MULTI CHANNEL MAC FOR WIRELESS SENSOR NETWORKS

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ABSTRACT

In this work, Sensor Multi Channel (SMC) Medium Access Control (MAC) has been proposed for wireless sensor networks. The SMC MAC uses a dedicated control channel and multiple data channels. The effective solution for the multi channel hidden terminal problem and missing receiver problem has been proposed in this work. The performance of the SMC MAC has been compared with that of the single channel CSMA/CA MAC by taking the throughput and latency as performance metrics. It has been shown that the multi channel MAC gives high throughput and less latency in high traffic conditions.

KEYWORDS

Multi Channel Medium Access Control, Wireless Sensor Networks, Multi channel hidden terminal problem

1. INTRODUCTION

Wireless Sensor network is the network of tiny devices which has both sensing and communication capabilities. Nowadays many sensor network hardware platforms like MICAZ, Telos, etc have the RF transceiver which is capable of communicating at different channels which can be dynamically selected from the firmware. The multi channel capability gives another degree of freedom for the medium access in wireless sensor networks. Still multi channel medium access control inherently has some issues which has to be dealt carefully, while doing the MAC design to improve the network performance. In the multi channel MAC design, there are three types of implementations. They are split phase, dedicated control channel and channel hopping. In literature, multi channel MAC has been proposed for system with multiple transceivers and single transceiver. To keep the cost and power consumption low, sensor nodes are equipped with single transceiver. The SMC MAC is proposed for wireless nodes with single half duplex transceiver and it uses a dedicated control channel for the channel negotiation. Multi channel protocol performs better for one to one topology rather than in a star topology or the topologies in which multiple source nodes communicates with a single sink node. In general, In an ad hoc wireless sensor network, multi channel MAC protocol improves the throughput and latency performance as it allows concurrent transmissions in different orthogonal channels. This kind of multi channel MAC is inherently suitable for Wireless Network Control System (WNCS) where Multi channel MAC makes many wireless control loops co exist with each other. This significantly improves the network delay which is the major influencing factor in the system performance in WNCS.

The paper is organized as follows. The section 2 describes the multi channel MAC proposed in the literature and section 3 discusses about the proposed sensor multi channel MAC.

Section 4 discusses about the MATLAB based discrete event simulation of the proposed Sensor Multi channel MAC and section 5 reports the results and discussion on it. Section 6 gives the conclusion of this work.

2. RELATED WORK

In reference [1] a TDMA based multi channel MAC for wireless sensor networks, TFMAC has been proposed. TFMAC requires Time Synchronization and it uses single half duplex transceiver. This protocol divides each channel into time slots and the slot scheduling has been done for the medium access. The frame has been divided into contention access period where the slot scheduling and channel allocation has been done and contention free period where the data transfer has been done. In reference [2] multiple frequency Medium access control for wireless Sensor Networks (MMSN) has been proposed which divides the protocol into two functionalities. They are frequency assignment and medium access. In the frequency assignment, four different techniques are proposed. They are, 1. Exclusive frequency assignment 2. Even Selection 3. Eavesdropping 4. Implicit consensus and the medium access is done by dividing the frame into broadcast contention period (Tbc) and transmission period (TTran) and the node content for the channel for both broadcast and unicast with a non uniform back off. In reference [3] asynchronous multi channel protocol has been proposed. The two issues, information asymmetry and flow in the middle which happens while using CSMA/CA in multihop environment has been stated. The multi channel MC issues such as multi channel hidden terminal problem and missing receiver problem also has been stated. And the bottleneck analysis of dedicated control channel also reported and the theoretical upper bound for the number of data channels for a given channel capacity has been given.

In reference [4] the performance evaluation of multi channel extension of 802.11 MAC has been done. It is stated that the channel assignment can be done by the measurement based method and status based method. In our proposed multi channel MAC protocol we use status based method for the channel assignment and measurement based method for avoiding loss of channel information problem which is prevalent in the multi channel medium access control protocols. In reference [5], a cooperative multi channel MAC (CAM –MAC) has been proposed in which loss of channel information problem can be solved by getting the channel information from the cooperating neighboring node to select collision free channel for communicating nodes. In reference [6] On Demand Channel Switching (ODC) has been proposed for the multi channel medium access control. In this protocol each node will stay in a channel as long as its traffic share in that channel does not go below a threshold value. If the traffic share of the node in a channel goes below the threshold then the node will switch to different channel after broadcasting the switching event. In reference [7], signal strength measurement based channel selection has been done in the proposed multi channel CSMA MAC. In [8] MMAC has been proposed which is a split phase multi channel medium access control protocol, at the starting of the beacon interval in ATIM window, the node which has packets to transmit will negotiate for the channel and if the channel is acquired, then the communicating nodes switch to that data channel and do the data transfer.

3. MULTI CHANNEL MEDIUM ACCESS CONTROL FOR WIRELESS SENSOR NETWORKS

The proposed SMC MAC uses a single dedicated control channel and eight data channels. The SMC MAC has been designed by taking the following points into consideration.

All the nodes are equipped with single half duplex transceiver, which has the capability to switch from one channel to another channel dynamically. The switching can be done via the software control. There are eight control channel and one data channel and the entire channel has equal capacity. The channel switching time is assumed to be negligible and all the channels are orthogonal and non-overlapping.

As a single channel is dedicated for the control packet flow, it creates a bottleneck [3]. It poses a constraint on the number of data channels that can be used in the multi channel MAC. The number of data channels that can be used in a dedicate control channel MAC is given by the following expression by neglecting the back off time [3].

$$M = \frac{T_D + T_R + T_C}{T_R + T_C}$$

Where

T_D DATA and ACK transfer period

T_R RTS packet transfer period

T_C CTS packet transfer period

M Maximum Number of data channels

If the packet transfer period is quantified in bytes for convenience, then the T_D, T_R and T_C in the proposed SMC MAC protocol are 107(100+7), 7 and 7 bytes respectively. By substituting this we get $M \approx 8$.

The Sensor Multi Channel (SMC) MAC is described as follows

1 Initially all the nodes stay in the control channel. The channel negotiation is done via RTS/CTS control packets

2 When a packet arrives in a node, it sends RTS with its channel status. The channel status is an eight bit field in which 0 indicates free channel and 1 indicates busy channel.

3 When the node for which RTS has been transmitted, receives this packet, then it selects the first common free channel for both transmitter and receiver and intimate the selection through setting the corresponding bit in the channel status field. Then CTS is transmitted with this channel status field.

4 After the transmission of CTS packet, transmitting node switches to the selected channel 5 When the CTS packet is received by the intended node, it switches to selected data channel. When the CTS is received by the unintended nodes, the selected channel is marked as busy channel in channel status table. Then the channel is marked as idle channel, after the DATA+ACK transfer period.

6 The DATA and ACK are transmitted in the data channel. After transmission and reception of ACK packet node measures the RSSI for each channel and updates then

Channel status table. Thus the loss of channel information problem is countered. Then the node switches to control channel

Control channel is used as the broadcast channel to support the broadcast which is required for the route discovery process of some routing protocols. The figure below illustrates the channel assignment and data transfer

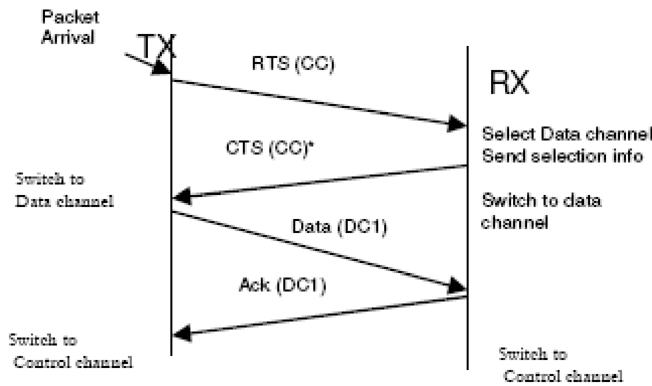

Figure 1. Unicast packet flow in SMC MAC

The following scenario explains how the multi channel hidden terminal problem is solved in SMC MAC. To illustrate the solution, first the scenario, at which multi channel hidden terminal problem occurs, will be analyzed.

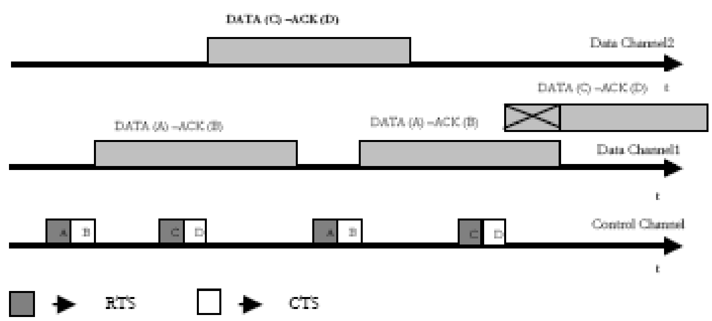

Figure 2. Multi Channel Hidden terminal problem

In this scenario, A transmits RTS and gets CTS from B and gets the data channel for the communication. Then CD gets ch2 at t2 as channel 1 is used by AB. Again AB gets the channel 1 for data communication. Now when CD tries to communicate in data channel 1, collision will occur. This happens due to the loss of channel information for the nodes C, D.

SMC MAC solves this problem by sensing all the channels after the data transfer as shown in Figure 3. In the missing terminal problem shown in Figure 4, the node A tries to communicate to node C by sending the RTS packet, while C is busy in data transfer in channel 2. This problem can be alleviated in SMC MAC by increasing the RTS timeout value, when the transmitter has detected that some data channel has gone to busy state while it was doing its previous data transfer. RTS timeout happens in the wireless environment, due to low SNR for the RTS in the receiver. In the multi channel environment as the data transfer is offloaded from the control channel, the probability of getting high noise (low SNR) in the control channel is low.

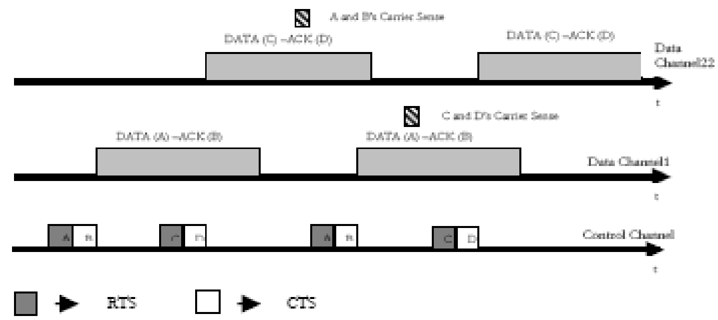

Figure 3. SMC MAC solution for multi channel hidden terminal problem.

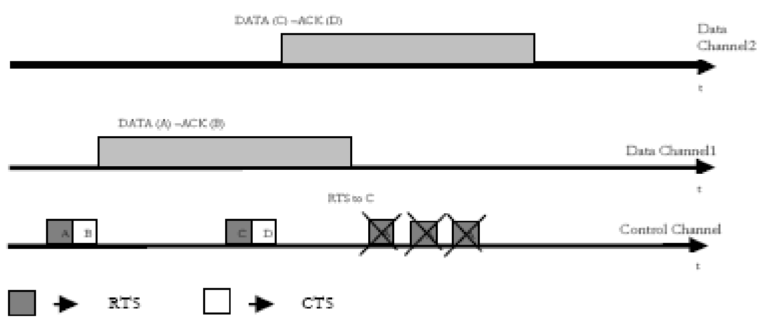

Figure 4. Missing Terminal Problem

4. SIMULATION

A discrete event simulation has been done in MATLAB to analyze the performance of the proposed multi channel MAC. The simulation has been done for the single hop topology. In single hop environment nodes are placed in random and the one to one traffic is given. The simulation is repeated by using packet inter arrival time. Through the simulation the performance metrics, throughput and latency of single channel MAC has been compared with that of SMC MAC.

Table I. Channel Status Table

	Ch1	Ch2	Ch3	Ch4	Ch5	Ch6	Ch7	Ch8
Status	0	1	0	0	0	0	1	1
Tx	-	2	-	-	-	-	4	-
Rx	-	3	-	-	-	-	5	-

0 –IDLE channel; 1 –BUSY channel

In the physical layer log-shadowing radio model is used. CSMA/CA with RTS/CTS and random back off mechanism has been used in the MAC layer. Each node has a channel status table which has the structure shown in Table I. The simulation parameters are summarized in the following table.

Table II. Simulation Parameters

S.No	Simulation Parameters	Value
1.	Number of Data Channels	8
2.	Radio Model	Log-Shadowing Model
3.	MAC Layer	CSMA/CA with RTS/CTS & Multi Channel extension
4	Data rate	115 kbps
5.	Max. Power	+13dBm
6.	Area	30x30m
7.	Topology	Single hop Random Topology
8	$SNR_{threshold}$	+30dBm
9	Size of packets : RTS/CTS/DATA/ACK	7/7/100/7 Bytes
10	$CS_{threshold}$	-70dBm

4. RESULTS AND DISCUSSION

Simulation has been repeated for different values of packet inter arrival time and the network throughput and latency has been observed for various traffic loads.

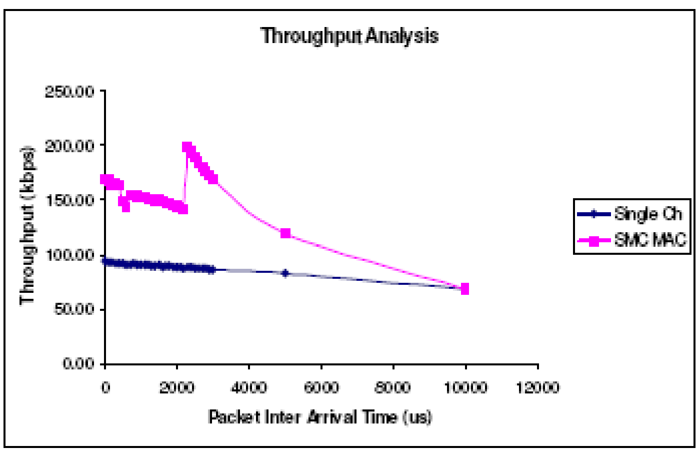

Figure 5. Throughput Analysis

From Figure 5 it is observed that the throughput of the sensor multi channel MAC (SMC MAC) is higher than the single channel MAC during the high traffic conditions. When there is light traffic load, then the performance of the multi channel and single channel MAC are similar. It is observed from the figure 6 that the latency in the high traffic conditions for the SMC MAC is lower than the Single channel MAC.

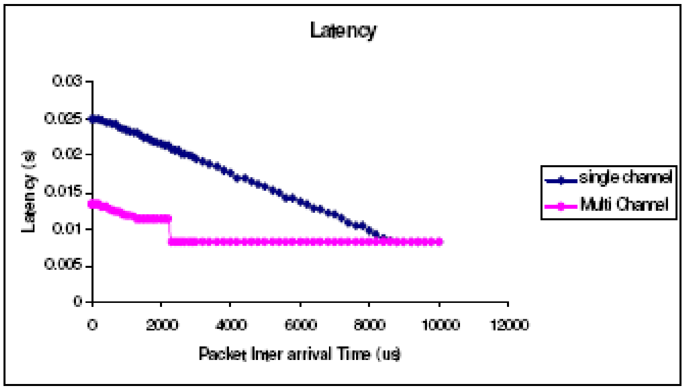

Figure 6. Latency Analysis

In this protocol, a random back off scheme is implemented for the access of the control channel. The contention in the control channel limits the latency performance of SMC protocol in high traffic condition.

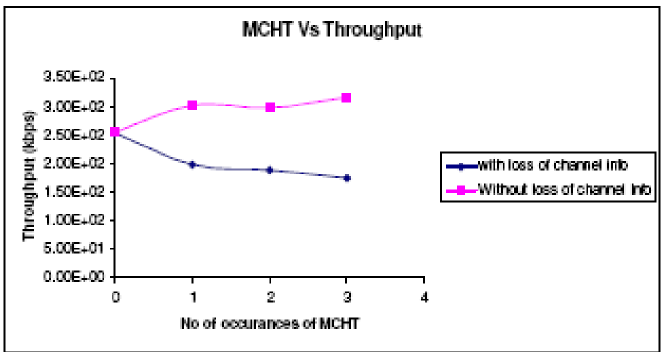

Figure 7. Effect of Multi Channel Hidden terminal Problem on Throughput.

Figure 7 shows the effect of Multi Channel Hidden Terminal (MCHT) Problem on the throughput. Due to the loss of channel information, nodes select the data channel which is busy. This causes the collision of data packets, which decreases the throughput significantly. From the figure 7 it is observed that the carrier sensing to retrieve the channel information helps avoiding the Multi channel Hidden Terminal Problem in SMC MAC.

5. CONCLUSION

In this paper a Sensor Multi Channel (SMC) MAC has been proposed for wireless sensor network. The proposed multi channel protocol uses a dedicated control channel and eight data channels. The contribution of the paper is it combines the status based channel assignment and measurement based channel information retrieval. The paper proposes the scheme to alleviate the issues in multi channel MAC like multi channel hidden terminal problem and the missing receiver problem. By taking the throughput and latency as the performance metric, the performance of SMC MAC has been compared with that of the single channel CSMA/CA with RTS/CTS for various traffic loads. It is observed that the performance of SMC MAC outperforms the single channel MAC in the high traffic conditions.

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