Wireless Networks 8, 249–263, 2002

Receiver-Initiated Collision Avoidance in Wireless Networks

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Abstract. Many medium-access control (MAC) protocols for wireless networks proposed or implemented to date are based on collision-avoidance handshakes between sender and receiver. In the vast majority of these protocols, including the IEEE 802.11 standard, the handshake is sender initiated, in that the sender asks the receiver for permission to transmit using a short control packet, and transmits only after the receiver sends a short clear-to-send notification. We analyze the effect of making the collision-avoidance handshake, receiver initiated and compare the performance of a number of receiver-initiated protocols with the performance of sender-initiated collision avoidance protocols. Analytical and simulation results show that the best-performing collision avoidance MAC protocol based on receiver-initiated or sender-initiated collision avoidance is one in which a node with data to send transmits a dual-purpose small control packet inviting a given neighbor to transmit and asking the same neighbor for permission to transmit. The receiver-initiated protocols we present make use of carrier sensing, and are applicable to either baseband or slow frequency-hopping radios in which an entire packet can be sent within the same frequency hop (which is the case of frequency hopping spread spectrum (FHSS) commercial radios).

Keywords: Medium Access Control, MAC, receiver-initiated, performance analysis, collision avoidance, ad hoc networks, wireless

1. Introduction

There is a large body of work on the design of MAC (medium access control) protocols for wireless networks with hidden terminals. Kleinrock and Tobagi [8] identified the hidden-terminal problem of carrier sensing, which makes carrier-sense multiple access (CSMA) perform as poorly as the pure ALOHA protocol when the senders of packets cannot hear one another and the vulnerability period of packets becomes twice a packet length. The BTMA (busy tone multiple access) protocol was a first attempt to solve the hidden-terminal problem by introducing a separate busy tone channel [11]. The same authors proposed SRMA (split-channel reservation multiple access) [12], which attempts to avoid collisions by introducing a control-signal handshake between the sender and the receiver. A station that needs to transmit data to a receiver first sends a request-to-send (RTS) packet to the receiver, who responds with a clear-to-send (CTS) if it receives the RTS correctly. A sender transmits a data packet only after receiving a CTS successfully. ALOHA or CSMA can be used by the senders to transmit RTSs.

Several variations of this scheme have been developed since SRMA was first proposed, including MACA [7], MACAW [1], IEEE 802.11 [6], and FAMA [3]. These examples, and most protocols based on collision-avoidance handshakes to date are sender-initiated, in that the node wanting to send a data packet first transmits a short RTS asking permission from the receiver. In contrast, in the MACA by invitation (MACA-BI) protocol [10], the receiver polls one of its neighbors asking if it has a data packet to send. A receiver-initiated collision avoidance strategy is attractive because it can, at least in principle, reduce the number of control packets needed to avoid collisions. However, as we show in this paper, MACA-BI cannot ensure that data packets never collide with other packets in networks with hidden terminals.

In this paper, we present MAC protocols with receiver-initiated collision avoidance that do provide *correct collision avoidance*, i.e., prevent data packets addressed to a given receiver from colliding with any other packets at the receiver. The key contributions of this paper are recasting collision avoidance dialogues as a technique that can be controlled by senders, receivers, or both; showing that receiver-initiated collision avoidance can be even more efficient than sender-initiated collision avoidance; and presenting a method for proving that a receiver-initiated collision avoidance strategy works correctly.

Section 2 introduces fundamental aspects of receiver-initiated collision-avoidance handshake, and section 3 presents a number of receiver-initiated collision-avoidance MAC protocols. These protocols require that nodes accomplish carrier sensing, which can be done with baseband radios and today's commercial slow frequency hopping radios, in which complete packets are sent in the same frequency hop. Section 4 proves that, in the absence of fading, all these protocols solve the hidden-terminal problem of CSMA, i.e., they eliminate collisions of data packets. Section 5 uses an analytical model to study the throughput and average delay of these protocols in fully-connected networks. We use a fully-connected network topology to discern the relative performance advantages of different protocols, because of two reasons: (a) it allows us to use a short analysis that can be applied to several protocols; and (b) our focus on protocols that provide correct collision avoidance means that the relative performance differences in a fully-connected network are very much the