COMPARATIVE PERFORMANCE ANALYSIS BETWEEN IEEE 802.11 DCF AND PROPOSED COOPMAC+

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Abstract: *Medium Access Control (MAC) protocol is used to ensure that signals from different stations across the same channel collide. In this paper, a novel idea of user cooperation in wireless networks has been exploited to improve the performance of the IEEE 802.11 medium access control (MAC) protocol. The new MAC protocol leverages the multi-rate capability of IEEE 802.11b and allows the mobile stations (STA) far away from the access point (AP) to transmit at a higher rate by using an intermediate station as a relay. CoopMAC protocol is able to increase the throughput of the whole network and reduce the average packet delay. Moreover, CoopMAC also maintains backward compatibility with the legacy 802.11 protocol. The performance improvement is further evaluated by analysis and extensive simulations.*

Keywords: *MAC, IFS, AHN, CoopMAC, BER*

1. Introduction

Interference is an increasing challenge in all wireless local area networks (WLANs) environments. Any types of interference can have a harmful and destructive impact on WLAN performance. By effectively transmitting multiple copies of the same signal over essentially independent channels, known as diversity, is an efficient technique that can be used to alleviate the negative effects of fading. Some well known forms of diversity to combat fading are spatial diversity, temporal diversity, and frequency diversity [1].

Independently of whether other forms of diversity are being used, special diversity depends on deployment of antenna array on small mobile unit. Unfortunately, this is infeasible due to the small size of the mobile node. In order to overcome this limitation, a new concept of diversity that has emerged called cooperative diversity is realized through utilizing cooperative communications [2-6]. Cooperative diversity has been proposed to take the advantage of the spatial diversity gains, by allowing different nodes in a wireless network to share their resources and cooperate through distributed transmission. This is achieved by relaying overheard information at stations surrounding a source and, thus, forming multiple transmission paths to the destination. The idea of cooperative communications has been meanly interpreted in the form of innovations at the physical layer to allow stations to cooperate in their transmissions in order to improve the overall performance of the wireless networks. However, research at the physical layer should be combined with higher layers, in particular the MAC layer to realize a fully cooperative networks. We adopt these ideas and design a new MAC protocol to increase the throughput of a wireless networks.

Cooperative communication fully leverages the broadcast nature of the wireless channel and spatial diversity, thereby achieving tremendous improvements in system capacity and delay. By enabling additional collaboration from stations that otherwise will not directly participate in the transmission, cooperative communications ushers in a new design paradigm for wireless communications. In this paper, we extend a cooperative MAC protocol called CoopMAC into the ad hoc network environment. The new protocol is based on the idea of involving in an ongoing communication an intermediate station that is located between the transmitter and the receiver. The intermediate station acts as a helper and forwards to the destination the traffic it receives from the source. Thus, a slow one-hop transmission is transformed into a faster two-hop transmission, thereby decreasing the transmission time for the traffic being handled. Extensive simulations in a large scale wireless ad-hoc network (150 stations) show that CoopMAC significantly improves the ad hoc

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network performance in terms of throughput and delay, and indicate how such cooperative schemes can boost the performance of traditional solutions (e.g., IEEE 802.11).

2. Medium Access Control Protocols in Ad Hoc Networks

MAC layer is responsible for regulating the shared wireless medium access among the nodes. This being the primary task in AHN greatly influences the performance of the network. MAC layer is expected to judiciously utilize the scarce wireless medium to improve throughput and reduce delay while keeping the collisions to a minimum.

Collisions can occur due to two nodes transmitting simultaneously or due to hidden terminals. MAC protocols in AHN are broadly classified as synchronous and synchronous protocols [7]. Synchronous protocols allocate their users with specific time slot (Time Division Multiple Access (TDMA) based) or specific data channels (based on Frequency Division Multiple Access (FDMA) or Code Division Multiple Access (CDMA)). The synchronous protocols based on TDMA allocate timeslots to the users which makes it suitable for heavy and medium traffic conditions only, where all or most slots are utilized. The asynchronous protocols are well suited to low traffic conditions. These protocols are based on the Carrier Sense Multiple Access (CSMA) and its variants. In CSMA based protocols, the node senses the medium and if it observes the medium free for a defined interval it transmits or else it defers its transmission. These protocols are effective and easy to implement as these allow transmission with minimum delay. One of the most widely tested and deployed asynchronous protocol is the IEEE 802.11.

3. Design Issues for MAC Protocols in Ad Hoc networks

With the increasing bandwidth demand in AHN, it is important to devise MAC protocols for efficient utilization of bandwidth. The distributed nature of MAC protocols in AHN makes it difficult and gives rise to enormous challenges. Some of the important design considerations [8 - 11] for the MAC protocol developers are listed below:

- **Distributed Operation:** AHN are required to operate in special circumstances and are self configurable. It is expected that these should be autonomous and distributed in nature with minimum overheads.
- **Synchronization:** Synchronization is important for the TDMA based MAC protocols as it is used to improve the utilization of bandwidth and battery.
- **Hidden Terminals:** Hidden terminals are nodes that are not in the range of the source but are in the range of destination. These nodes can cause collision at destination. This may result in a retransmission which will reduce the overall throughput.
- **Exposed Terminals:** Exposed terminals are the nodes in the source's transmission range, which are blocked from transmitting due to an ongoing transmission. In order to improve the bandwidth utilization it is important to allow parallel transmission in a controlled manner.
- **Throughput:** Throughput is an average rate of data received successfully. To enhance throughput it is important to reduce collisions, maximize the channel utilization and keep the control overhead to a minimum.
- **Access Delay:** Access delay is an average delay that a packet experiences before it is transmitted. The MAC protocol should minimize this delay to improve the channel utilization.
- **Fairness:** Fairness is an equal distribution of bandwidth to all nodes. Some MAC protocols tend to support nodes with previous successful transmission, which results in some nodes being deprived of access to medium and causes successful nodes to drain its resources much faster.
- **Power Control:** Energy consumption is linked to transmission power control and can be minimized by judicious power control mechanisms (which also reduces the interference to other nodes). Power control in the MAC layer affects the contention region.
- **Rate Adaptation:** Varying channel conditions can reduce the overall system throughput. It is important for the MAC protocol to adapt the transmission rate to

varying channel conditions i.e. lower the data rate for bad channel and increase the data rate for good channel conditions.

- **Mobility:** The mobility in AHN is an important characteristic but at the same time it makes things difficult for the MAC protocols. For the best performance MAC protocols should be able to provide support for the mobility.

4. IEEE 802.11 DCF

The default scheme used for data transmission in DCF is the two-way handshaking technique called basic access mechanism. This includes the CSMA/CA with binary exponential backoff (BEB). The BEB mechanism chooses a random number which represents the amount of time that must elapse after DIFS where there is no transmission taking place.

Another scheme is an optional Request-To-Send (RTS)/Clear-To-Send (CTS) four-way handshaking mechanism used to combat the effects of collisions and to facilitate transmission of large data packets. Though the RTS/CTS exchange reduces the likelihood of collision, it causes several drawbacks, such as low channel utilization due to no parallel transmissions, wasting node's energy and creating interference to other nodes.

The IEEE 802.11 defines three main Inter Frame Space (IFS) periods of time: 1) Short IFS (SIFS), 2) DCF IFS (DIFS) and 3) Extended IFS (EIFS). These are used to determine the priority levels to access the channel. The SIFS being the shortest is used between two subsequent frames involved in the transmission such as between RTS and CTS. The SIFS interval is linked to particular physical layers. The DIFS duration is used by the nodes to sense the medium idle before starting a new transmission. A node is able to transmit when it observes the medium free for DIFS duration and the relevant backoff time. DIFS is equal to SIFS plus two slot times. EIFS is a much larger duration than the others and is meant to prevent the collision with an ongoing transmission. When a node intending to transmit is able to sense some activity on the channel and is unable to decode due to collision/ error or distance, it defers its transmission for EIFS duration.

In DCF when a source node is ready to transmit a packet, it first senses the activity on the transmission channel until an idle period equal to DIFS is detected. This is physical carrier sensing (PCS). In this instance, the source waits for another random backoff interval before transmission to avoid collision with other nodes. The duration of this random backoff is a random value within

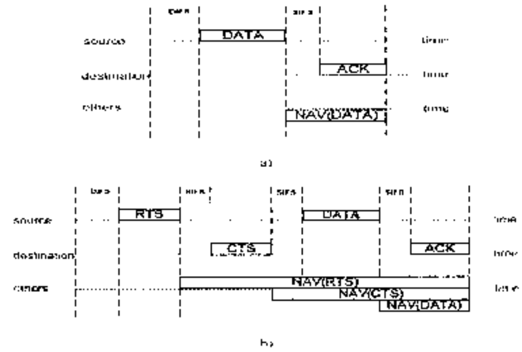

Figure 1: IEEE 802.11: a) Basic access, and b) Optional RTS/CTS access

the interval [0, CW], where CW is the contention window. The random backoff time counter is decremented in terms of time slots as long as the channel is sensed free. The counter is suspended once a transmission is detected on the channel. It resumes with the old remaining backoff interval when the channel is sensed idle again for a DIFS period. The source transmits its packet when the backoff time becomes zero.

In the case of basic access (Fig 1a) the source starts by sending the data packet. If the data packet is received correctly, the destination responds by sending an acknowledgement (ACK) packet after SIFS interval. The CW is reset to initial value upon successful transmission. If the ACK is not received at the source, a collision is assumed to have occurred. The value of CW is doubled upon each failure until it reaches the maximum value. The CW is reset if a failure occurs at the maximum retry limit. In the case of failure at the maximum contention window, the packet is dropped. The source attempts to send the data packet again when the channel is free for a DIFS period followed by the random backoff interval.

In the RTS/CTS access, control packets are used to reserve the channel for transmission of data packets. The RTC/CTS control overhead is suitable to transmit large data packets as a collision would lead to waste of less bandwidth. On the other hand, it makes no sense to transmit short data packets with the control overhead as this would lead to consumption of extra bandwidth. In the RTS/ CTS case (Fig 1b), the source starts the process by sending an RTS control packet. If the control packet is received correctly, the destination sends a CTS control packet after a SIFS interval. Once the CTS frame is received, the source transmits its data packet after a SIFS interval. If the source does not receive the CTS, a collision is assumed to have occurred.

In this case, the source attempts to send the RTS packet again when the channel is free for a DIFS period followed by the new backoff. In addition to the physical carrier sensing, DCF also makes use of virtual carrier sensing (VCS). VCS is implemented by means of the network allocation vector (NAV). The NAV is maintained by all nodes that are not currently involved in any transmission or reception of packets. A non zero NAV means that the node needs to block its own transmission to yield another ongoing transmission. It tracks the remaining time of any ongoing data transmission. When a node receives RTS, CTS or DATA packet which is not destined for it, it sets its NAV according to the information received in the Duration/ ID field of that particular packet. The Duration field contains the reservation duration of this whole packet exchange sequence. The RTS/CTS with the NAV settings is able to resolve the hidden terminal problem to some extent. A node blocks its own transmissions if either PCS or VCS shows a busy channel.

In order to highlight the issues in 802.11 DCF and look for appropriate solutions, accurate modeling of the 802.11 DCF is very important. As such, the next section presents some information on the modeling of 802.11 DCF.

5. The Proposed Cooperative MAC Protocol (MAC+)

The proposed cooperative MAC protocol is based on the CoopMAC protocol; therefore it is based on the distributed Coordination function (DCF) of IEEE 802.11 It assumed that the transmission power is fixed for all stations. Transmitting stations choose the best modulation scheme based on the received signal to noise ratio (SNR). It assumes also the channel between each station and its destination is symmetric, because the uplink and downlink traffic use the same frequency.

6. CoopMAC+ Outline

1. When a station Ss has data packet with length L bytes to transmit to a destination Sd, it first checks the CoopTable and calculate the required transmission time via each potential helper. The transmission occurs in two steps, first from the source to the potential helper with rate Rsh and then from the potential helper to the destination with rate Rhd, so the transmission time is 8L/Rsh + 8L/Rhd , ignoring the overhead time. After checking all the potential helpers, the one with minimum transmission time is chosen. If the rate Rd between Ss and Sd, 8L/Rd is the direct transmission time. If 8L/Rsh + 8L/Rhd< 8L/Rd, two hope transmission is more efficient.
2. Ss sense the channel first. If the channel is idle for a DIFS time and Ss completed the required backoff mechanism, a MRT frame will be sent, reserving the channel for NAV duration for the data transmission. Format of the MRT and the CoopMAC RTS is shown in figure 2(a). In the MRTS frame, will reserve the channel for time needed to receive the helper reply, in contrast with CoopMAC protocol which reserve the channel for duration of direct transmission. The MRTS frame includes the helper ID and the XOR ing ID of the source and the destination, so MRTS length is equal to RTS frame in IEEE 802.11 and less by ten bytes than CoopMAC protocol. This procedure has two advantages. First, it reduces the overhead time, second, it reduces also the probability of the collision with any other stations RTS. As a result, it will help to improve the network performance.

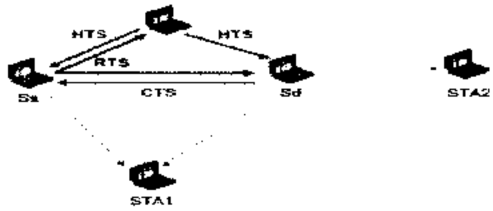

Figure 2: CoopMAC +

3. If the helper station which has the same MAC address as indicated in Helper ID field in the MRT frame can decode the RTS frame, it will reply with BusyTone signal after a SIFS period to confirm helper ready to send. The BusyTone signal length is from one to tow time slots (20- 40 us, in IEEE 802.11b). We replaced HTS with busy tone to reduce the overhead as well as the BusyTone is more reliable than HTS. This packet will be heard both by Ss and Sd.
4. Sd receives MRT first, each station will calculate the result of XOR ing it's ID with the received one to get the source ID and compares it with sources look-up table. If the ID is found in the table, Sd will confirm that it is the intended receiver. So destination station Sd will be expecting the BusyTone after receiving the MRT frame. If the BusyTone is received, the Modified-Clear-To-Send (MCTS) frame will sent and reserve the channel for the time needed for two hope transmissions. An illustration of the exchange of the control packet for the cooperative MAC protocol is shown in figure 1(b).
5. Once the source receives the MCT frame from the Sd, The data packet starts transmission. If BusyTone signal ha been received, Ss the data packet to Sh using rate Rsh. Sh checks the CRC field of the data packet and forwards the packet to Sd, if it is not corrupted, using rate Rhd after a SIFS time.
6. After Sd receives the data packet, an ACK packet is sent. Otherwise Sd stays idle. In the later case the source will notice the failure transmission after a time out period and start the binary exponential backoff procedure similar to the IEEE 802.11 standard.

7. Experimental Description:

In this simulation several nodes has been used and among them one node wants to transmit data to the receiver using IEEE 802.11b. But due to distance data rate is not so good so it uses a node to help them to send data as cooperative node. The data rate between these nodes is much achievable. Here source node first finds its cooperative node in the beacon period.

When a node is ready to acts as cooperative it will give its response and make its color green. Source then communicate with the Access Point (AP) with the helper node.

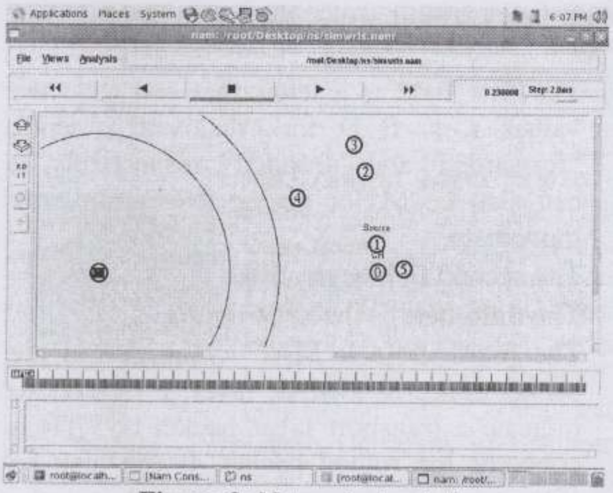

Figure 3: Network simulation

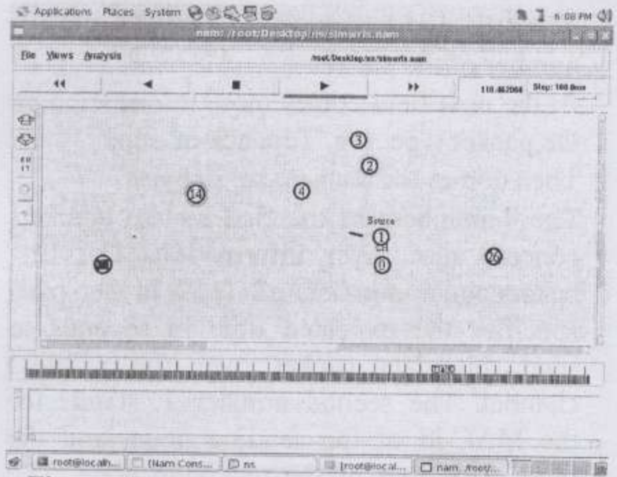

Figure 4: Packet transmission (source to helper)

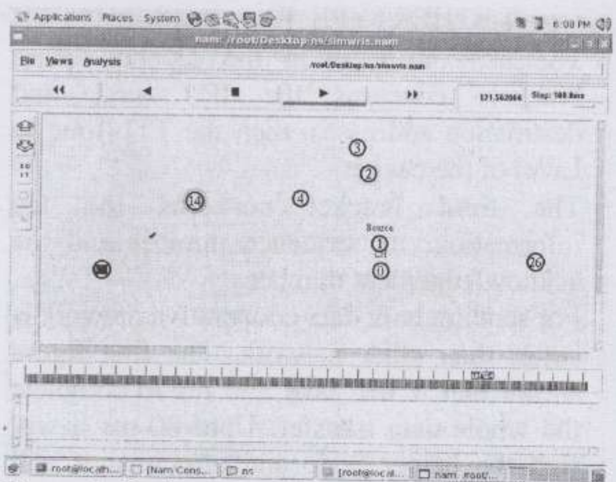

Figure 5: Packet transmission (helper to destination)

8. Simulation and Results

During the experiment, 7912 packets have been sent on Channel and 35521 packets have been received, and 21 packets have been dropped. The above mentioned trace packet format is as follows:

r 40.639943289 _1_ AGT --- 1569 tcp 1032 [a2 1 2 800] ------- [0:0 1:0 32 1] [35 0] 2 0

- The first field is a letter that can have the values r, s, f, D for "received", "sent", "forwarded" and "dropped", respectively. It can also be M for giving a location or a movement.
- The second field is the time.
- The third field is the node number.
- The fourth field is MAC to indicate id the packet concerns a MAC layer, it is AGT to indicate a transport layer packet or RTR it concerns the routed packet. It can also be IFQ to indicate events related to the interference priority queue.
- After the dashes comes the global sequence number of the packet.
- At the next field comes more information on the packet type. (eg. Tcp, ack or udp)
- Then comes the packet size in bytes.
- The 4 numbers in the first square brackets concern mac layer information. The first hexadecimal number, a2 (162 in decimal) specifies the expected time in seconds to send this data packet over the wireless channel. The second number 1, stands for the MAC-id of the sending node, and the third, 2, is that of the receiving node. The fourth number, 800, specifies that the MAC type is ETHERTYPE_IP.
- The next numbers in the second square brackets concerns the IP source and destination addresses, then the TTL(time to Live) of the packet.
- The third bracket concerns the tcp information: its sequence number and the acknowledgement number.

  For sending bulk data cooperative network is better than other network. The first figure shows that it will take 150 ms to complete the whole data transfer. Upto 80 ms it will find the helper node and after that it will transfer data at 11 Mbps and it will take less time.

  But if the cooperative network is not used then the source directly contact with Access Point (AP). Then to send the same data it will take more than 400 ms.

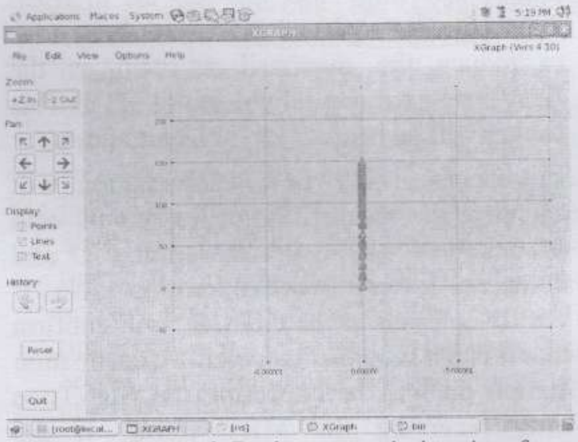

Figure 6: Packet transmission time for CoopMAC +

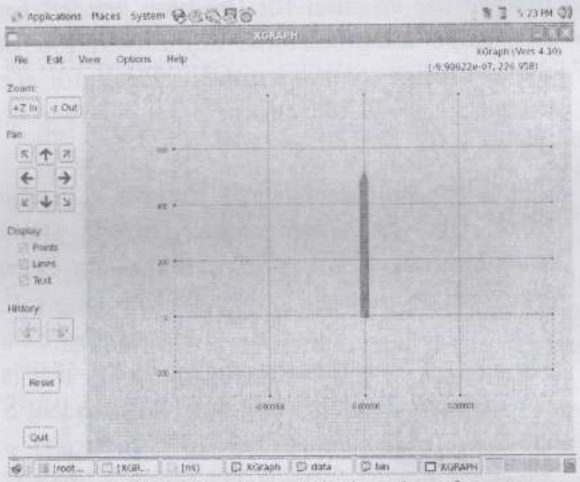

Figure 7: Packet transmission time for non-cooperative

9. Conclusions

In this paper, we have proposed a new MAC protocol for IEEE 802.11b wireless LAN. This scheme is totally compatible with the legacy systems and can extend to higher physical rate systems. The proposed protocol is evaluated via theoretical analysis and the result shows that a throughput improvement using the same physical layer as in IEEE802.11b. For future work, we will need to build a simulator to evaluate the proposed algorithm and apply for the IEEE802.11 a/g. We will also extend the proposed algorithm to Ad-Hoc networks.

References

[1] J. G. Proakis. Digital Communications. New York: McGraw-Hill, 1995.

[2] E. Erkip A. Sendonaris and B. Aazhang. "User cooperation diversity- part I: system description," IEEE Trans. Comm., 51:1927–1938, Nov. 2003.

[3] E. Erkip A. Sendonaris and B. Aazhang. "User cooperation diversity- part II: implementation aspects and performance analysis pp.1939-1948. IEEE Trans. Comm.,51:1939–1948, Nov. 2003.

[4] T. E. Hunter and A. Nosratinia. "Cooperation diversity through coding". In Proc. IEEE ISIT, page 220, Laussane, Switzerland, July 2002.

[5] D. N. C. Tse J. N. Laneman and G. W.Wornell. "Cooperative diversity in wireless networks: efficient protocols and outage behavior." IEEE Trans.Inform. Theory, 50:3062–3080, Dec. 2004.

[6] J. N. Laneman and G. W. Wornell. "Distributed space-time coded protocols for exploiting cooperative diversity in wireless networks." IEEE Trans. Inform. Theory, 49:2415–2425, Oct. 2003.

[7] S. Kumar, V. S. Raghavan and J. Deng,"Medium Access Control Protocols for Ad Hoc Networks: A Survey," Ad Hoc Networks, vol. 4, pp. 326 - 358, 2006.

[8] C. S. R. Murthy and B. S. Manoj, Ad Hoc Wireless Networks: Architectures and Protocols, First ed. New Jersey: Prentice Hall, 2004.

[9] S. Kumar, V. S. Raghavan and J. Deng,"Medium Access Control Protocols for Ad Hoc Networks: A Survey," Ad Hoc Networks, vol. 4, pp. 326 - 358, 2006.

[10] S. V. H. Romaszko and C. Blondia, "A Survey ofMAC protocols for Ad Hoc Networks and IEEE 802.11," in Proc. 4th National Conference MiSSI 2004, Poland, 2004, pp. 23 - 33.

[11] H. Zhai, J. Wang, X. Cheng, and Y. Fang, "Medium Access Control in Mobile Ad Hoc Networks: Challenges and Solutions," Wireless Communications & Mobile Computing, vol. 6, pp. 151 - 170, Mar. 2006

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