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Energy Efficiency Scheduling Methods for congestion free Wireless Sensor Networks

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ABSTRACT

In Wireless Sensor Network (WSN), the IEEE 802.15.4 (Zigbee) protocol stack is a promising technology to attain minimum power transmission in the minimum-rate and short rangewireless Personal Area Network (PAN). The cluster tree topology of IEEE 802.15.4 consists of a PAN coordinator, cluster coordinator and numerous sensor devices. During a period of time, the PAN coordinator transmits the beacon frame to its cluster coordinators;likewise the cluster coordinate node transmits the beacon frames periodically to their sensor nodes. The main issue in this network is the collision among beacons or even between the data frames and the beacon, which impact badly the network performance. Additionally, the energy efficiency is a prime concern in WSN. Hence this paper proposes an Energy Efficiency Scheduling Methods for congestion free Wireless Sensor Networks. A superframe duration scheduling algorithm based on the preemptive approach is presented to the QoS constraint WSN application. Additionally, an energy efficient duty cycle based on the data aggregation is proposed. The proposed approach is compared with the existing Time Division Beacon Scheduling approach and has been evaluated using the NS2 simulationin terms of energy efficiency, delay, throughput, packet delivery ratio.

Keywords: WSN, Zigbee (IEEE 802.15.4) protocol, energy efficient, super frame duration scheduling, QoS, duty cycle management

1. INTRODUCTION

Nowadays, the key concept of Wireless Sensor Networks has fascinated in the field of research due to the numerous potential applications such as machine failure diagnosis, battlefield surveillance, home security and so on. However, the WSN developed by the IEEE 802.15.4/Zigbee specifies the medium access control (MAC) sub layer and physical layer for minimum power consumption, small communication range and wireless personal area network with Low –Rate (WPAN-LR) (M.Prakash, S.Nandhini, 2014)(Himanshu Sharma, *et al.*, 2012). The IEEE 802.15.4 standard supports various topologies such as peer- to-peer, star and cluster tree topologies that can function over beacon and non-beacon-enabled modes (Young-Ae Jeon, *et al.*, 2015). Specifically, the beacon-enabled mode has the unique characteristics of IEEE 802.15.4, where it is controlled by the central coordinator that broadcast periodic beacons for node rendezvous and association control.

Amongst the Zigbee topologies, the cluster tree network has great attention due to adequate power saving procedure and light-weight routing. A cluster tree network composes several clusters, each one has cluster coordinators and numerous device nodes. A PAN coordinator works as a root to organize the clusters in the network. The beacon frames have been broadcast by the PAN coordinator and coordinators at regular interval to complete the entire cluster networks. In a cluster tree topology, the beacon frames have been periodically transmitted by the PAN coordinator for its coordinator nodes same way the beacon frames has been periodically transmitted by the coordinator node for their device nodes. Moreover, while the coordinator nodes transmit the beacon frames at a time, collisions will take place among these beacon frames. Hence,

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the child nodes in the cluster will not able to synchronize and interconnect with their coordinator nodes. The collision seems to be a main issue in the cluster tree network of IEEE 802.15.4 beacon-enabled mode, where the network performance can get degraded.

The above mentioned problem is solved by using the mechanism of Time Division Beacon Scheduling (TDBS) and Super frame Duration (SD) scheduling. The concept of TDBS is to manage the beacon frame, broadcast from coordinator nodes in a non-collision way while the concept of SD scheduling is to allocate the duty cycle of router nodes. Since the WSN supports various potential applications (Vaishali S. Nikam, Shiv Om Tiwari, 2014), which may contain a real and non-real time data so prioritizing the data and scheduling the Beacon order and super frame duration becomes essential in Zigbee based WSN. So in this paper, a preemptive based super frame duration scheduling algorithm has been proposed. Additionally an energy efficient duty cycle based on data aggregation is proposed for energy constraint WSN.

The rest of the paper is organized as follows: Section II discusses the recent related works done on the Zigbee based WSN. An overview of the IEEE 802.15.4 has been presented in section III. Section IVexplains the proposed system model. Section V describes the proposed preemptive based super frame duration scheduling algorithm. The proposed energy efficient duty cycle based on data aggregation is explained in the section VI. The results and discussion of the proposed energy efficient scheduling methods have been given in the section VII. Finally, section VIII renders the conclusion.

2. RELATED WORK

A multichannel superframe scheduling algorithm is proposed by the author (Toscano E, Lo Bello L, 2012) for cluster-tree IEEE 802.15.4/ZigBee networks. This technique schedules the super frames for various radio channels to mitigate the beacon collision problem. This approach performs better than the standard time division approach for beacon collision.

Massive and complex data are generated every day in many areas. Complex data referto datasets that are so sizable voluminous that conventional database management anddata analysis tools are insufficient to deal with them[16]. (Z. Hanzalek, P. Jurcik, 2010) proposes an Energy Efficient Scheduling for Cluster-Tree Wireless Sensor based on Time-Bounded Data Flows. This algorithm determines the collision-free superframe schedule which faces a data flow from an end- to- end deadlines while reducing the energy consumption of nodes.Cluster-Tree is a common technique for Wireless Sensor Networks. In General Clusteringprovides partitioning of a data set into subsets of similar objects or data clusters [15].

(Bih-Hwang Lee, *et al.*, 2012) proposes a superframe adjustment and beacon transmission scheme order for IEEE 802.15.4 standard based WS in order to reduce the collision by assigning the perfect values of superframe order and beacon order for the PAN, cluster coordinators and device nodes and determining the accurate time for the beacon transmission of PAN and coordinator nodes. By considering the packet retransmission, acknowledgement and defer transmission, a Markov chain model is developed for the cluster tree network. This approach performs better than IEEE 802.15.4 standard interms of network goodput, energy consumption and the probability of successful transmission.

(Bo Gao, Chen He, 2008) proposes an Individual Beacon Order Adaptation (IBOA) algorithm for IEEE 802.15.4 based WSN. In this approach, the beacon interval and duty cycle of each node are adapted individually based on the performance requirements. This approach performs better in terms of energy consumption, end to end delay and throughput.

The Binary Exponential Backoff (BEB) function is employed in the CSMA/CA algorithm of the IEEE 802.15.4 MAC layer to estimate the backoff delay for every node. Utilizing BEB function, it is possible that the nodes may collide when they choose the similar backoff exponent value. In order to overcome this the author (Muneer Bani Yassien, *et al.* 2012) proposes a Fibonacci Backoff (FIB) function to estimate the backoff periods, where every node can wait for an incremental backoff time while they require to access the channel.

(Sadik K. Gharghan, *et al.*, 2014) proposed a Redundancy and Converged Data (RCD) algorithm for ZigBee based WSN in order to minimize the energy consumption. This approach fuses the data to minimize the data packet to be transmitted in the network. This approach performs better in terms of cost, size and energy consumption.

(Jamila Bhar, 2015) proposed two ideas to improve the traffic efficiency by IEEE 802.15.4 MAC layer optimization. The First idea is to adjust the backoff exponent dynamically based on the queue level of each node. The next idea is to alter the amount of successive clear channel assessment for data packet transmissions. This approach minimizes the resource wastage in the network.

(Francesca Cuomo, *et al.*, 2013) proposes a cross-layer approach, namely PANEL for IEEE 802.15.4/ ZigBee Wireless Sensor Networks (WSNs). The PANEL allocates the role of PAN coordinator to various nodes in the tree. This is accomplished by using the distributed approach. This approach minimizes the number of hops between the source and sink and reduces the paket drop at the MAC layer.

3. PRELIMINARIES

In this section, the overview of the IEEE 802.15.4 has been presented.Figure 1 illustrates a structure of superframe, which is bounded by two consecutive beacons.Each node in the IEEE 802.15.4 enabled by beacon mode employs two system parameters such as Beacon Order (BO), Superframe Order (SO), that characterize Beacon Interval (BI) and Superframe Duration (SD), respectively, as follows

$$\left.\begin{aligned} BI &= aBaseSuperframeDuration \cdot 2^{BO} \\ SD &= aBaseSuperframeDuration \cdot 2^{SO} \end{aligned}\right\} for 0 \leq SO \leq BO \leq 14 \tag{1}$$

aBaseSD=15.36ms (taking into account of 250kbps in the 2.4 GHz frequency band) represents the lowest duration of the superframe, respective to SO=0

The BI is the time between two successive beacon frames. The active period in BI is defined by the SD and is divided into sixteen equal time slots, when data frame transmissions are permitted. While in inactive period, the nodes may go into the sleep state in order to save energy. The Beacon. Based on the demands, the active portions divided into parts, namely Contention Access Period (CAP) and Contention Free Period (CFP). The CSMA-CA procedure will be followed by the devices in the CAP. In CFP, the Guaranteed Time slots are allocated to support the time sensitive applications.

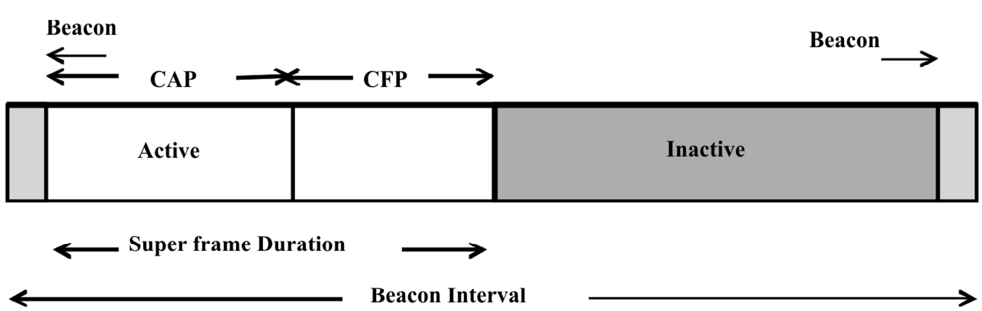

Figure 1: Superframe structure of the IEEE 802.15.4

4. NETWORK MODEL AND PROBLEM FORMULATION

In this paper, beacon enabled IEEE 802.15.4 cluster tree topology based WSN is considered and it has been exemplified in figure 2. The network consists of n number of sensor nodes, k number of cluster coordinators and 1 PAN coordinator (sink node). Each cluster coordinator will act as a cluster head for all its child nodes connected to it and it will transmit a periodic beacon frame with a given SO and BO to keep them coordinated. Let SD_i and BI_i indicates the superframe duration and beacon interval of the i^{th} cluster coordinator. The issue is how to allocate the beacon frames of the various coordinators to avoid collision with other beacon and data frames utilizing the time division approach. The direct idea is the beacon frame transmissions is organized in a non overlapping way, i.e., no beacon frames should collide with one another, even though the cluster coordinators are in direct or indirect neighborhood. Additionally, the energy efficiency is a prime concern in WSN. So the scheduling mechanism should avoid the collision in an energy efficient way.

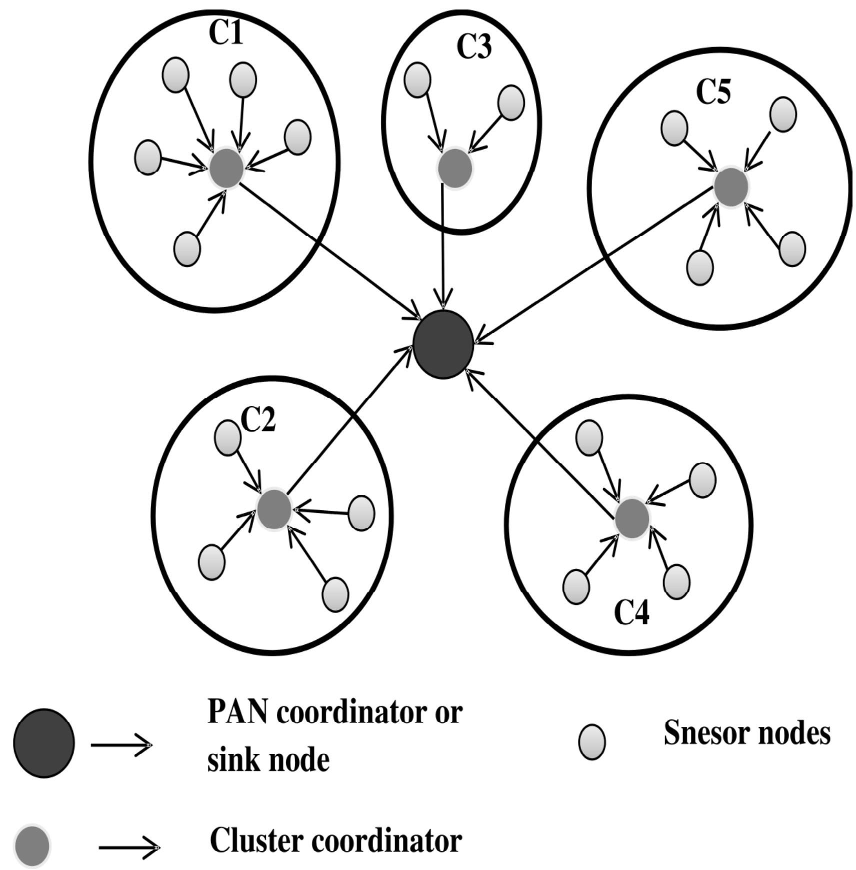

Figure 2: Beacon Enabled IEEE 802.15.4 Cluster Tree Topology based WSN

5. A PREEMPTIVE BASED SUPER FRAME DURATION SCHEDULING ALGORITHM (PBSFDSA)

Wireless Sensor Network (WSN) supports numerous applications, where the sensed data have to be reached to the sink node or a base station in a particular time period or before the expiration time. Furthermore, real-time emergency data should be transmitted to a base station with the minimum probable delay. The author in (Koubaa A, et, al., 2007) used non preemptive Super Frame Duration Scheduling Algorithm approach for the beacon enabled IEEE 802.15.4 cluster tree topology based WSN. Here the real-time emergency data suffered a larger delay in the network. This issue has been resolved in this paper, by using a preemptive based super frame duration scheduling algorithm, which considers the emergency situation and allocate an accurate beacon order and superframe order for the PAN coordinator, cluster coordinators and device nodes.

PBSFDSA aims to provide the accurate values of BO and SO for the PAN coordinator, cluster coordinator and device nodes based on the interval arrival time and the child nodes. The BI of the PAN coordinator should assure the data transmission from its coordinator nodes, so it should be the round function of the inter arrival time of the packets respectively, as follows

$$BO_{PAN} = \left\lfloor \left(Log_2 \left(\frac{N_{cn} \times INTV \times Rs}{Bs \times Ns} \right) \right) \right\rfloor \quad (2)$$

Where N_{cn} denotes the number of child nodes, Ns, Bs and Rs indicates aNumSuperframeSlots, aBaseSlotDuration and symbol rate. The beacon order of the cluster coordinator can be assigned based on the number of child nodes it handles.The computation of the beacon order for the cluster coordinators has been given in the algorithm 1.

Algorithm 1 Beacon order allocation for the coordinators

1 Input: prev BO=BO_{PAN}
2 Output: BO for n coordinators
3 For $i := 0$ to n; where n is the number of coordinators
4 {
5 Count$_i$:= Number of child; i++;
6 }
7 Organize an array $A := \{count\}_i^n$ in the decreasing order
8 Allocate BO for the elements in the array A such as
9 For i:= 0 to n
10 {
11 $BO \rightarrow coordinator \in A[i] = prevBO - 1$
12 i++
13 prevBO=BO current coordinator
14 }

The SO of the PAN coordinator is equal to the BO of the PAN coordinator. The SO of the coordinator node can be computed using the following equations

$$SO_{co} = \left\lfloor Log_2 \left(\frac{2^{BO_{coord}}}{N_{cn}} + 0.15 \right) \right\rfloor \quad (3)$$

The BO and the SO for the sensor nodes are decided by its cluster coordinates. The BI and the SD of the PAN, Cluster coordinators and the device nodes are computed based on the equation 1 with respective BO and SO. The SD of the PAN will be allocated to the cluster coordinators in increasing order of the beacon order.

In order to achieve the preemptive based Super Frame Duration Scheduling, a special type of circuit, namely a wakeup radio (Moshaddique Al Ameen, et, al., 2012) is equipped to each sensor node. Emergency events (real time data) can occur randomly in a wireless sensor network, where it is totally unpredictable and must be transmitted quickly than the non real time data. If the wakeup radio receives any emergency event, it produces an interrupt signal to wake up the main radio. Let us consider a scenario while a sensor node has a some real time data to be sent to the Cluster Coordinator (CC_i). In this case, a SN wakes up and transmits a wakeup radio to the CC_i. Likewise, the CC_i will send a request to the Pan Coordinator about the emergency data. The PAN coordinator acknowledges the cluster coordinate with ACK packet, then the CC_i will transmit the ACK packet to the sensor node. Now, the PAN coordinator will preempt the current process of a cluster coordinator CC_j, which uses the current SD. The PAN will count the unused time slot by the CC_j in order to provide that time slot to CC_j after transmitting the emergency data. The proposed PBSFDSA has been illustrated in the algorithm 2

Algorithm 2 Algorithm for the proposed PBSFDSA

```
begin
Construct an array X[i] with increasing BO of the Cluster Coordinates
                    X[i] ← {BO}_i^n
for (i=0 to n)
        SD[PAN] ← SD[X[i]]
        i++
end for
//Emergency data arrives from sensor node X ∈ cluster coordinator i
Sensor node send wakeup radio to CC
CC send the information about the emergency data to PAN
PAN send ACK to CC and CC send ACK to sensor node.
//The SD of PAN is now allocated to the CC_j
count the time slot unused by the CC_j
Preempt CC_j
Allocate a time slot for CC_i for emergency data transmission
reduce one time slot in the SD[CC_i]
SD[PAN] ← unused time slot [CCj ]
end
```

6. ENERGY EFFICIENT DUTY CYCLE MANAGEMENT BASED ON DATA AGGREGATION

In this section, a methodology has been proposed for assigning the sufficient duty cycles to each coordinator in the cluster-tree networkin order to attain an energy efficient WSN. A numerous steps have been followed on the proposed duty cycle adaptation algorithm. The sensor nodes generally use only a half duty cycle to sense the data, if it senses the target data, then it uses the duty cycles based on the sensed traffic level. Otherwise, if it does not sense the any data in the half duty cycle, it will turn off its radio and goes to sleep state in order to save the energy. The node which all senses any data will send its data to its cluster coordinates within allocated duty cycles. After the Data aggregation has been processed at the cluster coordinates in order to remove the redundant data arrived from the sensor nodes, which generates a substantial amount of redundant data. This process will reduce the traffic level of the data, which needs to be transmitted to the PAN coordinator. After the data aggregation process, a dynamic duty cycle is followed at the cluster coordinators based on the traffic level. The cluster coordinate will send a SYNC message to the PAN coordinator about the traffic level. The PAN coordinator will take decisions about the duty cycle allocated to cluster coordinator. If there is a heavy traffic, the superframe duration will be increased and the inactive period will be reduced. Otherwise, in low traffic the SD will be reduced and increase the SD for the succeeding cluster coordinate in order to reduce the wastage of resources such as energy and bandwidth. The algorithm for the proposed duty management cycle has been illustrated in algorithm 3.

Algorithm 3 Dynamic duty cycle management algorithm

1 Begin
2 for i=0 to n; where n is the number of cluster coordinators
2. For k = 0 to n; where k is the number of sensor node
2 Send beacon
2 Use only half duty cycle to sense the data
3 if target detected
4 Use duty cycle based on the sensed data traffic
5 Transfer the data traffic to the cluster coordinates
5 else
6 switch off the radio
7 end if
8 end for
9 Data Aggregation is processed at CC_i *to remove redundant data*
10 Count the traffic at queue
11 Send SYNC message to PAN with traffic level
12 if high traffic
13 Increase the SD of the CC_i
14 Decrease the SD of the subsequent CC_j
15 else if low traffic
16 Decrease the SD of the CC_i
17 Increase the SD of the CC_j
18 end if
19 end for
20 end

7. SIMULATION RESULTS

The performance of the proposed PBSFDSA in beacon enabled mode of IEEE 802.15.4 was evaluated using the NS2 Simulation. Table 1 shows the simulation setup. The proposed approach is compared with the existing Time Division Beacon Scheduling approach (TDBS). The performance comparison is attained by evaluating each approach on an IEEE 802.15.4 based cluster tree consists of 50 sensor nodes that are one hop away from a PAN coordinator (sink node). The Performance metrics such as end to end delay of the real time data traffic, throughput, packet delivery ratio, energy utilization factor are used to evaluate the performance of the proposed approach.

Table 1
Simulation Setup

Parameter	*Value*
Area	250×250
Physical and MAC model	IEEE 802.15.4
Number of nodes	50
Transmission range	12 m
Simulation time	1000s
Channel frequency	2.4 GHZ
Traffic type	CBR
Initial energy	10 joule
Transmission speed	250 kbps

7.1. Performance Metrics

End to End Delay

The average time consumed by a packet to reach the destination. It includes the packet waiting time in a queue, propogation delay and processing delay. These delays have been caused by the exchanging messages in MAC control and routing events.

$$Delay = QD + PD + PGD \tag{4}$$

Here QD is the queuing delay, PD is processing delay, and PGD is the propagation delay.

Energy Utilization Factor

Energy Utilization Factor (EUF) is the ratio of total energy utilized (EU) during the whole lifetime to the total energy (TE) provided to the network at the time of deployment.

$$EUF = \frac{EU}{TE} \times 100 \tag{5}$$

Throughput

Throughput is the data rate upon when a network receives or send the data packet to the PAN.

$$Throughput = Number\ of\ frame\ transmitted\ /\ Time\ Interval\ \ (bps) \tag{6}$$

Packet Delivery Ratio

Packet Delivery ratio (PDR) is the ratio of the number of packets, delivered correctly to the sink node to the number of packets generated at the sensor node.

$$PDR = \frac{number\ of\ \ packets\ delivered}{number\ of\ \ packets\ generated} \tag{7}$$

7.2. Discussions

Figure 3 shows the packet delivery ratio with respect to number of transmissions in the network. In the proposed PBSFDSA, the data traffic is considered to allocate the duty cycle, which maximize the packet delivery ratio in the network, while in TDBS, duty cycle is same for all types of data traffic generated from the sensor node.The PBSFDSA attains 0.77% packet delivery ratio for 60 transmissions in the network, while TDBS attains 0.56% packet delivery ratio.

Delay will increase when the number of transmission increases in the network. Figure 4 illustrates the end-to-end delay of real-time tasks over a number of time periods. The PBSFDSA outperforms the TDBS by giving the priority to the real time data packets and also permit real time packets to preempt the processing of non-real time packets. Hence the real time packets have minimum end to end delay in the PBSFDS.

Figure 5 shows the Energy Utilization Factor (EUF) with respect to various time periods.Basically the energyof a node depletes when the node is utilized constantly for a continuous number of time periods. From the graph it can be observed that with the proposed PBSFDSA technique the energy of the network is sustained (i.e.) the energy is not utilized to its maximum extent while performing a certain operation. This is due to the allocation of the effective duty cycle (an appropriate duty cycle that is required for a particular operation) to the CC and sensor nodes. It is also obvious from the graph that the EUF of existing TDBS is more compared to the PBSFDSA. The reason is that the TDBS does not consider duty cycle into account which may also result in the depletion of energy of thenetwork resource.

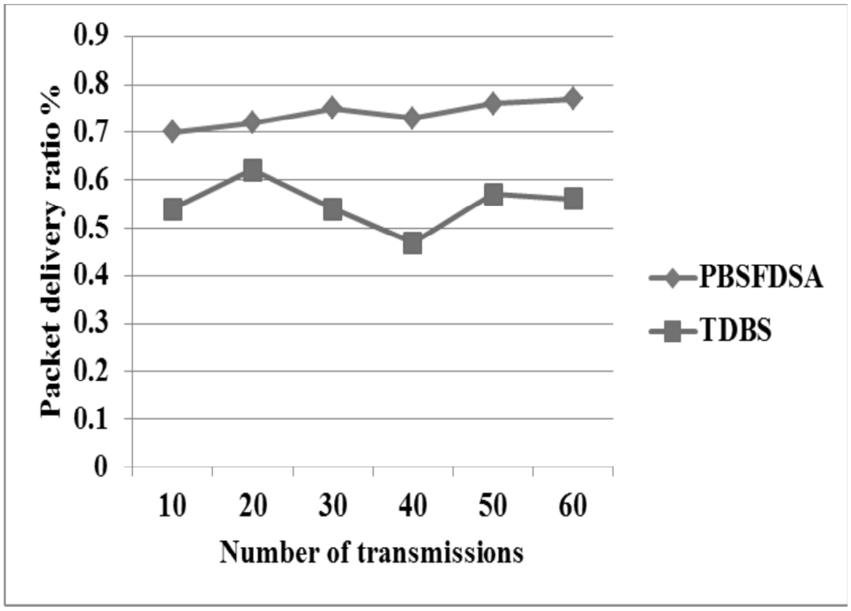

Figure 3: Packet Delivery ratio with respect to Number of transmissions

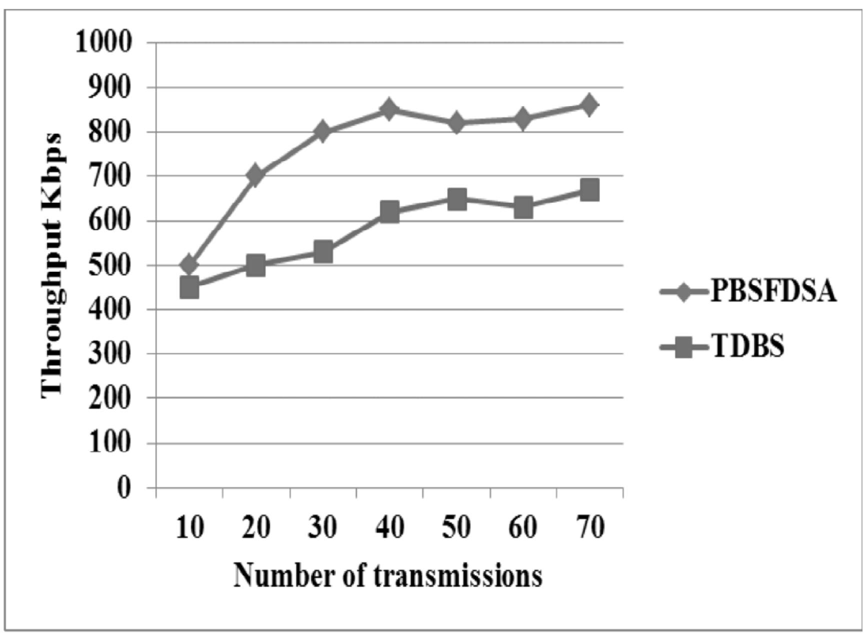

Figure 4: Delay with respect to real time data transmissions

When the time period increases, the load of the network will increase gradually, which increase the throughput factor considerably. Figure 6 shows the throughput with respect to number of transmissions in the network. In PBSFDSA, the duty cycle is managed effectively based on the aggregated traffic, which increases the throughput factor in the network. The PBSFDSA attains 860 Kbps for 70 data transmission, while TDBS attains 670 Kbps.

8. CONCLUSION

In this paper, a super frame duration scheduling algorithm based on the preemptive approach is presented to support the QoS in the WSN. An effective beacon order and superframe order is allocated to the PAN coordinator, cluster coordinator and sensor nodes. Moreover, the preemptive based SD is accomplished by

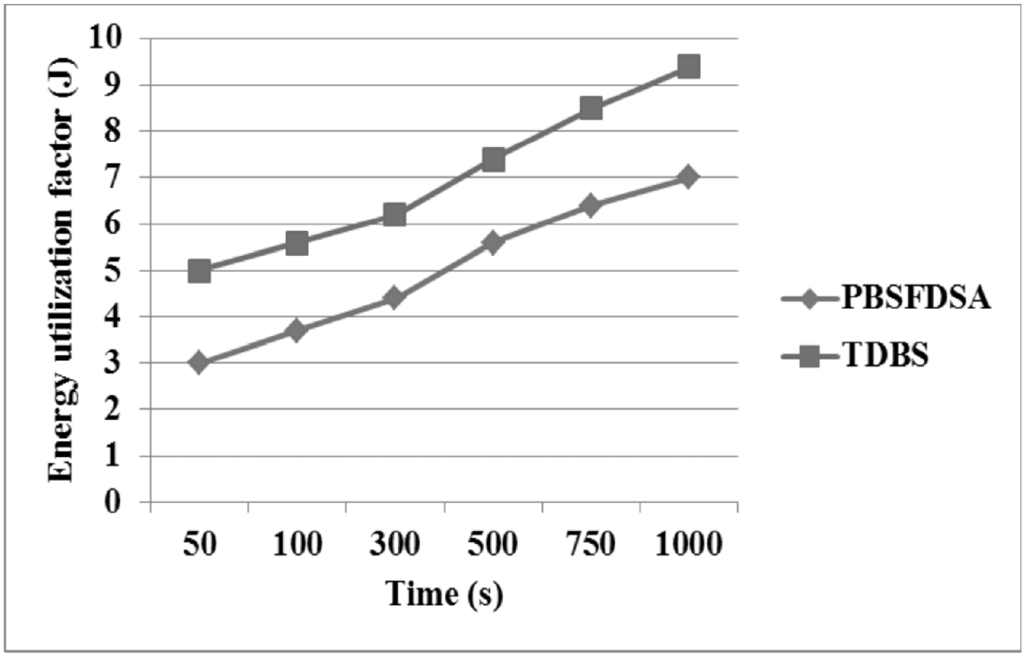

Figure 5: Energy utilization factor with respect to time

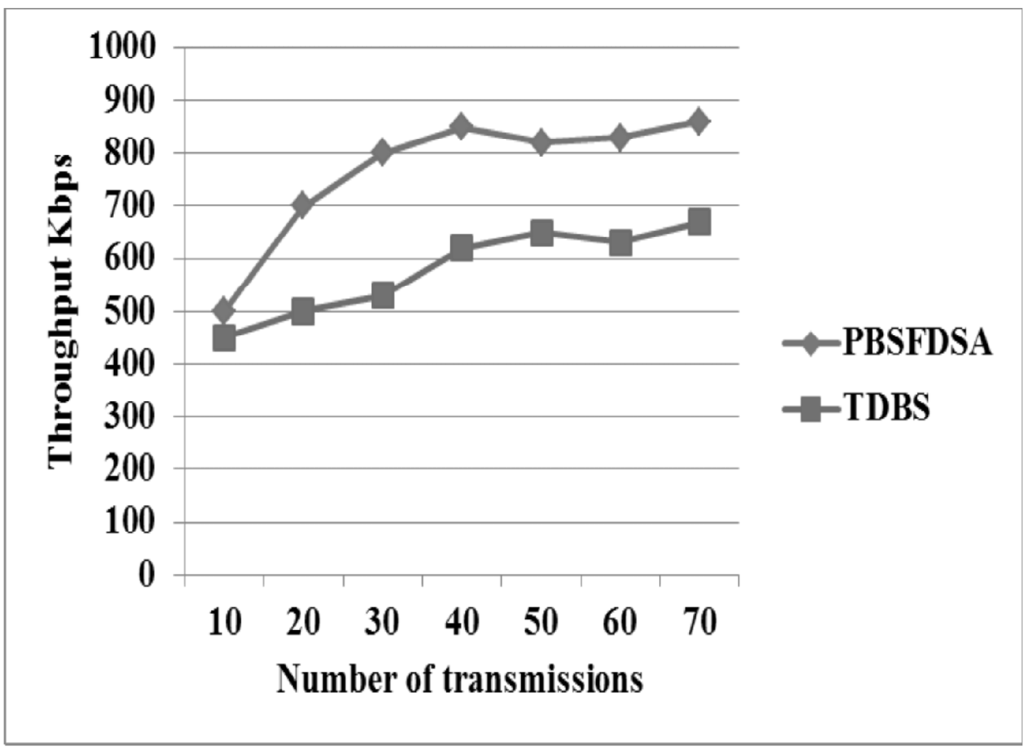

Figure 6: Throughput with respect to number of transmissions

using a wakeup radio concept. Additionally, an energy efficient duty cycle based on the data aggregation is proposed to reduce unnecessary energy consumption and bandwidth utilization in the network. Based on the traffic level, the duty cycle will be allocated to the nodes and the cluster coordinates. The data aggregation is performed at the cluster coordinates to remove the redundant information before transmitting the data to PAN coordinates. The simulation results show that the proposed PBSFDSA performs better than the TDBS in terms of throughput, delay, energy utilization factor and packet delivery ratio.

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