A CONTENTION FREE MULTI-CHANNEL MAC PROTOCOL WITH IMPROVED NEGOTIATION EFFICIENCY FOR WIRELESS AD-HOC NETWORKS

Abdalrahman Arafeh [1]), Feras Chikh Oughali [1]), Tarek Sheltami [1]), Ashraf Mahmoud [1]), Khaled Daabaj [2])

Abstract

In this paper we present an Improved Contention-Free Multi-Channel Medium Access Control protocol (ICM-MAC) for wireless Ad-hoc networks. The proposed MAC is based on split phase approach, and uses a single transceiver. Channel negotiations are done on a predefined channel that is used for both control and data transmissions. Nodes contend to get access to the contention-free data period based on their knowledge of their neighbors' activities and the availability of free channels. We evaluate the proposed MAC via simulation and compare with the Multi-channel MAC protocol (MMAC) and Progressive Back Off Algorithm (PBOA) algorithms.

1. Introduction

Wireless ad-hoc networks are collections of nodes that communicate over wireless channels. Each node transmits data over shared medium. Since the emergence of wireless ad-hoc networks, many efforts have been made to increase its performance by reducing the loss of data packets caused by undesirable collisions. Many MAC protocols were introduced to avoid collisions and increase throughput. IEEE 802.11 is the widely used single-channel MAC protocol which uses CSMA/CA as a mean for medium access. However, as network size increases, the performance of single-channel MAC protocols decreases. Other single channel protocols, such as PBOA (Progressive Back Off Algorithm) and PRUA (Progressive Ramp Up Algorithm) [11] were proposed to improve the throughput of single channel MAC.

The ICM-MAC protocol proposed in this paper uses single radio transceiver. It is based on split phase negotiation strategy, hence synchronization is required. The control channel used for negotiation is utilized in data transmission after a negotiation period. The data transmission period is a contention-free period.
The rest of this paper is organized as follows. In Section II, the related work is presented. In Section III, details about the proposed MAC are discussed. Section IV evaluates the performance of the proposed MAC. Finally, Section V provides the conclusion of the paper.

2. Related Work

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[1] Collage of Computer Science and Engineering, King Fahd University Of Petroleum & Minerals, Dhahran 31261, KSA {arafeh, foughali, tarek, ashraf}@kfupm.edu.sa

[2] School of Information Technology, Murdoch University, Perth, WA 6150, Australia. k.daabaj@murdoch.edu.au

Many efforts have been made in the field of multi-channel MAC protocol for wireless ad hoc networks and wireless sensor networks WSN. The motivation of all these efforts is to achieve a high throughput in a large scale networks. The use of multiple channels offers great potential for having simultaneous transmission pairs and avoiding energy wastes. Many multi-channel MAC protocols have been proposed and categorized based on channel selection and channel negotiation strategies. Multiple channels can be negotiated using Dedicated Control Channel (DCC) [5], time division, or channel hopping [6]. Other protocols have used two transceivers [7][8], for control and data transmission [1][9][10]. Demand Channel Assignment (DCA) protocol [3] divides bandwidth into one control channel and n data channels. Each mobile host is equipped with two half-duplex transceivers. One of which operates on the control channel to exchange control packets, while the other is used for data transmission on the selected data channel. This protocol alleviates the missing RTS/CTS and hidden-terminal problems, but at the expense of more hardware and increased energy consumption. Another MAC protocol, that outperforms DCA, is MMAC [4].

The MMAC is a split phase multi-channel medium access control protocol where a single half-duplex transceiver is utilized. The protocol exploits the ad-hoc traffic indication message (ATIM) window and a control channel for channel negotiation. Each host maintains a preferred channel list (PCL) which indicates the preferred channels. The control channel is also used for data transmission outside the ATIM window. However, data transmission period is not a contention-free period. Nodes still need to contend within the selected data channel for data transmission. This means more overhead is encountered in the period assigned for data transmission. As the number of nodes pairs assigned for a certain channel increases the contention increases, and fewer data packets will be sent during data transmission period.

3. ICM-MAC Protocol

The main motivation for ICM-MAC is to make nodes arrive at informed decisions based on their awareness of the network channels utilization. The use of fixed RTS-CTS-RES rounds eliminates the hidden terminal problem in Multi-Channel MAC. Furthermore, nodes balance their access to the contention medium based on the success probability of this access.

3.1. Main Features

ICM-MAC protocol uses a single half-duplex radio transceiver. It operates based on split phase negotiation strategy, hence synchronization is essential and assumed to be maintained. Each frame is divided into two periods. The first is a contention period associated with a predefined control channel and the second is a contention-free data period. The contention period is divided into many RTS-CTS-RES rounds. Nodes can start negotiating for channels by contending at the beginning of each round. In the contention-free data period, the predefined control channel is used along with other channels for data transmission.

The only packets in this period are data packets and their acknowledgments ACK as depicted in Figure 1. Data transmission period is fixed; thus, the size of data packets has a certain limit and no extra control is required.

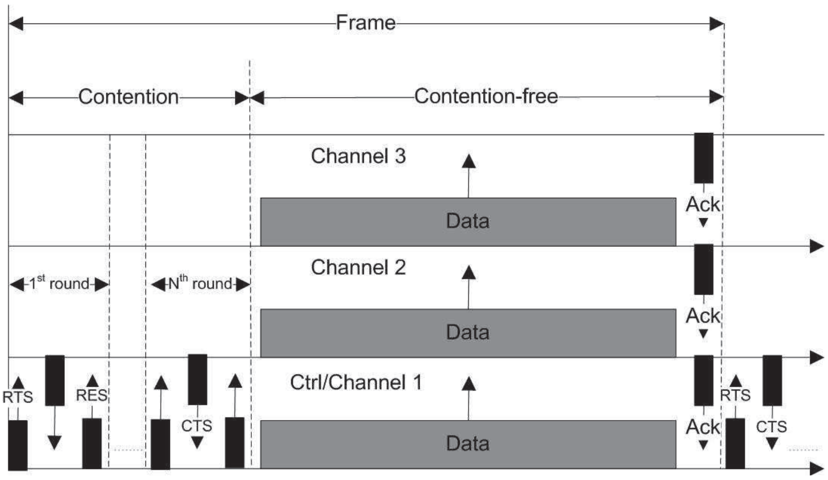

Fig. 1. ICM-MAC Channel Negotiation & Data Exchange

3.2. Description

- Each node maintains a Channels Status List (CSL) that indicates which channels are available to use for data exchange. First, the status of all channels is set to idle, and then it is updated as negotiations among nodes take place. Nodes that do not have a full picture about the status of channel availability will not contribute in the remaining rounds.
- Nodes that have packets to be sent start to contend in the contention period with initial back off value in order to alleviate collisions that might take place in the first round of RTS-CTS-RES. If a collision happens nodes either back off for a random number of rounds, or become silent. In effect these terminals stop contending.
- In the RTS packet period, the transmitter includes its channel list status to the receiver; indicating the channels used by its neighbors.
- After receiving RTS packet, receiver starts the channel selection process depending on its CSL and the transmitter's CSL. Details about the selection criteria are discussed later.
- When a data channel selection is made, a CTS packet is broadcasted including the selected data channel. All of the receiver's neighbors update their CSL accordingly.
- A RES packet is broadcasted by the transmitter to confirm the selected channel. RES packet serves to update the transmitter's neighbors CSL.
- If a node has a packet destined to one of the confirmed nodes for the next data period, it refrains from contention and tries to select another destination based on packets in its queue.
- A node may not receive an update packet during CTS or RES due to collision. This scenario is shown in Figure 2. As this node does not have a full picture of channels status, it remains silent for the rest of RTS-CTS-RES rounds to avoid creating wrong decisions.

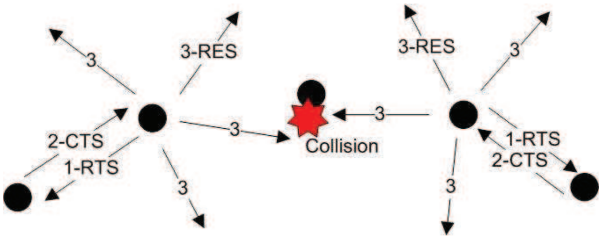

Fig. 2. Update Packets Collision

- While listening to the update packets, each node in the network gains information about channels' status to make an educated decision. If a node has a packet intended for a neighbor, it will contend for this packet and negotiate for a data channel. Negotiation may fails due to one of the following reasons:

  1. There are no available channels at the receiver side.
  2. The channels available at the receiver side don't correspond to the channels available at the transmitter side.
  3. A collision happens that prevented CTS from reaching the transmitter.

  In this case, the node stays contending based on the availability of free channels. The more free channels are available, the higher the chances it has to stay contending for packet transmission. The node picks up a new destination from its queue, if such is available, or it tries to reach the old destination again. Otherwise, the node becomes silent for the remaining contention rounds.

- If any of the contention packets RTS, CTS, or RES haven't been received (due to a collision, lack of channels, or receiver unavailability) the process is considered incomplete. In this case nodes investigate the probability to stay contending, and pick up new destinations if possible.

- Although, power control mechanism is not part of the work presented in this paper, it can be highlighted that nodes may switch to their designated channels after finishing negotiation and apply some power control strategy.

3.3. Channel Selection Criteria

Initially the status of all channels is set to be idle. The transmitter starts with sending its CSL to the receiver encoded in the RTS packet. Upon receiving this list, the receiver tries to find a free channel match between its list and the transmitter's list. If there is more than one free channel, the receiver chooses one arbitrarily. If there isn't any free channel match between the two lists, the receiver discards the request. After choosing a channel, the receiver updates its CSL to indicate that the channel is busy and replies back with a CTS packet including the selected channel to notify the transmitter and all neighbor nodes. The transmitter changes the status of the selected channel into busy in its CSL and includes the selected channel within a RES packet back to the receiver for confirmation and to notify all neighbor nodes. The status of the three available channels is encoded in the three contention packets (RTS, CTS, and RES) to simplify required processing.

3.4. Back-off Mechanism

In order to justify the contention within the negotiation period, a progressive back-off mechanism depending on the number of available free channels is used. When a node does not receive a CTS packet due to collision problem or channel unavailability at the receiver side, the node will have many choices. The probability for this node to stay contending is based on the number of free channels at its side. If it has one free channel out of three, then the probability is 1/3, while if two channels are free, then the probability is 2/3 and so on. Intuitively, the node remains silent if it does not have any free channel. After succeeding to stay contending, the node picks up another packet from its queue with a different destination, if such packet is available andbacks off for a random number of RTS-CTS-RES rounds. This way, nodes which have stayed contending have a better chance to gain access. In addition, selecting another destination gives the node a better chance if its old destination has no free channels.

4. Performance Evaluation

4.1. Simulation Parameters

For all simulation results, we are assuming that nodes transmit with 1 Mbps. Data packets are already generated and available at nodes' buffers. Our simulation uses the same parameters as indicated in reference [7] for PBOA. The duration of each RTS-CTS pair is 80 μsec. The size of data packets is 10 Kbit. In MMAC protocol each ATIM window requires 156 μsec. This time takes into consideration the time required to send 96 bits for RTS-CTS-RES along with 3 SIFS periods and additional time to account for channel propagation delay and receiver's synchronization. The data transmission period in MMAC follows IEEE 802.11 standard [2]. For our ICM-MAC protocol, each of RTS, CTS, and RES is 32 bits in length: 8 bits for local source address, 8 bits for local destination address, 8 bits for channel list status, and 8 bits for packet type, status, and control command. The time required for the transceiver to switch from one channel to another is 224 μsec [2]. Number of channels used is 3.

4.2. Simulation Results

Since the contention period that is being used for channel negotiation has significant impact on the performance of the protocol we consider this factor first. Figure 3 shows the aggregated throughput as a function of number of rounds Figure 3 depicts the change in aggregated throughput versus the number of RTS-CTS-RES rounds and the optimum number of contention rounds in order to accommodate for the data traffic generated by three different networks consisting of 50, 100, and 200 nodes respectively. The size of data packets is 1 Kbit. The presented results are the average of 50 randomly generated networks with the indicated node numbers. Each of the values is an average of 100 simulation result. Simulation time is limited to 10 frames.

It's clear that 20 rounds correspond to the highest throughput that could be achieved. Increasing the number of rounds above this value produces time overhead for contention period over the time required to send the data packets (1000 μsec), thus reducing total throughput. The collision takes place when rounds are less than 20 is preventing node's traffic from being assigned to free channels and thus reducing throughput.

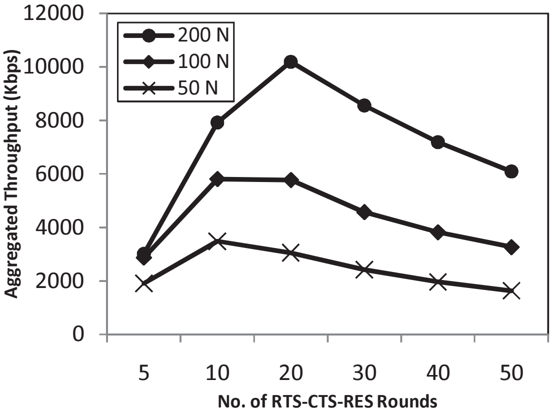

Fig. 3. Aggregated Throughput vs. No. of Contention Rounds for Three Different Networks

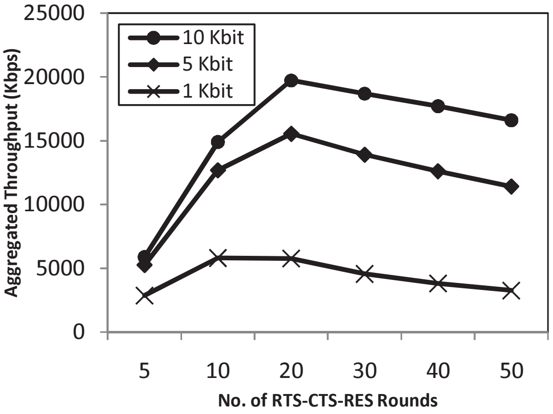

Fig. 4. Aggregated Throughput vs. No. of Contention Rounds for Three Different Packets Size

Figure 4 shows the aggregated throughput for three different packets size with the change of RTS-CTS-RES Rounds. At the optimum value of contention rounds the aggregated throughput increases with the increase of packet size.

The relation between aggregated sent packets and RTS-CTS-RES rounds is shown in Figure 5. This depicted behavior supports the results in Figure 3 by showing that additional RTS-CTS-RES rounds, beyond the optimal number, do not increase the number of sent packets. The saturation shown in the Figure 5 is due to the fact that the maximum concurrent transmissions in the corresponding networks have been reached using sufficient control rounds. Any additional rounds will induce control overhead and only serves to degrade throughput.

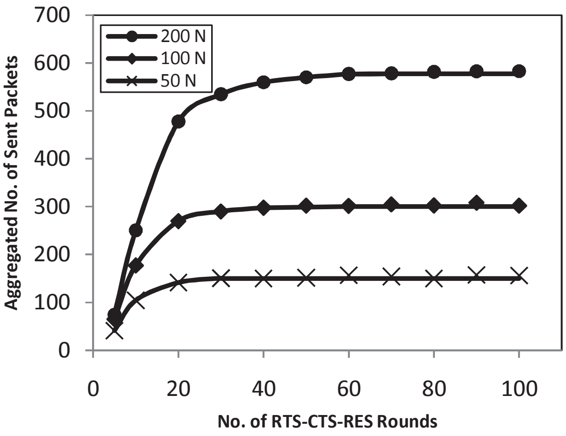

Fig. 5. Aggregated No of Sent Packets vs. No. of Contention Rounds

4.3. Comparison with MMAC and PBOA

The performance of the proposed ICM-MAC is compared to MMAC and PBOA, in terms of aggregated throughput in Figure 6 for networks that range in size between 10 nodes and 200 nodes. Data presented are gathered during simulation time of 1 second. Data packets for both ICM-MAC and PBOA are 10 Kbit. MMAC Data Packets are 4 Kbit.

As networks scales up in size, more nodes are contending for channel selection. In ICM-MAC the back-off mechanism and the spatial reuse reduces collision rate and allow more simultaneous transmissions to be established over different channels. Unlike ICM-MAC, MMAC suffers from contention in data period. As the number of assigned nodes to a certain channel increases, the probability of collision increases, and thus less data packets are sent. In addition, MMAC does not introduce any solution for the update packets collision problem. Thus, more nodes in MMAC are assigned to the wrong channels, which results in reduced performance.

For ICM-MAC and PBOA performance comparison, it can be noted that in ICM-MAC, any pair of nodes that have agreed on channel for data transmission will either be silent for the rest of control rounds or switch to their specified channels. Any further packets intended for power control can be exchanged in these channels and not on the control channel. As a result other nodes in the network will not be deferred from commencing transmissions on control channel. On contrary, locked nodes in PBOA cause their neighbors to have collisions in every successive mini-slot. This variation explains why ICM-MAC outperforms PBOA.

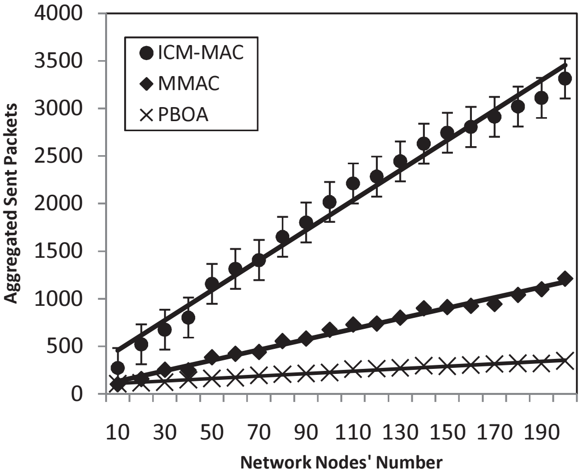

Fig. 6. Aggregated Throughput vs. No. of Network Nodes for ICM-MAC, MMAC, PBOA

5. Conclusion

In this paper an Improved Contention-Free Multi-Channel MAC protocol (ICM-MAC) was presented. The new MAC protocol enables nodes to make educated decisions based on the information from their neighbors. Simulation results demonstrate the importance of the back-off mechanism along with the spatial reuse in boosting throughput and reducing contention. The update packets collision problem have been solved by making the effected node defer from participating in any subsequent contention in order to reduce undesired collisions.

Acknowledgement

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