Energy Efficient Clear Channel Assessment for LR-WPAN

Praveen Kaushik[1] , Nilesh kumar R. Patel[2], Jyoti Singhai[3]

[1]Department of CSE, MANIT
Bhopal, M.P., India

[2]Department of CSE, MANIT
Bhopal, M.P., India

[3]Department of EC, MANIT
Bhopal, M.P., India

Abstract

IEEE 802.15.4 LR-WPAN is a specification for low-cost, low-powered and low data rate transmission. This standard uses CSMA/CA protocol for contention resolution. One of the tasks performed by CSMA/CA algorithm is Clear Channel Assessment (CCA), used to find the status (IDLE or BUSY) of the channel. There are three operating modes to perform CCA. As per the standard CCA mode 2 and 3 are based on carrier sensing where as CCA mode 1 is based on Energy Detection Threshold (EDThreshold). CCA in most of the WPAN is based on carrier sense. EDThreshold dependent CCA mode 1 is more advantageous in case of energy constraint networks, as minimum energy is consumed in channel allocation using EDThreshold. This property of EDThreshold is utilized in CCA for LR- WPAN and is implemented in NS2. Simulation results of EDThreshold based mode 1 CCA indicate that number of packets dropped decreases, network as well as node throughput increases and energy consumption is also less when compared to Carrier Sense Threshold (CSThreshold) based mode 1 CCA, It is also observed from the results that MAC_PACKET_ERROR is also acceptable (i.e $< 1\%$).

Keywords: *CCA, Carrier sensing, EDThreshold, LR-WPAN.*

1. Introduction

In the past few years, many new wireless standards exploiting non-licensed frequency bands, such as 2.4 GHz ISM (Industrial, Scientific and Medical), have been developed. The advantages of wireless networks compliant with these standards, like IEEE 802.15.4 are in terms of transmission capability and reduced costs [1,2]. IEEE 802.15.4 supports total 27 channels in three different bands. In these there are 16 channels supported by 2.4GHz band. This shared band is used to transfer data from one IEEE 802.15.4 compliant entity to other. But when more than one entity tries to access the medium at the same time and propagates on the same channel, it obliterates each other's signal. This kind of contention is avoided by using a medium access mechanism called Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) [1, 5, 6, 10]. CSMA/CA senses the in-channel power before transmission and if the channel appears idle the transmission can begins, while it is sensed busy, the device waits for a suitable backoff period and then retries. CSMA/CA cannot assure any real-time communication because there is no upper bound for the transmission time. Nevertheless, CSMA/CA based systems increase the effectiveness of the channel access by sharing the band with other users and leading to a theoretically reliable communication. Several methods can be followed to perform this medium access algorithm, and in every standard a different version of CSMA/CA is introduced. For instance, IEEE 802.15.4 exploits three clear channel assessment (CCA) methods, based on: detection of in-channel energy above a given threshold referred to mode 1, detection of an IEEE 802.15.4 compliant signal referred to mode 2 and combination of mode 1 and 2 referred to mode 3 [1]. In the literature review [7, 8], the network performance was found to be improved such as network lifetime, packet delivery ratio by means of various routing protocol [12] and other methods for improvements are CSMA/CA based. Several proposals offered, based on a CCA threshold choice [9] or mode selection with different criteria. Such works provide interesting information but imply heavy modification to the IEEE 802.15.4 standard. LR-WPAN operates at very low power; therefore energy consumption plays a key role in performance of lifetime of network [12]. Carrier Sense based mode 2 or mode 3 channel assessment technique consumes more power because Carrier Sense continuously senses the channel. Therefore, for low power networks EDthreshold based mode 1 CCA is more suitable. EDThreshold dependent CCA is more advantageous in case of energy constraint networks as minimum energy is consumed in channel allocation using EDThreshold This property of EDThreshold is utilized in CCA for LR- WPAN and is implemented in NS2.

The rest of the paper is organized as follows in section II overview of LR-WPAN is described, section III describes the EDThreshold based mode 1 CCA method, section IV discusses the performance evaluation and conclusion is given in section V.

2. 802.15.4 Overview

2.1 Introduction

IEEE 802.15.4 defines the standard for the devices to transfer information over short distances. It doesn't involve any infrastructure. Due to this it provides simple, small, power-efficient and inexpensive solutions with limited throughput to be implemented for a wide range of devices. The main objectives of an LR-WPAN are ease of installation, reliable data transfer, short-range operation, extremely low cost, and a reasonable battery life, while maintaining a simple and flexible protocol.

IEEE 802.15.4 defines the physical layer (PHY) and medium access control (MAC) sub layer specifications for devices typically operating in the personal operating space (POS) of 10 m. MAC and PHY are discussed in following subsections.

2.2 PHY layer

The PHY layer acts as the interface between the MAC sub-layer and the physical medium.

Tasks performed by IEEE 802.15.4 PHY layer:

- Activation and deactivation of the radio transceiver
- Energy detection (ED) within the current channel
- Link quality indicator (LQI) for received packets
- Clear channel assessment (CCA) for carrier sense multiple access with collision avoidance (CSMA-CA)
- Channel frequency selection
- Data transmission and reception

One of the primary reasons for the failure of several proprietary technologies is the inability to adapt. However, IEEE 802.15.4 has been designed to be applied worldwide supporting three different operating frequency bands, with a 27 numbers of supporting channels. In these there are 16 channels supported by 2.4 GHz band with data rate of 250 Kbps, 10 channels of 915 MHz band with data rate of 40 Kbps and 1 Channel of 868MHz with data rate of 20 Kbps. The 2.4GHz is license free Industrial Scientific and Medical (ISM) band. That's why 2.4 GHz band is under consideration throughout this paper. This paper can as well as applicable on 915MHz and 868 MHZ bands too.
As listed above, one of the tasks performed by PHY layer is to perform Clear Channel Assessment (CCA). CCA is necessary ingredient of the most important protocol CSMA/CA that is implemented in MAC layer. MAC layer and CSMA/CA are discussed in following subsection.

In IEEE 802.15.4 standard, three different modes to implement CCA are allowed:

- *CCA mode 1: Energy above threshold*. Medium is busy if the measured power level is higher than an Energy Detection threshold denoted as *EDThreshold*.

- *CCA mode 2: Carrier sense only*. Medium is busy if at least one signal with the modulation and spreading characteristics of IEEE 802.15.4 is detected.

- *CCA mode 3*: *Carrier sense with energy above threshold*. Medium is busy if at least one signal with the modulation and spreading characteristics of IEEE 802.15.4 and with power above a Energy Detection threshold is detected.

2.3 MAC layer

Tasks performed by IEEE 802.15.4 MAC layer:

1. Generating network beacons if the device is a coordinator
2. Synchronizing to network beacons
3. Supporting PAN association and disassociation
4. Supporting device security
5. Employing the CSMA-CA mechanism for channel access
6. Handling and maintaining the GTS mechanism
7. Providing a reliable link between two peer MAC entities

The MAC layer supports both star and peer-to-peer topologies, and also to access the medium, it exploits the CSMA/CA protocol, which may be performed in two modes: beacon and beaconless. In the former, a deterministic time slot subdivision of the channel resource is applied, while in the latter the channel is not a-priori assigned to a given terminal for a given time interval. In beaconless mode, each station wishing to transmit:

1. Waits for a random *back-off* period uniformly distributed in the interval $(0, 2^{BE} - 1)$, where *BE* is a term called Back-off Exponent.
2. Senses the status of the channel (IDLE or BUSY) through a Clear Channel Assessment (CCA) procedure.
3. If the channel is IDLE, transmits.
4. Else, if the channel is busy, then increments *BE* by one, up to a maximum *BE* level.
5. If the retransmission number overpasses a pre-assigned maximum threshold, signals failure, else restarts from the beginning.

A relevant feature of CSMA/CA protocol is that it can use any of the CCA modes from three supported modes for sensing the status (IDLE or BUSY) of the channel. Both Carrier Sense (CS) and Energy Detection (ED) are mechanisms for CCA in LR-WPANs; there are significant differences between the two in terms of performance and complexity. Due to such differences, the choice of the CCA method has considerable impact on MAC performance metrics such as throughput and energy efficiency. Often, the throughput and energy efficiency objectives are conflicting. It greatly depends on the CCA method used.

In the proposed work, the particular case of a wireless personal area network using IEEE 802.15.4 is used and thoroughly describes the effect of the PHY CCA on MAC performance.

3. ED Threshold Based Mode 1 CCA

IEEE 802.15.4 standard is uniquely designed for low data rate wireless personal area networks (LR-WPANs). As per the IEEE 802.15.4 standard, WPAN operates in any of the three CCA modes, and CCA mode 1 of IEEE 802.15.4 performs channel assessment based on the *EDThrehold,* as discussed above in section II. *EDThreshold* based mode 1 CCA is more advantageous in case of energy constraint network as minimum energy is consumed in channel allocation using EDThreshold, for instance battery powered devices for industrial and medical sensors should last from several months to many years. In energy constraint network, EDThreshold based mode 1 CCA consume minimum energy as compared to other methods. In the proposed work, method for CCA is given based on EDThreshold.

To perform CCA in mode 1, first step is to measure EnergyLevel in current channel; this is measured as depicted in the flow chart shown in Fig. 1. Now second step is to compare this measured EnergyLevel with *EDThreshold* to assess the status (BUSY or IDLE) of the channel.

As shown in Fig. 1, MAC Layer Management Entity (MLME) generates a request and sends it to local PHY layer Management Entity (PLME) to perform energy measurement or received signal power using *PLME-ED.request ()* in current channel.

PHY layer receives this request and checks that:

If TX is ON or TRX is OFF, then it perform no action and sends status as TX_ON or TRX_OFF to MAC layer.

Else if RX is ON, it performs energy measurement on current channel. Send *EnergyLevel* with SUCCESS status to MAC layer. This current channel is indicated by *phyCurrentChannel* attribute. This attribute value is stored in PHY PAN Information Base (PIB). To scan a particular channel set this attribute to the desired value.
PHY layer performs this energy measurement for a duration of at least 8 symbol periods or 128 μs. Range of this measured *EnergyLevel* value is linearly distributed in the range of 0x00 to 0xff.

Now second step to perform CCA is to assess the channel using *EDThreshold,* if LR-WPAN is using CCA mode 1. As per the IEEE 802.15.4 standard, this decision is taken by comparing measured EnergyLevel in current channel and *EDThreshold* in mode 1 CCA.Value of the *EDThreshold* is very important, it should follow the standard and it depends on Receiver sensitivity.

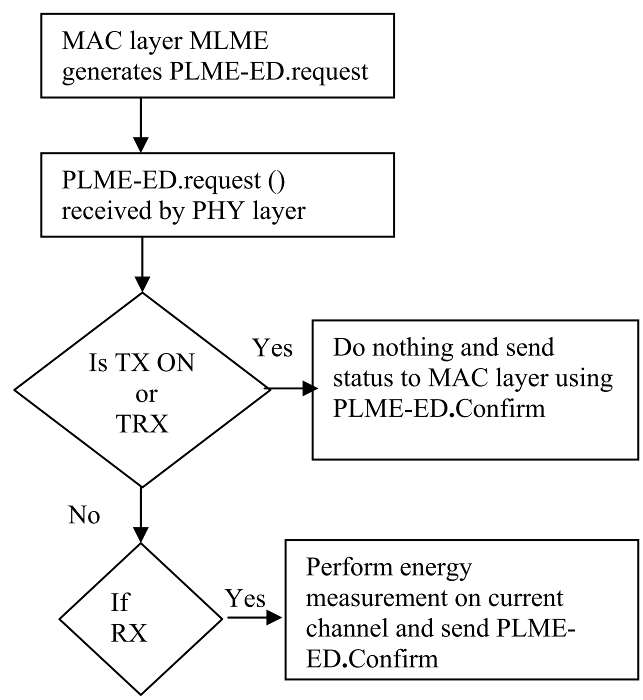

Fig. 1: Flow chart for energy measurement

Receiver sensitivity definitions:

- *Receiver sensitivity:* It is the minimum signal strength required to receive the data successfully. It can be also defined as the Threshold input signal power that results in a specified Packet Error Rate (PER) limit.

  Necessary conditions for the receiver sensitivity are:

  - Length of the data unit (PSDU) is 20 bytes.
  - Packet error rate must be less than 1 percent (PER < 1%)

- *Packet error rate (PER):* Percentage of packets are in error at the receiver side.

  - Measured over random PSDU data

Now we have the base to calculate the value of *EDThreshold*. As per the standard value of *EDThreshold* depends on receiver sensitivity and it should be at most 10dB above receiver sensitivity.

EDThreshold = RxSensitivity + 10dB

Where, RxSensitivity is receiver sensitivity value in dBm.

The *EDThreshold* value so obtained is used for CCA mode 1 in NS2. The value of *EDThreshold* is used by PHY layer to perform CCA as described in code given below.

If EnergyLevel > EDThreshold

Then

Channel BUSY

Else

Channel IDLE

In the above code *EnergyLevel* indicates the measured signal power in current channel given by *phyCurrentChannel* as described above and *EDThreshold* is also calculated as above.
If the given *phyCurrentChannel* is BUSY then PHY layer set another channel as current channel and perform CCA on that channel and so on until it doesn't find IDLE channel.

4 Performance Evaluation

Simulation of CCA mode 1 for IEEE 802.15.4 is done using NS-2. In order to evaluate the performance of proposed *EDThreshold* based mode 1 CCA is compared with Carrier Sense Based mode 1 CCA, following simulation parameters have been used

4.1 Simulation parameters

Simulation is done by using 80 X 80 m^2 area and 101 nodes for the duration of 100 sec with simulation setup time of 20 sec. At different times specific pair of nodes generates traffic. We have used mix traffic i.e. CBR and Poisson. Size of packet is 80 and 70 bytes for CBR and Poisson traffic respectively. Propagation model used is Two Ray Ground; Queue length is 50 packets with Drop tail and transmission range is 9 meters with Omni directional antenna.

4.2 Performance results

This sub section evaluates the efficiency of *EDThreshold* based mode 1 CCA by comparing results in terms of packet drop due to LQI, IFQ and packets drop due to all reasons. Node and network throughput is also calculated. Simulation results of *EDThreshold* based mode 1 CCA indicate that number of packet dropped (due to LQI, IFQ and packets drops by all reasons) decreases; Network as well as node throughput increases and energy consumption is also less while compared to *CSThreshold* based mode 1 CCA. It is also observed from the results that MAC_PACKET_ERROR is also acceptable as per the standard using *EDThreshold* based mode 1 CCA in comparison to *CSThreshold* based mode 1 CCA. To do this, simulation script (.tcl) with above mentioned parameters have been created.

Remaining subsection discusses results generated while running simulation for *EDThreshold* based mode1 CCA and *CSThreshold* based mode 1 CCA. Here consideration is given to three important performance metrics

(1) Number of Packet dropped

(2) Network throughput and node throughput

(3) Remaining node energy of nodes

1) Number of Packet dropped: There are many reasons for packet drop. Number of packets dropped, while using *EDThreshold* based mode 1 CCA and *CSThreshold* based mode 1 CCA are compared.

- *Link Quality Indication (LQI):* A packet drop caused by LQI indicates that the link quality of packets arriving at the MAC layer is not within the acceptable threshold.

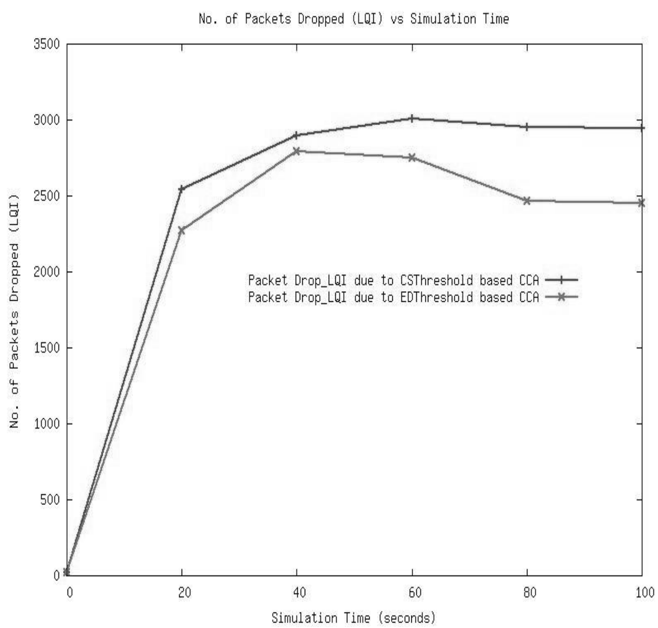

Fig. 2: Number of packet dropped vs. simulation time due to LQI

Graph for the same has been plotted in Fig. 2. The graph indicates that after the network is setup more packets are dropped in *CSThreshold* based mode 1 CCA in comparison to *EDThreshold* based mode1 CCA.

- *Error (ERR):* DROP_MAC_PACKET_ERROR: A packet drop caused by ERR indicates that if there is any error in packet while received by MAC layer. Number of packet dropped due to ERR is 0 during simulation. So it is acceptable as per the standard (<1%).

- *IFQ*: A packet drop caused by IFQ indicates that queue is full and all subsequent received packets will be dropped. Graph for the same has been plotted in Fig. 3, indicating that the performance of *EDThreshold* based mode 1 CCA work is better than packets dropped due to *CSThreshold* based mode 1 CCA

- Consideration is also given here to number of dropped packets due to all drop reasons. While using *CSThreshold* based mode 1 CCA in comparison to *EDThreshold* based mode 1 CCA, this comparison graphs is illustrated in Fig. 4.

2) Node and network throughput:

- *Node throughput:* It is a measure of the total number of data packets successfully received at the node, having the total number of bits computed over the simulation runtime. Node throughput is Refer to “(1)” and Throughput of each node during simulation has been calculated using below equation and values of all nodes' throughput are used to calculate Network throughput.
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$$NT = \frac{\text{TBR}}{\text{ST}} \qquad (1)$$

Where,

NT is Node throughput of CBR transmission,

TBR is Total bits received by nodes,

ST is simulation time

- *Network throughput:* It determines the amount of data that is transmitted from a source to a destination node per unit time (bits per second). While ignoring the overheads in the network, only the data of the CBR packets are considered. The network throughput that is Refer to “(2),” is then derived from the average throughput of all nodes involved in the CBR packet transmission. Network throughput is given by following equation and that for *EDThreshold* based mode 1 CCA and *CSThreshold* based mode 1 CCA is listed below in Table III. The values in table indicate that *EDThreshold* based mode 1 CCA resulted is better.

$$\text{Network throughput} = \frac{\sum NT}{\# Nodes} \qquad (2)$$

Where,

No. of Nodes is total number of nodes

Table 1: Network Throughput

Method	*Network* Throughput
CSThreshold based mode 1 CCA	7.60%
EDThreshold based mode1 CCA	16.16%

3) Remaining node energy: The remaining node energy of nodes those are part of paths for CBR and Poisson traffic at the end of simulation has been plotted in Fig. 5.

The graph shows that most of the nodes having more remaining energy while uses proposed *EDThreshold* based CCA instead of Carrier Sense based CCA.

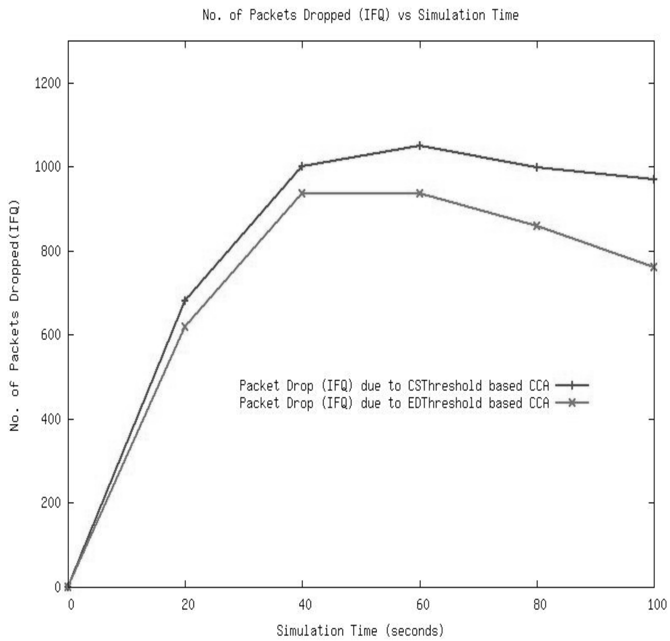

Fig. 3: Number of packet dropped vs. simulation time due to IFQ

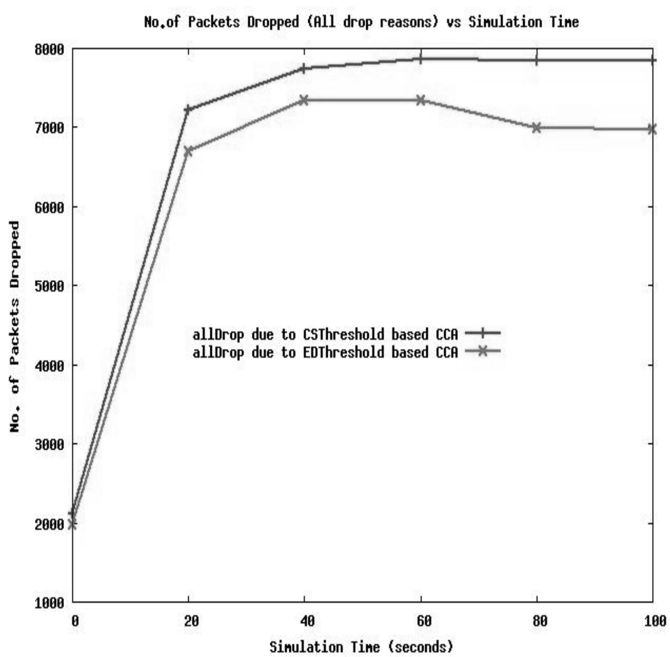

Fig. 4: Number of packet dropped vs. simulation time due to all drop reasons

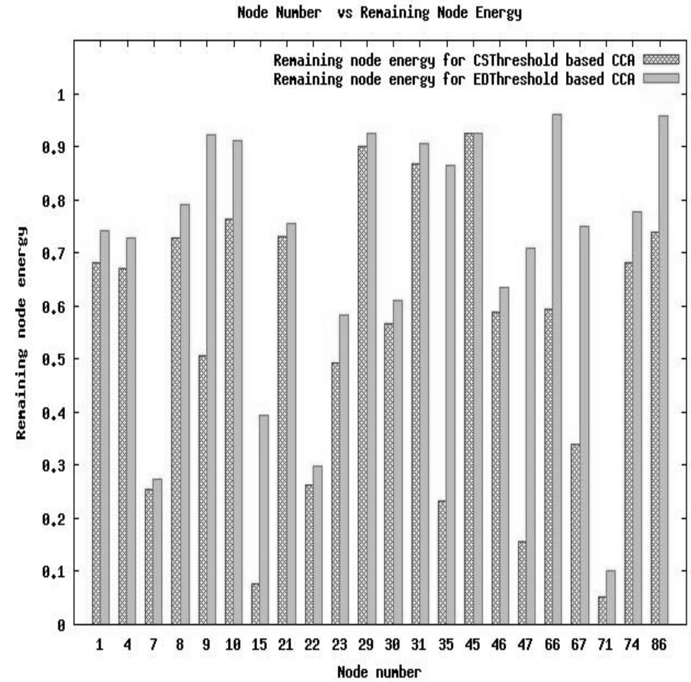

Fig. 5: Remaining node energy of nodes, which are part of path**.**

5. Conclusion

In this paper, a method is proposed to perform Clear Channel Assessment (CCA) with mode 1 in accordance with the standard specification using Energy Detection Threshold (*EDThreshold)* and compare the result with Carrier Sense based CCA. The proposed method is implemented using NS-2 and uses *EDThreshold* for assessing the channel. CCA is an ingredient of CSMA/CA, which is important part of MAC layer. So by improving CCA we have improved the performance of CSMA/CA and in turn we have improved the performance of MAC layer. The proposed method achieves network throughput which is 200% more as compared to existing method, number of packets dropped while using proposed CCA mode 1 is also less compared Carrier Sense based CCA, and higher remaining energy per node is obtained while using proposed CCA.

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Praveen Kaushik Mr. Praveen Kaushik is Assistant Professor in Maulana Azad National Institute of Technology (MANIT) Bhopal, India. He is pursing PhD in WSN. His general research interests include WSNs, Ad hoc Network and Wireless Communication

Nilesh kumar R. Patel[2] is Assistant Professor in Jaypee University of Engineering and Technology College Guna, He holds MTech (CSE) degree from MANIT, India. His general research interests include wireless communication, image processing, WSN and network security.

Jyoti Singhai Dr. Jyoti Singhai is Associate professor in Maulana Azad National Institute of Technology(MANIT), Bhopal, India. She holds Ph.D. degree from MANIT, India. Her general research interests include wireless communication, image processing, WSN and network security.