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Performance improvements of integrating ad hoc operations into infrastructure IEEE 802.11 wireless local area networks

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Abstract

In the infrastructure configuration, the standard IEEE 802.11 wireless LAN employs an access point (AP) to forward all packets regardless of their destinations, resulting in significant system performance degradation in terms of throughput and packet delay when a significant portion of packets have intra-cell destinations. These intra-cell packets could be more efficiently delivered to the destinations directly in an ad hoc manner. In this paper, we propose methods to seamlessly integrate such ad hoc operations into the infrastructure mode. By inserting a 2β delay in the frame exchange sequence, the proposed 2β ad hoc awareness direct connection (2β AHADC) scheme brings ad hoc awareness to the infrastructure setting and minimizes the number of packets forwarded by the AP. Furthermore, a direct cut-through forwarding (DCTF) scheme is introduced to minimize the intra-cell packet forwarding delay. We evaluate the performance of the proposed methods by theoretical analysis and simulations. Numerical results show that in systems with significant fraction of intra-cell packets, the DCTF and 2β AHADC schemes effectively reduce packet delays and increase system throughput. The proposed methods extend the capability and performance of existing standards in a backward compatible manner, by introducing minor modifications that do not require explicit mode switching or extra modules.

Keywords: WLAN; 802.11; Infrastructure; Ad hoc

1. Introduction

Applications of IEEE 802.11 wireless local area networks (WLANs) have expanded rapidly in recent years and become one of the focal points of the wireless services industry. The basic medium access mechanism in IEEE 802.11 is the distributed coordination function (DCF), which is a random access method based on carrier sensed multiple access with collision avoidance (CSMA/CA) and binary exponential backoff for collided packet retransmissions [1]. DCF defines a basic access method with two-way handshakes as well as an optional four-way handshake method by exchanging request-to-send and clear-to-send (RTS/CTS) control frames. Most of WLANs deployed today are configured to operate in the infrastructure mode, where central nodes called access points (APs) are employed to provide access to the distribution system (DS) by forwarding all packets to and from the cells, each one under the radio coverage of an AP. The AP is normally used to provide Internet access for the associated stations in a WLAN. However, with the wide adoption of WLANs in enterprises, offices and even homes, more and more WLANs are used to totally replace the wired LANs such that network servers may also be connected via the WLANs. For the purpose of accessing the WLANs, servers and clients are all considered as indistinguishable wireless stations. Besides accessing the Internet via the APs, many stations also need to exchange data among themselves, e.g. clients accessing the local network servers, and peer-to-peer file and stream transfers among users. Therefore, intra-cell packets, which sources and destinations are stations within the same cell, could represent a significant fraction of the WLAN traffic in these scenarios. However, in the infrastructure configuration of IEEE 802.11 WLANs, the MAC protocol assumes that all packets are sent to or from

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the AP in each cell. As a result, the AP has to forward all intra-cell packets even if both source and destination stations are within radio range of each other. Therefore, the infrastructure mode is very inefficient for delivering intra-cell packets. Furthermore, the AP becomes the bottleneck of the system and requires a big buffer size to store the forwarding packets. In the presence of heavy intra-cell traffic, the forwarded packets would experience long queuing delay or be dropped due to buffer overflow, which could lead to undesired packet retransmissions. Moreover, as the congregated traffic at AP results in unbalanced traffic load, service differentiation techniques need to be implemented to ensure traffic fairness. Therefore, if the intra-cell packet ratio is high, a WLAN operating in the infrastructure mode could experience severe performance degradation.

For an intra-cell packet, if its source and destination can communicate directly with each other, direct delivery under the ad hoc mode of IEEE 802.11 would be a better choice. However, the current IEEE 802.11 standard does not allow a station to operate simultaneously in both the ad hoc and infrastructure modes. In a pure ad hoc network, if the destination is out of the range of the source station, the packet cannot be delivered directly but needs to be forwarded towards the destination using an ad hoc routing process at the IP layer, which increases traffic load in the system and incurs extra delay for packet delivery. On the contrary, in the infrastructure mode no IP layer routing is required within the WLAN as the APs forwards for all packets over the DS. As the DS usually also provides access to a router, the infrastructure mode is the most common configuration that enables stations to access the Internet beyond the WLAN. Therefore, to improve the overall system performance, an integration of infrastructure and ad hoc operations is desired. Moreover, the current MAC protocol in 802.11 DCF has not been designed to efficiently accommodate packet forwarding operations in that a received packet will need to undergo another round of contention when it is being forwarded. Thus an efficient packet forwarding technique can further enhance the system performance by reducing the forwarding delay for intra-cell packets.

There are many research works on IEEE 802.11 protocols. The throughput and delay performance of 802.11 DCF has been extensively studied in the literature [2–6]. Several methods have been developed to adjust the protocol to achieve its theoretical saturation throughput [7–10]. However, none of these investigations have specifically taken into account of forwarding of intra-cell packets. In Ref. [11], the intra-cell packet problem is studied and a mixed-mode solution is proposed, in which extra mode switching control and channel management modules are introduced and need to be added above the current standard.

This paper presents a novel solution to transfer intra-cell packets by integrating ad hoc operation into the infrastructure mode in a manner that is backward compatible and does not require explicit mode switching. Our solution includes a 2β ad hoc 2β awareness direct connections (AHADC) scheme and a direct cut-through forwarding (DCTF) scheme. The 2β AHADC scheme allows all intra-cell packets to be received by the most efficient method; i.e. if the destination is directly reachable, the packet is received directly in ad hoc mode by the destination station, otherwise, the packet is forwarded by the AP as normal. This is achieved by inserting an extra 2β (where β represents the maximum propagation delay in the WLAN system) delay into the packet exchange sequence, so that the AP can sense whether the destination station responds to indicate successful direct delivery, and if not, forward the packet normally. For further enhancement, the DCTF scheme is introduced at the AP to minimize the packet forwarding delay of intra-cell packets that cannot be directly delivered, by eliminating access contention and immediately forwarding intra-cell packets after a short inter-frame space (SIFS). While the 2β AHADC scheme and the DCTF scheme can be deployed separately, our performance evaluations show that the combination of both techniques can yield substantial performance gain in both system throughput and packet delay.

The rest of the paper is organized as follows: Section 2 presents the proposed schemes and the modifications required on the current standard. Section 3 first derives the direct connection probability for a random intra-cell packet, and then gives a theoretical analysis on the different schemes. Analytical and simulation results are presented in Section 4 followed by conclusions in Section 5.

2. The proposed schemes

2.1. Direct cut-through forwarding (DCTF) medium access scheme

To minimize the intra-cell packet delay due to packet forwarding at the AP, we propose the DCTF scheme. In Ref. [12], a data-driven cut-through medium access (DCMA) method is proposed for multihop IP packets in IEEE 802.11 networks, which generates acknowledgment (ACK) and RTS packets to the next hop. While it is advantageous for multihop forwarding, DCMA is not optimized for packets forwarding in the infrastructure setting. Since a packet sent by an AP can be sensed by all stations in the cell, there is no need for another RTS/CTS exchange when forwarding the packet. Therefore, to minimum the intra-cell packet forwarding delay, instead of waiting for another CSMA/CA backoff contention process or performing another RTS/CTS exchange, the DCTF scheme forwards the packet to its destination immediately when the channel has been idle for SIFS after the ACK has been returned to the sender. Fig. 1 shows the DCTF frame exchange in the RTS/CTS access method for an intra-cell packet transmission. The same principle holds for the basic access method. The DCTF scheme can be employed independently or be implemented together with the 2β AHADC scheme described in Section 2.2.