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Research Article

Multiple Cluster Tree Routing and Scheduling for Collision Avoidance in 802.15.4. Sensor Networks

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Abstract: To avoid collisions in cluster tree routing and improve the network performance in IEEE 802.15.4 sensor networks, effective scheduling mechanisms need to be developed. In this study, a multiple cluster tree routing technique along with scheduling, for collision avoidance is proposed. Multiple cluster trees are designed in which the Cluster Heads (CH) are responsible for scheduling. Each CH schedules it member nodes with appropriate time slot considering the amount of data to be transmitted with regard to the time interval. Apart from this, cluster tree rejoining procedure is designed in which suitable parents are selected based on link quality indicator. Through simulation results, the proficiency of our technique is proved.

Keywords: 802.15.4 sensor networks, Cluster Head (CH), scheduling

INTRODUCTION

IEEE 802.15.4 sensor networks: The wireless network with minimum data rate, reduced energy consumption and minimum cost is formed by IEEE 802.15.4 standard. The distinctive characteristics of the standard makes it more approving module for wireless sensor networks and remote monitoring applications. The physical layer and medium access control layer of data link layer are the lowermost layers of the protocol that is defined by the standard (Fariborzi and Moghavvemi, 2009). It offers a minimum power, economic and a consistent protocol for wireless connectivity among low-cost, permanent and moveable devices. These devices can Fig out into a sensor network or Wireless Personal Area Network (WPAN) (Kaur and Ahuja, 2011a). The network holds two categories of the devices such as Full Function Devices (FFD) and Reduced Function Devices (RFD). FFD functions as a router. It is capable of linking to other FFD and RFD devices. RFD has capability to link with FFD devices. Al-Harbawi *et al*. (2009) IEEE 802.15.4 is utilized to interlink minimum cost sensors, actuators and processing devices in the wireless manner. The several applications of 802.15.4 devices includes industrial control, environmental and health monitoring, home automation, entertainment and toys, security, location and asset tracking, emergency and disaster response (Cuomo *et al*., 2007).

The most hopeful minimum span wireless communication technology corresponds to Bluetooth that is depended on Time-Division Multiple Access (TDMA) and Frequency Hopping Spread Spectrum (FHSS). The main features such as interference flexibility and power efficiency are possessed by this network that is required by the wireless sensor networks (Zhang and Riley, 2005). The ultimatum of portability of mobile connections has resulted in the recurrent raise of attention for Bluetooth Wireless Personal Area Network (WPAN) technology. It offers new personal communication prospects and services (Chen and Lin, 2006).

Scheduling techniques for IEEE 802.15.4 sensor networks: In WSN topologies, cluster tree topology is the well-suited topology to achieve energy efficiency. In this topology, routing decisions are made unique and to hold back energy they may go in low power mode. Here, the nodes are customized into logical groups known as clusters. A single node called cluster head maintains the nodes in cluster. Jurcik *et al*. (2009) and Juric *et al*. (2010) the term scheduling in ZigBee sensor networks refers to the allocating active period to each node by means of providing time slots and thereby alleviating all possible collision (Yen *et al*., 2012). Wireless sensor network has stringent energy constraints.

The Power-Aware Real-time Message scheduling algorithm (PARM) (Stankovic, 2006) minimizes the energy expenditure of real time wireless network. It includes two general components and a scheduler. First component is an admission controller as it facilitates the role of controlling and maintaining the flow. The accepted packets are scheduled by the scheduler by

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means of Earliest Deadline First scheduling algorithm. The second component is energy consumption controller that lessens the energy consumption rate of nodes by looping over the incoming message packets. Though PARM provide energy consumption by means of various components, it is impossible for large-scale network and real time messaging of multimedia content.

In Sleep/wakeup scheduling algorithm (Kaur and Ahuja, 2011b) for multi-hop WSNs, nodes transmit data efficiently with minimum energy consumption by switching between sleep and active mode. The sleep/awake algorithm follows the tree based architecture to transmit data between source and sink.

Issues of clustering and scheduling in zigbee sensor networks:

- Hidden node problem is one of the challenging problems in single and multi hop network of 802.15.4. Due to this problem, network suffers collision and packet overlapping problem (Chen and Lin, 2006).
- In cluster tree topology, each node has to keep track all the information of child nodes. This makes the nodes to endure memory overhead (Chen and Lin, 2006) the cluster tree network in beacon-enabled mode is vulnerable more interference especially local interference (Han *et al*., 2011).
- To avoid the overlapping the active periods, beacon scheduling is used as a straightforward approach. Nevertheless, this approach shows poor performance when the network includes more Zigbee Routers (ZRs) (Buratti *et al*., 2009; Wang and Peng, 2012).

Problem identification: In our previous paper (Santhi and Venkatachalapathy, 2012), we have proposed an Ant based Multiple Cluster Tree Routing for 802.15.4 Sensor Networks. In this approach, a node is randomly selected among the available nodes as the PAN coordinator. The PAN coordinator utilizes the swarm intelligence based ant colony optimization technique to select the nodes within the transmission range for cluster formation that corresponds to the trees. In order to achieve the diverse topologies of different trees, a proper parent is selected based on the link quality index. Further, each node selects the tree with minimum cost as the main routing tree adaptable to fault free multimedia traffic. Finally, a QoS based routing is utilized for cluster based multi tree topology using ant agents. As an extension to Santhi and Venkatachalapathy (2012), in this study, we propose multiple cluster tree routing technique along with scheduling, for collision avoidance in 802.15.4 sensor networks.

LITERATURE REVIEW

Yen *et al*. (2012) have proposed a ZigBee-compliant, distributed, risk aware, probabilistic beacon scheduling algorithm. Their proposed algorithm permits a node to assess locally the risk of slot reuse and based on the assessed risk it adopts the slot with the lowest latency to its parent. They have predicted such a risk as risk probability, that is, the probability that slot reuse between two nodes will cause beacon collisions as seen by a future joining node. To assess this risk probability, they classify pairs of nodes that are at most two hops apart into Inhibited Pairs (IPs), Visible Pairs (VPs), Hidden Pairs (HPs) and Uninhibited Pairs (UPs); and according to the pair type, calculate the corresponding risk probability.

Hanzalek and Jurcik (2010) have proposed a Time Division Cluster Scheduling (TDCS) mechanism. Their proposed scheme is constructed based on the cyclic extension of RCPS/TC (Resource Constrained Project Scheduling with Temporal Constraints). It is a problem for a cluster-tree WSN and it assumes bounded communication errors. It is designed to meet all end-to-end deadlines of a predefined set of time-bounded data flows while minimizing the energy consumption of the nodes by setting the TDCS period as long as possible. Since each cluster is active only once during the period, the end-to-end delay of a given flow may span over several periods when there are the flows with opposite direction. Theie scheduling mechanism assists system designers to efficiently configure all required parameters of the IEEE 802.15.4/ZigBee beacon-enabled cluster-tree WSNs in the network design time.

Koubâa *et al*. (2008) have introduced a scheduling mechanism that utilized Time Division Beacon Scheduling approach (TDBS). It is presented for building a ZigBee cluster-tree WSN based on a time division approach. More importantly, their proposed TDBS mechanism can easily be integrated in the IEEE 802.15.4/Zig-Bee protocol stack with only minor add-ons. Initially, they have identified and analyzed the beacon frame collision problem and the different approaches proposed in Task Group. Further, they have also proposed a beacon frame scheduling mechanism (TDBS) based on the time division approach to build a synchronized multi-hop cluster-tree WSN. Finally, they have concluded by introducing a duty-cycle management methodology for an efficient utilization of bandwidth resources in the cluster-tree network.

Salhi *et al*. (2010) have presented a CoZi, which is 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. Their scheduling mechanism entirely 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.

Watfa 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.

MATERIALS AND METHODS

Overview: In this study, we propose multiple cluster tree routing technique along with scheduling, for collision avoidance in 802.15.4 sensor networks. In this technique, each Cluster Head (CH) is responsible for scheduling time slots to their child nodes. To achieve this, periodically, every child node transmits amount of data to be transmitted to their corresponding CH. By receiving this value, the CH performs scheduling using collision free scheduling algorithm. It allocates time slots considering the amount of data to be transmitted concerning the time interval. Further, we also propose an improved node rejoin procedure. Each cluster head periodically calculates Link Quality (LQ) and broadcasts to its child nodes. By receiving LQ value, it stores in its Neighbor Quality (NQ) table. When a node lost its connection with its parent node, it selects the suitable parent node with high link quality. When two nodes have similar LQ value, it selects the suitable parent in terms of tree depth value. This process is completed by processing network response and reply message.

Link Quality (LQ) estimation: The quality of a link is estimated considering two metrics as the Packet Reception Rate (PRR) and the Received Signal Strength Indicator (RSSI) as given in (2008).

Received Signal Strength Indicator (RSSI): In ZigBee network, transmission power (T_p) at the transmitter device has direct relation to remaining power (R_p) at the receiver device. The value of R_P is computed using Friis free space transmission equation as:

$$R_P = T_P \cdot TG \cdot RG\left(\frac{\delta}{4\pi d}\right) \quad (1)$$

where, TG, RG are transmitter and receiver gain, respectively. Wavelength is denoted as δ and d is the distance between sender and receiver.

The computed RSS can be converted into Received Signal Strength Indicator (RSSI) by finding ratio of received transmission power R_P to the reference power (Ref_P). Usually, Ref_P is set to 1mW. The conversion is given as, [full text]:

$$\text{RSSI} = 10\log\frac{R_P}{\text{Re}\,f_P} \quad (2)$$

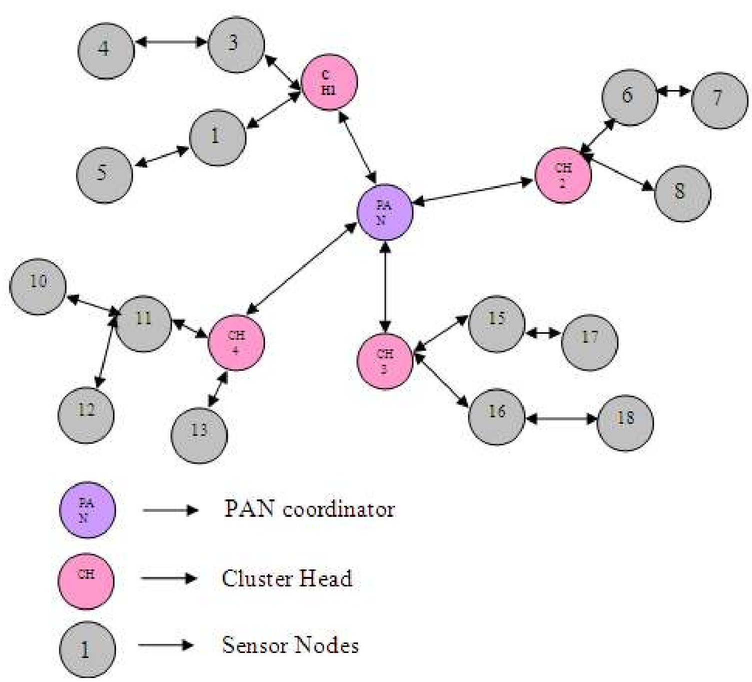

Fig. 1: Network architecture

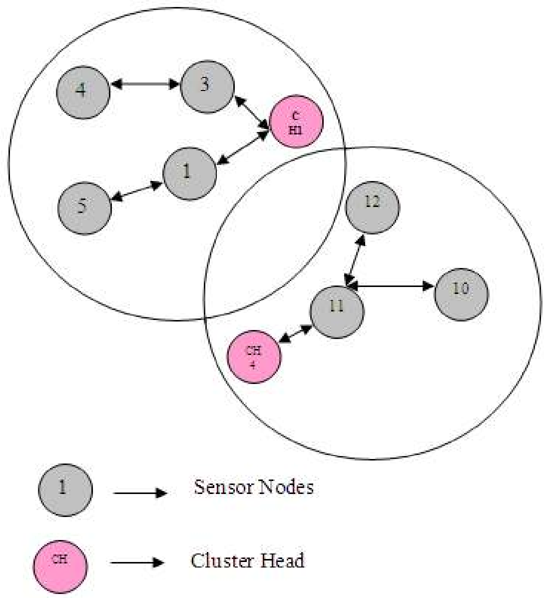

Fig. 2: Overlap region of two clusters

Packet Reception Rate (PRR): It is the probability of successfully receiving a packet between two neighbor nodes. In wireless sensor network, this metric has been used widely to predict the quality of link:

$$LQ = PRR \times norm(meanRSSI) \quad (3)$$

The mean *RSSI* takes value of range [-100, -40] of the dBm.

Network architecture: Our network made up of PAN coordinator and a set of sensor nodes (S_1, S_2 … S_n). Cluster tree topology is considered to facilitate cluster tree formation. The PAN coordinator utilizes the swarm intelligence based ant colony optimization technique to select the nodes within the transmission range for cluster formation, which corresponds to the trees. In order to achieve the diverse topologies of different trees, a proper parent is selected based on the link quality index. Further, each node selects the tree with minimum cost as the main routing tree adaptable to fault free multimedia traffic. Thus, this multiple cluster tree construction technique is described at length in our previous paper. Santhi and Venkatachalapathy (2012) further, cluster management processes are processed in beacon-enabled mode for WSN suffers from stringent energy and delay requirement. Our network architecture is given below in Fig. 1.

Scheduling technique for collision avoidance: In multiple cluster architecture of WSN, beacon frames are transmitted over the network using ZigBee Routers (ZR). This kind of broadcasting is performed by means of cluster tree topology. In general, the transmission range of a node is often overlaps with transmission range of other nodes. Similarly, when nodes with same transmission range transmit data at same time, it directly or indirectly leads to the circumstance of data collision. This data collision significantly reduces the packet delivery ratio and thereby overall network performance. Our collision free scheduling algorithm reduces and prevents the occurrence of collision by proficiently scheduling the access time of each node. The overlap region of two cluster is picturized in Fig. 2.

The scheduling algorithm schedules access time to each node based on size of data (number of packets) to be transmitted by it and it is represented as (N_{PT}). Let n_1, n_2, n_3 … n_n be the set of nodes in the network and T = t_1, t_2 … t_n be the cyclic time schedule indices allocated to the nodes. Let us assume the node set with different N_{PT} value. Based on these considerations, the scheduling algorithm validates the schedulable and non-schedulable node sets. Scheduling algorithm is given below in algorithm-1.

Algorithm-1:

1) Construct the cluster tree network with CH_1, CH_2, CH_3 … CH_n as set of cluster heads and n_1, n_2, n_3 … n_n as child nodes
2) Initialize T = t_1, t_2 … t_n intervals
3) Let OT be the order of time schedule and represented as $T = \{2^{OT_i}\}_{1 \le i \le n}$
4) $T_{min} = 2^{OT\min}$ be the minimum time interval
5) Arrange the set T in ascending order of t_i
6) If (for every CH_i, CH_j, and the time interval $t_i = t_j$) Then
   (6.1) If (N_{PT}(i) $\geq$ N_{PT}(j)) then place time interval t_i is placed before t_j in set T
   (6.2) Else place t_j before t_i in set T
7) Let T_{max} be the maximum time interval when the access time slot is equal to min $(N_{PTi})_{1 \le i \le n}$
8) For (every element i in T)
9) Do
   (9.1) find first available consecutive time slots with a length equal to N_{PT}(i)
   (9.2) allocate N_{PT}(i) for consecutive time slots from the available time slot
10) Iterate
11) If (N_{PT}(i) successive time slots for each interval = unavailable) then
   (11.1) The set is not schedulable
12) Until come to an end of maximum cycle
13) Other wise the packet is schedulable

At each periodic interval, child nodes of each cluster transmit their N_{PT} value to the Cluster Head (CH). The description of scheduling algorithm is as follows; consider the set T contains the time schedule indices. The variables T_{min} and T_{max} are the minimum and maximum values of time interval. The set T is arranged in the ascending order of their values. When (N_{PT}(i) $\geq$ N_{PT}(j)) then place time interval t_i is placed before t_j in set T, otherwise place t_j before t_i in set T. For

Table 1: Header of NQ table

Neighbor Node ID	Sequence Number	Link Quality (LQ)	Duration	Possible Parents

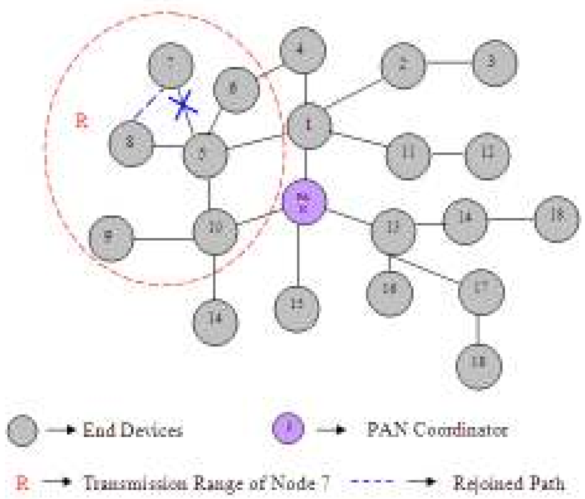

Fig. 3: Rejoin procedure

every time slot, first schedule N_{PT} with consecutive time slots. This process is repeated for all consecutive time slots of N_{PT} until it reaches the maximum cycle time. During scheduling, when N_{PT} does not find successive free slots for allocation, then the set is concluded as not schedulable set and other sets as schedulable.

Tree rejoin procedure: Each node maintains a neighbor quality table (NQ) (as per Eq.3) for its neighboring node. The NTQ table is used by each node to keep tracks the quality of each node. The NQ table contains the neighboring node ID, sequence number, duration field, LQ value and possible parent. Here, the duration field refers to the time interval since a last link quality status is received. This field is maintained to check the newness (freshness) of link quality. The field possible parents can be any neighboring node that a node wants to join with it after it disconnects the connection with previous parent. The header format of NQ table is given (Table 1).

Each Cluster Head (CH) periodically estimates and broadcasts the LQ of its child nodes. By receiving the LQ value, each node updates its neighbor table. When the parent node is out of power and failed, the child nodes of corresponding parent trigger the rejoin procedure to find suitable parent to connect with the coordinator. Let n_i be node i, where i = {1, 2 ... n} The rejoin procedure of a node is as follows:

- When node i lost connection with his parent node it triggers rejoin procedure.
- It looks NQ table and finds all neighboring nodes that exist within its transmission range.
- The field possible parents can be constructed by choosing the nodes with latest duration field.
- The chosen possible parents' nodes are stored in NQ table for selecting suitable parent node.
- From stored possible parent nodes, n_i selects the node with high LQ value.
- When more than one node has similar LQ value then the further parent node selection is based on depth of a node in the tree structure.
- The node with low depth is elected as suitable parent.
- After the selection of suitable parent, node n_i transmits Nwk-Join (Network Join) message to the selected suitable parent.

  Node $n_i \xrightarrow{Nwk-Jin}$ Suitable Parent
- While receiving the Nwk-Join message, the suitable parent node transmits back the Nwk-Res (Network Response) message to the corresponding node.

  Node $n_i \xleftarrow{Nwk-Res}$ Suitable Parent
- By receiving the Nw-Res message, node ni joins with the selected parent.
- If node n_i does not receive the Nw-Res meassge even after the time interval of I_{res}, the corresponding repeat the same process again to find the suitable parent.

Consider the scenario given in Fig. 3; we can observe that node n7 lost its connection with its parent node n5; this disconnection may be due to the failure of node n5. After the failure of n5, node n7 invokes the rejoin process. It has four successful neighbor nodes in its NQ table. By considering duration time, n7 selects 8, 6 and 9 as possible parents. After checking LQ value of three nodes, n7 found that n6 and n8 has similar high LQ value than n9. Now, it selects node n8 as its suitable parent by considering depth value. Using Nwk-Join and Nwk-Res messages, n7 joins with n8.

RESULTS AND DISCUSSION

Simulation setup: The performance of the proposed Multiple Cluster Tree Routing with Scheduling (MCTS) technique for Collision Free Scheduling is evaluated using NS2 (Wang and Peng, 2012) simulation. A network which is deployed in an area of 50×50 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

Table 2: Simulation parameters

No. of Nodes	21, 41, 61, 81 and 101
Area Size	50×50
Mac	IEEE 802.15.4
Simulation Time	20, 40, 60, 80 and 100 sec
Transmission Range	12 m
Routing Protocol	MCT
Traffic Source	CBR
Packet Size	80 bytes

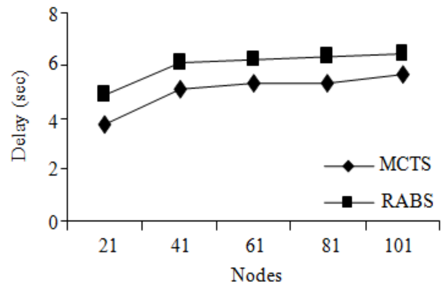

Fig. 4: Nodes Vs delay

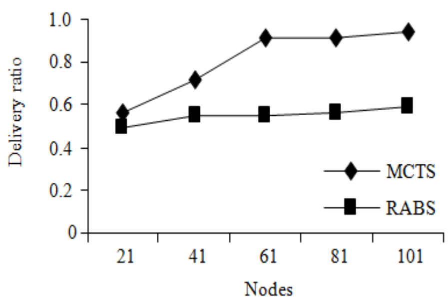

Fig. 5: Nodes Vs delivery ratio

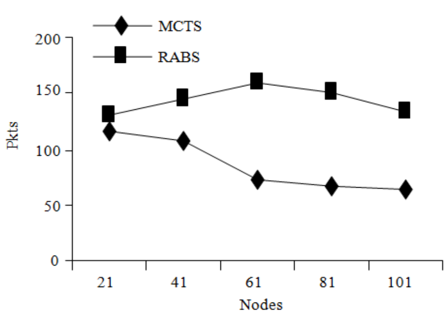

Fig. 6: Nodes Vs drop

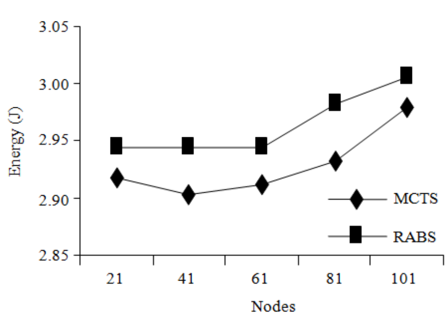

Fig. 7: Nodes Vs energy

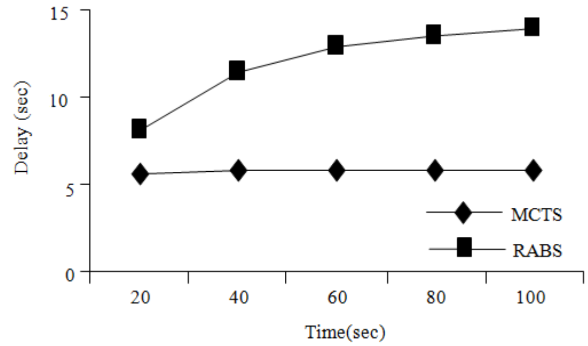

Fig. 8: Time Vs delay

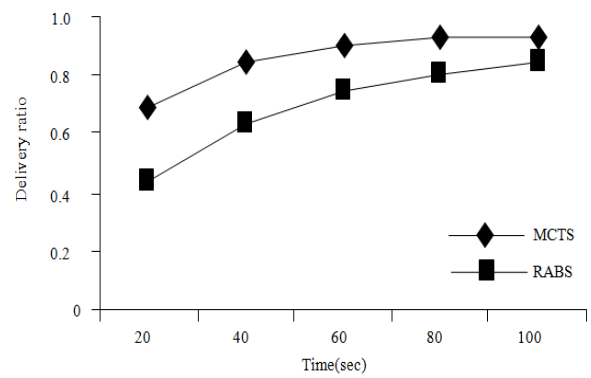

Fig. 9: Time Vs delivery ratio

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

Performance metrics: The performance of MCTS is compared with the Risk-Aware Beacon Scheduling (RABS) protocol (Yen *et al*. 2012). The performance is evaluated mainly, according to the following metrics.

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

Average packet delivery ratio: It is the ratio of the number of packets received successfully and the total number of packets transmitted.

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

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

Energy consumption: It is the average energy consumed by the nodes for the transmission process.

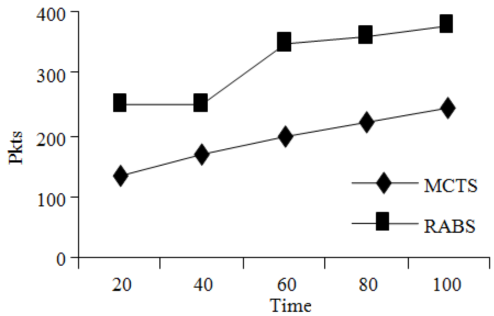

Fig. 10: Time Vs drop

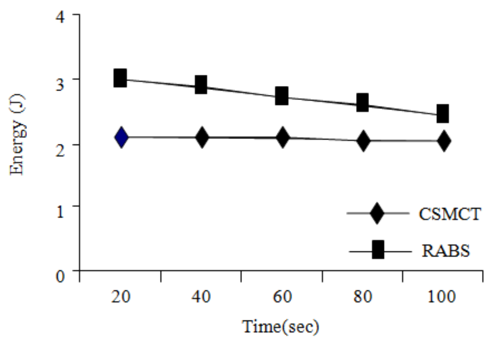

Fig. 11: Time Vs energy

The simulation results are presented in the next section.

Results:

Based on nodes: In our first experiment we vary the number of nodes as 21, 41, 61, 81 and 101.

Figure 4 to 7 show the results of delay, packet delivery ratio, packet drop and energy consumption for MCTS and RABS, respectively, for varying the nodes from 21 to 101. From the figures, it can be observed that MCTS outperforms RABS in terms of delay by 16%, delivery ratio by 30%, packet drop by 39% and energy consumption by 1.2%.

Based on simulation time: In our second experiment we vary the simulation time as 20, 40, 60, 80 and 100 sec.

Figure 8 to 11 show the results of delay, packet delivery ratio, packet drop and energy consumption for MCTS and RABS, respectively, for varying the simulation time from 20 to 100. From the figures, it can be observed that MCTS outperforms RABS in terms of delay by 49%, delivery ratio by 20%, packet drop by 39% and energy consumption by 23%.

CONCLUSION

In this study, we have proposed a multiple cluster tree routing technique along with scheduling, for collision avoidance in 802.15.4 sensor networks. In this technique, each Cluster Head (CH) is responsible for scheduling time slots to their child nodes. To achieve this, periodically, every child node transmits amount of data to be transmitted to their corresponding CH. The CH schedule nodes with appropriate time slot considering the amount of data to be transmitted about the time interval. In addition to scheduling algorithm, improved tree rejoin procedure is used to select the suitable parent considering link quality indicator. The scheduling algorithm prevents data collision and the rejoin procedure reduces time delay and energy consumption by avoiding rescanning of entire network. Through simulation results, the proficiency of our technique has proved. Our technique avoids collision and improves throughput. Similarly, our rejoin procedure conserves more energy and incurs low delay.

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