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Design of Efficient and Reliable MAC protocol for Wireless Technologies

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Abstract—In this paper, the performance of IEEE 802.11 MAC protocol is analysed in terms of efficiency and reliability in wireless networks. In the IEEE 802.11, an exponential backoff has been adopted, which means whenever a collision occurs, the contention window (CW) of the station is doubled until it reaches the maximum value. The purpose of increasing CW is to reduce the collision probability by distributing the traffic into a larger time space. In this paper, fixed contention window scheme is used and then correlate the CW size and network size. The interaction of TCP with the MAC protocol is also analysed. For static multi hop network that uses IEEE 802.11 protocol for access, TCP performance is mainly determined by hidden terminal effects (and not by drop probabilities at buffers) which limits the number of packets that can be transmitted simultaneously in the network. TCP throughput is improved by decreasing the ACKs flows, using delayed ACK, with d=2. Simulation results shows when choosing large maximum window, the delayed ACK considerably outperform standard TCP.

Index Terms- contention window size, MAC protocols, maximum window size, spatial reuse, TCP

I. INTRODUCTION

The IEEE 802.11 standard defines a detailed medium access control (MAC) and physical layer (PHY) specification for wireless local area networks (WLANs) [1]. WLANs are growing in popularity because of the advantages such as mobility while providing flexibility and elimination of unsightly cables. In the IEEE 802.11 MAC layer protocol, the basic access method is the distributed coordination function (DCF). DCF is based on the mechanism of carrier sense multiple access with collision avoidance (CSMA/CA). The standard also defines an optional point coordination function (PCF), which is a centralized MAC protocol supporting collision free and time bounded services. This paper limits interest to DCF.

CSMA/CA protocol works on a "listen before starting transmission" scheme. Whenever there is packet to transmit by station, a station first senses the medium and ensures that the medium is idle for the specified DCF interframe space (DIFS) duration. If such station initially senses the medium to be busy, then the station has to wait until the medium becomes idle for DIFS period, and then chooses a random "backoff counter". This backoff counter determines the amount of time the station must wait until it is allowed to transmit its packet. During the period in which the medium is idle, the transmitting station decreases its backoff counter. If during this time the medium becomes busy, its backoff counter is frozen. It can decrease its backoff counter again only after the medium is idle for DIFS. This process is repeated until the backoff counter reaches to zero and the station is allowed to transmit. CW is the idle period after a DIFS period.. The IEEE 802.11 MAC layer protocol adopts exponential backoff. CW is initially assigned the min/zimum contention window size CWmin. Then, the CW is doubled each time the station experiences a collision until the CW reaches to CWmax which is the maximum contention window size. When the CW is increased to CWmax, it remains the same even if there are more collisions. After every successful transmission, CW is reset to the initial value CWmin. A packet will be discarded if it cannot be successfully transmitted after it is retransmitted for a specific retry times.

Each transmission of a DATA packet at the MAC level is part of a four-way handshake protocol. The mobile that wishes to send a packet, which is M1, first sends an RTS (Request to Send) packet to destination mobile, M2. If M2 can receive the packet, it sends a CTS (Clear to Send) packet. If M1 receives the CTS it can send the DATA packet (e.g. TCP data or ACK packet). Finally, M2 sends a (MAC layer) ACK so that M1 knows that the data packet has been well received. This handshake protocol is intended to reduce the probability of “hidden terminal” collisions but it does not eliminate them. To understand how such collision may occur, let’s take a scenario with the geographical range of interference and reception. Suppose the transmission range is about 250m and carrier sensing range as well as the interference range is about 550m. Consider the chain topology in Fig. 1, here distance between nodes is 200m. Nodes that are two hops apart are not hidden from each other but nodes that are three hops apart are hidden, and may create collisions. Indeed, if node M4 wishes to send packet to M5 during a transmission from node M1 to M2, it cannot hear the CTS from node M2 because it is out of the 250m for good reception. It cannot hear M1’s RTS or DATA packet since it is more than 550m away from M1. Therefore M4 may initiate transmission to M5 that will collide at node M2 with transmission from M1. This paper focus on impact of this type of collision on TCP performance.

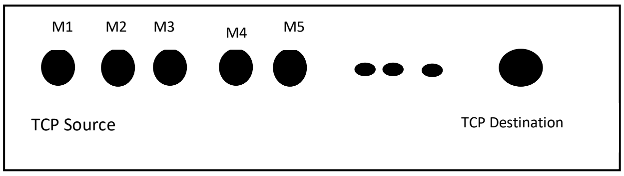

Fig. 1: The Chain Topology

The remainder of the paper is organized as follows: Section II presents the related work. Section III presents efficient and reliable MAC protocol in terms of impact of contention window size on IEEE 802.11 MAC protocol and interaction of TCP with the MAC protocol. Section IV gives the simulation results and finally Section V concludes the paper.

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II. RELATED WORK

Recently, the concept of wireless networking has become immensely popular and there is an increased interest in the transmission of integrated data and voice. For different types of applications, there are different requirements for the quality of service (QoS). For example, real-time applications such as voice are delay sensitive. However, the delay is not critical for non real-time applications such as ftp and some delays can be tolerated [2]. The IEEE 802.11 DCF can only provide best-effort service and cannot guarantee QoS. IEEE 802.11e working group is engaged in such work to enhance the MAC performance to support the integrated service. Till now, this group proposed a draft of IEEE 802.11e, in which enhanced distributed coordination function (EDCF) is included. The basic idea is to introduce Traffic Categories (TC) and provide different priorities to different TCs.

There has been a notable amount of research done on the performance of ALOHA in ad hoc networks. Kaynia and Jindal [3] evaluated the performance of ALOHA and CSMA MAC protocols in terms of outage probability. In given network model, packets belonging to specific transmitters arrive randomly in space and time according to 3-D Poisson point process, and are then transmitted to their intended destination using a fully distributed MAC protocol. A packet transmitter is considered successful if the received SINR is above a predefined threshold for the duration of a packet. For continuous time transmissions, CSMA with receiver sensing is shown to yield best performance.

Load Adaptive MAC (LA-MAC) protocols for MANET’s [4] offers both latency and throughput advantages over CSMA. LA-MAC operates in CSMA mode for low contention levels associated with light traffic loads and switches to TDMA mode for high contention levels associated with heavy traffic loads. Through results it has been found that LA-MAC achieves a better throughput performance than TDMA over both one and two -hop MIMO MANET topologies when the traffic load allows nodes to compete for unused time slots.

The focus is on a static multihop network that uses the IEEE 802.11protocol for access [5]. For such scenarios it has been shown in [5] that TCP performance is mainly determined by the hidden terminal effects (and not by drop probabilities at buffers) which limits the number of packets that can be transmitted simultaneously in the network (this is called the “spatial reuse”). In particular, for the chain topology in this paper, the spatial reuse factor of the network has been shown in [5] to have some limit which was around 1/4, which means that given h nodes, only around h/4 can transmit packets simultaneously. This allowed the authors to conclude that there is an optimal size for the maximum window of TCP which is close to the value of h/4. Any increase in the maximum window size results in decreasing TCP throughput, although the loss in performance is not large (around 20%).

Two techniques have been proposed in [5] to improve the performance, one based on RED type technique and the other on adaptive spacing at the link layer. The reported gains in TCP throughput were between 5% and 30%.

The performance of DCF and EDCF has been widely investigated by both simulations and analytical models [6, 7]. But all these papers used the exponential back off. Fixed contention window (FCW) scheme is discussed [8] and introduced an optimal contention window (OCW) scheme. The results are only approximate. In this study however, a variant of 802.11 where the contention window size is fixed, i.e., CWMin=CWMax=CW is considered and then correlate the CW size and network size.

It has been found that performance of CSMA MAC protocol is better than ALOHA especially when receiver is allowed to sense the channel and inform the transmitter to start a transmission or not. But it is yet to find the impact of fading on the performance of CSMA in wireless adhoc networks. LA-MAC is found better than CSMA and TDMA, but its role in routing is yet to found.

The bottleneck of the static multihop network that uses IEEE 802.11 protocol for access is the spatial reuse: the number of packets that can be transmitted simultaneously. So aim is thus to decrease the flow of ACKs so as to give more bandwidth to TCP data packets. To reduce the ACK flow, the delayed ACK option of TCP is used, in which an ACK is generated for every d TCP packets, with one exception: if the first packet (of an expected group of d packets) arrives at the destination, then after some time interval (typically 100ms) if d packets have not yet arrived, then an acknowledgement is generated without further waiting. The standard delayed ACK option has the value d = 2 (see RFC 1122).

Related from review of literature it has been found that work has been done to analyse the performance in areas such as MAC with fixed contention window scheme and TCP with IEEE 802.11 MAC. But the results are only approximate. So more work can be done in these areas.

III. EFFICIENT & RELIABLE MAC PROTOCOL

This section presents the simulation scenarios firstly to find the impact of contention window size on the performance of the IEEE 802.11 MAC protocol and secondly interaction of TCP with the MAC protocol. NS2 [9] is used to simulate both the scenarios.

A. IEEE 802.11 MAC Protocol & Contention Window Size

IEEE 802.11 specification requires all nodes to choose a random back off interval between zero and CW (contention window), and wait for the chosen number of slot times before trying to access the channel. Initially, CW is set to CWMin (minimum contention window size). However, when there is a collision, the contention window size is doubled, until a maximum value: CWMax. This technique of randomization and scaling the contention window size is used to reduce collisions. In this study however, a variant of 802.11 where the contention window size is fixed, i.e., CWMin=CWMax=CW is considered. Here the contention window is not scale, but still use randomization.

A topology is needed under which to study the effect of contention window sizes. For this, let us choose a single hop network where all nodes are in range of each other. Specifically here consider a 150m X 150m area. All nodes are involved in two Constant Bit Rate (CBR) conversations: one as source, and one as destination. Simulation parameters are summarized in Table 1.

Table 1

SIMULATION SETUP

Parameter	Value
Radio Propagation	Two ray ground
MAC type	IEEE 802.11

Antenna Model	Omni-directional
Interface Queue Length	50
Total number of nodes	49
Routing Protocol	AODV
Packet Size	512
RTS	On

Next obtain and plot aggregate CBR throughput and Packet Delivery Ratio vs. CW size.

B. IEEE 802.11 Mac Protocol & TCP

Chain scenario consists of n nodes over a line separated by a distance of 200m, as seen in Figure 1. For each wireless node, the transmission range is 250m, the carrier sensing range is 550m and the interference range is about 550m. Simulation parameters are summarized in Table 2. The simulation lasted for 150 sec.

Table 2

SIMULATION SETUP

Parameter	Value
Radio Propagation	Two ray ground
MAC type	IEEE 802.11
Antenna Model	Omni-directional
Interface Queue Length	50
Total number of nodes	9
Routing Protocol	AODV
TCP data packet size	1040 bytes
TCP version	New Reno

IV. RESULTS

In order to correlate the CW size and network size in 802.11 WLAN, plot aggregate CBR throughput and Packet Delivery Ratio (PDR) vs. CW size for rlen =7 (total 49 nodes). Here vary CWMin=CWMax to take the following set of values: 2, 7, 15, 63 and 127. So throughput and PDR for each value of contention window size is calculated. AWK program is used to calculate PDR from a trace file generated by NS2 simulations. To get throughput, since all flows are a CBR, with a constant packet size of 512 bytes, just multiply number of packets received with 512 X 8 and divide by total simulation time (25 seconds for this scenario), i.e., Throughput in bits/sec=512 X 8 X [Packets Received] / 25.

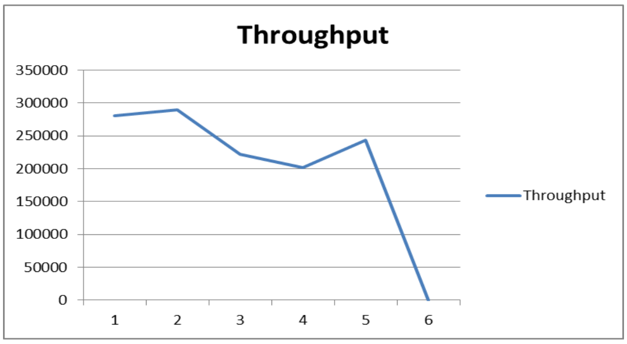

Fig. 2: Contention Window size Vs. Throughput.

As seen from Fig. 2. optimal contention window size for network with 49 nodes is 7. The throughput decreases with increase in contention window size.

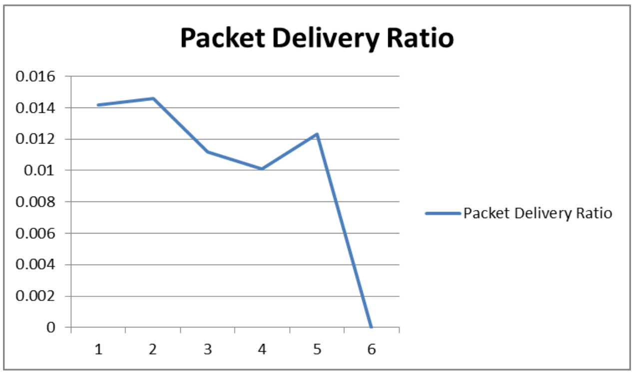

Fig. 3: Contention Window Size vs PDR

Fig. 3 shows packet delivery ratio also decreases with increase in contention window size.

In order to measure performance of standard TCP and Delay TCP in 802.11 WLANs, the throughput of each scenario is calculated and compared. The formula to calculate the average throughput can be represented as:

Throughput (kbps) =sum of packets received / effective time interval * 8 / 1000

AWK language is used to calculate throughput from a trace file generated by NS2 simulations.

The simulation results for n=9 and 30 nodes are summarized in Table I and Table II. In all these cases the hidden terminal effect (rather than buffer overflow) causes losses. It is being found that standard Delayed Ack option (d=2) slightly outperforms the standard TCP for n=9, and largely outperforms (more than 10%) the standard TCP for n=30. Delayed ACK version is better than the standard TCP for maximum window sizes of more than 3.

Maximum Window Size	Standard TCP	Delay TCP
3	112.99	114.68
5	83.69	114.64
10	43.36	65.41
15	56.95	81.84
31	56.95	75.12

Table I Throughput during 149sec for n=9

Maximum Window Size	Standard TCP	Delay TCP
3	112.48	117.06
5	68.11	107.08
10	68.28	78.93
15	55.85	99.09
31	55.85	82.92

Table II Throughput during 149sec for n=30

The most important conclusion from the tables is the robustness of the Delayed Ack options. In practice, since do not know the number of nodes, there is no reason to limit the maximum window size to a small value, since this could deteriorate the throughput considerably. When choosing large maximum window, the delayed ACK considerably outperform standard TCP.

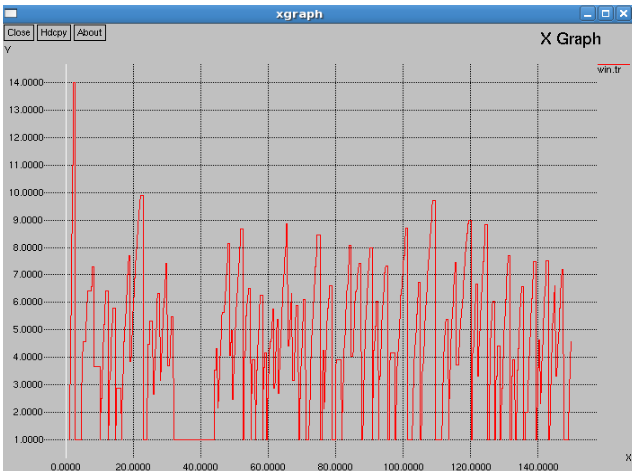

Fig. 4. Window size evolution for standard TCP with maximum window size of 2000

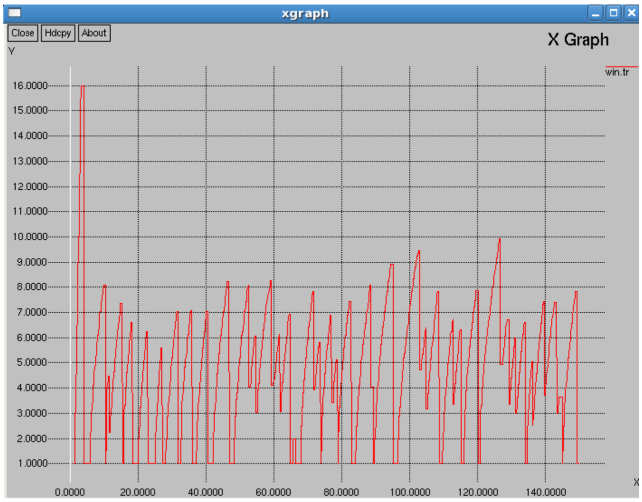

Fig. 5. Window size evolution for DelAck TCP with d=2, with maximum window size of 2000

Here plot the window size evolution for n=9 for standard TCP in Fig. 4 and for TCP with delayed ACK option in Fig. 5 with d=2. The window size is sampled every 0.1 sec. From Fig. 4 it is found that although the maximum window size is 2000, the actual congestion window does not exceed the value of 14. From the figures it is found that in standard TCP, losses are more frequent and more severe (resulting in timeouts) whereas the d=2 version of delayed ACK does not give rise to timeouts.

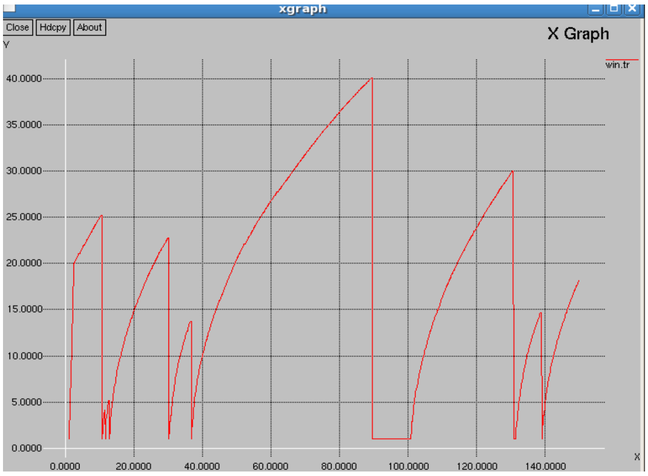

Fig. 6. Window size evolution for standard TCP with 9 nodes and maximum window size of 3

	Throughput (kbps)	
WinMax	Standard TCP	Delayed TCP d=2
3	112.99	117.09
2000	56.95	99.94

Table III Throughput during 149 sec for n=9 as a function of the maximum window size.

For a fixed small size of maximum window size (mws=3), the Delayed Ack option does not outperform the standard TCP version since most of the time, the window size limits the number of transmitted TCP packets to less than 2, which means that the delayed ACK option has to wait until the timer of 100ms expires before generating an ACK; during that time the source cannot transmit packets. In Fig. 6. present the evolution of the congestion window size for standard TCP with a maximum window size of 3 for the case of 9 nodes. Seen from Fig. 6. that there are almost no losses (the window is seen to decrease only few times, in contrast to a much larger number in previous figures). This is also shown by throughput for n=9 as a function of the maximum window size in Table III.

Delayed ACK is better than the standard TCP for maximum window sizes of more than 3 unlike earlier work. Instead of sending ack for every successfully transmitted TCP packet, delayed ack decreases the flow of ACKs so as to give more bandwidth to TCP data packets.

V. CONCLUSION

Efficient and reliable MAC protocol for wireless technologies is designed in this paper. Simulation result of contention window size and MAC protocol shows that optimal contention window size for network with 49 nodes is 7. The throughput and packet delivery ratio decreases with increase in contention window size.

Bottleneck of chain topology is spatial resuse. The flow of ACKs is decreased to give more bandwidth to TCP data packets. Delayed ACK option of TCP is used, in which an ACK is generated for every 2 TCP packets. Delayed ACK version is better than the standard TCP for maximum window sizes of more than 3. Simulation results shows when choosing large maximum window, the delayed ACK considerably outperforms standard TCP. When maximum window size is 2000 with n=9 nodes, in standard TCP losses are more frequent and more severe whereas delayed ACK (d=2) doesn’t gives rise to timeouts. When maximum window size is 3 with n=9 nodes, the Delayed Ack option does not outperform the standard TCP version since most of the time, the window size limits the number of transmitted TCP packets to less than 2, which means that the delayed ACK option has to wait until the timer of 100ms expires before generating an ACK; during that time the source cannot transmit packets. Thus large wireless network efficiency can be improved by using delayed ACK option of TCP.

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