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Performance of coopMAC Protocols over CSMA/CA 802.11 protocols

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Abstract

Wireless communication is very fast becoming the most frequently used form of communication. Ad-Hoc networks can be easily set up anywhere without any infrastructure cost and its mobility adds to its advantage. Hence with increase in its demand the quality of the setup comes under scrutiny, hence calling for its development. This paper presents the concept of Cooperative MAC protocols. Cooperative MAC protocols are found to be more efficient over 802.11 MAC protocols and improve the network performance substantially. Comparison of 802.11 MAC protocols and CoopMAC protocols on NS2 platform is carried out and successfully proved that cooperative MAC protocols offer much higher throughput.

Keywords

CoopMAC, Cooperative Communication, new MAC Protocols Wireless Networks, Increased Throughput, Low BER

1. Introduction

The basic ideas behind cooperative communication can be traced back to the ground breaking work of Cover and El Gamal [1] on the information theoretic properties of the relay channel. This work analysed the capacity of the three-node network consisting of a source, a destination, and a relay. However, in many respects the cooperative communication we consider is different from the relay channel. First, recent developments are motivated by the concept of diversity in a fading channel, while Cover and El Gamal mostly analyse capacity in an additive white Gaussian noise (AWGN) channel. Second, in the relay channel, the relay's sole purpose is to help the main channel, whereas in cooperation thetotal system resources are fixed, and users act both as information sources as well as relays. Therefore, although the historical importance of Cover and El Gama is indisputable, recent work in cooperation has taken a somewhat different emphasis. In a cooperative communication network each wireless agent is considered as a cooperative agent to the other nodes present in the network as well as transmits its own data. In cooperative communication, when due to bad channel conditions or other reasons the packet is not delivered to the source, the best neighbour conditioned to deliver the packet (provided it is available and free for transmission and it has received the data packet when broadcasted by the source), will assist the sending node in transmitting the packet to the destination node. When power consumption is considered it is argued that the nodes consumes extra power because they transmit their own data as well as send other cooperative node's data, while individually the power consumption while cooperation goes on might be high than the overall power consumption.

The biggest difficulty that is faced in wireless networks data transmission is related to the wireless Channel characteristics. Wireless channels are known to be susceptible to occasional transmission errors and failures caused by fading related problems. Collisions cannot be detected in wireless networks and due to this reason data transmission suffers a big drawback, like at times the acknowledgement packet (ACK), is not received, this leads the source node to retransmit the data, hence wasting precious time and bandwidth. When a node is out of range of another transmitting node, it is unaware of the activities of that node, hence it may sense the channel as free and transmit data when actually the channel may be busy hence causing un-necessary collisions, while in case of exposed terminal the sensing node may sense the channel busy due to data being transmitted by a neighbouring node but it can send the packet without any worry because the channel may be free for transmission of data to another node. Hence this causes Un-necessary delay. Near and far terminal is another major problem faced in wireless transmission.

2. Cooperative mac protocols

The CoopMAC protocol is based on the MAC 802.11 protocol. The throughput basically depends on the following things:
1. Successful Transmissions
2. Collisions
3. Idle slots due to back-off at the contention period.

In CoopMAC protocols, idle slots are reduced through means of constant window size. Collisions between colliding nodes are resolved more quickly by assigning the collided nodes with a shorter Distributed Inter

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Frame- Space (DIFS) than the other nodes. When a node has a packet to be sent, it first senses the channel. If the channel is idle for the required DISF amount of time, the node sends the packet. If not then the node will defer sending the packet till the channel is idle as specified by the DISF time. After DISF time, the node will generate a random back-off counter chosen from the range 0 to CW-1, where CW is the Contention Window size. The back-off timer starts decrementing as long as the channel is sensed to be idle. If the channel becomes busy the back-off counter is stopped till the channel is idle for DIFS time. Once the counter reaches zero it sends the Request to Send (RTS), if it uses the IEEE 802.11 four-way handshake scheme. When the packet is received by the receiving node, it waits for Short Inter Frame-Space (SISF) and then sends the Clear to Send (CTS) packet. Any node that has heard the RTS and CTS packets will send their Network Allocation Vector (NAV), so they will wait to send their packets. When the sending node receives the CTS it sends the data packet. If the receiving node receives the data packet it will send an ACK. If the sending packet was successfully transmitted, the sending node chooses a new back-off counter uniformly from the range of CW to 2*CW-1. It chooses a different time because it gives the other nodes a greater chance of capturing the channel and sending the packet. If the sending node doesn't receive the ACK or CTS it assumes that collision has occurred.

When collision occurs the sending node generates a new back-off counter uniformly based on the range of 0 to 3CW. It then senses the channel, and if the channel is idle for the duration of Priority Inter Frame Space (PIFS) instead of a normal DIFS amount, then the node starts to decrement off its back-off counter. (DISF is equal to PISF plus four times the SlotTime). Since collided nodes have shorter range from which their back-off counter is chosen, they have a higher priority for packet transmissions than other nodes. If there is another collision on the channel before the collided nodes back-off counter reaches zero, the sending nodes sets its back-off counter to zero then waits for DISF amount of time and transmits the packet. The collided node has higher priority than nodes not involved in collision. The nodes that do not receive the RTS and CTS correctly sense the channel to be busy and set their NAV to Extended Inter Frame Space. When the node has successfully transmitted a packet it will choose a range uniformly from within CW to 2*CW-1.

A packet queue is a structure to store packets that are to be sent. Packets are dropped from the tail. The queue size is important as it dictates how many packets the queue can hold, as we can't have an infinite queue size. Overflow is a common occurrence when the queue is full and we try adding packets to it. The packet queue affects the throughput for a couple of following reasons:-

1. If the packet is dropped before it reaches the destination hence there is the fact that a packet was not delivered.
2. If a packet with high priority is put in the end of the queue then not only many packets which might not be as important as this will go through but also there is a high probability that this packet will be dropped.

A priority queue solves this problem, a simple FIFO implementation will ensure that packets with highest priority go into the top of the queue and are transmitted first.

3. Designing coopMAC protocol

A. Proposal

Following situations are taken into account when CoopMAC protocols are designed:-

1.) Channel is slow varying i.e., channel conditions don't change instantaneously.

2.) The protocols are modifications over the CSMA/CA protocols so it’s backward compatible.

When a cooperative communication is induced in a network, the throughput of the network shoots up. Basically a link is provided between the source and the destination with the help of neighbouring nodes to make the transmission of data as fast as possible with as few errors.

It is assumed that there is only one sender node and one destination node marked by Ss and Sd, basically just like in 802.11 MAC protocols there is a RTS which is broadcasted from the source to the destination requesting for the data packet transmission. Now making use of the broadcast property of the channel which ever node in the neighbour of the source and destination node receives the RTS packet sends an ATS (assist to send) packet, nodes which are marker by Sh, this contains the power of the RTS received by the node at them, that the ideal path for transmission of the cooperative packets can be calculated as all the assisting nodes can be tracked using a Coop Helper table. This provides the perfect path for transmission of the data,in case the direct broadcast link fails to deliver the packet, or in case there is requirement for the packet to be transmitted by a better path which leads to faster delivery of the packet based on the availability of the assisting nodes orhelper nodes. Now when cooperative MAC is implemented, there are certain things that is to be kept in mind regarding the packets as to what is to be sent to the helper i.e., which is the cooperative packet and which is the packet for the node itself. In this regard we introduce a numbering concept, say (00, 01) for the node itself and (10, 11) for the helper packets. This way a tab is kept as to which packet needs to be forwarded and which packet is to be received by the node itself. This can be labelled with the header of the packet itself hence when a node receives a data packet it knows where the packet belongs. Next in priority is to classify as which packet should be given highest priority. In this regard cooperative packets are chosen to be given highest priority as when the system require cooperation then in that case the packet delivery has already failed or the node sending the packet is requesting cooperation out of utmost necessity hence the node should behave selflessly. This can be achieved by optimizing the queuing process by putting in the cooperative packet in the top of the queue and sending them out first, as in the FIFO policy (first in first out). The packets with lowest priority, be introduces in the end of the stack. To store the two data types of packets individually we introduce a new queue called as the cooperative queue which can store the cooperative packets.

B. Theoretical analysis

Comparison is done between 802.11 protocols and Cooperative MAC protocols on the most basic level. Considering free space loss-P_r is proportional to $1/d^2$ (inverse square law).

It is known from above that as the signal propagates from source to destination directly in case on 802.11 MAC protocols free space loss will cause bit loss. When considered for CoopMAC, the packet when broadcasted various nodes capture them and simultaneously assist the sender node to transfer the packet at a faster rate. Hence the packets received at the destination can be compiled together to minimize the bit error, hence leading to a low BER.

C. Mathematical analysis

All stations are uniformly distributed in the coverage area and are assumed to be stationary. It is assumed that the maximum transmission range for 11 Mbps, 5.5 Mbps, 2 Mbps, 1 Mbps are r11,r5.5,r2,r1 meters respectively. Since only mobile stations which are more than r5.5 meters away from the AP (Access Point) can reduce their transmission time using two hop transmissions, these stations are focussed on. If a third node is within rx meters to the source node and ry meters to the destination, but not within any other region that can transmit at a higher speed, it can help the transmission in a two hops manner using rate x Mbps and y Mbps. The probability that a node exists in such region will be denoted by Px,y .

The probability that no helper is present is 1 − P11,11 − P5.5,

11 − P5.5,5.5 − P5.5,2 .

Let the transmission time for one packet, if the direct transmission rate is x Mbps, be represented by Tx .

We have [1]:

T11 = Tcont(n) + Toverhead + 8L/R11

T5.5 = Tcont(n) + Toverhead + 8L/R5.5

Where Toverhead = TPLCP + TDIFS + TRTS + TCTS + 3TSIFS + TACK

AndTcont(n) accounts for the time spent in the contention period. For stations which have a direct transmission rate of2 Mbps, the transmission time is averaged over where a helper is present and the time needed if the helper is not available.

T2 = Tcont(n) + (P11,11 + P5.5,11 + P5.5,5.5)*TCoopOH + (16P11,11L)/ R11 + (8P5,11L)/R11 + (8P5,11L)/R5.5 + (16P5.5,5.5L)/R5.5 +(1 − P11,11 − P5.5,11 − P5.5,5.5)*(Toverhead + 8L/R)

Where TCoopOH = 2TPLCP + TDIFS + 5TSIFS + TRTS + 2TCTS +TACK for CoopMAC I and Rx is x Mbps.

Similarly it can be derivedthat the average transmission time T1 for stations with a direct rate of 1 Mbps. Because of the long term channel access fairness guaranteed by the CSMA/CA protocol, each station in the network have an equal expected number of packet transmissions over a long period of time. This is assuming that all stations have a backlog of packets for transmission. Let us denote the fraction of stations of rate x Mbps by fx. The average transmission time for one packet can then be calculated as follows:

T = f11T11 + f5.5T5.5 + f2T2 + f1T1 (5) and

f11 = r21.1/r21

f5.5 = (r25.5 − r211)/r21

f2 = (r22 − r25.5)/r21

f1 = (r21.1 − r22)/r21

D. Probability of Collision

If multiple hosts attempt to transmit at the same time, the transmissions will collide and the sending stations will start exponential back-off. Each station picks a random number X from [0, CW], where CW is the size of congestion window, and retransmit after X time slots. [1] If the retransmission is successful, CW is set to CWmin, otherwiseCW = min(2 Ã—CW,CWmax). It is obvious that the time spent in the contention procedure for each station increases with the number of stations in the network:

Tcont (n) ≈ SLOT x (1 + Pc(n))/2 x CWmin/2

Where Pc (n) = 1 − (1 − 1/CWmin) n−1 and SLOT is the time period corresponding to one time slot. The throughput of the network, in bps, is given by the following equation: S = 8L/T

4. Introduction to ns2

NS2 (Network Simulator Version 2) developed by UC Berkeley is a kind of open-source free software simulation platform in allusion to network technology. It's essentially a discrete event simulator. There's a virtual clock in itself and all the simulation are driven by discrete events...The Basic Composition of NS2 is a software package including some basic components like Tcl/Tk, OTcl, NS2, Tclcl, etc. (such as Fig.1).

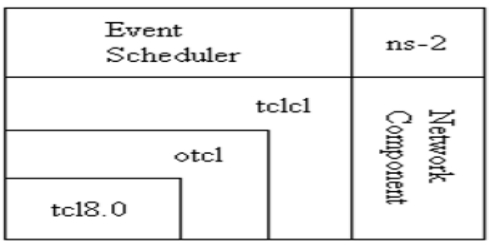

Figure 1: Structure of NS2

Tcl is an open-script language which is used to program NS2; Tk is a development tool of graphical interface which can help users to develop graphical interface in graphic environment; OTcl is an object-oriented extension based on Tcl/Tk and it has its own class hierarchy; NS is the core of this software package, and also object-oriented simulator programming with C++, with OTcl interpreter to be front end; Tclcl provides interfaces of NS2 and OTcl, it is object and variable appeared in two languages. In order to observe and analyse the simulation results intuitively, NS2 provides selectable Xgraph, Gnuplot, selectable component Nam.
Process of network simulation using NS2 NS simulation can be divided into two layers. One layer is based on OTcl programming. Another layer is the one based on C++ and OTcl programming. If there aren't required network elements in NS, it's needed to extend NS, adding required ones which also mean adding new C++ and OTcl class, then to compile OTcl script.

5. Results

A. TABULAR ANALYSIS OF DATA GATHERED

Table 1: CSMA/CA (802.11 MAC) Throughput Table

Num. of Nodes	Average Through put in Kbps	Average Through put in Mbps	Simuulation start time	Simuulation End time
9	1415.01	1.382	**1.20**	149.99
10	1359.96	1.328	1.20	149.99
11	1326.90	1.296	1.20	149.99
12	1143.77	1.117	1.20	148.47
13	1124.34	1.098	1.20	140.26
14	1232.71	1.204	1.20	149.99
15	1250.66	1.221	1.20	150.00
16	1464.66	1.430	1.20	150.00
17	943.73	0.922	1.20	143.96
18	1293.99	1.264	1.20	149.98
19	1235.88	1.206	1.20	149.97
20	1383.54	1.351	1.20	149.99
21	1052.96	1.028	1.20	149.95
22	1443.30	1.409	1.20	147.46
23	1266.41	1.237	1.20	150.00
24	921.05	0.900	1.20	144.71
25	1571.53	1.535	1.20	146.99
26	1352.50	1.516	1.20	149.99
27	1171.34	1.144	1.20	150.00
28	1196.55	1.169	1.20	143.31
29	1361.93	1.330	1.20	149.99
30	1431.47	1.398	1.20	150.00

Table 2: Cooperative Mac Throughput Table

Num. of Nodes	Average Through put in Kbps	Average Through put in Mbps	Simuulation start time	Simuulation End time
9	7779.72	7.597	1.18	150.00
10	7891.94	7.707	1.18	149.61
11	7922.39	7.737	1.18	150.00
12	7780.41	7.598	1.18	150.00
13	7781.88	7.600	1.18	150.00
14	7965.93	7.779	1.18	150.00
15	7928.58	7.743	1.18	150.00
16	7701.08	7.521	1.18	150.00
17	7809.28	7.626	1.18	149.84
18	7860.60	7.676	1.18	150.00
19	7790.17	7.607	1.18	150.00
20	7887.98	7.703	1.18	150.00
21	7911.64	7.726	1.18	150.00
22	7589.49	7.412	1.18	150.00
23	7516.61	7.340	1.18	150.00
24	7777.43	7.595	1.18	150.00
25	7834.63	7.651	1.18	150.00
26	7838.12	7.652	1.18	150.00
27	7879.04	7.694	1.18	150.00
28	7834.82	7.651	1.18	150.00
29	7005.94	6.842	1.18	150.00
30	7622.87	7.444	1.18	150.00

B. GRAPHICAL ANALYSIS

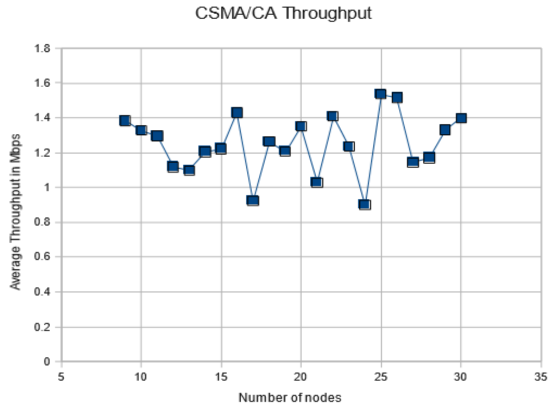

Figure 2: CSMA/CA Throughput

It can be seenin fig.2in the graphical analysis that as the number of nodes increases the throughput of the network falls due to increase in the number of collisions.

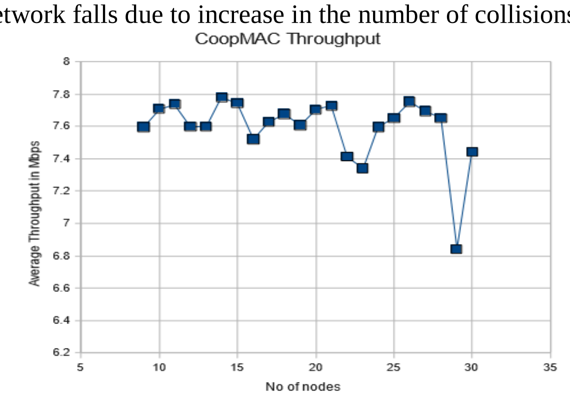

Figure 3: CoopMAC Throughput

It can be seen in fig.3 in the graphical analysis that as the number of nodes increases the throughput of the network rises due to the availability of cooperative partners.

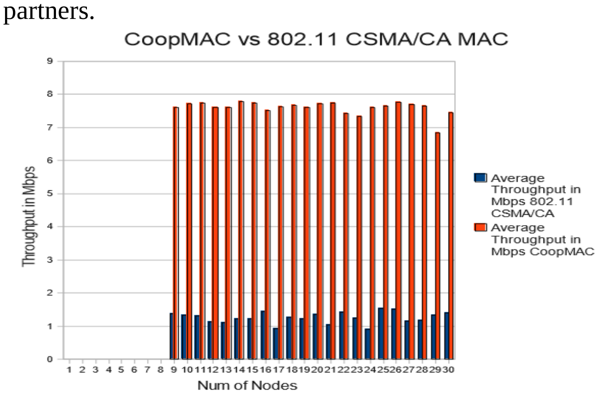

Figure 4: CSMA/CA (802.11) vs. CoopMAC Throughput

As it can be seen from the Graph the CoopMAC protocols provide a far greater throughput than the 802.11 CSMA/CA MAC protocols. Also by simulations carried out by other researchers it has been shown to have a far lower delay and BER which makes it an ideal choice to be implemented.

6. Conclusions and future work

From the simulations and analysis it found that Cooperative Communication provides many more advantages than the traditional CSMA/CA MAC protocols or any improvement on them.

CoopMAC protocols are easily implemented on the present hardware with modification in the hardware drivers, which basically makes it very cost effective and they are also backward compatible i.e., they can operate with the 802.11 MAC protocols and don't conflict the working. Upon comparing the CoopMAC protocols and 802.11 MAC protocols using NS2 it is found that the throughput for CoopMAC far exceeds the 802.11 MAC protocols, also with reference to work carried out by other in the same field it would be safe to conclude that the BER and delay is much lower. Also as the number of nodes increase while the throughput for 802.11 MAC reduces due to more chances of collision, the throughput only increases for CoopMAC as the number of stations increase as more the number of stations, higher is the rate of cooperation and hence higher throughput and faster delivery of data packets. From this study it is concluded that CoopMAC protocols provide a significantly higher throughput, have a much lower BER (bit error rate), lower delay in data transmission and are more energy efficient.

For future work, a lot of improvement can be made over these protocols, which includes analternate queue for the cooperative nodes, introducing priorities for the data packet transmission asto whose packet to transmit first etc., that way there shall be fairness in the system for data packetdelivery. Also since multiple nodes are using the cooperative node packets, some form of control protocol needs to be developing which ensures packet safety. Also some forms of security measures need to be developed to safe guard from the misuse of the information.

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