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An SDMA-based MAC protocol for wireless ad hoc networks with smart antennas ☆

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ABSTRACT

A wireless ad hoc network consists of a set of wireless devices. The wireless devices are capable of communicating with each other without the assistance of base stations. Space Division Multiple Access (SDMA) is a new technology designed to optimize the performance of current and future mobile communication systems. In this paper, an SDMA-based MAC protocol (S-MAC) for wireless ad hoc networks with smart antennas is proposed. The proposed protocol exploits the SDMA system to allow reception of more than one packet from spatially separated transmitters. Using SDMA technology provides collision-free access to the communication medium based on the location of a node. The proposed protocol solves the hidden terminal problem, the exposed terminal problem, and the deafness problem. Simulation results demonstrate the effectiveness of the proposed S-MAC in improving throughput and increasing spatial channel reuse.

1. Introduction

A wireless ad hoc network is a network of self-organizing wireless devices able to directly communicate with one another [1–3]. Each node in a wireless ad hoc network functions both as a host and as a router. Two nodes can communicate directly if they are within transmission range of each other.

The design of IEEE 802.11 assumes an omni-directional antenna at the physical layer. Existing antenna systems are equipped with omni-directional antennas in wireless ad hoc networks. Therefore, the mobile nodes share a single wireless channel. Using omni-directional antennas leads to lower spatial channel utilization because only one pair of communicating nodes can transmit data at the same time.

New ideas about increasing network throughput by using smart antennas, which allow the nodes to transmit packets in different spatial channels, have been proposed. Smart antennas [4–6] can enhance network throughput more efficiently than omni-directional antennas in wireless ad hoc networks [7–10]. Smart antennas offer some advantages that enhance spatial reuse of the wireless channel and extension of the transmission range. To use the advantages of smart antennas in wireless ad hoc networks requires an efficient MAC protocol. In this paper, a new MAC scheme designed to improve network throughput performance and spatial channel utilization is proposed.

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In recent studies, several MAC protocols have been proposed that suitably adapt IEEE 802.11 for directional antennas. However, directional transmissions in wireless ad hoc networks result in serious location information problems [11,12]. The transmitter must know the location of a receiver to turn the beam in a suitable direction before transmitting Request-to-Send (RTS) frames. The transmitter creates the appropriate beam patterns, depending on the location of a receiver. Some studies assume that the location of a node may be obtained using a Global Positioning System (GPS) [3,7,13,14]. Other studies assume the transmission of data through the routing layer in order to acquire information about the location of a receiver, or the location of a receiver. In [15], RTS frames are transmitted omni-directionally in order to find the location of a receiver. Korakis et al. [11] proposed a MAC protocol for full exploitation of directional antennas that scans the entire area around a transmitter in order to find the location of a receiver or a transmitter. Although this scheme attempts to extend the communication range, circular transmission increases delay time and incurs a large control overhead. Ko et al. proposed a MAC protocol that utilizes the directional transmission capability of a directional antenna to improve bandwidth efficiency, called Directional MAC (D-MAC) [7]. Lal et al. proposed a MAC protocol that exploits the creation of spatial channels designed to enhance the throughput for ad hoc networks [9]. This scheme uses Space Division Multiple Access (SDMA) technology with smart antennas.

The rest of this paper is organized as follows. In Section 2, related work is presented. Section 3 describes the proposed SDMA-based MAC protocol in detail. In Section 4, the performance of the proposed protocol is compared with other MAC protocols through simulation. Conclusions are provided in Section 5.

2. Related work

In this section, the relevant background that includes the concept of IEEE 802.11, D-MAC, and Lal's MAC is introduced.

2.1. IEEE 802.11

IEEE 802.11 [16] is a popular protocol that defines the functions of the MAC and PHY layers in wireless ad hoc networks and infrastructure networks. This popular protocol assumes the use of omni-directional antennas at the physical layer. IEEE 802.11 MAC protocol uses a handshake mechanism implemented by exchanging small control packets identified as Request-to-Send (RTS) and C1ear-to-Send (CTS) packets. The successful exchange of these two control packets reserves the channel for transmission thereby preventing collision occurrences. However, this mechanism wastes the network capacity because the control packets reserve the wireless media over a large area. The IEEE 802.11 MAC protocol exploits the binary exponential backoff algorithm to resolve channel contention. When a frame exchanging sequence between two nodes is in progress, all other nodes within range of the transmitter or the receiver defer their transmission to avoid interference with the ongoing sequence. In IEEE 802.11, every station maintains a duration value, known as the Network Allocation Vector (NAV).

According to the RTS/CTS handshaking, the transmitter sends the RTS frame to the receiver before transmitting the data frame. The receiver replies to the CTS frame after receiving the RTS frame. Other nodes overhear the RTS or CTS frame and awake to someone who wants to send packets, update the NAV, and wait for the end of transmission. A node updates the value of the NAV with the duration field specified in every frame. The duration field records how long the medium is to be reserved during this period.

In wireless ad hoc networks, RTS/CTS handshaking is normally used to deal with the common hidden terminal problem, which is intended to reduce collision occurrence. All nodes share the medium when a frame is in the process of exchanging a sequence. Although this ensures that reservation of the wireless media will prevent collision occurrence, it will also squanders spatial channel utilization. This problem is the so-called exposed terminal problem.

2.2. Directional MAC (D-MAC)

Ko et al. proposed a Directional MAC (D-MAC) using directional antennas to improve bandwidth efficiency [7]. D-MAC protocol is similar to IEEE 802.11 in many ways. D-MAC send an acknowledgment (ACK) immediately after the DATA, as in 802.11. However, with D-MAC, the ACKs are sent using a directional antenna rather than using an omni-directional antenna.

In IEEE 802.11, if a node *N* is aware of an on-going transmission between two other nodes, node *N* will not participate in a transfer itself. That is, *N* will not send all RTS, or send a reply to an RTS from another node while the transfer between other two nodes is in progress. In brief, if antenna *T* at node *N* has received an RTS or CTS related to an on-going transfer between two other nodes, then node *N* will not transmit anything using antenna *T* until that other transfer is completed.

Antenna *T* is considered to be "blocked" for the duration of that transfer and each node can determine when a blocked antenna should become unblocked. When using directional antennas, while one directional antenna at some node may be blocked, other directional antennas at the same node may not be blocked. This allows transmission using the unblocked antennas. With D-MAC, omni-directional transmission of a packet requires the use of all the directional antennas; an omni-directional transmission can be performed if none of the directional antennas are blocked.