OSLMAC: One-Step Look-ahead MAC protocol for concurrent transmission over wireless ad hoc networks

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Abstract—The IEEE 802.11 DCF mechanism is a basic ad hoc MAC protocol. This protocol, however, is prone to the hidden terminal problem. To solve this problem, the incorporation of the request-to-send/clear-to-send (RTS/CTS) mechanism has been suggested; however, this can in turn result in the exposed terminal problem. Concurrent transmission can reduce the exposed terminal problem. The use of concurrent-transmission-based medium access control (MAC) protocols has been considered as a means of improving throughput in wireless ad hoc networks. In this paper, we propose a one-step look-ahead MAC (OSLMAC) protocol that uses a back-off reservation mechanism to increase throughput and utilizes control messages, which are required for concurrent transmission of messages. Currently, where a concurrent transmission state is not possible, redundant overhead comprising exchanged control messages is incurred. However, our proposed mechanism utilizes these wasted control messages to reserve the next data transmission. Thus, this mechanism decreases the number of collisions and reduces back-off waiting times. Evaluation of the performance of our proposed scheme, by means of simulations and comparison of its throughput with those of an existing scheme and the basic IEEE 802.11 DCF MAC, indicate that the measured performance metrics are improved when our proposed scheme is used.

Keywords—Wireless ad hoc MAC protocol, throughput, Exposed terminal problem

I. INTRODUCTION

In wireless ad hoc networks, nodes can communicate with their neighbor nodes without the support of an established infrastructure. To communicate with other nodes in ad hoc networks, a medium access control (MAC) protocol is needed to obtain an opportunity to conduct transmission among neighbor nodes.

The IEEE 802.11 Distributed Coordination Function (DCF) [1] is the most basic MAC protocol for wireless ad hoc networks. DCF is based on the carrier sense multiple access with collision avoidance (CSMA/CA) mechanism, where each node senses whether the channel is idle during the distributed inter-frame space (DIFS). When the channel is idle, a node waits until its back-off counter has decremented to zero. If the channel is busy, the counter is frozen at that point. Using the MAC protocol, the probability of collision decreases; however, the waiting time is wasted, which decreases performance [2].

The hidden terminal problem [3] can arise in DCF. For example, in Fig. 1(a), nodes a and b can hear each other. Nodes b and c can also hear each other. However, nodes a and c cannot hear each other. If nodes a and c each sense the idle state of the channel and transmit, a collision will occur at node b. To solve this problem, the request-to-send (RTS) and clear-to-send (CTS) handshake was proposed [4], following which, it was included in the standard protocol [1]. However, another problem, the exposed terminal problem [5] (Fig. 1(b)), must also be considered. Transmission from node a to node d and from node b to node c is possible because they do not interfere with each other, but the RTS packet of node a prevents the transmission of data from node b until the reserved data transmission period of node a is over. To avoid this situation, concurrent transmission has been proposed.

Concurrent transmission is an efficient way of increasing throughput. In recent years, wireless technologies have become popular; as a result, there is a dense deployment of wireless devices [6]. In a dense deployment environment, the exposed terminal problem can degrade throughput significantly. Efficient concurrent transmission is important for increasing spatial reuse. Therefore, many researchers have proposed concurrent transmission-based mechanisms [6], [7],[8],[9] to improve performance. In our research, we found scope for increasing throughput further using a one-step look-ahead method that reserves the next back-off counter and reduces the overhead of the control message.

In this paper, we propose a one-step look-ahead concurrent-
transmission-based ad hoc MAC protocol that can decrease the time wasted during the back-off period. The waiting time until the back-off counter reaches zero can significantly decrease throughput [2]; we found further performance improvements therein. Furthermore, we do not add any special message to do this. We instead utilize the control messages that are currently exchanged in concurrent transmission. We utilize these control messages to increase throughput by attaching reservation information to them. This control message can be valuable because in cases where concurrent transmission is impossible, the control message can be discarded.

The remainder of this paper is organized as follows. In Section II, we introduce the background to our research and discuss existing schemes that employ concurrent transmission mechanisms. Section III describes the proposed scheme in detail. In Section IV, we discuss the evaluation of our scheme conducted via simulations. Section V gives concluding remarks.

II. BACKGROUND AND RELATED WORKS

A. Overview of concurrent transmission

Wireless ad hoc networks typically use the 802.11 DCF MAC protocol [1]. However, this protocol can give rise to the hidden terminal problem. To solve this problem, each node gives notice of its existence and willingness to transmit via RTS/CTS handshaking; however, this in turn can cause the exposed terminal problem, which decreases throughput. To resolve this, concurrent transmission, which can remove the weak point of the RTS/CTS mechanism, has been suggested.

In concurrent transmission, a node that wants to concurrently transmit listens to the transmitted messages from other nodes and notifies others of its intention. Thus, an additional control gap is required between the control messages exchange period of RTS/CTS and the data transmission period (Fig. 2). Concurrent transmission negotiation is conducted during this control gap. Nodes capable of conducting concurrent transmission exchange RTS/CTS messages to discover whether the exposed terminal problem has occurred (Fig. 2). They then synchronize the data transmission and acknowledgement (ACK) points.

B. Related works

Many concurrent transmission schemes geared towards increasing the concurrent transmission MAC efficiency have been proposed.

In MACA-P [7], data transmission is delayed until the internal control phase is completed. During this period, several sender-receiver pairs have the opportunity to transmit and synchronize their data transfers. Using this mechanism, concurrent transmissions avoid collisions and improve system throughput. However, when concurrent transmission is prohibited, the control message-exchange period is wasted time. In CMAP [8], a conflict map to increase the number of successful concurrent transmissions is proposed. Using this map, each node can estimate the number of exposed terminals and exclude transmissions that have collided. Each node calculates its relationship to its neighbor nodes and stores this information in the conflict map using feedback. This feedback contains the probability of packet loss, which is low under poor channel conditions. However, if the information obtained is unreliable, the node is overburdened in trying to make the correct decision, and thus this scheme is not practical. In CTMAC [9], a control-capture effect is introduced to find those cases where concurrent transmission is possible. This results in an increase in the probability of concurrent transmission. This protocol also proposes a period that changes according to prior behavior. The protocol uses three additional control messages to avoid missing concurrent transmission opportunities. They utilize the opportunities in which concurrent transmission from a node is prohibited and canceled by RTS but it is not known whether it has in fact been canceled. However, if it is still impossible to transmit concurrently, then the process wastes time. In ARMAC [6], to acquire more information about the transmission and channel-state information, a cost-efficient technique is proposed. For efficient concurrent transmission, this protocol exchanges the ongoing sender-receiver pair and two-hop-neighbor node information by using attachment coding and a neighbor-node list. The scheme allows control information to be attached onto data packets. The appended control information provides accurate channel status for nodes in real time. Therefore, nodes can identify exposed terminals and utilize them for concurrent transmission. However, this protocol also wastes time when nodes cannot transmit concurrently.

Our MAC protocol can utilize control messages for concurrent transmission fully and minimize control message overhead.

III. RESERVATION-BASED AD HOC MAC PROTOCOL

A. Reserve back-off timer

We propose a new method that increases concurrent transmission throughput in ad hoc networks by decreasing the amount of time that is wasted. A node that is based on IEEE 802.11 DCF is required to wait for the back-off counter to reach zero. During this period, time is wasted, as the node just waits and does nothing. If the transmission times of the other nodes (i.e., the back-off times) are known, then a suitable back-off time that also avoids collision could be chosen for the node.
To realize this, we utilize control messages for concurrent transmission and reduce the time wasted.

For concurrent transmission, a few control messages need to be exchanged to avoid interference with the original data transmission. After the RTS/CTS exchange is complete, the control gap period starts. Nodes that have transmission requests and can transmit concurrently try to send a modified RTS message. On receiving this packet, the destination node decides whether concurrent transmission is possible. According to the decision made, a modified CTS message transmission is determined. Our proposed protocol allows nodes to exchange their next back-off counter number via a modified RTS message. In this way, we can give priority to nodes whose attempt at concurrent transmission have failed for the next transmission, and can reduce the probability of collisions. The operation of our proposed mechanism is illustrated in Fig. 3. In the figure, node A transmits data to node B. At the control gap period, node E sends a modified RTS containing a back-off count number to node F. If node F is in a concurrent transmission impossible state, node F does not respond and the neighbor of node E reserves the next back-off time. Thus, the back-off counter works during the next transmission period.

The RTS structure needs very few modifications because the reservation information is placed at the end of the RTS message. Three bits are sufficient to convey a reserved back-off time. A neighbor node that receives the RTS message with this back-off information memorizes its number and does not use it. Whenever this node receives the RTS of another node, it adds the number of back-off counter of the new node to a node table to ensure that the priority information is protected.

However, if neighbor nodes do not receive the next back-off time reservation information, collisions can occur. To avoid this kind of collision, we set the reserve bound to reserve the back-off number as the IEEE 802.11 standard has limitations on the maximum for the back-off counter. This bounded period is only allowed in order to try concurrent transmission node. This can prevent collision with others that do not receive the reservation information.

Our proposed scheme also keeps the control packet valuable at all times. In the current setup, in situations where concurrent transmission is impossible, the control gap period is wasted. By giving priority to the banded concurrent transmission node in the next contention period, we reduce the time wasted waiting for the back-off counter to reach the end, and thus utilize the control message completely.

After the control gap period, nodes notify of their next back-off time in a fully distributed manner. Thus, in the next contention period, nodes broadcast their RTS in that order without collision.

**B. Reducing the number of control messages exchanged for concurrent transmission**

We can further decrease control message overhead in a concurrent transmission-based ad hoc network. For concurrent transmission, existing approaches need to exchange at least two messages to instantiate concurrent data transmission. A node that concurrently transmits with other node sends a modified RTS packet and, on receiving this modified RTS, the node sends its response. Some researchers [9] use more than two control messages to enable concurrent transmission. Although this method helps to increase accuracy, some control message exchange time can be wasted.

We propose an exchange scheme that requires only one or two control messages. When transmission of RTS/CTS has completed and the control gap period for concurrent transmission has started, other nodes that have transmission requests try to send modified RTS messages. On receiving a modified RTS packet, the destination node decides whether concurrent transmission is possible. In cases where it is possible, the receiving node sends a CTS message to notify of its clear state. Nodes C and D in Fig. 3 illustrate a case of successful concurrent transmission. Where it is not possible, the receiving node does not send any message. The node that sent the RTS message

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**Fig. 3. Example of proposed idea**

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\caption{Fig. 3. Example of proposed idea}
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waits the amount of the short inter-frame space (SIFS) plus the
time for the CTS message to reach the other node. According
to the existence of the message, a determination is made as to
whether concurrent transmission should be done. Accordingly,
only one or two message exchanges are needed to conduct
concurrent transmission.

IV. SIMULATION RESULTS

A. Simulation environment

We simulate our proposed OSL MAC by extending the
802.11 DCF MAC in the ns-2 simulator [10]. We evaluated
the throughput of our OSLMAC protocol and compared it
with that of the 802.11 DCF MAC and CTMAC [9]. We
consider one-hop throughput, and thus the m transmission
pairs are set within one-hop range. We assumed our topology
to be a square which divided into an n x n small square. In
this small square, nodes have random positions. We followed
the CTMAC simulation parameters, which corresponded to
realistic hardware settings [11]. The data packet size was 2 KB
and data rate was set at 2 Mbps. The number of transmission
pairs used ranged from 2 to 4 and the transmitter was saturated.

B. Performance evaluation

To increase throughput, the OSLMAC employs next back-
off time reservation with concurrent transmission. We evalu-
ated our scheme by comparing it with the existing protocol
CTMAC.

Below 9 nodes (n = 3), the throughput of all protocols was
similar (Fig.4, 5, 6) because few opportunities for concurrent
transmission existed. On the other hand, above 9 nodes (n =
3), the throughput of CTMAC and OSLMAC increased. This
occurred because as the node density increases, the number of
nodes that can transmit concurrently increases. However, the
802.11 DCF MAC could not transmit data concurrently and
so it had almost the same throughput in every scenario.

OSLMAC increased the throughput by approximately 10%
compared to CTMAC. This increase by OSLMAC is pos-
sible because it utilizes control messages fully by adding
information on the next back-off time reservation. CTMAC
only works when concurrent transmissions are conducted. If
concurrent transmission is not possible, CTMAC wastes the
control message exchange period. Compared with Fig. 4,
Fig. 5 and 6 had a higher throughput because there was a
high probability for the back-off reservation mechanism to be
used. As the density increased, both the throughput and the
transmission pairs increased.

V. CONCLUSION

In this paper, we proposed a back-off reservation-based
MAC protocol called OSLMAC to increase the throughput in
concurrent-transmission-based ad hoc networks. Our proposed
protocol prioritizes nodes that try to transmit data concurrently
but fail in the attempt. The results of comparisons of our
proposed protocol with the existing protocol and the IEEE
802.11 DCF MAC protocol by measuring the throughput
indicated that our proposed protocol increases throughput by
an average of 10%.
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