

Ad Hoc WLAN Throughput Improvement by Reduction of RTS Range

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Abstract— In this paper, we evaluate a novel method for reducing exposed nodes in IEEE 802.11 ad hoc WLANs using asymmetric transmission ranges for RTS and CTS frames. The RTS/CTS handshake communication control mechanism used in IEEE 802.11 networks solves the hidden node problem but causes the exposed node problem. Our proposed method uses asymmetric transmission ranges for RTS and CTS control frames to solve the exposed node problem. Simulations using the Network Simulator 2 (NS-2) show that asymmetric transmission of RTS and CTS frames improves overall network throughput compared to the standard RTS/CTS method.

Keywords— IEEE 802.11, ad hoc, RTS, CTS, transmission range, asymmetric, NS-2, AODV

I. INTRODUCTION

With the “Internet of Things” (IoT)/Cyber Physical Systems (CPS) soon coming into existence and the imminent deployment of 5G mobile technologies, the use of wireless networks is set to increase rapidly [1] [2]. Different types of devices will be connecting to each other wirelessly in ad hoc network setups. Ad hoc networks consist of wireless nodes/devices that build automatic connections to other nodes/devices with no centralized infrastructure. The IEEE 802.11 wireless local area network (WLAN) technology is the most used wireless network standard but its communication control is not a completed mechanism [3]. Techniques for dealing with interference in IEEE 802.11 ad hoc networks still need improvement and should be optimized to support increasing required throughput while utilizing limited radio resource efficiently [4].

IEEE 802.11 multi-hop ad hoc networks especially suffer from interference between nodes which substantially limits the reliability and the throughput of these networks [4]. The media access control (MAC) layer in IEEE 802.11 networks

controls access to the shared wireless medium using two techniques: Physical Carrier Sensing and RTS/CTS (Request to Send / Clear to Send) handshake (Virtual Carrier Sensing) [5]. However, both Physical Carrier Sensing and the RTS/CTS method introduce additional problems to the wireless medium in that they suffer from the hidden node problem and the exposed node problem respectively.

A. Hidden Node Problem

In wireless networks, the hidden node problem occurs when a node is visible from one intermediate wireless node, but not from other nodes communicating with that intermediate node. In Fig.1 below, B is the intermediate node. Node A can communicate with intermediate node B and node C can also communicate with intermediate node B. However, nodes A and C cannot sense each other since they are outside each other's communication ranges and this leads to difficulties in the media access control layer.

If node A and node C both start transmitting to intermediate node B at the same time, this causes packet collisions and loss at intermediate node B.

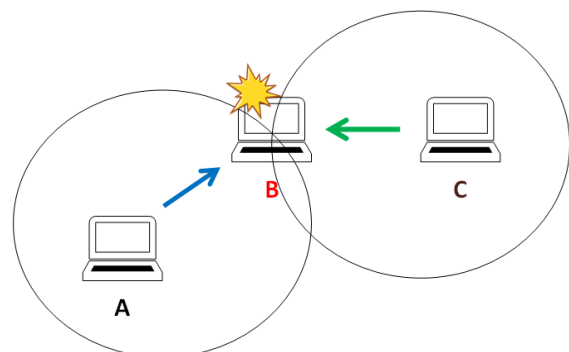


Figure 1: The Hidden node problem

B. Exposed Node Problem

Exposed nodes are wireless nodes that are prevented from communicating with other nodes in their transmission ranges because they are close to a sending node and overhear the RTS frame [5]. Fig. 2 below explains the exposed node problem:

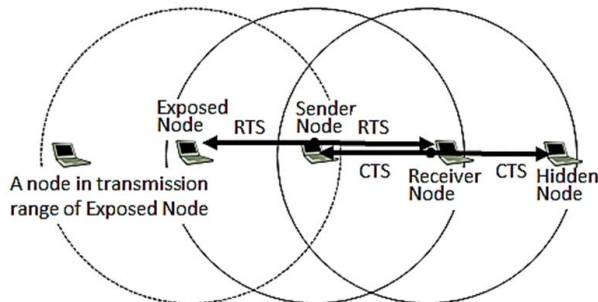


Figure 2: The Exposed node problem

Exposed nodes in the network decrease network performance because they have to hold their transmissions for the NAV (Network Allocation Vector) period defined in the RTS frame [3]. This leads to overall network throughput degradation.

Since ad hoc nodes do not rely on fixed, centralized infrastructure, they are increasingly used in several networking applications such as in military, rescue operations, meetings and conventions [4]. On the other hand, the RTS/CTS handshake has been shown to be especially detrimental to network throughput performance in large IEEE 802.11 based wireless ad-hoc networks [6]. Thus methods of improving the effectiveness of the RTS/CTS handshake are necessary.

The rest of this paper is organized as follows: Section II describes related literature; Section III describes the Asymmetric RTS/CTS idea; Section IV the use of Network Simulator-2 (NS-2) simulations and Section V discusses the simulation results. Section VI concludes the paper.

II. RELATED WORKS

Our first research of the proposed method was reported in [3]. However, the simulations in [3] were limited to evaluating the basic performance of the asymmetric RTS/CTS idea on a simple MAC layer setup and do not take into consideration other network conditions such as random distribution of nodes and mobility. Our research aims to extend the performance of this idea by taking the

abovementioned into consideration during our simulations.

Other methods have been proposed in literature to solve the exposed node problem such as that described in [6]. The method called Selective Disregard of NAVs (SDN) selectively ignores certain physical carrier sense and NAVs. This method needs additional functionalities to be implemented in all nodes and lacks compatibility with the IEEE standard. MAC protocols based on Multiple Access with Collision Avoidance (MACA) proposed in [7] that exploit control gaps between the RTS/CTS exchange and the subsequent DATA/ACK have also been proposed.

Another method that effectively solves the hidden and the exposed node problems is the Dual Busy Tone Multiple Access (DBTMA) method described in [8]. DBTMA uses two out-of-band busy tones to protect the RTS packets and the DATA packets from interfering stations. This protocol however assumes separate channels or data streams for tones and data, our method only assumes a single channel.

III. ASYMMETRIC RTS/CTS

A. Overview

The basic idea of Asymmetric RTS/CTS is to have different transmission ranges for RTS and CTS frames by simulating the transmission range of RTS frames to be less than that of CTS frames. Reducing the transmission range of RTS frames means we eliminate some of the nodes that overhear the RTS frame from the sending node thereby reducing the total number of exposed nodes in the network. When the RTS range is completely included in the CTS range, there are no longer exposed nodes. Fig. 3 shows the concept of our proposed method.

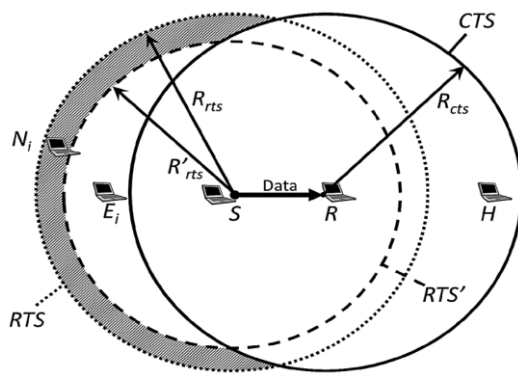


Figure 3: Asymmetric RTS/CTS

B. Effect of Adjusting Transmission Range

RTS frames do not need to have such a wide transmission range as they only need to reach the receiving node in order to provoke a CTS response [3]. Thus if the transmission range of RTS is set to the minimum distance, only reaching the receiving node, this is enough to provoke CTS from the receiver node.

CTS frames on the other hand should reach all possible nodes that may cause collisions at the receiving node. Hence CTS frames are assigned a larger transmission range so that Data frame reception at the receiving node is protected. Based on this strategy, the transmission ranges for the RTS and CTS frames is thus asymmetric.

IV. NS-2 SIMULATION

A. Overview

To test the performance of the proposed asymmetric RTS/CTS idea, we simulate different wireless topology scenarios using NS-2. NS-2 is an open-source; event-driven simulator designed specifically for research in computer communication networks [9]. Having been under constant enhancement for years, NS-2 contains modules for numerous network components such as routing, transport layer protocols and applications; and it has become the most widely used open source network simulator.

In NS-2, the transmission range of a packet is determined by the power such a packet is transmitted with from the sending node [9]. To reduce the transmission range for RTS frames, we defined a RTS power threshold variable, $newRTSThresh_$, to add to the MAC layer component of NS-2. This is where the MAC control

functions of receiving and sending RTS and CTS packets are defined. The $newRTSThresh_$ variable was defined in function `recvRTS` under class `Mac802_11` (`mac-802_11.cc`). The `recvRTS` function checks for a received RTS packet's power level and compares it to the $newRTSThresh_$ variable we set in the tcl simulation file to determine whether the RTS packet being received should be discarded or not.

B. Grid Topology Simulation

To start off the simulation, we simulate grid topologies to reflect real world environments where deployments of wireless nodes are often governed by artificial objects such as walls, furniture and building structures, and as such follow a geometric arrangement [3]. We assumed an environment where each node can communicate with its adjacent nodes using a set transmission range. The distance between nodes was set to an interval of 70m. Simulations for grid topologies ranging from 3x3 (9) nodes to 15x15 (225) nodes were evaluated. To simulate the Standard RTS/CTS method, we set both transmission ranges for RTS frames and CTS frames to 140m. For the Asymmetric RTS/CTS method, we set transmission range for RTS packets to 70m and CTS packets to 140m. Random communication time and selection of receiver nodes was used.

C. Random Topology Simulation

To simulate the randomly distributed node topology, we assume that each node can communicate with at least one neighbouring node within a certain transmission range. Once again, the distance between nodes was set to an interval of 70m. RTS and CTS frames were set to 140m for the Standard method and for the Asymmetric method, to 70m and to 140m respectively. After the RTS/CTS exchange is complete, the Data packet is routed to the destination node using the AODV routing protocol [10].

Table 1 below presents the simulation parameters and conditions:

TABLE 1. SIMULATION PARAMETERS AND CONDITIONS

Frame Type	IEEE 802.11b	
	Grid Topology Transmission range (Distance)	
	Standard	Asymmetric
RTS	140m	70m
CTS	140m	140m
Data	70m	70m
ACK	70m	70m
Other parameters		
RTS threshold	1000 bytes	
Data packet size	3000 bytes	
Propagation model	TwoRayGround	
Routing protocol	AODV	
Simulation conditions		
Simulation time	60 seconds	
Simulation frequency	x500	
Comm. time between nodes	Random	

V. RESULTS AND DISCUSSIONS

In this section, we analyse the simulation results from the grid topologies and the random distribution topology by looking at network throughput and then performing a statistical analysis. Overall, the simulations showed that the proposed Asymmetric RTS/CTS method improves network throughput over the Standard RTS/CTS method.

A. Throughput Analysis

Here we show the throughput comparison between the Standard RTS/CTS and the proposed Asymmetric RTS/CTS methods. Fig. 4 below shows the throughput results for a 15x15 grid topology (225 nodes). We can clearly see that the Asymmetric RTS/CTS method has better network throughput than the Standard RTS/CTS method. We attribute this to the elimination of exposed nodes in the network.

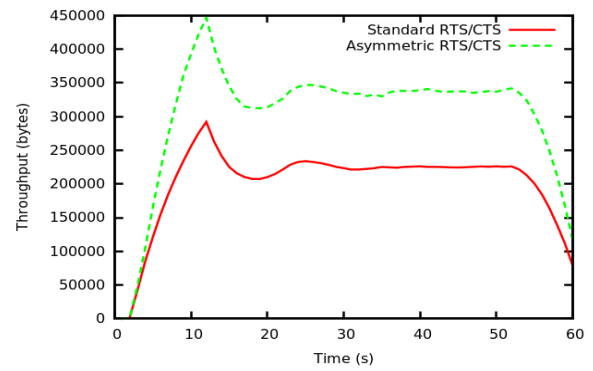
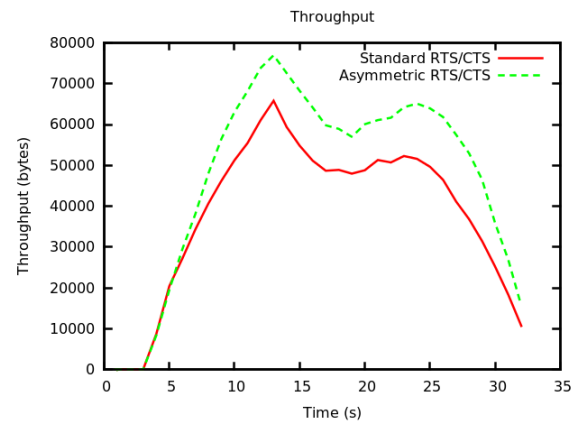
**Figure 4:** Grid topology throughput results (225)

Fig. 5 below show random distribution results for 20 nodes:

**Figure 5:** Random distribution throughput results

Due to the increased presence of exposed and hidden nodes in the random distribution topology, the difference in throughput between the Standard RTS/CTS method and the Asymmetric RTS/CTS method is not as pronounced as in the grid topology setup; however Asymmetric RTS/CTS still performs better.

B. Statistical Analysis

For the statistical analysis, we use the Standard Error [11] and the paired T-Test [12] to confirm that the difference in mean throughput between the Standard RTS/CTS and the Asymmetric RTS/CTS is due to the elimination of exposed nodes and not due to random chance. Fig. 6 below shows the standard error for the mean for all groups of grid topology nodes at a 5% significance level. Since the error bars do not overlap, we can assume that there is less than a 5% chance that the throughput data from the simulations misrepresents the true difference between the two method's results.

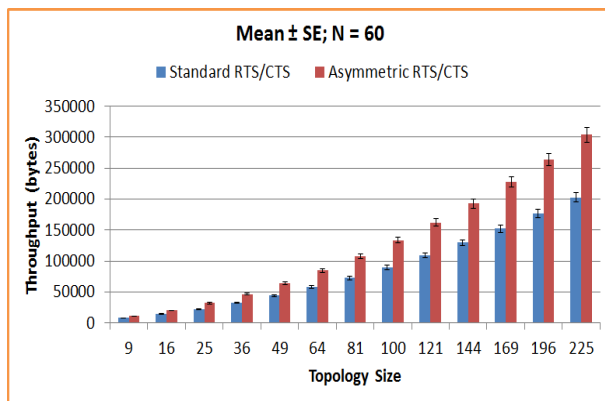


Figure 6: Standard error of the mean

The calculated P-Value from the Paired T-Test was less than 0.05 (i.e. P-Value < 0.05) for all topologies. This implies statistical significance and we can say with 95% confident that the difference in the throughput results between the Standard RTS/CTS and Asymmetric RTS/CTS is due to the elimination of exposed nodes

VI. CONCLUSIONS

In this paper, we evaluate a method of using asymmetric transmission ranges for RTS and CTS frames for the purposes of reducing exposed nodes in ad hoc WLANs. Simulation results show that the proposed Asymmetric RTS/CTS method has better overall network throughput than the Standard RTS/CTS method. Future work will look at changing the transmission range of RTS and CTS

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frames in topologies of mobile, randomly distributed nodes.

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