CBH-MAC Protocol for Multihop QoS in Wireless Sensor Networks

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Abstract
This paper proposes an efficient hybrid MAC for multihop QoS protocol in Wireless Sensor Networks for delay sensitive data traffic. We present Contention Based Hybrid MAC (CBH-MAC) protocol for both chain and cross topology, which reduces end-to-end delay, energy efficiency and maximizes the packet delivery ratio by minimizing the contention at the nodes. Here, a node operates the reservation procedure at the contention-based period and reserves a time slot in the adaptive contention-free time. All the neighbor nodes of the sender and receiver receive their own reservation control packets. Once reserved, the sender transmits data and receives ACK packets at the adaptive contention-free time. Since reservation packets occur in nodes along the routing path, the nodes reserve time slots successively in multi-hop. Simulation results show that the proposed protocol has significantly reduced the end-to-end latency and improved other QoS parameters energy efficiency and packet delivery ratio. The performance of CBH-MAC protocol is better than the existing MAC protocols: Hybrid-MAC and Sensor-MAC.

Key words:
Energy efficiency, Contention Based Hybrid (CBH), Hybrid medium-access control (H-MAC), Latency, Reservation Control, Quality of Service (QoS).

1. Introduction

Wireless Sensor Networks (WSNs) consists of a large number of sensor nodes. A sensor node includes a processor, wireless radio and various sensors. After the initial deployment sensor nodes are responsible for self-organizing an appropriate network infrastructure with multihop connections between sensor nodes. It is used in a wide variety of critical applications such as military, environmental monitoring, industrial process monitoring and health-care units etc.. Low communication ranges confirm the dense deployment of sensors and only an efficient Medium Access Control (MAC) protocol can handle a number of medium sharing nodes in a better way and form an efficient infrastructure to establish communication links between nodes. Energy efficiency is a major concern in WSNs, since the batteries cannot be replaced or recharged. In scheduled access, a node can be active only if it is capable of sending or receiving the data.

In WSNs, cross-layer design significantly improves energy-efficiency, because WSNs report data wirelessly across multiple hops to a sink node.

The energy is mainly consumed in MAC protocols when the node is just listening and waiting for a packet to be sent. Traffic in WSNs is very low and is triggered by sensing events which is in the form of bursts[1]. Due to this reason, energy consideration has dominated most of the research at MAC layer level in WSNs[2][3][4]. A long delay is highly undesirable for time-sensitive applications such as critical situation monitoring and security surveillance. For handling real time traffic of event triggering in monitoring based sensor network requires end-to-end latency within acceptable range and the variation of such delay is acceptable[5]. Such performance metrics are usually referred to as Quality of Service (QoS) of the communication network. Therefore, collecting the sensed real time data requires QoS aware MAC protocol in order to ensure efficient utilization of energy resources of the sensor node and effective delivery of the gathered measurements.

In this paper, we propose a new hybrid MAC protocol called Contention Based Hybrid-MAC (CBH-MAC) protocol, which is explicitly designed for WSNs. Almost all hybrid MAC protocols combine two periods, which are contention-based period and contention-free based period. CBH-MAC protocol reserves time slots in contention-based time and nodes transmit data during an assigned slot time using adaptive contention-free access time.

Motivation
Most of the existing MAC protocols for Wireless Sensor Networks are classified into three categories: contention-based protocols, schedule-based protocols and hybrid protocols. The Hybrid-MAC uses channel reservation technique to reduce end-to-end delay for delay sensitive applications. It uses short slotted frame format with small size of data packets to achieve high-energy performance,

Manuscript received July 5, 2012
Manuscript revised July 20, 2012

low delivery latency and improved channel utilization. So, the design of adaptive contention-free access time and contention access protocol is required for the variable traffic load.

Contribution

We have designed a novel CBH-MAC protocol for WSNs, which could be efficiently utilised for real-time and energy efficient applications. Our cross-layer CBH-MAC protocol provides quality of service at MAC layer and good performance interms of self-configuration of the nodes easily, high scalability of sensor nodes, minimizes energy consumption by adapting varying traffic conditions inherent to WSNs, low end-to-end latency and increases Packet delivery ratio.

Organization

This paper is divided into seven sections. Literature Survey is discussed in Section II, Background in Section III. Problem Definition and Implementation in Section IV, and Mathematical Model in Section V. Performance Evaluation is discussed in Section VI and Conclusions in Section VII.

2. Literature Survey

Dam et al., [3] propose an energy efficient algorithm by introducing adaptive duty-cycle that dynamically adjusts the length of active periods according to the traffic load variations. T-MAC is proposed to address the S-MAC nodes not participating in the data exchange. Time-out MAC (T-MAC) protocol is similar to S-MAC, but adaptively shortens the listen period. T-MAC is capable of adapting to traffic fluctuations and outperforms S-MAC. Joseph et al., [4] designed a B-MAC (Berkeley MAC) protocol, which uses an unsynchronized contention-based MAC protocol and long preambles to wake up receivers. In order to reduce the power consumption, B-MAC periodically sleeps and wakesup. The energy and latency performance of B-MAC depends on the preamble length. B-MAC uses the clear channel sensing technique to improve the channel utilization. B-MAC has higher throughput and better energy efficiency than Sensor-MAC and Timeout-MAC.

G. Lu et al., [6] designed an energy efficient and low-latency MAC for unidirectional data gathering tree. Transmission slots are assigned to a set of nodes based on a data gathering tree. When a target node receives the slot, all its children can transmit, thus contending over the medium. As slots are successive in the data transmission path, the end-to-end latency is low. Ye et al., [7] developed a CSMA/CA based protocol, which uses periodic listening and sleeping to save energy consumption in WSNs. In order to reduce latency due to the low-duty-cycle operation, adaptive listening is employed to improve the sleep delay. Chen et al., [8] divide the frame into two slots, each node is assigned one slot for transmission and another slot for wakeup. The TDMA-MAC protocol is collision free for data traffic so reliable transmission is guaranteed for all types of traffic.

Rhee et al., [9] present a hybrid MAC protocol which dynamically switches between CSMA and TDMA depending on the level of contention. Z-MAC is hybrid MAC protocol designed for Wireless Sensor Networks and combines different strengths of TDMA and CSMA protocols. Z-MAC uses the DRAND algorithm to assign each node a time slot to guarantee that no two-hop neighbors share the same slot. Rajendran et al., [10] developed a TDMA-based MAC protocol based on the idea of Neighbor-Aware Contention Resolution. In this approach, each node calculates the priority of its one-hop and two-hop neighbors by applying MD5 (Message-Digest algorithm 5) hash of the concatenation of the node *id* and the time slot *t*. The sensor node with highest priority is the owner of slot *t*.

Syrotiuk et al., [11] combines TDMA and CSMA/CA, to obtain hybrid access scheme that provides good throughput under both low and high traffic loads. Sridharan et al., [12] propose algorithm for assigning time slots in multi-hop network called MMF-TDMA (min-max fairness TDMA). The performance of their greedy algorithm for assigning time slots does not provide an optimal solution. The algorithm ensures that concurrent transmissions occur only at three or more hops. When a new node is added, the algorithm needs to be rerun in order to assure that new node assigns time slot.

Mangharam et al., [13] propose probability TDMA-based protocol to improve throughput, latency and energy consumption. Each node that wants to transmit data periodically sends Hello messages by randomly selecting slots within the contention slot. A Hello message is transmitted using multi-hop to the sink node, which is responsible for network-wide slot assignment. The node is active in its assigned slot(s).

Chen et al., [14] propose PR-MAC (Path-oriented Real-time MAC protocol) used for monitoring applications where data are sent periodically. Once all relaying nodes are contacted, the path is set up and the sink node expects data message to reach in a real-time fashion. Watteyne et al., [15] present a schedule in distributed way designed for linear networks. Alarm messages are transmitted in *"unprotected mode"* as long as there are no collisions. Each node relays message when backoff time proportional to its distance to the sink elapses. In case of collision, the protocol switches to *protected mode*, which avoids collision by channel reservation. Because the unprotected mode allows for faster transmission, the protocol switches back to this mode when possible. This protocol does not require synchronization and constructs schedule in a fully distributed manner.

Kim et al., [16] designed to decrease latency in WSNs, in which nodes are synchronized and reception slots are assigned to each node on a common base channel. It has to send multiple packets to the neighboring nodes, but successive packets are sent each on a different frequency following pre-determined hopping sequence. This hopping sequence starts at the base channel, resulting bursts of messages ripple across channels, significantly reducing latency. Incel et al., [17] propose to enhance TDMA-based L-MAC with multi-channel support. In L-MAC (Lightweight MAC), nodes in 2-hop neighborhood decide on TDMA schedule in a distributed way, assigning different slots to different nodes. The number of potential slots are roughly multiplied by the number of frequency channels. Hence, this protocol allows more nodes to communicate in L-MAC.

Du et al., [18] uses a Pioneer Control Frame (PION) to reserve channel over several hops during the data period, then, it transmits data packet through the reserved channel during the SLEEP period. RMAC can deliver data packet across multiple hops within a single cycle, which not only reduces delivery latency significantly but also handles traffic contention efficiently.

3. Background

In recent years, hybrid MAC protocols have been proposed which incorporates the advantages of both contention-based and TDMA-based MAC protocols. All these protocols divide the access channel into two parts, in which control packets are sent in random access period and data packets are transmitted in the scheduled time. The control channel schedules the data access. Compared to contention-based and TDMA-based MAC protocols, hybrid protocols gain high energy savings and offer flexibility.

Wang et al., [19] propose a hybrid MAC protocol that combines energy-efficient scheme of contention-based and TDMA based MAC protocols for WSNs to improve network performance. H-MAC uses channel reservation technique to reduce end-to-end delay for delay sensitive application by allowing packets to go through multihops with a single MAC frame to reduce the queue delay, highest priority is given to channel access and uses a short frame format to speed up packet delivery ratio.

4. Problem Definition

The energy efficiency and end-to-end latency of a WSNs are interdependent on each other. A node operates the reservation procedure during the contention node and reserves a time slot in the adaptive contention-free time. All the neighbor nodes of the sender and the receiver receive their own reservation control packets. End-to-end latency is minimized significantly with the presence of the reservation packets in the nodes along the given routing path.

4.1 Assumptions

1. All the sensor nodes are static and homogeneous.
2. Nodes are equipped with omni directional antennas.
3. Nodes communicate with each other through packets.

4.2 Objectives

The main objectives of our work is to minimize end-to-end transmission delay, improve packet delivery ratio and minimize the energy-consumption in Wireless Sensor Networks.

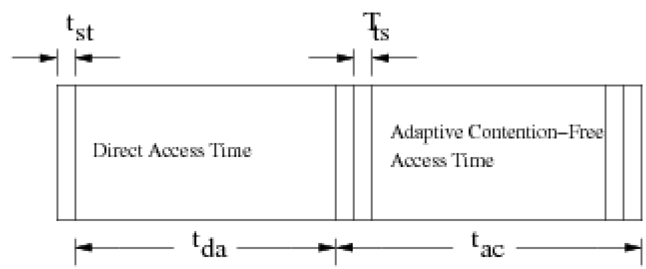

Fig. 1. CBH-MAC Frame Format

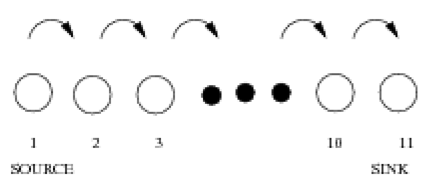

Fig. 2. 10-hop Linear Chain Topology

4.3 Implementation

We assume that sensor nodes are high-end devices and all nodes are synchronized at the initial stage. The frame format of CBH-MAC protocol is divided into three periods, as shown in Figure 1. It consists of sync time t_{st}, direct access time t_{da} followed by adaptive contention-free access time t_{ac}. In this case, a node operates the reservation procedure during the contention-based period and reserves a time slot in the adaptive contention-free time. First reservation control packets are transmitted by all the neighbor nodes of the sender and the receiver receives their own reservation control packets. Once reserved, the sender transmits data and receives ACK packets at the adaptive contention-free time. The reservation packets occur in nodes along the routing path and the nodes reserve time slots successively in multi-hop. The data traffic is transmitted in the order of RTS/CTS/DATA/ACK sequence at the contention-based time through CSMA/CA technique. Moreover, the traffic is transmitted in the same way as slotted CSMA/CA if there are free slots in adaptive contention-free time.

The reservation control packets are allowed in different interface space and small contention window size because the packets are transmitted through contention. The designated nodes must broadcast the slot information of the adaptive contention-free time. The slot information indicates whether the time slot is reserved. The adaptive contention-free time is divided into 12 time slots. Each sending node sends the data, receive ACK packet according to the reservation procedure. If there are free slots in adaptive contention-free time, nodes can contend to acquire the slots by slotted CSMA/CA technique. In this reservation procedure, a node transmits sensor data, thus improving the channel throughput.

Once the reservation procedure has been completed, the source node (one) sends data and receives the ACK packet during the reserved slot time in the adaptive contention-free time. The slot information is very important for reserving nodes to avoid collision. In the contention-based time, reservation packets and RTS packets for sending sensor data will contend for channel acquisition. The protocol gives priority to the reservation control packets more than RTS packet.

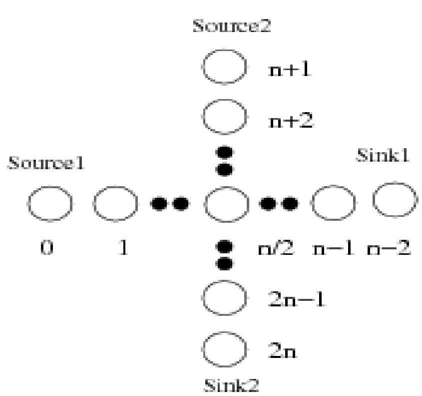

Fig. 3. Multi-hop Linear Cross Topology

The H-MAC protocol [19] has long end-to-end delay and QoS cannot be guaranteed, due to unstable wireless channel and collision among the reservation packets, and nodes do not maintain neighborhood information. In order to solve this problem, specific nodes broadcast the slot information during reservation packet transmission. The specific nodes that send or receive the reservation control packets during contention-based time should broadcast the slot information according to random back-off scheme. The exact reservation will be maintained among the neighbor nodes.

The adaptive contention-free time consists of a number of fixed time slots. The length of a time slot depends on the traffic load. During the free time slots, nodes can transmit data through a slotted CSMA/CA technique. Nodes without sending or receiving data can sleep during the time slots.

Table 1: Notations

Symbols	***Definition***
t_{fr}	Frame length time
t_{st}	Synchronization time
t_{da}	Direct access time
t_{ac}	Adaptive Contention-free access time
N	Number of time slots
T_{ts}	Time of adaptive contention-free access slot
T_d	Data transmission time
T_{ack}	ACK packet time
T_{sifs}	Time of short interframe space
T_g	Time of guard
L_p	Data length
T_b	Time of transmission or receive a byte
T_{cw}	Contention window time
T_{ifs}	Time of interframe space
E[t]	Expected time of a reservation procedure
H_{max}	Maximum number of hops
d_{rate}	Generated data rate
N_{hop}	Number of hops
τ	Transmission probability for a node in any time slot

5. Mathematical Model

In this paper, we analyse the CBH-MAC performance under multihop linear chain and cross topology for different traffic flows. Figure 2 and Figure 3 shows the topology for multihop transmission. We find both optimal direct access time and adaptive contention-free access time for minimum end-to-end latency according to traffic load of the sensor network.

Direct access time is a multiple access technique based on CSMA/CA. The time period of this transmission is called the contention window and consists of a pre-determined number of transmission slots. The node, which enters back-off, randomly selects a slot in the contention window. It also continuously senses the medium until it selects the contention slot. If it detects transmission from some other node during that time, it enters the back-off state again. If no transmission is detected, it transmits the access packet and captures the medium. In Figure 2, node one is a source node that generates data traffic and delivers to sink node eleven through multihop transmission. A multihop design results in better coverage and reduces power requirement as compared to the single-hop sensor network. A multihop Wireless Sensor Network is a collection of sensor nodes that self-configure through multihop routing to form a network. The results of our research show that there is reduced energy consumption and low end-to-end latency by using cross-layer design. We assume processing delay, queuing delay and propagation delay to be negligible at each hop and can be ignored. Efficient scheduling can effectively guarantee quality of service, enable adaptive data rates and minimize end-to-end latency. We study effective scheduling to achieve these goals with respect to CBH-MAC based multihop sensor networks.

Our objective is to minimize the end-to-end latency (*L*) from source node (one) to sink node (eleven). We use variables of the optimization problem to determine the number of time slots in adaptive contention-free access time and length of the direct access time. Hence, the optimization problem is

$$\text{Minimize} \quad \{L\} \qquad t_{da} \geq 0 \tag{1}$$

The notation for the analysis parameters for the performance evaluation is shown in Table I. We define a frame time (t_{fr}) that consists of three parameters, synchronization time (t_{st}), direct access time (t_{da}) and adaptive contention-free access time (t_{ac}). The following equation expresses a total frame time.

$$t_{fr} = t_{st} + t_{da} + t_{ac} \tag{2}$$

The adaptive contention-free access time is divided into *N* time slots. Therefore, adaptive contention-free access time is expressed as the product of *N* and time slot as,

$$t_{ac} = N * T_{ts} \tag{3}$$

One time slot should have enough time to receive and send data packets. As shown in equation (4), T_{ts} is the overall time consumed for data transmission time, ACK packet time, receiving time which is three times of short interframe space time and guard time. Overall time consumed is calculated as,

$$T_{ts} = T_d + T_{ack} + 3*T_{sifs} + T_g \tag{4}$$

where, $T_d = L_p / T_b$

The expected time of a reservation procedure proceeds in the direct access time. In other words, the CSMA/CA technique is used for channel acquisition. The random back-off time for contention follows interframe space *(IFS)* time. The average value of the random back-off time is half of contention window size. The expected time *E[t]* of a reservation procedure is

$$E[t] = T_{ifs} + T_{cw} / 2 + 2*T_{sifs} \tag{5}$$

The maximum number of completed reservation procedure in a frame time, H_{max}, is expressed in equation (6). Reservation procedures is performed in direct access time. So, the maximum number of completed reservation procedures is the value of direct access time divided by expected time of a reservation procedure.

$$H_{max} = [t_{da} / E[t]] \tag{6}$$

The probability of one more hop's transmission during a frame time is possible when the sending node reserves a preceeding time slot than a time slot of the relay node in the adaptive contention-free access time. The transmission probability *P[20][21]* is expressed in equation (7) for each node in any time slot is $\mathcal{T}$. We assume that the number of the unreserved time slots is *m*. If the sending node selects a time slot, the relay node chooses one of the following time slots other than the selected time slot. The probability is independent of the value of *m*.

$$P = [1-(1-T)]^{(m-1)} \tag{7}$$

The probability of one more hop's transmission to find the average hop count of the relayed packets during a frame time. The probability of one more hop's transmission is same regardless of the value of *m*, the average hop count of the relayed packets is expressed as the sum of probability from one hop transmission to maximum hops transmission during a frame time.

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$$E[max_h] = \sum_{H_{max=1}}^{N_{hop}} H_{max} * P^{H}{}_{max} - 1 \qquad (8)$$

Average end-to-end latency (L_{avg}) : The average end-to-end latency in the multihop transmission condition is obtained by first finding the average number of a frame time spent for multihop transmission. The value is that the hop number from a source node to a destination node is divided by the average hop count of the relayed packets. The average end-to-end latency is equal to the product of the average number of a frame time and frame period. The following equation shows the average end-to-end latency as,

$$L_{avg} = [N_{hop} / E[max_h] * t_{fr} \qquad (9)$$

We assume both arrival and service rate are constant and apply D/D/1 queuing model in sensor nodes, where, D/D/1 queuing delay is considered to be negligible. The arrival rate is smaller than the service rate. However, there is waiting delay due to channel contention. The constraint function of direct access time is the product of expected time of a reservation procedure and generated data (d_{rate}) during a frame time:

$$t_{da} \geq E[t] * (d_{rate} * t_{fr}) \qquad (10)$$

The following constraint is the minimum number of time slots, i.e., the generated data during a frame time. The value *N* is integer,

$$N \geq [d_{rate} * t_{fr} + 1] \qquad (11)$$

The optimization problem is formulated as follows:

$$\begin{gathered} \text{Minimize} \quad \{L\} \\ t_{da} \geq E[t] * (d_{rate} * t_{fr}) \\ N \geq [d_{rate} * t_{fr} + 1] \\ t_{da} \geq 0, \text{ and } N \geq 0, \end{gathered} \qquad (12)$$

Optimization end-to-end latency (L_{opt}): The optimal direct access time and number of time slots in each sensor node is calculated according to the data rate from the source node. Hence, the following equation shows the final optimization problem of the end-to-end latency.

$$\begin{aligned} &\text{Minimize} \quad \{L_{opt}\} \\ &= [N_{hop} / E[max_h] + 1] * (t_{st} + t_{da} + N*T_{ts}) \\ &\text{for} \quad t_{da} \geq 0 \text{ and } N \geq 0, \end{aligned} \qquad (13)$$

6. Performance Evaluation

6.1 Simulation Setup

The performance of CBH-MAC has been evaluated using NS2 simulator[22] and compared with S-MAC and H-MAC. The topology that we set up for our simulation model is a ten-hop chain and cross network with source at the first node and sink at the end node as shown in Figure 2 and Figure 3 respectively. In our simulation model, we used two-ray ground reflection model for radio propagation and omnidirectional antenna. Each node is situated at a distance 200 metres from adjacent node and carrier sensing range is 550 meters.

Table 2: Simulation Parameters

Parameters	***Value***
Receiving Power	0.5 watts
Transmission Power	0.5 watts
Idle Power	0.05 watts
Sleeping Power	0.001 watts
Simulation Run Time	1000s
Channel Bandwidth	20 kbps
Channel Coding	Manchester
S-MAC	10% duty cycle

6.2 Simulation

In our simulation, the following performance metrics are considered to evaluate the QoS in CBH-MAC networks.

1. *Average End-to-End delay:* It indicates the length of time taken for a packet to travel from the CBR source to the destination. It represents the average data delay an application experiences when data is transmitted.
2. *Packet Delivery Ratio (PDR):* It is the ratio between the number of data packets that are sent

by the source to the number of data packets that are received by the sink.

3. *Energy Consumption:* It is the ratio of total energy consumed during the simulation to the total number of nodes in the network.

The two types of scenarios used in our simulations are Multi-Hop Chain Topology and Multihop Cross Topology.

1. Multi-hop Chain Topology

Figure 2 shows chain topology, which consists of a single source node one, a single sink node eleven, with intermediate nodes addressing packets and relaying them in the direction of sink node eleven. All nodes are equally spaced in a straight line and neighboring nodes are placed 200 metres apart. One single Constant Bit Rate *(CBR)* flow sends packets from source node one to sink node eleven. The length of the chain varies from 1 to 14 hops. The chain topology helps us to study the protocols for multi-hop delivery.

2. Multi-hop Cross Topology

Figure 3 shows cross topology. Two straight chains of nodes cross each other at the center node. Both chains are of the same length and single node at the crossing point is shared by the two chains. All the neighboring nodes are placed 200 meters apart. There are two CBR flows, each along one chain of nodes.

6.3 End-to-End Latency

End-to-End latency plays a very important role in Wireless Sensor Networks. It refers to the total time taken for a single packet to be transmitted across a network from source node one to sink node eleven. There are many factors affecting the end-to-end latency, among them the routing path and the interference level.

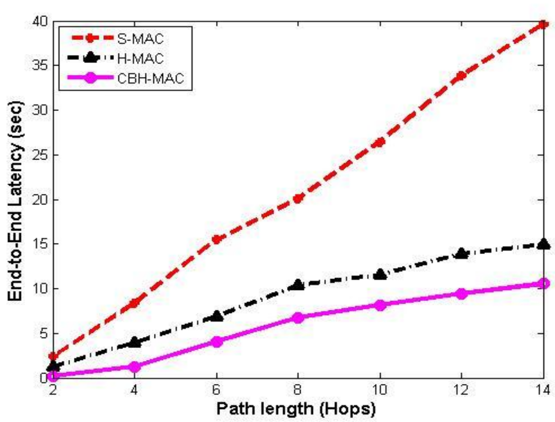

Fig. 4. End-to-End Latency in a 10-hop Chain Topology

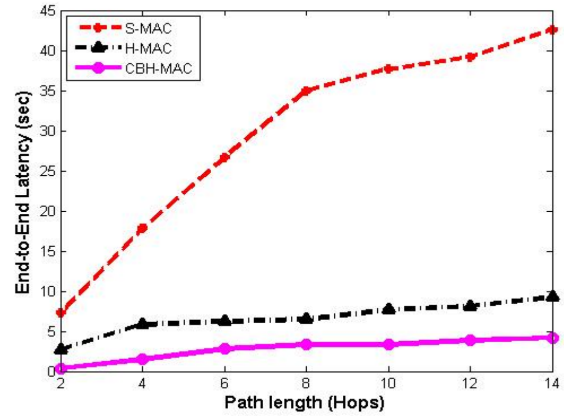

Fig. 5. End-to-End Latency in a 10-hop Cross Topology

Figure 4 shows performance of end-to-end latency with varying number of hops. For the multi-hop chain topology, end-to-end latency in S-MAC, H-MAC and CBH-MAC increases as the number of hop length increases. However, end-to-end latency in S-MAC increases at a much faster rate, because it has a shorter duty cycle. H-MAC uses a short slotted frame format in which slots are dynamically shared. CBH-MAC outperforms both H-MAC and S-MAC. In addition, our proposed CBH-MAC protocol makes shorter end-to-end latency due to low collision rate of the reservation control packets. It stabilizes the sensor data traffic transmission through reservation of time slots in adaptive contention-free access time.

Figure 5 shows the end-to-end latency results of S-MAC, H-MAC and CBH-MAC in the multi-hop cross topology. Traffic contention is much less important for CBH-MAC compared to H-MAC and S-MAC. CBH-MAC transmits packets quickly through the contention area, thus avoiding collisions. As shown in Figure 3, the two sources generates CBR traffic simultaneously and flows through the intersection of the two chain topology without collision. Thus, both the data packets are delivered to their sink nodes respectively. We present our simulation results End-to-End latency and compare them with the mathematical model as designed in Section V.

We have designed chain and cross topology by setting different hops, packet size and packet arrival interval to evaluate the performance of CBH-MAC networks. For analysis purpose, we have used only cross scenario, which consists of two sources which simultaneously generate their CBR traffic to intentionally create channel congestion at the intersection of two chains. From the results shown in Figure 6, our simulation results agrees with the analysis quite well, since (i) Each CBH-MAC node operates the reservation procedure and (ii) Reserves time slot in adaptive contention-free successively in multi-hop node.

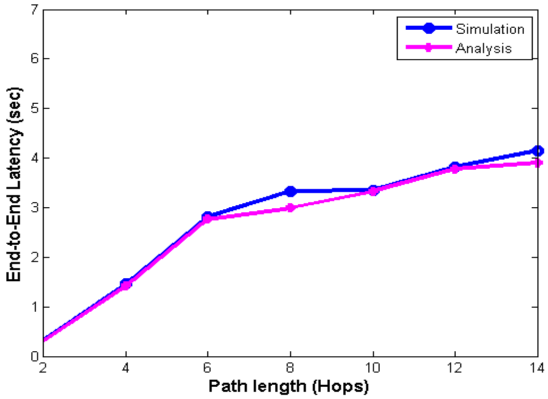

Fig. 6. Simulation versus Analytical results in a 10-hop Cross Topology

6.4 Packet Delivery Ratio (PDR) Performance

Figure 7 and Figure 8 shows performance of the packet delivery ratio under different packet arrival intervals (sec) in chain and cross topologies. The packet arrival intervals is varied from 1 packet per second to 1 packet per 40 second to evaluate the network performance of CBH-MAC, H-MAC and S-MAC. As the number of packet arrival intervals per second increases, nodes can control a time slot. After 10 second packet arrival intervals, CBH-MAC performs very close to 100% maximum packet delivery ratio and packet delivery ratio is poor before 10 second packet arrival intervals, packet loss is due to the collisions that may occur.

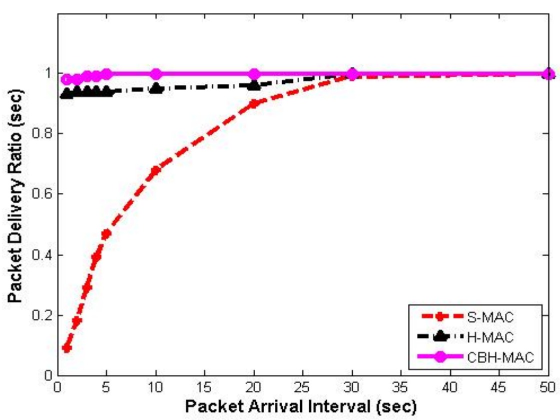

Fig. 7. Packet Delivery Ratio in a 10-hop Chain Topology

In Figure 7 and Figure 8 our simulation results shows that CBH-MAC is higher delivery ratio than H-MAC and S-MAC. CBH-MAC protocol supports fast packet delivery ratio is important for when the topology experiences heavy traffic load. For example, when an event occurs within an area, the nodes in this area may simultaneously report the event's data, which dynamically creates heavy traffic. Figure 8 shows that CBH-MAC significantly reduces packet collisions under high traffic load.

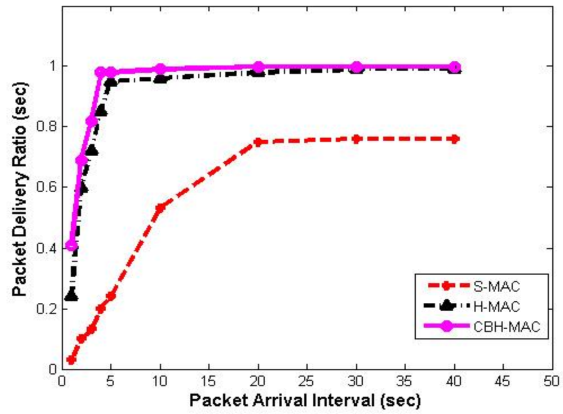

Fig. 8. Packet Delivery Ratio in a 10-hop Cross Topology

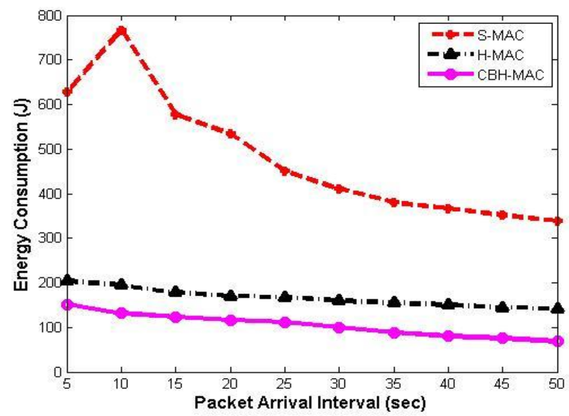

Fig. 9. Energy Consumption in a 10-hop Chain Topology

6.5 Energy Consumption

We varied our traffic load by varying the packet arrival interval time. If the simulation has multiple packets to send for the chain and cross topology, each CBR flow generate traffic load at the rate of 1 packet for every 5 seconds. As the packet arrival interval time increases, H-MAC and S-MAC increase their energy consumption, but

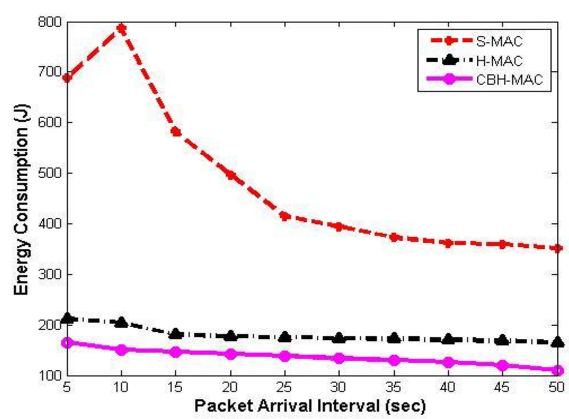

Fig. 10. Energy Consumption in a 10-hop Cross Topology

CBH-MAC has a smaller rate of increase than other two protocols. S-MAC node consumes less energy at packet arrival interval of time 5sec than that of arrival time of 10sec as shown in Figure 9 and Figure 10. Since, more packets are dropped at nodes due to collision at increased traffic loads, so the MAC layer does not cache more than one packet. CBH-MAC is more energy efficient than H-MAC and S-MAC. Both H-MAC and S-MAC consume more energy in cross topology than in chain topology, due to difference in contention handling by the two protocols. As shown in Figure 11, it is observed that the nodes remaining energies in CBH-MAC are more evenly distributed than in both S-MAC and H-MAC. Therefore, CBH-MAC is efficient in contention handling, due to the reservation of time slots in adaptive contention-free access time and hence, increases the network lifetime.

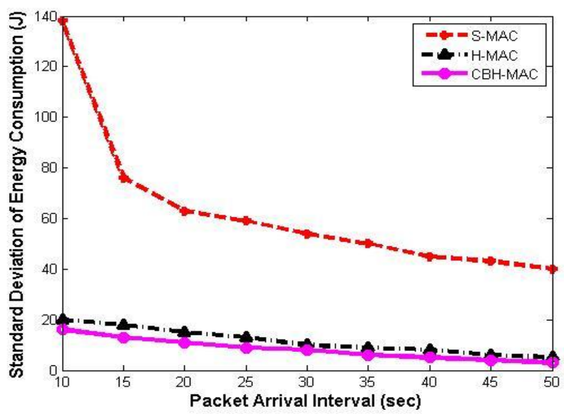

Fig. 11. Standard Deviation of Energy Consumption in a 10-hop Cross Topology

7. Conclusion

This paper presents CBH-MAC protocol for both chain and cross topology, a hybrid medium access control protocol specifically designed for Wireless Sensor Networks. It reduces the end-to-end latency in Wireless Sensor Networks for delay sensitive data traffic QoS support for multihop routing in WSNs. In this case, a node operates the reservation procedure during contention-based period and reserves a time slot in the adaptive contention-free time. All the neighboring nodes of the sender and receiver receive their own reservation control packets. The reservation packets occur in nodes along the routing path. As a result, nodes reserve the time slots successively in multi-hop path. Simulation results demonstrate that the proposed protocol has significantly reduces end-to-end latency and improves other QoS parameters *i.e.*, energy efficiency and packet delivery ratio.

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