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A POWER EFFICIENT MAC PROTOCOL FOR QUALITY OF SERVICE EVALUATION IN WIRELESS SENSOR NETWORKS

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Abstract: Wireless sensor networks represent a key technology enabler for enhanced health care and assisted living systems. Recent standardization efforts to ensure compatibility among sensor network systems have produced the IEEE 802.15.4 standard, which specifies the MAC and physical layer behaviour. Energy and network life time are two critical factors for WSN performance. IEEE 802.15.4 is a standard used for low data rate Wireless Personal Area Networks (WPANs). Medium Access Control layer (MAC) of IEEE 802.15.4 plays an important role in the performance of Wireless Sensor Network (WSN). The unique feature of this MAC layer is the superframe structure, which allows devices to access channels in a Contention Access Period (CAP) or Collision Free Period (CFP) and use beacon based synchronization mechanism. In this paper, we propose a cross-layer framework to prolong the network lifetime, to improve the energy and to lower the latency of WSNs based on the IEEE 802.15.4/ZigBee standards. To cover all the scenarios, we have considered hierarchical topology and peer to peer beacon enabled network. The performance metrics are evaluated using simulation results.

Keywords: IEEE 802.15.4, Wireless Sensor Networks, Medium Access Layer, Hierarchical and peer to peer topology,

I. INTRODUCTION

Wireless Sensor Networks are a new class of ad hoc networks that will find increasing deployment in recent years. Sensor networks enable reliable monitoring and analysis of the unknown and untested environment. Ease of deployment, extended range, fault-tolerance and mobility are some of the advantages of wireless sensor networks. Wireless sensor nodes are expected to be extremely small and battery operated. Protocols for these networks must be designed in such a way that the limited power in the sensor nodes should be used in the most efficient manner. The ageing population in many developed countries highlights the importance of novel technology-driven enhancements to current health care practices. Recent technological developments in the fields of sensing, actuation, processing, wireless communication, and information management have increased interest in technology-enhanced health care. For example, a wireless network of sensor and actuator nodes can be deployed in an elderly person's home (with the person's consent) to assist the person in living independently for as long as possible. Another example is the use of wireless sensor networks to monitor hospital patient vital signs to allow the patient's greater freedom of movement.

A major enabling technology of enhanced health care systems is wireless sensor networks (WSN). The large scale adoption of WSN technology for health care systems will depend on the Quality-of-Service (QoS) provided by these networks, namely the reliability, latency, and efficiency. QoS provision in WSN's is tightly coupled with the medium access control (MAC) protocol. The MAC layer is responsible for coordinating channel access, such as transmission scheduling to maximize throughput and to avoid packet collisions. To ensure network longevity and acceptable end-to-end packet delay, MAC protocols for sensor networks target a balance between energy efficiency and end-to-end packet delay at the expense of data throughput.

A. Why 802.15.4 MAC?

A new standard IEEE 802.15.4 was uniquely designed to suit personal wireless networks requirement consuming low power, provides low data rate and low cost. IEEE 802.15.4 is a short-range wireless technology intended to provide applications with relaxed throughput latency requirements in wireless personal area networks (PANs). The IEEE 802.15.4 standard has received considerable attention as a low data rate and low power protocol for wireless sensor network (WSN) applications in industry, control, home automation, health care, and smart grids. The key features of 802.15.4 are low complexity, low cost, low power consumption, and low data rate transmissions. The development of low-power MAC protocol for WSN has been a hot research topic for the last few years.

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Some of the MAC Protocols available are: S-MAC, TMAC, D MAC, med MAC, B-MAC, G-MAC and IEEE 802.15.4 etc. Among all, the IEEE 802.15.4 MAC is the most promising for wireless sensor networks because of several reasons: It is well layered and provides a combination of link management mechanisms that can be enabled selectively depending on the user configuration. Also has a comprehensive specification which addresses the basic deployment requirements such as network configuration, management and security services to guarantee data confidentiality and integrity. It is the first standard which allows simple sensors and actuators to share standard wireless platform. Highly configurable and supports acknowledgements which can be turned on and off based on the requirement. It also achieves efficient reliability with fewest numbers of retransmissions.

B. Device Classes

There are two kinds of devices used in WBAN which can be classified as Reduced Functionality Device (RFD) and Full Functionality Device (FFD). Star topology is an example for RFD. Device can communicate only with the Network Coordinator and devices cannot become a Coordinator as shown in Fig. 1(a). Any topology i.e., Peer-to - peer or Cluster- Tree can be used as an example for FFD. All devices have the Network Coordinator capability and device can communicate with any other device as in Fig 1(b).

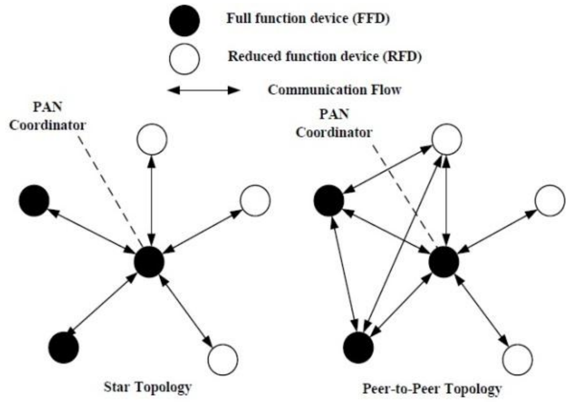

Fig 1.Network Topologies of IEEE 802.15.4

(a) Star topology (b) peer-to-peer topology

II. IEEE 802.15.4 ARCHITECTURE

The Architecture for 802.15.4 standard is entirely based on OSI model in the network. Each layer is responsible for one part of the standard and offers services to higher layers. 802.15.4 Standard defines both Physical and MAC layers of ZigBee Standard as shown in Fig. 2. Main features of PHY layer are activation and deactivation of the radio transceiver, Energy Detection (ED), Link Quality Indication (LQI) for received packets and Clear Channel Assessment (CCA). MAC sub-layer provides an interface between the Service Specific Convergence Sub-layer (SSCS) and PHY. MAC Sub-layer handles all access to the physical radio channel and is responsible for providing services to the Application layer through two groups: MAC Data Service and MAC Layer Management Entity. MAC Layer Management Entity (MLME) is the Management Entity included in MAC Sublayer. This is accessed through MLME-SAP. MLME also responsible for maintaining a database of managed objects referred to as the MAC sub-layer PIB. MAC data service is accessed through the MAC Common Part Sub-layer (MCPS) data SAP.

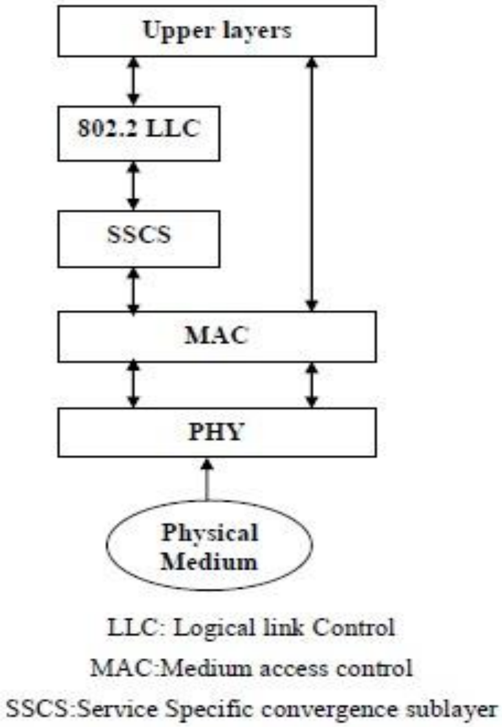

Fig 2. IEEE 802.15.4 LR-WPAN device architecture

A. PHY Layer

The PHY layer specification dictates how IEEE 802.15.4 may communicate with each other over the wireless channel. Use of frequency bands are allowed with varying data rates. The bit rates are 20 Kbps in the European for 868 MHz band (868-868.6 MHz) with a single channel between this band, 40 Kbps in the North American for 915 MHz band (902-928 MHz) with 10 channels and 250 Kbps in the worldwide for 2.45 GHz band (2.4-2.4835 GHz) with 16 channels between this band. All these frequency bands are based on Direct Sequence Spread Spectrum (DSSS) spreading technique. The 865 MHz and the 915 MHz radio map each data symbols onto a 15-chip PN sequence, followed by binary phase-shift keying (BPSK) for chip modulation. On the other hand, 2.45 GHz Industrial Scientific Medical (ISM) radio band maps each 4 bits of information onto a 32 chip PN sequence followed by offset orthogonal phase shift keying (O-QPSK).

B. 802.15.4 MAC Operational modes

MAC layer is responsible for Beacon Management, Channel Access, Frame Validation, Acknowledged Frame delivery, Association and Dissociation. The MAC supports two operational modes as described in Fig. 3.

Non-Beacon Enabled mode: A network node can send data to the coordinator at its will by using unslotted CSMACA and to receive data from the coordinator, the node must power up and poll the coordinator. Advantage is that the node's receiver does not have to regularly power-up to receive the beacon. The disadvantage is the coordinator cannot communicate at will with the node but must wait to be invited by the node to communicate.

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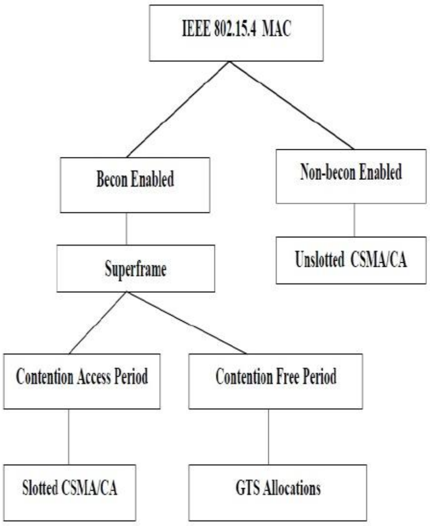

Fig 3.Operation Modes of IEEE 802.15.4 standard

Beacon Enabled mode: The network is fully synchronized as the coordinator sends out periodic packets or beacons. This mode uses the Superframe structure of 802.15.4 MAC.

C. Superframe Structure

Key feature of 802.15.4 MAC layer are the superframe structure, which allows devices to access channels in a Contention Access Period (CAP) or a Collision Free Period (CFP) and the beacon based synchronization mechanism .The format of the superframe structure is determined by the coordinator. Structure of superframe is described by the values of macBeaconOrder (BO) and macSuperframeOrder (SO) as in Fig. 4. MacBeaconOrder defines the interval at which the coordinator shall transmit its beacon frames. MacSuperframeOrder defines the length of active portion of the superframe along with the beacon.

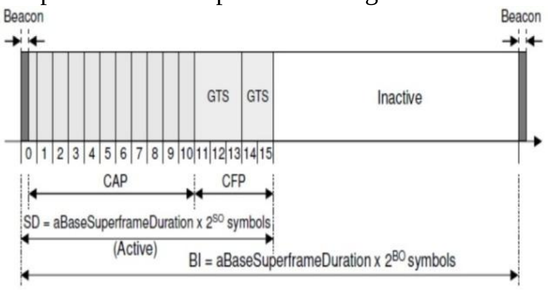

Fig 4. Superframe structure in IEEE 802.15.4 standard

III. DATA TRANSFER MODELS

There are three kinds of Data Transfer transactions exist in 802.15.4 w. r. t Beacon Enabled and Non-Beacon Enabled modes. First is the data transfer to a Coordinator from a device. Second is the data transfer to a device from a Coordinator. Third transaction is between two peer devices. In case of Beacon Enabled mode, when a device wishes to transmit data to a coordinator, it listens for network beacon. If beacon found, device start synchronizing to the Superframe Structure. At a particular time, device transmits data using Slotted CSMA-CA to the coordinator .Acknowledgement frame is optional. But in case of Non-Beacon Enabled Mode, device transmits data frame using un-slotted CSMA-CA to the coordinator. Acknowledgement is again an option. Sequences are summarized in Fig. 5(A) and Fig. 5 (B) respectively.

In case of Beacon Enabled mode, when a coordinator wishes to transmit data, it indicates in the network beacon that the data is pending. Device listens for network beacon and transmits MAC command requesting data using slotted CSMA-CA. Acknowledgement frame is sent from the coordinator for data request and pending data frame is sent to the device immediately after the acknowledgement. But in Non-Beacon Enabled mode, Coordinator stores the data for the appropriate device to make contact and request the data. This contact is done by transmitting the MAC command requesting the data, using un-slotted CSMA-CA. This data request command is acknowledged by transmitting an acknowledgement frame. If a data frame is pending, coordinator transmits the data frame to the device using unslotted CSMA-CA. If no data frame is pending, this is indicated by the coordinator in the acknowledgement frame or data frame with a zero-length payload. Sequences are summarized in Fig. 6(A) and Fig. 6(B).

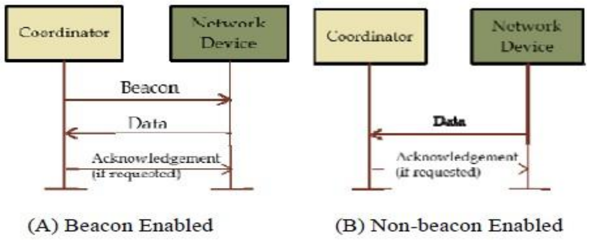

Fig 5. Communication to a coordinator in 802.15.4 MAC

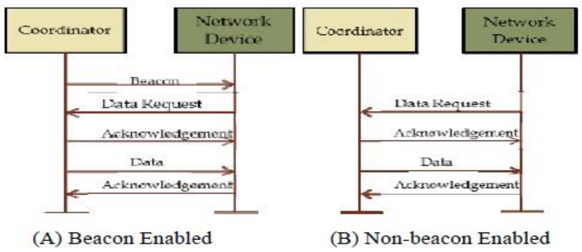

Fig 6. Communication of coordinator in 802.15.4 MAC

In case of Peer-to-Peer transaction, every device may communicate with every other device in its radio sphere of influence. Devices wishing to communicate must be constantly synchronized with each other.

IV. PROPOSED ARCHITECTURE

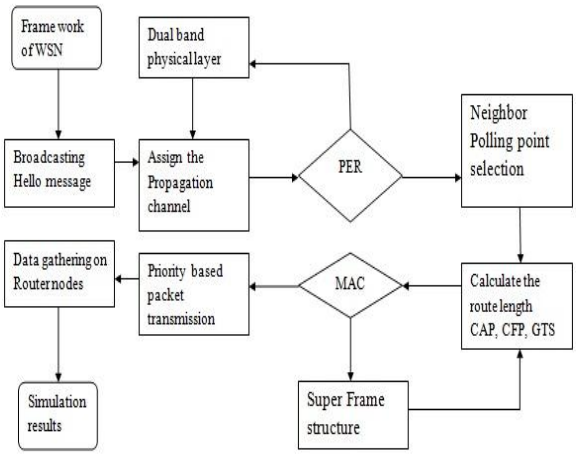

Fig 7. Architecture of Proposed System

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The working sensor networks (WSN) is shown in Fig. 7 which describes all the modules involved. Initially the network is created by assigning the nodes in the framework of WSN. Then the assigned nodes are broadcasted for their route request and route reply. In the PHY layer, propagation channel is assigned using two ray models. Then it is routed using LEACH protocol for selection of neighbour polling point.

Low Energy Adaptive Clustering Hierarchy (LEACH) , a wireless sensor network routing protocol which employed as a widely known communication protocol in today's era based on the concept of hierarchical routing. The prime focus of this protocol is to enhance the energy utilization. It works as a stand in protocol for wireless sensor network which help to deal with consumption of energy at particular level. LEACH protocol, network nodes are arranged in cluster, random algorithm select some number of node that act as cluster head. Cluster head which are the nodes that having their own significant and added rights than normal cluster node. Cluster head accumulates data and aggregate to the base station. LEACH has two phase protocol as in Fig 8.

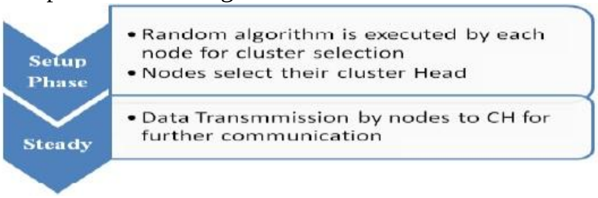

Fig 8. Phases of LEACH

In the MAC protocol superframe structure, changes has been made for power efficiency and GTS is allocated for proper delivery. The entire connection is established using peer-to-peer network topology and priority based packet transmission is obtained. The obtained data of router nodes are gathered and their performance metrics are analysed using simulation results.

V. SIMULATION RESULTS

The simulations have been performed using GloMoSim a scalable wireless networks simulator. The simulation parameters are listed in the Table. To evaluate the performance of beacon enabled peer-to-peer topology using leach routing protocol is analysed using the following performance metrics.

Packet Delivery Ratio

It is the ratio of the number of data packets successfully delivered to the destination nodes to the total number of data packets sent by source nodes.

Average End-to-End Delay

It indicates the length of time taken for a packet to travel from the CBR (Constant Bit Rate) source to the destination. It represents the average data delay an application or a user experiences when transmitting data.

Throughput

It is the number of bits passed through a network in one second. It is the measurement of how fast data can pass through an entity (such as a point or a network).

Energy Consumption

This is amount of energy consumed by devices for the periods of transmitting, receiving, idle and sleep. The unit of energy consumption used in the simulations is mJoule.

Network Lifetime

This is defined as the minimum time at which maximum number of sensor nodes will be dead or shut down during a long run of simulations.

PARAMETER	VALUE
No of nodes and Area	30 and 1000m*1000m
PHY and MAC Model	IEEE 802.15.4
Channel frequency	2.4 GHz
Data rate	250 kbps
Transmission range	250 meter
Routing Protocol	LEACH
TX-Power	15 dBm
Path Loss Model	Two Ray Model
Simulation Time	140 sec
Traffic	CBR
No of items and Payload	1000 and 50 bytes
Packet Size	512

Table 1. Parameters of GloMoSim Config

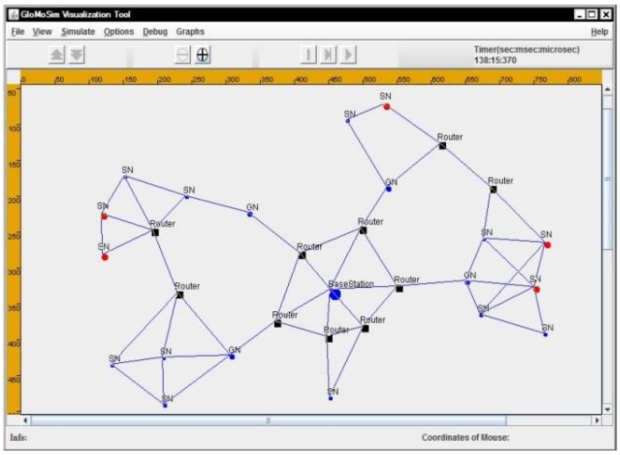

Fig 9. Simulation of Sensor Network

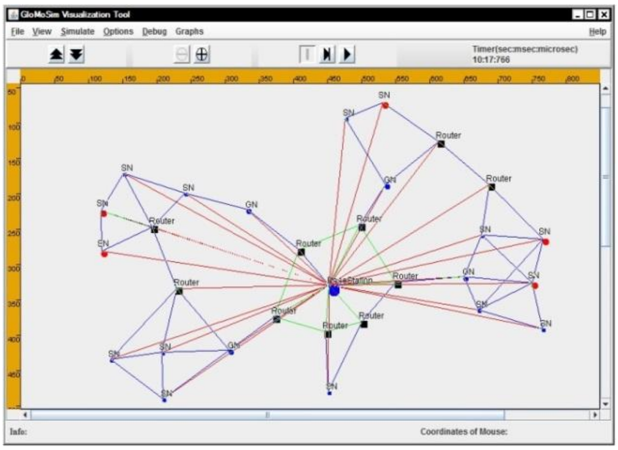

Fig 10. Routing Information of all the nodes in the network

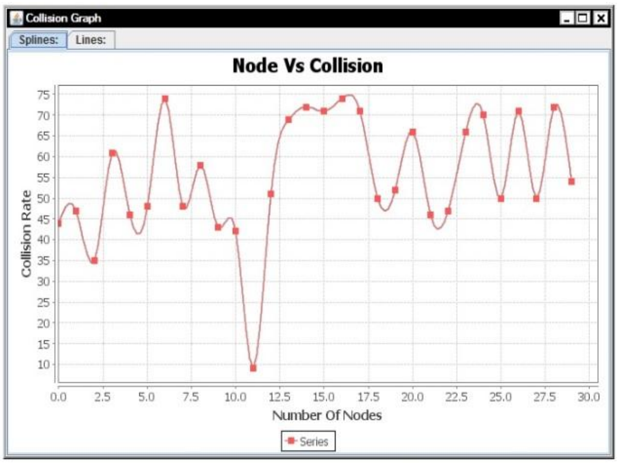

Fig 11. Simulated Result of Node Vs Collision

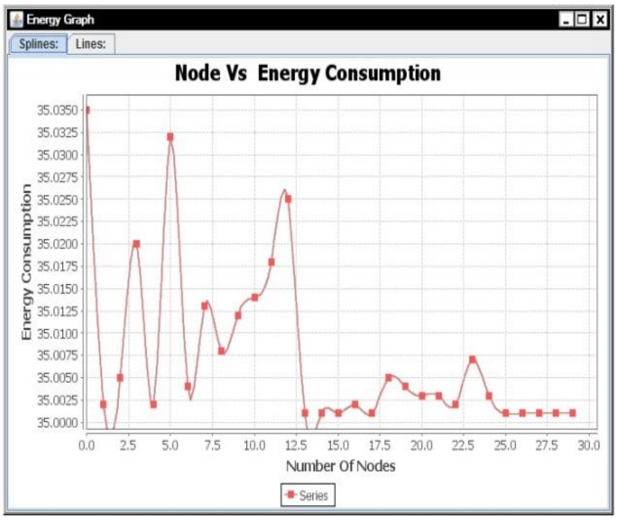

Fig 12. Simulated Result of Node Vs Energy Consumption

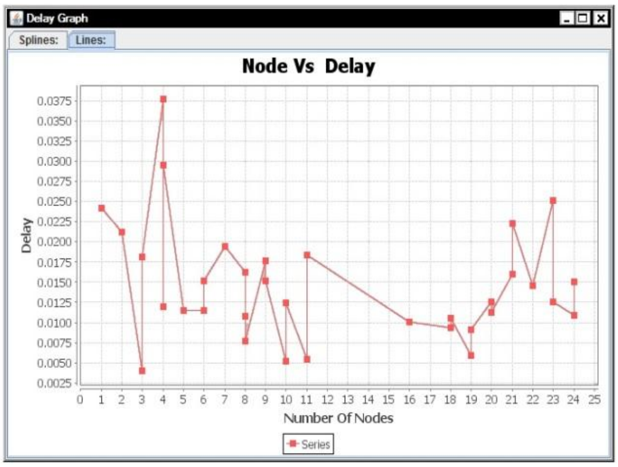

Fig 13. Simulated Result of Node Vs Delay

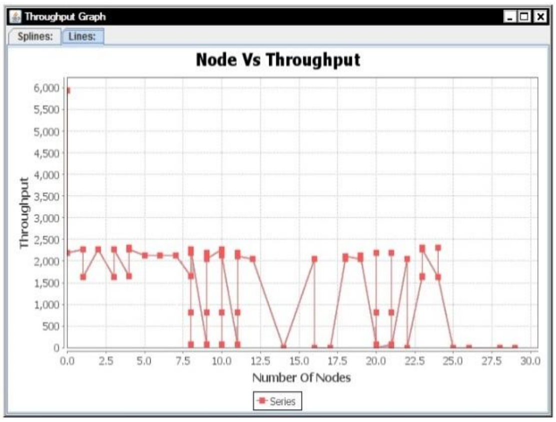

Fig 14. Simulated Result of Node Vs Throughput

VI. CONCLUSION AND FUTURE WORK

Wireless sensor networks are mainly designed for application requiring very low power consumption and medium communication ranges. In this paper effectiveness of 802.15.4 networks supporting WSN applications were investigated using simulation results. Sleep and ACK modes were also investigated to obtain understanding of the capability of 802.15.4 technology. It was found that the sleep mode could largely reduce the energy consumption at price of throughput which can be used in low-rate and limited energy constraint to achieve long battery life. ACK mode could effectively increase the communication reliability when a large number of sensor nodes is deployed. Moreover, in the simulation results the evaluation of per node sensor of throughput, energy consumption, collision and delay are done. The Quality of Service parameters will be evaluated for the entire network and fault tolerance detection will also be included in the future work.

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BIOGRAPHIES

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Shalini.K was born in the Nilgiris, Tamilnadu, India. She has received her B.E. degree in Electrical and Electronics Engineering from C.S.I. College of Engineering, Anna University, Chennai, in the year 2010 and M.E. degree in power electronics and drives from the same Institution in the year 2014. She has published two International Journals and four International Conferences. Her research interests include input power-factor-correction techniques, high-frequency soft-switching power converters and power converters for telecommunications applications. She is an active member of IET Student forum.