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Address-free contention in wireless access networks with common control channel for throughput improvement

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ABSTRACT

In wireless local area network (WLAN) with common control channel (CCC), where the spectrum bandwidth is divided into two separate channels for access control and data transmission, concurrent transmissions of control and data frames can improve the spectrum efficiency by pipelining data transmissions. However, the state-of-the-art MAC schemes cannot fully exploit the channel separation due to large control overhead and receiver contention problem, where the former causes bandwidth erosion reducing the data transmission rate and the latter prevents the pipelining when two consecutive transmissions involve a common node as the receiver. In this paper, we focus on the two problems, and develop a novel CCC-based MAC scheme with address-free contention resolution for wireless access networks. Through both analysis and simulations, we show that the proposed scheme minimizes the control overhead and significantly improves the spectrum efficiency: It achieves as twice throughput as the conventional CCC-based MAC and 30% average performance gain over IEEE 802.11 MAC.

1. Introduction

For the recent decade, although transmission rate at Physical (PHY) layer has greatly improved thanks to advances in communication technology, Medium Access Control (MAC) layer has relatively little changed, and many wireless local area networks (WLANs) still operate under the standard IEEE 802.11 MAC [1,3]. It has been shown that while the IEEE 802.11 MAC is robust and scalable in a wide range of network settings, the embedded nature of exponential backoff mechanism and large control frames incur substantial overhead for the contention resolution [4–7]. As a result, the high transmission rate of PHY layer cannot be exploited in full due to long channel idle time caused by lengthy contention resolution in the medium access.

Channel separation technique using common control channel (CCC) has been proposed to address the problem and to take advantage of high transmission rate of PHY layer to the fullest [8–16]. In general, these schemes divide the spectrum bandwidth into two parts: control channel and data channel. Nodes that have data to send first contend in the control channel and reserve the data channel. Upon a successful reservation, the sender and the receiver switch to the data channel and the sender starts transmitting data frames. During the data transmission, the other nodes continue contending in the control channel to reserve the next time slot of the data channel. In this way, the CCC-based MAC schemes can make transmissions pipelined in the data channel and increase its spectral efficiency. So far, however, the effectiveness is limited mainly due to the following weaknesses:

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(1) The overhead of the lengthy control frames requires substantial amount of bandwidth and undermines the gain from transmission pipelining. Most CCC-based schemes adopt Ready-To-Send (RTS) and Clear-To-Send (CTS) type of control messages as in the standard IEEE 802.11 MAC, which contain the address field to identify the sender and the receiver. However, the MAC address is often lengthy (48 bits for the standard IEEE 802.11) and the bandwidth allocated to the control channel is typically small, which results in long contention period for exchanging the control frames. It has been shown that the CCC-based schemes may achieve even lower performance than the single-channel schemes due to the large control message overhead [15].

(2) Receiver contention may break the pipelining of data transmissions. Suppose that two consecutive data transmissions involve a common receiver that has a single transceiver. While the receiver is receiving a data frame in the data channel, it can neither receives RTS nor sends CTS in the control channel due to the single transceiver constraint. Hence, the second transmission can occur only after the receiver completes the current data transaction and returns to the control channel. It is known as the receiver contention problem [16], and it becomes acute when the traffic is concentrated on a few wireless nodes, e.g., Access Point in backhaul wireless networks.

In this paper, we develop a novel common-control-channel based MAC scheme that addresses these two weaknesses in wireless access networks. Our main contributions are as the following:

- We improve the spectrum efficiency of the common control channel by eliminating the address field of the control frames. We design our MAC such that each node contends without the address information of the sender and the receiver in the control channel, and minimize the control message overhead.
- We further promote the pipelining of data transmissions by resolving the receiver contention problem. We show that a short waiting time after each data transmission can significantly improve the performance without additional hardware cost.
- We evaluate our proposed scheme through both analysis and simulations. The results demonstrate that our proposed scheme outperforms comparable schemes achieving higher spectrum efficiency.

The rest of the paper is organized as follows. In Section 2, we briefly introduce related works. A review of the plain CCC-based MAC protocol that uses the RTS/CTS message exchange is provided in Section 3. The basic design of new control frames and address-free medium access scheme is presented in Section 4. The performance of our proposed scheme is analytically evaluated in Section 5. We further address practical issues in Section 6, and empirically compare with other schemes in Section 7. Finally, we conclude our paper in Section 8.

2. Related work

Many different types of multi-channel MACs have been developed in the last two decades. Based on the principles of operation, they can be classified into common (or dedicated) control channel, common hopping, split phase, and multiple rendezvous approaches [16]. In this paper, we focus on the common control channel approach and develop a novel scheme that improves the channel spectral efficiency. We refer interested readers to [16] for general multi-channel MAC protocols.

It has been shown that, by allowing nodes to contend in a separate control channel, the spectral efficiency of the data channel can be improved through transmission pipelining [13]. In [13], the contention resolution is performed in two stages: the nodes first contend using a tone signal in the control channel, and (possibly multiple) winners move to the data channel and start the second contention by exchanging control messages. While the control channel serves as a pre-contention and alleviates the contention level in the data channel, this two-stage contention causes additional control overhead. In [14], the two-stage contention has been simplified to a single-stage contention. The nodes contend in the control channel by exchanging the control messages and the winner transmits data in the data channel. Although it allows transmission pipelining with only control-channel contention, exchanging lengthy control frames in the narrow-band control channel undermines the gain of transmission pipelining. Also the receiver contention, which is common in an infrastructure wireless network, breaks the transmission pipelining and decreases the spectral efficiency. In this paper, we develop a novel CCC-based MAC scheme that reduces the control overhead with single-stage contention, and provide a simple solution to the receiver contention.

Common control channel approach has been also extended to multiple data channels [8–11]. Most multi-data-channel MAC schemes have focused on negotiating the data channel for transmission and require two-stage contention. In [8], multiple sender–receiver pairs negotiate in the control channel to determine the data channel for transmission. It successfully resolves the multi-channel hidden terminal problem that comes from the single transceiver constraint. However, the requirement of precise time synchronization among nodes adds significant overhead. The requirement of tight synchronization has been loosened in [9], where a cooperative MAC scheme has been proposed such that data channel occupancy information can be shared among neighboring nodes in an asynchronous manner. In [10], the authors have further improved throughput performance by reducing the number of channel switching between the control channel and the data channels. In this paper, we consider wireless access networks with single data channel and briefly discuss extension of our results to multiple data channels in Section 6.

3. System model

In this section, we describe our system model and explain the basic operations of the plain CCC-based MAC