status and decreases the network throughput. However, if a neighbor receiving the control signal of the ongoing communication pair communicates with another node, it may occur signal interference. This study proposes a Space Overlapping MAC (SO-MAC) protocol to increase the communication pairs and avoid interferences in single radio for multi-rate wireless network. The SO-MAC protocol uses a channel division mechanism to avoid interference between the data and control signals. This study also proposes a bandwidth allocation strategy for the sub-channels to maximize the utilization of the bandwidth of the divided sub-channels. To solve the interference between the data signals, SO-MAC allows a neighbor of the sender and the receiver to use the received signal strength to determine whether it can send or receive the data signal to increase the communication pairs. Simulation results show that, compared to the IEEE 802.11 DCF protocol and DCA protocol, the proposed SO-MAC protocol with the bandwidth allocation strategy can increase the communication pairs, achieve better throughput, reduce the number of handshake failures, and decrease the delay of transmitting a packet.

1. Introduction

Mobile ad hoc networks (MANETs) that consist of mobile nodes make it possible to communicate without any infrastructure or base stations, and can be formed rapidly anytime and anywhere. Given their characteristics of rapid deployment and easy establishment, MANETs are useful in many environments, and particularly battle zones, secluded areas, or any hard-to-reach places.

In MANETs, mobile nodes use radio waves to communicate with each other. Therefore, the design of the medium access control (MAC) protocols must account for the interference of radio waves to allow multiple communication pairs to communicate simultaneously. The IEEE 802.11 protocol uses the Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) mechanism to avoid interference. In this protocol, when a mobile node wants to communicate with another mobile node, it must listen to the channel for a period of time called the back-off time. This node can communicate with the receiver if it does not detect any signals in the channel. However, the CSMA/CA mechanism encounters the hidden terminal problem (HTP) [1]. To solve HTP, previous research proposed the Multiple Access with Collision Avoidance protocol (MACA) [2]. In MACA, the Ready to Send (RTS) frame and Clear to Send (CTS) frame contend for and reserve the channel in the MAC layer. In addition, IEEE adopted the MACA protocol and named it IEEE 802.11 DCF (Distributed Coordination Function).

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One way to increase throughput is to increase the transmission rate of the data signals through a multiple transmission rate. For example, IEEE 802.11a, IEEE 802.11b, and IEEE 802.11g use multiple data transmission rates to increase throughput. Two modulations can achieve multiple rates, including the Complementary Code Keying (CCK) modulation and the Orthogonal Frequency Division Multiplexing (OFDM) modulation. The IEEE 802.11b standard uses CCK modulation to achieve multiple rates of 1, 2, 5.5, and 11 Mbps; IEEE 802.11a standard uses the OFDM modulation to achieve 6, 9, 12, 18, 24, 38, 48, and 54 Mbps; and IEEE 802.11g standard uses both modulations. With multiple transmission rates, a node can use previous transmission or environmental conditions, such as the received signal strength, to determine which transmission rates should be used to transmit data signals.

The MAC layer of wireless local area networks (WLANs) adopts the Distributed Coordination Function (DCF) protocol in the IEEE 802.11 standard [3]. The IEEE 802.11 DCF protocol delivers the RTS and CTS control signals with the basic transmission rate while the data signals are delivered with various transmission rates depending on the conditions of the communications between the sender and the receiver. To increase throughput, a high transmission rate is always used to transmit data at first. When the data signal loss rate is too high, a lower transmission rate is used to transmit the data signals. For example, IEEE 802.11b initially tries to transmit a data signal at 11 Mbps for several times. If these data transmission fail, a lower transmission rate is used. However, according to Broadcom [4], different transmission rates have different signal-to-noise ratio (SNR) thresholds. In other words, the transmission range of a lower transmission rate is larger than the transmission range of a higher transmission rate where the transmission range indicates the range at which the transmitted signals can be correctly received. Therefore, the larger transmission range of a lower transmission rate increases the nodes in the Network Allocation Vector (NAV) status, and decreases the throughput of the IEEE 802.11 DCF protocol.

In an effort to improve the spatial reuse by increasing the communication pairs simultaneously, previous studies propose a power control mechanism that shrinks the power of control signals to reduce their transmission range of the control signals. This can reduce the number of nodes that enter the NAV status due to receiving the control signals and conserve transmission power. However, when a communication pair reduces the power to transmit the control signals, the neighbors that do not receive the control signals may interfere with the ongoing communication.

The description and analysis above indicate that using the power control method to increase the communication pairs may result in the interference problem. Thus, how to design a MAC protocol that increases the communication pairs while avoiding the interference problem is a big challenge. To achieve the goal of increasing the communication pairs, if the neighbors of a communication pair want to communicate with other nodes, two interference problems must be solved. (1) The interference problem occurs between control signals and data signals. (2) The interference problem occurs between a data signal and another data signal. The following, discussion describes these two interference problems. Assume that a sender is communicating with a receiver. The first interference problem may occur when a neighbor that has received the control signal sent from the sender or the receiver sends a RTC/CTS control signal. The transmitted control signal sent from this neighbor may interfere with the ongoing data receipt of the receiver. The second kind of the interference problem may occur when a neighbor that has received a control signal transmits a data signal to another node. This is because the transmitted data signal may interfere with the data receipt of the receiver of the ongoing communication. As a result, designing a MAC protocol that increases communication pairs and solves these two kinds of interference problems remains an important task.

This paper analyzes the interference between a control signal and a data signal and the interference between different data signals when a neighbor node that has received a control signal wants to communicate with other nodes. This study proposes the Space Overlapping MAC (SO-MAC) protocol to solve these interference situations by increasing the communication pairs and avoiding interferences for multi-rate wireless network. This protocol uses a channel division mechanism to have three sub-channels in a radio, including a RTS/CTS sub-channel, a data sub-channel, and an ACK sub-channel, to solve the interference between the control and data signals. With regard to the interference between the different data signals each neighbor compares the received signal strength with the signal-to-interference and noise ratio (SINR) threshold to determine whether it can communicate with another node with interferences or must enter the NAV status to increase the communication pairs. To maximize the utilization of channel bandwidth, this study also proposes a bandwidth allocation strategy for the divided sub-channels. By increasing the communication pairs of nodes and adopting the bandwidth allocation strategy of the sub-channels to maximum the utilization of channel bandwidth, the proposed SO-MAC protocol can efficiently increase network throughput.

The rest of this paper is organized as follows. Section 2 introduces previous research on the improvement of MAC protocols. Section 3 proposes the SO-MAC protocol with bandwidth allocation strategy. Section 4 presents and analyzes the simulation results, while Section 5 offers a conclusion.

2. Related works

Section 2.1 below introduces the IEEE 802.11 DCF protocol and its related problems. Sections 2.2 and 2,3 and 2.4 introduce previous research on the improvement of throughput, including the multi-rate data transmission, the multi-channel, and the beamforming technique.

2.1. IEEE 802.11 DCF protocol and related problems

The IEEE 802.11 DCF [3] protocol is a contention-based mechanism that attempts to avoid collisions with virtual carrier sense transmission, *i.e.*, RTS/CTS/data/ACK, as Fig. 2.1 shows. When a node (sender) wants to transmit