

# Cluster Based Time Division Multiple Access Scheduling Scheme for Zigbee Wireless Sensor Networks

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## ABSTRACT

In IEEE 802.15.4 ZigBee Wireless Sensor Networks, an efficient scheduling mechanism is required for reliable data transmission. Further, concurrent transmission of huge data through CSMA/CA incurs more packet collision rate. This complicated condition has to be eliminated to improve the system throughput. In this study, we propose to deploy cluster based TDMA scheduling mechanism for IEEE 802.15.4 ZigBee Wireless Sensor Networks. This TDMA slot allocation strategy allocates slots to the nodes based on queue occupancy information. It assigns TDMA slots starting from nodes with high queue occupancy value. Nodes that have high queue occupancy value will probably get long TDMA slot period. We prove the proficiency of our mechanism using Network Simulator 2 (NS-2). Our approach fairly allocates slots to the nodes and considerably reduces packet collision rate.

**Keywords:** IEEE 802.15.4 ZigBee Wireless Sensor Networks, TDMA, CSMA/CA

## 1. INTRODUCTION

### 1.1. IEEE 802.15.4 ZigBee Wireless Sensor

A set of nodes that are organized in a mutual network is termed as wireless sensor network. In this network, a hundreds or thousands of sensor nodes are deployed in a compact way to carry out the process of sensing, wireless communication and computation. Some of the limitations in WSNs arise due to the factors such as memory, low-power consumption, fault-tolerance, low-latency and coverage. The applications of WSN are military field, public safety, medical, surveillances, environmental monitoring, commercial applications, habitat and tracking.

A group of protocol, which is established based on IEEE 802.15.4 wireless communication standard, is termed as ZigBee. It is the short-range wireless networking that contains low latency and low cost and

consumes minimum power. It offers transfer rate equal to 256 Kbps at 2.4 GHz within 10 m (Kaur and Ahuja, 2011). It is favorable standard for wireless sensor applications with regards to energy efficiency and communication overheads (Huang *et al.*, 2012). The applications of ZigBee are mainly cost sensitive concerned with industries, home building control, automation, security, PC peripherals, medical monitoring IP (Anitha and Chandrasekar, 2011).

The main advantages of ZigBee are as follows:

- It offers secured and reliable data transmission
- It offers easy and flexible network configuration
- It has low equipment costs and long-lasting batteries
- It offers exclusive characteristics such as redundancy in communication

The three types of devices used in ZigBee are described below.

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## 1.2. PAN Coordinator

The coordinator along with the process of relaying the packets, has capability of generating the network, exchanging the parameters such as network Identifier (ID), synchronization frame which is utilized by other nodes for communication and transmitting the network management commands.

## 1.3. Router

The routers are engaged in relaying the packet towards the intended destination when there is a lack of direct communication link.

## 1.4. End Devices

The end devices just perform the collection of data values from all sensors, adding the data to the appropriate packet and transmitting it to the destinations. They are also termed as Reduced Function Devices (RFDs) (Medagliani *et al.*, 2011).

Clustering and Scheduling in ZigBee Wireless Sensor Networks: The process of grouping nodes by which the data from sensor nodes of a group is compressed and send in dense manner is termed as clustering. In WSN, the cluster is a group of sensor nodes with one node acting as cluster head and remaining nodes acting as member nodes. The group may either exhibit overlapping or non-overlapping scenario. By clustering, load balancing and in-network data aggregation can be achieved. It also minimizes battery power of individual sensor nodes by minimizing the exchanged communications.

In ZigBee sensor networks, the term scheduling refers to allocation of active period to each node and thereby avoiding possible beacon collision. An efficient beacon-scheduling algorithm must avoid overlapping of active periods (Yen *et al.*, 2012). In emerging more scheduling algorithms, we consider the following two algorithms.

## 1.5. Power-Aware Real-Time Message Scheduling Algorithm (PARM)

In wireless networks, this algorithm reduces the power consumption for real time services. PARM encompass of two controllers namely admission controller and energy consumption controller and it includes a scheduler. Admission controller controls the admission of flow and rejects if it does not have a feasible solution. Conversely, Energy consumption controller controls the energy used by messages. Finally, the scheduling is accomplished based on Earliest Deadline First scheduling algorithm (Alghamdi *et al.*, 2005).

## 1.6. Sleep/Wakeup Scheduling in Multi-Hop WSNs

In this scheduling algorithm, nodes are organized as a tree and transmission is traversed from the source to the sink. This algorithm is defined by the communication period, which is the time interval between node collect and report data. Active period is the time interval when the node is awake. The level of contention and collision depends directly on active periods of nodes. By using this scheduling algorithm, nodes can communicate proficiently with low energy consumption.

## 1.7. Previous Work

In our previous study, (Meenakshi and Anandhakumar (2012) we have proposed a fuzzy based energy efficient clustering technique for ZigBee sensor networks. In this technique, fuzzy rules are formed on the input variables number of hops, residual energy, received signal strength and node degree and node rank is obtained as output. The node with highest rank is chosen as cluster head. When the sensor nodes want to transmit the data to the sink, it is compressed in the cluster head and then forwarded to the sink. During the cluster maintenance phase, the node rank is estimated for every time period T. When the rank of existing cluster head reduces, the node with highest rank is selected as new cluster head.

However, for reliable data transmission and increasing throughput, an efficient scheduling technique is required. Therefore, as an extension work, we propose to design a hybrid scheduling mechanism for IEEE 802.15.4 ZigBee Wireless Sensor Networks.

## 1.8. Related Works

Wafar and Shahla (2009) have proposed a novel scheduling algorithm for WMSNs. Their algorithm divides the frame sent from the cluster-head to the Base Station (BS) into slots and gives a percentage of these slots into each node. The Base Station (BS) sends a certain query to the cluster-head. Upon receiving query, the cluster head will propagate it to specified nodes and wait for these nodes to sense the medium and come back with needed data. The nodes will respond by sending packets of data to the cluster-head. The job of the cluster head is to schedule these packets coming from different nodes to send them in frames to the BS. One of the advantages of this algorithm is that it is derived for a multi-user network and it is shown to converge to the optimal schedule. Another advantage is that the setting is realistic and thus it is feasible.

Anastasi *et al.* (2010) had proposed several sleep/wakeup strategies for multi-hop WSNs, which are used for energy conservation. In sleep/wakeup scheme, the nodes in the network can communicate efficiently and with low energy expenditure. In this scheme, the network is organized as a tree and the traffic flows from sensor nodes to the sink, which is one of the most common cases in WSNs. Each sleep/wakeup scheme impact on the level on contention and collisions, depending on the way active periods are arranged among nodes. Staggered schemes reduce contention, since nodes do not relay the messages immediately, but they rather forward them according to the routing tree, i.e., only during the active period shared between a node and its parent.

Salhi *et al.* (2010) have proposed CoZi, a new packet scheduling mechanism for large scale ZigBee networks. CoZi aims at enhancing the reliability of the data delivery and the bandwidth utilization of the network. CoZi is a distributed packet scheduling, which is based on simple network coding at intermediate nodes to offer better bandwidth utilization and reliable communications with extremely negligible network overhead. Using clever topology inferring from ZigBee signalization messages, this mechanism helps to perform more optimized coding decisions in order to allow a larger range of decoding nodes whether for routed or dissemination based ZigBee sensor networks. CoZi can be included in sleep-awake mechanisms for better energy efficiency.

Tamilselvan and Shanmugam (2011) have proposed an adaptive transmission power aware cluster scheduling algorithm using multiple channels in a WPAN in the presence of WLAN interference. Their algorithm includes node identification, channel allocation, clustering and time scheduling. Their approach is more effective in an IEEE 802.15.4 cluster-tree network in the presence of multiple IEEE 802.11 interferers.

## 2. MATERIALS AND METHODS

### 2.1. Overview

In this study, we propose to deploy a hybrid scheduling mechanism for IEEE 802.15.4 Zigbee Wireless Sensor Networks. Our mechanism is hybrid that we design to implement both CSMA/CA and TDMA channel access schemes. In our mechanism, nodes in the network form clusters and cluster heads are directly connected to the coordinator. The cluster head estimates channel consumption level for every contention access period. When the channel consumption level becomes less than minimum threshold value, the Cluster Head (CH) forwards this information to the coordinator. While receiving channel consumption information, the coordinator checks the packet collision rate of the flow

with two threshold values as maximum and minimum. Once, the collision rate crossed the maximum threshold value, it invokes the TDMA slot allocation strategy. The coordinator accumulates the queue occupancy value of nodes and organizes them in the descending order. It assigns TDMA slots starting from nodes with high queue occupancy value. Nodes that have high queue occupancy value will probably get long TDMA slot period. Then, the coordinator sends this TDMA assignment statement to the CH. Based on TDMA assignment statement the CH allocates slots to the nodes.

### 2.2. Network Architecture

In our model, sensor nodes are grouped by clusters and cluster head is selected based on its rank. The rank is estimated using fuzzy logic and it takes received signal strength, residual energy and node degree as input parameters. Cluster formation and cluster head selection are described in our previous work (Meenakshi and Anandhakumar (2012)). In this work, consider the Cluster Heads (CHs) are connected to the coordinator. The coordinator is responsible for scheduling time slots to the nodes. As we consider 802.15.4 ZigBee Wireless Sensor Network with beacon-enabled nodes, accessing the network is made possible through Carrier Sense Multiple Access with Collision Detection (CSMA/CA) and Time Division Multiple Access (TDMA). **Figure 1** illustrates the network architecture.

### 2.3. Estimation of Metrics

#### 2.3.1. Measurement of Queue Occupancy (QO)

The Queue occupancy of a node is measured using Eq. 1 as follows:

$$QO(i) = \frac{nQ}{Q} \tag{1}$$

Whereas,

- QO (i) = Represent the queue occupancy of node i,
- nQ = Denote the number of packets in queue,
- Q = Stands for maximum size of the queue.

#### 2.4. Measurement of Channel Consumption (CC)

The average channel consumption can be measured by considering used and collided slots. The Channel Consumption (CC) is given using Eq. 2:

$$CC = \frac{nUS - nCS}{S} \tag{2}$$

where, nUS represents the number of used slots, nCS signifies number of collided slots and S is the total number of slots in the network.

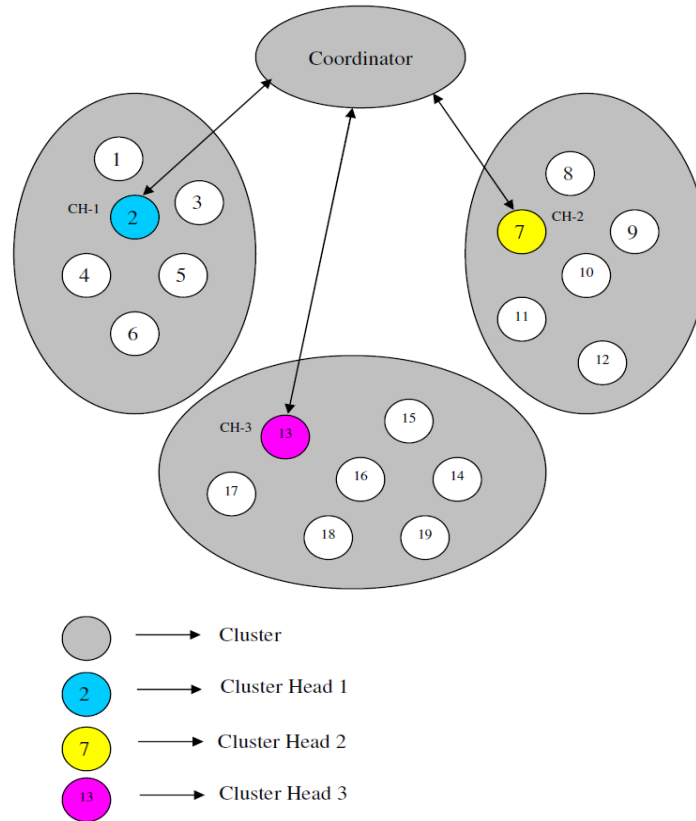


Fig. 1. Network Architecture

**2.5. Queue Occupancy (QO) Information**

Each Cluster Head (CH) in the network contains an array to store queue occupancy information of nodes, it is known as QO array. This contains multiple cells and each cell corresponds to the QO value of single sensor node. The format of QO array is shown below in **Table 1**

Each node measures its Queue Occupancy (QO) value and appends in its data packet. During data transmission, the CH gathers QO information from the node and keep track in QO\_array. While scheduling TDMA slots, this information is forwarded to the coordinator by the cluster head.

**TDMA Scheduling in ZigBee Wireless Sensor Networks:** Initially, data transmission is performed through CSMA/CA. Since, our approach is a hybrid-scheduling algorithm; it considers Channel Consumption (CC) as a metric to trigger the TDMA slot allocation. For every Contention Access Period (CAP), the CH measures the Channel Consumption (CC) using equation-2 and forwards it to the coordinator.

Upon receiving the CC value, the coordinator compares it with  $minTh_{cc}$ , which is the minimum channel consumption threshold value. Once the computed CC value becomes less than  $minTh_{cc}$  value, the coordinator triggers the TDMA slot allocation strategy by intimating corresponding CH.

**Algorithm-1**

```

If (CC > minThcc)
Then
Transmission is continued in CSMA/CA
Else if (CC < minThcc)
Then
TDMA Slot Allocation Strategy is invoked
End if
End if
    
```

**Table 1.** Format of queue occupancy array

Node ID	Queue Occupancy Value (QO)
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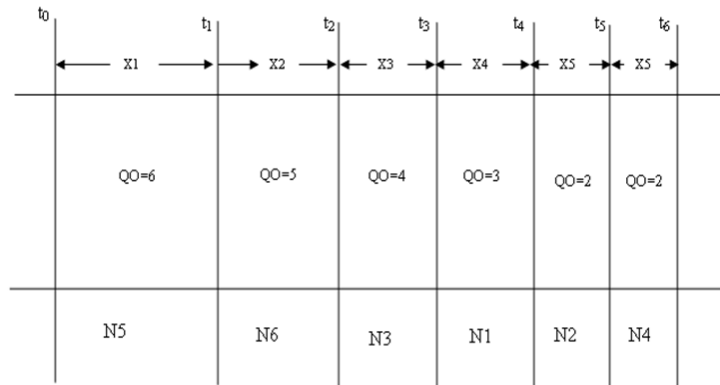


Fig. 2. TDMA Slot allocation strategy

### 2.6. TDMA Slot Allocation Strategy

TDMA slot allocation is performed as follows:

- When the computed CC is less than  $minTh_{cc}$ , the coordinator transmits GEN-TDMA (Generate TDMA) message to the corresponding CH
- While receiving the GEN-TDMA message, the CH monitors the packet collision rate in CAP and forwards back the information to the coordinator. This rate is evaluated against two predefined threshold values namely  $minTh_C$  and  $maxTh_c$  to allocate TDMA slots
- If packet collision rate is less than  $minTh_C$ , then the coordinator does not allocate TDMA slots. On the other hand, if packet collision rate is greater than  $maxTh_c$ , then the, CH sends the QO array information to the coordinator
- The coordinator retrieves the QO\_array and organizes it in the descending order of their QO values
- TDMA slots are assigned to the nodes in descending order of their QO values. (i.e) node that has high QO value will be assigned first and will have long TDMA slot period (X) vice versa. Such that, TDMA slot period will take the form of,  
 $X_1 > X_2 > X_3 > \dots > X_n$
- The TDMA assignment schedule is sent to the corresponding CH by the coordinator
- The CH allocates the slots to the nodes according to TDMA assignment schedule

Once TDMA slots are assigned to the nodes, it will transmit data through TDMA channel and not through CSMA/CA. Thus, the number of nodes accessing CAP is reduced and it decreases the collision rate. The TDMA slot allocation strategy is given in Algorithm-2.

#### Algorithm-2

Let  $minTh_C$  be the minimum threshold value of collision rate

Let  $maxTh_c$  be the maximum threshold value of collision rate

Let  $CR_i$  be the packet collision rate in CAP<sub>i</sub>

Let i be the sensor node, where (i = 1, 2, 3, ... n)

Let n1 be the node that has high QO value

Let  $X_1$  be the TDMA Slot Period

(1) If ( $CR_i < minTh_C$ ) Then

TDMA slots are not allocated to the nodes

(2) Else if ( $CR_i > maxTh_c$ ) Then

(2-1) QO array is sorted in the descending order

(2-2) Node with high QO value is allocated first

and

$$n1 = X_1$$

End if

End if

Consider the architecture given in Fig. 1, in that we have derived the TDMA slot allocation strategy for CH1. The corresponding TDMA slot allocation strategy and its QO\_Array are given in Fig. 2 and Table 3 respectively. We can observe that node N6 has high QO value and it is allocated first with slot period X1. In the same way, N6, N3, N1, N2 and N4 are assigned and allocated in a descending order.

## 3. RESULTS AND DISCUSSION

### 3.1. Simulation Setup

The performance of the proposed Cluster Based TDMA Scheduling (CBTS) scheme is evaluated using NS-

2 simulation. A network which is deployed in an area of 100 X 100 m is considered. The IEEE 802.15.4 MAC layer is used for a reliable and single hop communication among the devices, providing access to the physical channel for all types of transmissions and appropriate security mechanisms. The IEEE 802.15.4 specification supports two PHY options based on Direct Sequence Spread Spectrum (DSSS), which allows the use of low-cost digital IC realizations. The PHY adopts the same basic frame structure for low-duty-cycle low-power operation, except that the two PHYs adopt different frequency bands: low-band (868/915 MHz) and high band (2.4 GHz). The PHY layer uses a common frame structure, containing a 32-bit preamble, a frame length. The adaptive CSMA with TDMA slot allocation is used along with IEEE 802.15.4 standard. The routing protocol being used is Fuzzy Based Energy Efficient Clustering Technique (FBEEC) developed in (Meenakshi and Anandhakumar (2012).

The simulated traffic is CBR with UDP source and sink. **Table 2** summarizes the simulation parameters used.

### 3.2. Performance Metrics

The performance of CBTS is compared with the Probabilistic Risk-Aware Beacon Scheduling (PRBS) (Yen *et al.*, 2012) scheme. The performance is evaluated mainly, according to the following metrics.

### 3.3. Average End-to-End Delay

The end-to-end-delay is averaged over all surviving data packets from the sources to the destinations.

### 3.4. Average Packet Delivery Ratio

It is the ratio of the number of packets received successfully and the total number of packets transmitted.

### 3.5. Packet Drop

It is the number of packets dropped during the data transmission.

### 3.6. Energy

It is the average energy consumed by the nodes for the data transmission.

The simulation results are presented as follows

## 3.7. Results

### 3.7.1 Based on Rate

In our first experiment we vary the transmission rate as 10,20,30,40 and 50Kb.

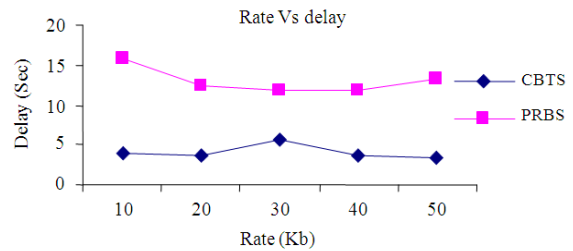


Fig. 3. Rate Vs delay

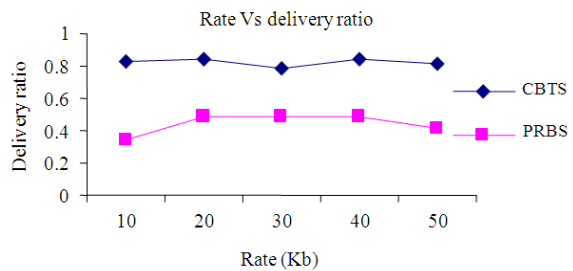


Fig. 4. Rate Vs delivery ratio

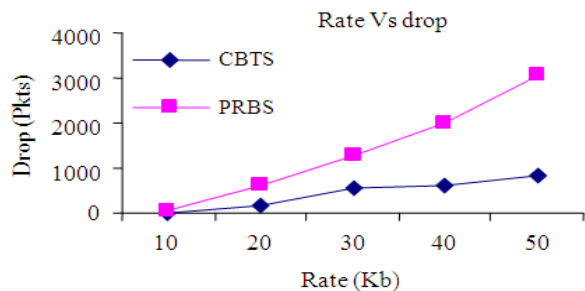


Fig. 5. Rate Vs drop

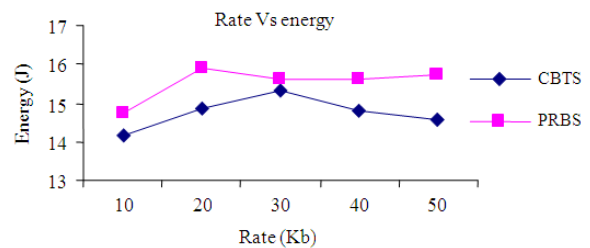


Fig. 6. Rate Vs energy

Table 2. QO Array of CH1

Node ID	Queue Occupancy Information (QO)
N5	6
N6	5
N3	4
N1	3
N2	2
N4	2

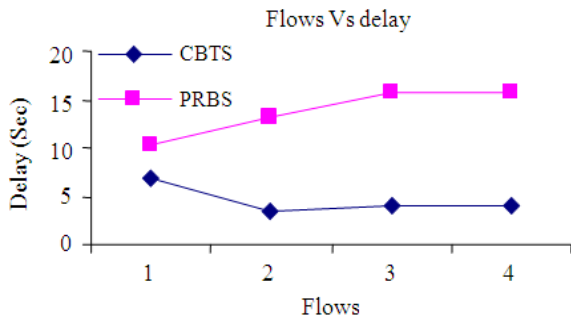


Fig 7. Flows Vs delay

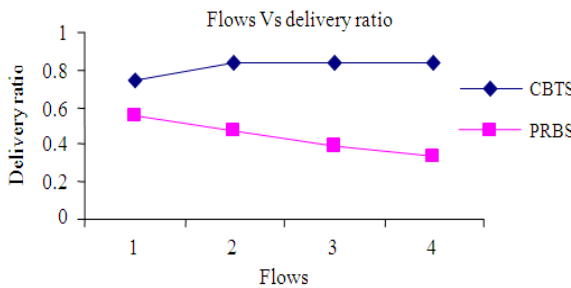


Fig 8. Flows Vs delivery ratio

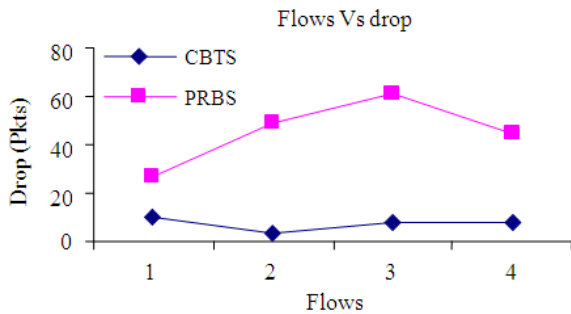


Fig 9. Flows Vs Drop

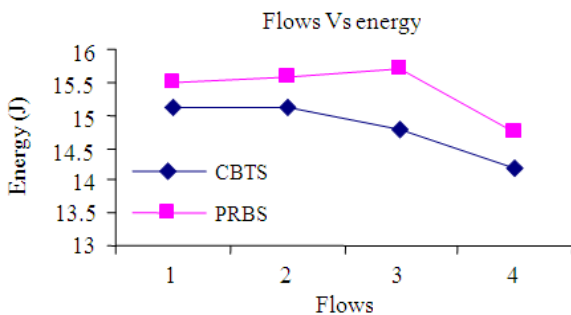


Fig 10. Flows Vs Energy

Table 3. Simulation parameters

No. of Nodes	50
Area Size	100×100
Mac	Adaptive TDMA
Routing Protocol	FBEEC
Simulation Time	50 sec
Transmission Range	20m
Traffic Source	CBR
Packet Size	80 bytes
Transmission Rate	10,20,30,40 and 50Kb
No. of Flows	1,2,3 and 4
Initial Energy	7.1 J
Sending Power	0.660 w
Receiving Power	0.395 w
Idle Power	0.035 w

From Fig. 3, we can see that the delay of our proposed CBTS is less than the existing PRBS protocol.

From Fig. 4, we can see that the delivery ratio of our proposed CBTS is higher than the existing PRBS protocol.

From Fig. 5, we can see that the packet drop of our proposed CBTS is less than the existing PRBS protocol.

From Fig. 6, we can see that the energy consumption of our proposed CBTS is less than the existing PRBS protocol.

### 3.8. Based on Flows

In our second experiment we vary the number of flows as 1, 2, 3 and 4.

From Fig. 7, we can see that the delay of our proposed CBTS is less than the existing PRBS protocol.

From Fig. 8, we can see that the delivery ratio of our proposed CBTS is higher than the existing PRBS protocol.

From Fig. 9, we can see that the packet drop of our proposed CBTS is less than the existing PRBS protocol.

From Fig. 10, we can see that the energy consumption of our proposed CBTS is less than the existing PRBS protocol.

## 4. CONCLUSION

In this study, we have proposed to deploy a hybrid scheduling mechanism for IEEE 802.15.4 ZigBee Wireless Sensor Networks. Our mechanism is hybrid for it makes use of both CSMA/CA and TDMA channel access schemes. The edge value between CSMA/CA and TDMA is estimated using channel utilization metric. Further, TDMA slot allocation strategy allocates slot to the nodes based on queue occupancy information. The coordinator in the network accumulates the queue

occupancy value of nodes and organizes them in the descending order. It assigns TDMA slots starting from nodes with high queue occupancy value. Nodes that have high queue occupancy value will probably get long TDMA slot period. Then, the coordinator sends this TDMA assignment statement to the CH. Based on TDMA assignment statement the CH allocates slots to the nodes. Nodes that have high queue occupancy value will probably get long TDMA slot period. We have proved the proficiency of our mechanism using (NS-2). Our approach fairly allocates slots to the nodes and considerably reduces packet collision rate. Simulation results show that, by applying CBTS scheme, the packet delivery ratio is increased and packet drop and delay are reduced.

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