EE360 – Paper Summary II

Fairness and Stability of Wireless MAC Protocols

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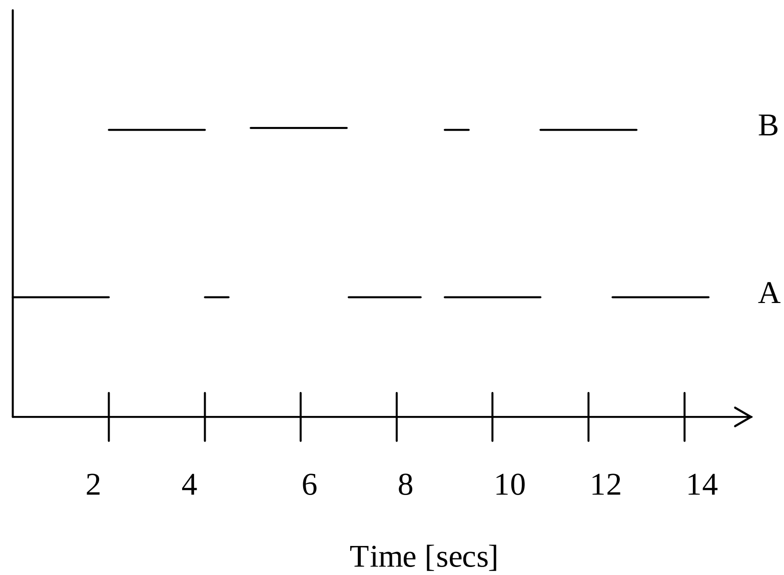
In this paper summary we investigate the fairness and stability properties of wireless MAC protocols. Since media access is important in the context of ad hoc and sensor networks, it is apparent that one understands the fairness and stability of MAC protocols. In this report, fairness refers to equal long term channel access probability for all nodes. Stability refers to predictability of throughput with respect to time when traffic generation within the network changes; however, there are no changes in the topology or the channel. Although the title of this summary and the papers references herein, refer to "wireless MAC protocols", they only really mean CSMA/CA protocol. Thus, all the observations made need not necessarily apply to other MAC protocols such as TDMA. This summary will first focus on the fairness property of CSMA/CA for both single-hop and multi-hop ad hoc networks. The later part of this summary will highlight how instability can arise when using TCP over multi-hop ad hoc networks using CSMA/CA protocol. Authors in [1, 3, 5] address the short-term unfairness of CSMA/CA while authors in [2, 4] address the performance of 802.11 type MAC layer in the case of multi-hop ad hoc networks. Since the observations are somewhat similar, we focus on [1] for short-term unfairness and [2] for instability and unfairness over multi-hop networks for brevity.

1. Fairness of CSMA/CA over Single Hop Networks

The basic components of CSMA/CA implemented in IEEE 802.11 based WLANs are, (i) carrier sensing, (ii) exponential back-off, and (iii) collision avoidance via RTS/CTS. With these basic properties, the MAC protocol can achieve long term fairness to all stations, as long as the source and destination are within one hop of each other. Thus, all nodes can achieve the same long term channel access probabilities [1-5]. If the application traffic characteristics (including the packet size) are the same, all nodes can achieve equal throughput as well. However, on a short time scale, such fairness has not been observed. In particular, the channel usage traces reveal that a single station monopolizes the channel for certain duration of time and then some other station monopolizes the channel for a certain time and so on. A simple figure illustrating such a behavior is shown in Figure 1 below for the case of two nodes, A and B. Such short-term unfairness does not have any drastic impact on system wide performance thought it can potentially disrupt the synchronous nature of multimedia communications. Authors in [1] present an approach based on Markov reward theory to analyze the performance of short-term fairness of CSMA/CA. The authors note that by using a reward function that is concave in the number of retries, short-term fairness is promoted as continuous backoffs are discouraged. Similar approach has been taken by authors in [5] so as to improve the performance of TCP flows in 802.11 networks. In conclusion, we can say that for single hop communications, CSMA/CA does achieve long term fairness but does not achieve short term (i.e., 1-2 seconds) fairness.

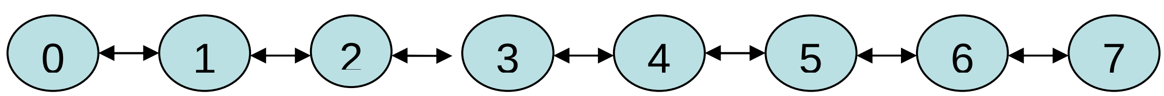
Figure 1 Short Term Unfairness of CSMA/CA



2. Fairness of CSMA/CA over Multi Hop Networks

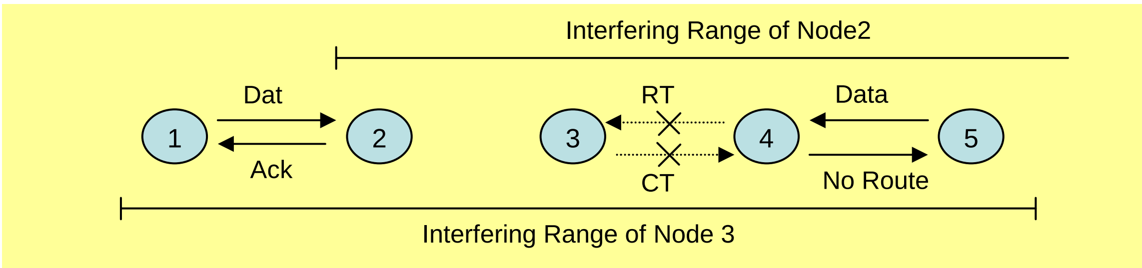
In case of multi hop communications, the fairness problem of CSMA/CA is aggravated. This problem has nicely been addressed in [2]. Consider the linear topology network as shown below.

Figure 2 Linear Topology to Illustrate Unfairness and Instability of CSMA/CA



The first network consists of data transfer from node 5 to node 3, through node 4. The second network consists of data transfer from node 1 to node 2. Traffic scenario simulates is as follows. At time 0, TCP traffic from node 5 is initiated. At time 30 seconds, TCP traffic from node 1 is initiated. The throughput results show that before the 2nd TCP connection was initiated, the node 5 was able to send data at a data rate of 450 Kb/s. However, when the second connection is initiated, the throughput of the first session drops to zero while the second connection achieves 900 Kb/s. The reason for this drastic drop in throughput is that the receiving node never really gets a chance to send the CTS back to the source. The further reason why a CTS is never transmitted is because node 3 is an exposed terminal as shown in Figure 3. It senses the channel to be busy when either node 1 is transmitting or when node 2 is transmitting. This brings us to the core of CSMA. A node may not be able to receive a data packet correctly if the data packet is received at a level lower than the Receive Threshold. However, it can detect that the medium is busy as long as it receives a signal that is above the Carrier Sense

Figure 3 Effect of Carrier Sense Threshold



Threshold. In typical devices, the Carrier Sense Threshold is much lower than Receive Threshold. Thus, although node 3 may receive packets from node 1 at a level below the Receive Threshold, it senses the channel to be busy as long its level is above the Carrier Sense Threshold. In this example, this is always the case. This explains the limitations of CSMA/CA for multi-hop communications. Note, however, that if one were to consider cases where the Receive and Carrier Sense Thresholds are taken be the same, such drastic performance degradations can be alleviated.

In summary, we can say that CSMA/CA is not even long term fair for multi hop communications. The problem is aggravated when TCP based connections are used as TCP needs timely ACK messages. If the ACK messages are not received in a timely manner, TCP throughput reduces either because it goes into a retransmission phase or because it witnesses a timeout. Regarding the linear network model used in the paper, although it is a somewhat extreme model, it does drive home the point of unfairness.

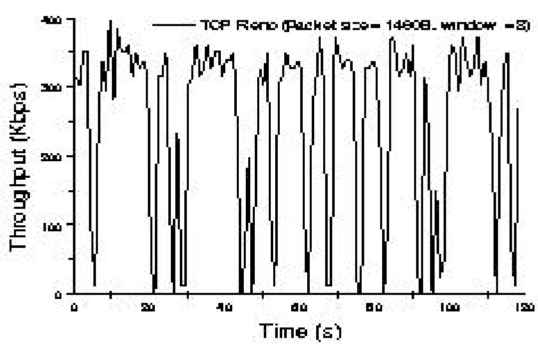
3. Stability of CSMA/CA in Single and Multi Hop Networks

In communications involving a single hop, CSMA/CA does not exhibit instabilities in that changes in traffic characteristics do not result in adverse network behavior. However, in multi-hop communications, it does exhibit instability. This subject has been studied in [2] as well. Consider the same linear topology as shown in Figure 2 with a single TCP connection between node 1 (source) and node 5 (destination). The throughput for this connection is found to be a strong function of the maximum window size used by TCP as depicted in Figure 3 below. Although, the relationship between the TCP window size and throughput is well understood, the dynamics in the current problem setting are quite different. First, when the TCP window size is large, the sender is busy sending data and since the data needs to reach the destination (node 5), all the intermediary nodes are equally busy. The problem comes when a node, say node 2, is in the hearing range of nodes 1 through 4. Thus, node 2 rarely gets a chance to respond to an RTS sent by node

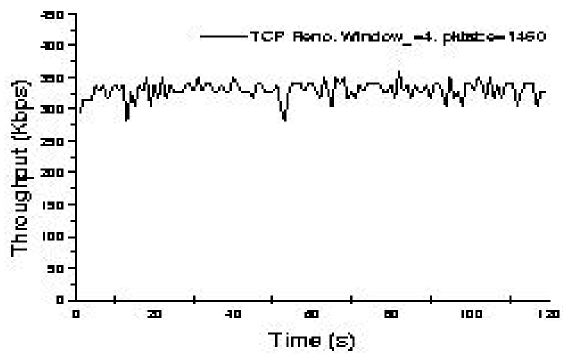
1, resulting in TCP timeouts and throughput degradations. This is shown as intermittent dips in the throughput for window size of 8 segments in Figure 4.

When the TCP window is small, i.e., 4 segments, we see that throughput is stabilized. The reason for this improvement is that with a small window size, the TCP sender is not as active as it was when the maximum window size used was 8. Thus, node 2 gets sufficient amount of channel idle time to transmit CTS and other packets.

In summary, we see that Carrier Sense Threshold lies at the core of long-term unfairness and instability problems of CSMA/CA. Since the technology is improving in that the Receive and Carrier Sense Thresholds are approaching to be equal, we should expect these effects to reduce as time goes by.



(b) Reno, window_=8



(c) Reno, window_=4

4. References

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