Research Article
Packet Scheduling Based General Self-organized Tree Routing Protocol for Wireless Sensor Network

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Abstract: In recent years, wireless sensor networks have attained more attraction owing to their potential ability in providing solutions in various areas. They have different restraint, such as computational power, storage capacity, energy supply and etc also the most important issue is energy constraint. The above challenges hold back the efficient use of WSNs to support different applications, such as the resource limitations of sensor devices and definite energy. The main reason for wasted energy consumption in WSN is packet collision. So packet scheduling algorithm is introduced to overcome this problem. Several packet scheduling algorithms can also influence and delay the data transmitting in the real-time wireless sensor networks. In this research, a novel cluster tree based routing protocol is proposed. The network is divided into several clusters using fuzzy possibility c means algorithm. The cluster tree is formed using shortest path algorithm. Hybrid time slot allocation is proposed for data transmission in order to overcome the delay. Hybrid time slot allocation is based on the combination of TDMA and CSMA/CA.

Keywords: Clustering, network lifetime, routing, tree based routing, wireless sensor network

INTRODUCTION

A Wireless Sensor Network (WSN) consists of several resources constrained, low power and memory sensor nodes, which are of two types: sensor node and Base Station (BS). The sensor node comprises of fundamental features of sensing, processing and communicating with other nodes. However, the sensor BS has more functionality in addition to these basic capabilities (Vijayakumaran and Janaky, 2014). Figure 1 show a typical WSN, in which a sensor node senses different environmental parameters such as temperature, pressure, humidity and sends data directly to the BS if the node is inside the communication range of BS or through other nodes by means of multi-hop routing. At last, data from BS reach end users through different communication networks, such as Internet.

In general, the WSN deals with several design issues like routing protocols and the data aggregation to minimize the energy consumption of sensor network, data transmission delay, packet scheduling at sensor nodes is highly significant as it make sure with delivery of different types of data packets based on their priority and evenhandedness with a minimum latency (Nidal *et al*., 2013). For example, data sensed for real-time applications have higher priority than data sensed for non-real-time applications.

All the sensor nodes share a single communications channel using a multiple access protocol. The packet transmission may possibly lead to a time overlap of two or more packet reception known as collisions. The main cause of packet collision problem creates packet loss, packet retransmission, decreasing throughput, increased delay/latency and increased wasted energy consumption. However wide research is carried out by the researchers for scheduling the sensor nodes (Xiao *et al*., 2010), only a few studies are present in the literature on the packet scheduling of sensor nodes (Edalat *et al*., 2009) that schedule the processing of data packets offered at a sensor node and also reduces energy consumptions.

A lot of research works on the MAC protocol has been proposed to work out on the packet collision problem (Bachir *et al*., 2010) such as Spatial TDMA traffic-adaptive medium access protocol (TRAMA) (El-Hoiydi, 2002), Sensor MAC (SMAC) (Ye *et al*., 2004) and Timeout MAC (TMAC) (Van and Langendoen, 2003). A MAC protocol based on IEEE 802.15.4 was designed for low-power communiqué. The IEEE 802.15.4 MAC protocol employs a random pull back in order to reserve and access the channel. A node is approved to send the packet when the channel is in idle case. On the contrary, random back off is activated when the channel is busy. Unluckily, this approach will not work appropriately for large scale WSN.

Certainly, most of the existing WSN operating systems make use of First Come First Serve (FCFS) (Zhao *et al*., 2009) schedulers that progression the data

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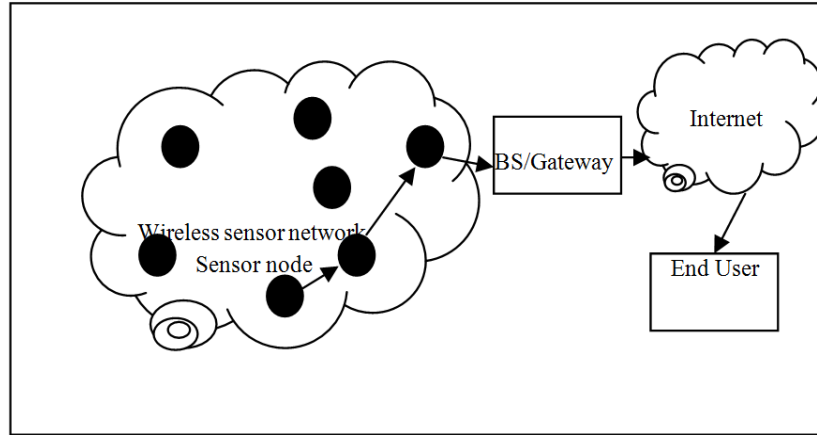
Fig. 1: A wireless sensor network

packets based on their arrival time and, therefore, need more time to deliver to a relevant base station. However, the sensed data have to reach the BS in a specific time period or before the end of a deadline. In addition, real-time emergency data should be delivered to BS with the shortest possible end-to-end delay. Therefore, intermediate nodes have need of vary the delivery order of data packets in their ready queue based on their significance and delivery deadline. Besides, most of the existing packet scheduling algorithms of WSN is neither dynamic nor fitting for large scale applications while these schedulers are predestined and static and cannot be changed in response (Lee *et al.*, 2010).

LITERATURE REVIEW

The author presented a multipath routing algorithm which facilitates the consistent delivery of data. By calculating the scheduling rate, it is likely to prevent congestion and packet loss in the network (Mary and Gopalakrishnan Nair, 2011). The introduced algorithm gives an efficient way to prevent the packet loss at each node. This results in congestion managing in the sensor networks.

In Santhi and Venkatachalapathy (2014), a multiple cluster tree routing method all along with scheduling for prevention of collision is proposed. Multiple cluster trees are structured in which the Cluster Heads (CH) is chargeable for scheduling. Each CH schedules it member nodes with suitable time slot considering the amount of data to be transmitted with reference to the time interval.

In Jandaeng *et al.* (2011) Packet Scheduling Algorithm (PSA) is introduced to reduce the packet congestion in MAC layer tends to reduce the overall packet collision of the network. The PSA is compared with the trouble-free CSMA/CA and other existing approaches by means of network topology benchmarks through mathematical method.

The designing of efficient power routing with definite delivery is a challenging task for sensor networks with unknown geographic areas (Mitton *et al.*, 2008). The author presented a HECTOR, which is a hybrid energy efficient tree-based optimized routing protocol, based on two sets of virtual coordinates. One set is based on rooted tree coordinates and the further one is based on hop distances in the direction of several landmarks.

The author described the basic idea about the different methods of data collection in WSN (Kshama and Tejas, 2014). The freshness of data is maintained as the process of data collection is as much faster as possible. TDMA is a type of MAC in contention-free medium, allocating the time slots to links or nodes. In TDMA, the node becomes active only at a particular allocated time slot. As a result, it minimizes the energy consumption with very less possibility of conflicts. It supports the fair data group in WSN with least amount of delay and less number of retransmission. Scheduling with TDMA can be made with minimum scheduling length and fair use of bandwidth and time.

PROPOSED METHODOLOGY

The system model is considered here with certain following properties:

- Sensor nodes are randomly distributed in the square field and there is merely one BS deployed far away from the particular area.
- Sensor nodes are stationary and energy constrained. Once deployed, they will keep functioning until their energy is exhausted.
- Sensor nodes are location-aware. A sensor node can get its location information through other mechanisms such as GPS or position algorithms.
- Each node has its unique Identifier (ID).

The proposed algorithm consists of the phases which are similar to existing GSTEB but the operations of each and every block are different.

The main phases or blocks of the proposed algorithm are:

- Initial Phase
- Tree Constructing Phase
- Self-Organized Data Collecting and Transmitting Phase
- Information Exchanging Phase

Initial phase: In first phase, the network parameters are initialized and the nodes are formed into group of clusters by means of fuzzy based clustering approach (Suganya and Shanthi, 2012). FPCM is a fuzzy approach used for cluster head selection. FPCM is a hybridization of Possibilistic C-Means (PCM) and Fuzzy C-Means (FCM) that often avoids various problems of PCM and FCM. The existing FCM methods are based on the L2-norm distance in the observation space; it does not perform well for more general clusters. In this proposed research work, to overcome the problem of FCM the Fuzzy Possibility C Means clustering (FPCM) is proposed.

Here a fuzzy logic approach is used for cluster-head selection based on three descriptors; they are energy, concentration and centrality of the sensor nodes. Based on network configuration a considerable increase in network lifetime can be compared to probabilistically selecting the nodes as cluster-heads using local information. For a cluster, the node chosen by the base station is the node with the maximum probability becomes the cluster-head based on node concentration, residual energy level in each node and node centrality regarding the entire cluster, reducing energy consumption for all nodes consequently increasing the lifetime of the network.

Let c be integer which represents the number of clusters with $2 \leq c \leq n$, where n is the number of nodes present in the network. Let x_i be the parametric value such as energy, concentration and centrality of the kth node and the objective function of FPCM algorithm is to minimize the following equation:

$$J_{m,\eta}(U,T,V;X) = \sum_{i=1}^{c}\sum_{k=1}^{n}(u_{ik}^m + t_{ik}^m)D_{ikA}^2 \quad (1)$$

$$\min_{(U,T,V)} \left\{ J_{m,\eta}(U,T,V;X) = \sum_{i=1}^{c}\sum_{k=1}^{n}(u_{ik}^m + t_{ik}^m)D_{ikA}^2 \right\} \quad (2)$$

where,

u_{ik}, t_{ik} = A membership and possibilities that belongs to node's degree

D_{ik} = The Euclidean distance between node j and the center of cluster

$$D_{ik} = \|x_i - v_i\|$$

where, v_i is a center of the fuzzy cluster i.

While m is real number $m \in [1, \infty)$ called the fuzzy constant.

Cluster formation algorithm:

Step 1: Nodes are initialized and considered as a data points and k is a number of desired clusters

Step 2: Choose a number of clusters.

Step 3: Initialize membership $U^{(0)} = [u_{ik}]$ and $T^{(0)} = [t_{ik}]$ for node g_n of cluster by random. The membership value is chosen between 0 and 1.

Step 4: Assign each nodes g_n to the cluster which has the highest membership values.

Step 5: Compute the centroid for each cluster using the below formula:

$$v_i = \frac{\sum_{k=1}^{n}(u_{ik}^m + t_{ik}^\eta) \cdot x_k}{\sum_{k=1}^{n}(u_{ik}^m + t_{ik}^\eta)} \quad (3)$$

Step 6: Update its membership values $U^{(k)} = [u_{ik}]$ and $T^{(k)} = [t_{ik}]$, of being in the clusters, using the below formula:

$$u_{ik} = \left(\sum_{j=0}^{c} \left(\frac{D_{ikA}}{D_{jkA}} \right)^{2/m-1} \right)^{-1}$$
$$1 \leq i \leq c; 1 \leq k \leq n \quad (4)$$

$$t_{ik} = \left(\sum_{j=0}^{c} \left(\frac{D_{ikA}}{D_{ijA}} \right)^{2/\eta-1} \right)^{-1}$$
$$1 \leq i \leq c; 1 \leq k \leq n \quad (5)$$

At the end of this phase, information about all the cluster nodes is delivered to cluster head. Each node in cluster sends its own information to the sink directly. It is important to know that, this phase is done once; therefore direct communication between cluster nodes and the cluster head is negligible.

Cluster tree constructing phase: In this phase, the information delivered to cluster node from the former phase. In a routing tree structure, for every cluster node a path to its cluster head is determined. Cluster head knows position of all nodes located in its cluster. Tree formation is explained briefly in following steps:

Step 1: Each and every cluster head generates sample packet and send it to base station. The sample packet contains cluster head ID and distance between the base station and cluster head. The distance between the nodes is calculated using Euclidean distance:

$$dist(x_1, x_2) = \sqrt{\left(\sum((x_{1i} - x_{2i})^2) \right)} \quad (6)$$

where, x_1, x_2 are two nodes

Step 2: Based on the distance between the nodes and BS, the nodes are arranged in ascending order. The node with respect to the shortest distance is assumed as a root node and it broad cast its ID and coordinates to other cluster head as root node ID and root coordinates.

Step 3: Again the distance between the root node and other cluster heads are calculated using the Euclidean distance and sort the nodes based on the distance.

Step 4: Shortest distance between the root node and the cluster head is considered as left node and second shortest distance is considered as right node.

Step 5: This process is continued until the number of nodes ends in cluster.

Cluster head using node information, links cost in which Dijkstra algorithm is employed to select least cost route within every cluster node and cluster head. By Dijkstra algorithm, route is selected between every node and cluster head is optimum and only one path is preferred between each node and cluster head as a result the set of all routes has a tree structure called as routing tree. If a node makes use of selected least cost route for transmitting its traffic, network will gain slightest possible energy for its traffic. However, it is noted that, the least cost route is not constantly the best route. Suppose continuously the least cost path is selected to forward other nodes data, nodes which are situated in mentioned path die so sooner than other nodes which located on paths with higher cost. Normally, if some parts of network die faster than other parts, network will be partitioned. Partitioned network is compared with normal network consumes more energy and has higher reliability. By using mechanism which provides fairness in network, network lifetime will be increased and then wireless sensor network can do its task more reliable and longer.

Balancing in cluster tree topology: After the tree construction process, need to balance the load in a network. The WSN routing tree is entrenched in the base station. The child sensor nodes loads sum up with the load of each upstream parent in the tree. Hence, the sensor nodes closer to the base station will be heavily loaded. The main aim of node-centric load balancing is to uniformly distribute packet traffic generated by sensor nodes across the different branches of the routing tree.

The Hölder's Inequalities is selected to evaluate the performance of load balancing metric. The definition of the Hölder's Inequalities is as follows:
For all,

$$a \subseteq C^N \text{ and } b \subseteq C^N$$
$$a = \{a_1, a_2, a_3, \ldots, a_n\}$$

$$b = \{b_1, b_2, b_3, \ldots, b_n\}$$

And,

$$a_1 \geq a_2 \geq a_3 \geq \cdots \geq a_n$$
$$b_1 \geq b_2 \geq b_3 \geq \cdots \geq b_n$$

Consequently,

$$n \sum_{k=1}^{n} a_k b_k \geq \left(\sum_{k=1}^{n} a_k \right) \left(\sum_{k=1}^{n} b_k \right) \tag{7}$$

Let W_i be the weight (cumulative load) on the ith branch of the routing tree. Form a vector of the weights $w = \{W_1, W_2, W_3, \ldots, W_n\}$. To assess the degree of balance among the different branch weights of w.

Let $a = b = w$. In this case, the inequalities will become:

$$n \sum_{i=1}^{n} W_i^2 \geq \left(\sum_{i=1}^{n} W_i \right)^2 \tag{8}$$

$$1 \geq \frac{\left(\sum_{i=1}^{n} W_i \right)^2}{n \sum_{i=1}^{n} W_i^2} \tag{9}$$

With equality if and only if $W_1 = W_2 = W_3 = \cdots = W_n$ for all $W_k, k \in [1, n]$ and E should be largest. The balance factor θ is defined as:

$$\theta = \frac{\left(\sum_{i=1}^{n} W_i \right)^2}{n \sum_{i=1}^{n} W_i^2} \tag{10}$$

As the weights in each branch converge contains same value, i.e., the load across the different branches of the routing tree becomes more balanced; the balance factor increases by 1. When the weights of all the branches are equal, the result of the difference will be 1, i.e., the maximum value.

Along with this the weight of residual energy is also calculated for each and every node. The formula used for energy calculation is:

$$E_i = \lceil residual_{Energy(i)} / \alpha \rceil \tag{11}$$

where, E_i is an estimated energy value rather than a true one and i is the ID of each node. α is a constant which reflects the minimum energy unit and can be changed depending on our demands. By considering the network lifetime as the time the first node in the network fails (dies), with load balancing and all nodes being depleted of energy slowly and uniformly causing all nodes to die nearly at the same time. By this, it results in lower maintenance cost and improves overall performance.

Proposed time slot allocation strategy: In this research, hybrid scheduling mechanism is proposed for Wireless Sensor Networks. In this research CSMA/CA

is implemented for collision avoidance in the network and TDMA for efficient data transmission based on assigning the time slot to the each node in the cluster tree. The mechanism in which base station is considered as root node and cluster head is considered as immediate child nodes. The cluster head measures the channel consumption level for every conflict access stage. When the channel consumption level becomes less than minimum threshold value, the Cluster Head (CH) forwards this information to the base station. While receiving channel usage information, the base station checks the packet collision rate of the flow among two threshold values as maximum and minimum. If, the collision rate crossed the maximum threshold value once, it appeals to the TDMA slot allocation strategy. The base stations stores the queue occupancy value of nodes by the Eq. (12) and arrange them in the descending order. It allocates TDMA slots first from nodes with high queue occupancy value. Nodes that have high queue occupancy value will almost certainly attain long TDMA slot period. Then, the base station sends this TDMA assignment statement to the CH. Based on TDMA assignment statement the CH allocates slots to the nodes.

Measurement of Queue Occupancy (QO): The Queue occupancy of a node is measured using Eq. (12) as follows:

$$QO(i) = \frac{nQ}{Q} \qquad (12)$$

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

Measurement of Channel Consumption (CC): The average channel consumption can be computed by considering used and collided slots. The Channel Consumption (CC) is given by:

$$CC = \frac{nUS - nCS}{S} \qquad (13)$$

where,
nUS = The number of used slots
nCS = Number of collided slots
S = The total number of slots in the network

Queue Occupancy (QO) Information: Each Cluster Head in the network contains an array to accumulate queue occupancy data of nodes which is called as QO array. This comprises of multiple cells and each cell represents the QO value of single sensor node. The QO array format is shown below in Table 1.

Table 1: Format of queue occupancy array

Node ID	Queue Occupancy value (QO)

Each node measures its QO value and appends in its data packet. During data transmission, the CH collects QO information from the node and keep track in QO_array. While scheduling TDMA slots, this information is forwarded to the base station by the cluster head.

TDMA Scheduling in WSN: Initially, data transmission is function through CSMA/CA. Since, the proposed approach is a hybrid scheduling algorithm considers Channel Consumption (CC) as a metric to trigger the TDMA slot allocation. For every Contention Access Period (CAP), the CH measures the CC using Eq. (12) and forwards it to the base station.

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.

TDMA Slot Allocation Strategy:
TDMA slot allocation is performed as follows:

- When the computed CC is less than $minTh_{cc}$, the base station transmits GEN-TDMA (Generate TDMA) message to the corresponding CH.
- Whereas receiving the GEN-TDMA message, the CH monitors the packet collision rate in CAP and forwards back the information to the base station. This rate is assessed next to two predefined threshold values that is $minTh_C$ and $maxTh_C$ to allocate TDMA slots.
- If packet collision rate is less than $minTh_C$, then the base station does not allocate TDMA slots. Then again, if packet collision rate is greater than $maxTh_C$, then the, CH sends the QO array information to the base station.
- The base station retrieves the QO_array and organizes it in the descending order of their QO values.
- TDMA slots are allocated to the nodes in descending order of their QO values. TDMA slot period will take the form of:

$$X_1 > X_2 > \cdots > X_N$$

- The TDMA assignment schedule is sent to the resultant CH by the base station.
- The CH allocates the slots to the nodes based on TDMA assignment schedule.

Once TDMA slots are assigned to the nodes, the leaf nodes tries to send their DATA_PKTs. After a node receives all the data from its child nodes, this node itself serves as a leaf node and tries to send the fused data in the next time slot.

However, the supplementary massive control packets will cause a large amount of energy to be wasted. By using the control of BS, the energy waste can be reduced and therefore the process may be much simpler. At the start of each round, the operation is also separated into numerous time slots. In i^{th} time slot, the node whose ID is i turns on its radio and receives the message from BS. BS uses the same approach to construct the routing tree in each round and then BS tells sensor nodes when to send or receive the data. In each TDMA time slot, the nodes work in turns defined by BS. When BS receives all the data, the network will start the next phase.

Information exchanging phase: Once the routing tree is built, the energy consumption of each sensor node in this round can be calculated by BS, therefore the information needed for calculating the topology for the next round can be known in advance. However, WSN may be deployed in an unfriendly environment; the actual EL of each sensor node may be different from the EL calculated by BS. To cope with this problem, each sensor node calculates its EL and detects its actual residual energy in each round. The calculated EL is defined as EL1 and the actual EL as EL2. When the two ELs of a sensor node are different, the sensor node generates an error flag and packs the information of actual residual energy into DATA_PKT, which needs to be sent to BS. When this DATA_PKT is received, BS will get the actual residual energy of this sensor node and use it to calculate the topology in the next round.

EXPERIMENTAL RESULTS AND DISCUSSION

The details of simulation parameters are listed in Table 2. In an area of 50×50 m2 sensor field, 100 sensors are deploying at random. Sensors are having a transmission range of 12 m. Number of executions is 2. The maximum Rate adjustment value is 70% and is also assumed that there is no interference from other nodes.

The lifetime of a WSN is constrained by the limited energy and processing capabilities of its nodes. To extend the life time of the sensor networks it is very important to have high energy efficiency at all the processing nodes:

Performance metrics: The performance of proposed protocol is compared with the existing GSTEB protocol and IGSTEB protocol. The performance is evaluated mainly, according to the following metrics.

Throughput: It is the number of packets successfully received by the receiver.

The graphical representation of throughput comparison is shown in the Fig. 2. The graph shows that the proposed protocol is better than the existing protocols such as GSTEB and IGSTEB.

Table 2: Simulation parameters

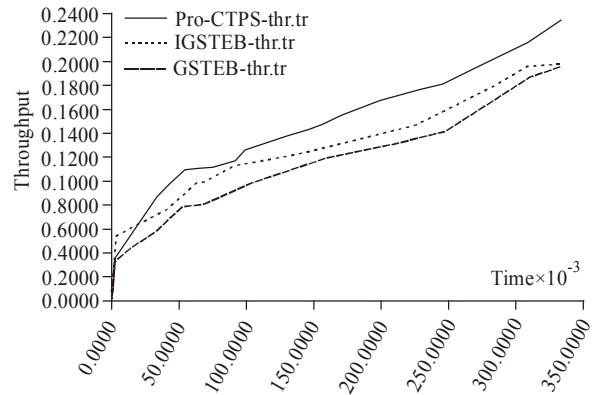| Number of nodes	100
Area size	50 × 50
Mac	IEEE 802.15.4
Simulation time	20, 40, 60, 80 and 100 sec
Transmission range	12 m
Packet size	80 bytes

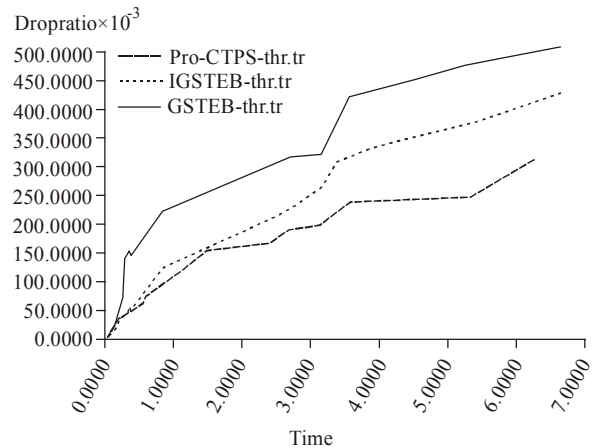Fig. 2: Throughput comparison of routing protocols

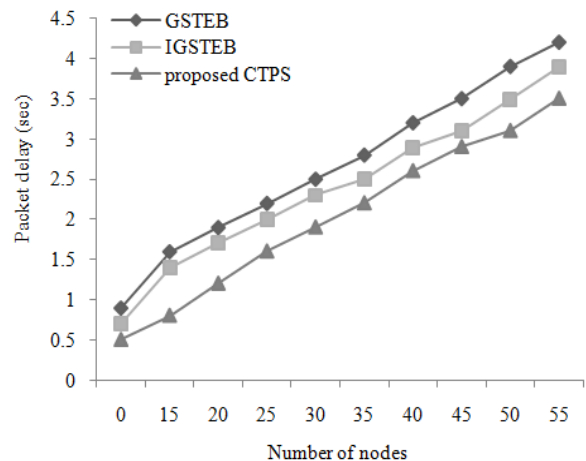Fig. 3: Packet drop comparison of routing protocols
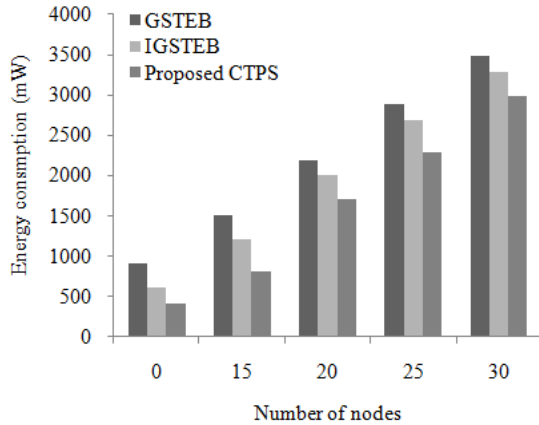

Fig. 4: Comparison of packet delay
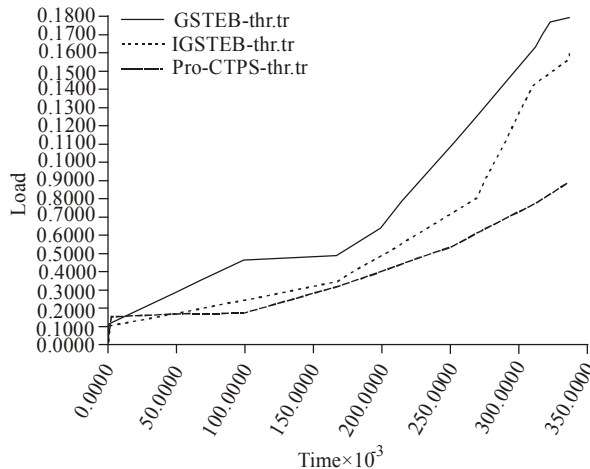
Fig. 5: Comparison of energy consumption

Fig. 6: Comparison of balancing the load in tree

Packet drop: It is the number of packets dropped during the data transmission.

The graphical representation of packet drop comparison is shown in the Fig. 3. The packet drop ratio is lesser when compared with existing algorithms such as GSTEB and IGSTEB.

The graphical representation of packet delay comparison is shown in the Fig. 4. The graph shows that the proposed protocol is better than the existing protocols such as GSTEB and IGSTEB. The packet delay is lesser when compared with existing algorithms such as GSTEB and IGSTEB

The graphical representation of energy comparison is shown in the Fig. 5. The graph shows that the proposed protocol is better than the existing protocols such as GSTEB and IGSTEB. The energy consumption is lesser when compared with existing algorithms such as GSTEB and IGSTEB.

The graphical representations of balancing the load in routing protocols are shown in the Fig. 6. The graph shows that proposed algorithm is inequality in the tree is lower than the tree in the existing algorithm.

CONCLUSION

In this research work, a hybrid time slot based packet scheduling using TDMA and CSMA is proposed with collision avoidance. In this study, improved GSTEB protocol is enhanced using the cluster tree topology and introducing packet scheduling in IGSTEB. Routing protocol divides network into many clusters, then using distance value, proposed protocol constructs a routing tree for each cluster. In routing tree, number of children for cluster nodes is determined. Proposed protocol manages load balancing using routing tree, node's neighbors average queue length and residual energy of nodes as parameters. The effectiveness of the protocol is validated by simulation. Simulation results show that our protocol achieved its goals.

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