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Performance Evaluation of S-MAC and IEEE 802.15.4 MAC Protocols for various Topologies of Wireless Sensor Networks

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A B S T R A C T

In Wireless Sensor Networks Medium Access Control is an important phenomenon because the energy consumed in a network is dependent on Medium Access Control protocols. Wireless Sensor Networks are generally deployed in a large scale for many applications like environmental monitoring, in military applications etc. Due to the limited resource constraints of nodes in Wireless Sensor Network energy consumption should be very less. To achieve the above said goals different types of Wireless Sensor Networks are chosen and performance of the two MAC protocols SMAC and IEEE802.15.4 are evaluated in terms of packet delivery ratio, throughput, average end-to-end delay, average energy consumption. The network overhead is also calculated for each protocol. The simulations are carried out using Network Simulator tool NS2 (NS2.35). Simulation results show that IEEE802.15.4 has better performance for larger networks. In this paper we have focused on increased network size and its performance with different MAC Protocols.

Keywords:Wireless Sensor Network, Medium Access Control, SMAC, IEEE802.15.4, contention, collisions.

1. Introduction

A wireless sensor network (WSN) is some spatially distributed sensors to monitor physical or environmental conditions such as temperature, sound, pressure etc and to cooperatively pass their data through the network to a main location. The wireless sensor Network is built of Nodes from a few to several hundreds or even thousands where each node is connected to one or sometimes several sensors. Each such sensor network node has typically several parts. A radio transceiver with an internal antenna or connection to an external antenna, a microcontroller, an electronic circuit for interfacing with the sensors, an energy source, usually a battery or embedded form of energy harvesting. A WSN can vary from a simple star network to an advanced multi hop wireless mesh network [1]. The propagation technique between the hops of the network can be routing or flooding. Wireless Sensor Networks require technologies from three different research areas i.e., Sensing, Communication, and Computing including hardware, software and algorithms. Because of the wide range of applications of Wireless Sensor Networks such as military systems, infrastructure security, environment and habitat monitoring, industrial sensing, traffic control etc [2] a Wireless Sensor Network has to be efficiently deployed and energy conservation has to be maintained to extend the Network Life time.

A MAC protocol provides slightly different functionality depending on the network, device capability, and upper layer requirements, but several functions exist in most MAC protocols. In general, a MAC protocol provides [3]: • Framing – Define the frame format and perform data encapsulation and decapsulation for communication between devices. • Medium Access – Control which devices participate in communication at any time. Medium access becomes a main function of wireless MAC protocols since broadcasts easily cause data corruption through collisions. • Reliability – Ensure successful transmission between devices. Most commonly accomplished through acknowledgement (ACK) messages and retransmissions when necessary. • Flow Control – Prevent frame loss through overloaded recipient buffers. • Error Control – Use error detection or error correction codes to control the amount of errors present in frames delivered to upper layers. The rest of the paper is organized as follows. It describes briefly about the existing MAC protocols in

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section 2, S-MAC in section 3, IEEE802.15.4 in section 4, Simulation set up and results and analysis in section 5, and Concludes and gives the Future Work in section 6.

II. Related Work

Medium Access Control protocols for Wireless Sensor Networks can be divided into two major types. One is contention-based MAC Protocols and the other is contention less MAC Protocols. The contention based category includes IEEE802.11 which is based on Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) and S-MAC (SensorMAC). IEEE802.15.4 was exclusively designed for Low Rate Wireless Personal Area Networks (LR-WPAN). It can be applied to WSNs as well. So we have simulated the two protocols for various networks of varying sizes starting from a simple 11 nodes to a larger 50 nodes topology. We have considered the random deployment of nodes as the nodes in real time will be randomly deployed for sensing applications. The Medium Access Control Protocols can be broadly categorized into Contention based MAC Protocols and Contention less MAC Protocols [4]. In the category of contention based MAC protocols there is always a contention is present to access the channel. 978-1-5386-4304-4/18/$31.00 ©2018 IEEE. International Conference on Electrical, Electronics, Computers, Communication, Mechanical and Computing (EECCMC) 446 S-MAC and IEEE802.15.4 are contention based MAC Protocols.

III. S-MAC Protocol

In WSN a sensor node can be in any of these following modes i.e., listening, sending, receive, idle, sleep mode. Among all these modes experiments show that sleep mode consumes the least energy. For instance, Chipcon radio used in a Mica2 mote only consumes 15μW in sleep mode, three orders of magnitude less than that in idle or receive mode. The major sources of energy waste in a typical wireless sensor network are collision, over hearing, idle listening. Hence Among the techniques to improve energy consumption of contention based protocols for WSNs the basic approach is to put the radio into sleep state when it is not needed [5]. S-MAC stands for Sensor-MAC Protocol has evolved as the suitable protocol for the wireless sensor networks. SMAC Protocol's main design goal is to reduce energy consumption, while supporting good scalability and collision avoidance. S-MAC Protocol reduces energy consumption from all the sources that cause energy waste such as idle listening, collision, overhearing and control overhead. S-MAC Protocol has three major components i.e., Periodic listen and sleep, collision and overhearing avoidance, and message passing. In addition, SMAC also has good scalability and collision avoidance capability. It achieves good scalability and collision avoidance by utilizing a combined scheduling and contention scheme [6].

A. Periodic Listen and Sleep:

Nodes are idle for a long time if no sensing event happens in many sensor network applications. Given the fact that the data rate during this period is very low, it is not necessary to keep nodes listening all the time. Hence, S-MAC Protocol reduces the listen time by letting node go into periodic sleep mode. For instance, if in each second a node sleeps for half second and listens for the other half; its duty cycle is reduced to 50%. So, we can achieve close to 50% energy savings. S-MAC Scheme requires periodic synchronization among neighboring nodes to remedy their clock drift. We employ two techniques to make it robust to synchronization errors. First, all timestamps that are exchanged are relative rather than absolute. Second the listen period is significantly longer than clock error or drift. Here, all nodes are free to choose their own listen/sleep schedules. However to reduce control overhead, we prefer neighboring nodes to synchronize together. That is they listen at the same time and go to sleep at the same time.

B. Choosing and maintaining Schedules:

Before starting the periodic listen and sleep a node has to choose a schedule and exchange it with its neighbors. Each node maintains a schedule table that stores the schedules of all its known neighbors. The node fallows the below steps to choose its schedule and form its schedule table. 1. The node first listens for a certain amount of time. If it does not hear a schedule from another node, it randomly chooses a time to go to sleep and immediately broadcasts its schedule in a SYNC message, indicating that it will go to sleep after t seconds. Such node is called synchronizer; since it chooses its own schedule and other nodes will synchronize with it. 2. If the node receives a schedule from a neighbor before choosing its own schedule, it follows that schedule by setting its schedule to be the same. Such a node is called Follower. It then waits for a random delay td and rebroadcasts this schedule indicating that it will sleep in t- td seconds. The random delay is for collision avoidance, so that multiple followers triggered from the same synchronizer do not systematically collide when rebroadcasting the schedule. 3. If a node receives a different schedule after it selects and broadcasts its own schedule, it adopts both schedules (i.e., it schedules itself to wake up at the times of both its neighbor and itself). It broadcasts its own schedule before going to sleep.

C. Maintaining Synchronization:

The listen/sleep scheme requires synchronization among neighboring nodes. Updating schedules is accomplished by sending a SYNC packet. The SYNC packet is very short and includes the address of the sender and the time of its next sleep. The next sleep time is relative to the moment that the sender finishes transmitting the SYNC packet (since propagation delays are short). Receivers will adjust their timers immediately after they receive the SYNC packet. A node will go to sleep when the timer fires. To enable a node to receive both SYNC packets and data packets the listen interval is divided into two parts. The first is for receiving SYNC packets and the second is for receiving RTS packets. Each part is further divided into many time slots for senders to perform carrier sense. Each node periodically broadcasts SYNC packets to its neighbors even if it has no followers. This allows new nodes to join an existing neighborhood. The new node follows the same procedure as discussed above to choose its schedule.

D. Collision and Overhearing Avoidance:

When two nodes transmit packets simultaneously collision occurs thus resulting in packet loss and reducing throughput. As the S-MAC is contention based protocol collision occurs here. When a packet is sent by a particular node it may be listened by all the neighboring nodes which can hear it even though it is intended for only one node. Overhearing makes contention based protocols less efficient in energy than Time Division Multiple Access (TDMA) Protocols. Hence it needs to be avoided. Collision avoidance is achieved by including both virtual and physical carrier sense and RTS/CTS exchange. Each transmitted packet consists of duration field that indicates how long the remaining transmission will be. Using this node decides how long it has to keep silent when it receives a packet destined to another node. The node records this value in a variable called Network International Conference on Electrical, Electronics, Computers, Communication, Mechanical and Computing (EECCMC) 447 Allocation Vector (NAV) and sets a timer for it. Every time when the NAV timer fires, the node decrements the NAV value until it reaches zero. When a node has some data to send first it checks for the

NAV value. If it is not zero, the node understands that the medium is busy. This is called Virtual Carrier Sense. At the physical layer by listening to the channel for possible transmission Physical carrier sense is done. If both virtual and physical carrier sense indicates that the medium is free then only the node determines that medium is free. All the sending nodes perform carrier sense before starting a transmission. If a node detects that the medium is busy and it will not get the medium it goes to sleep state and wakes up when the receiver is free and listens again. Interfering nodes go to sleep after they hear RTS or CTS packets. Normally data packets are much longer than control packets. So, this approach prevents neighboring nodes from overhearing longer data packets and the following acknowledgements (ACKs). To indicate the activity in its neighborhood every node maintains the NAV. When a node receives packet destined to other node, it updates its NAV by the duration field in the packet. If the NAV value is non-zero it indicates that there is an active transmission in its neighborhood. When the NAV timer fires the NAV value decrements. Thus a node should sleep to avoid overhearing if its NAV is not zero. It can wake up when its NAV becomes zero.

E. Message Passing:

A message is the collection of meaningful, inter related units of data. It can be a long series of packets or short packet. Usually the receiver needs to obtain all the data units before it can perform in-network processing or aggregation. When we transmit long message as a single packet it is disadvantageous because if few bits are corrupted it is high cost to retransmit long packet. However, on fragmenting the long message into many small independent packets, we have to pay the penalty of large control overhead and longer delay because RTS and CTS packets are exchanged in contention for each independent packet [7]. In S-MAC protocol the long message is fragmented into many small fragments and transmitted in burst. Hence only one RTS packet and one CTS packet is used. They reserve the medium for transmitting all the fragments. Every time the data frame is transmitted, the sender waits for an ACK from the receiver. If it does not receive ACK, it will extend the reserved transmission time for one more fragment and retransmit the current fragment immediately.

F. Increased Latency:

A packet moving through a multi-hop network experiences the following delays. Carrier Sense delay is introduced when the sender performs carrier sense. Its value is determined by the contention window size. If the node detects another transmission or collision occurs then Back off delay happens. Transmission delay is determined by channel bandwidth, packet length, and the coding scheme adopted. Propagation delay is determined by the node distance between sending and receiving nodes.IN WSNs, as the node distance is very small propagation delay can be ignored. The receiver processes the packet before forwarding it to the next hop. Such delay is called processing delay. It depends on computing power of the node and the efficiency of in-network data processing algorithms. Queuing delay depends on the traffic load. If the traffic is heavy the queuing delay is very dominant and becomes significant factor. All the above delays are inherent to a multi-hop network using contention based MAC protocols. These factors are same for both S-MAC and IEEE802.11-like protocols. But in S-MAC nodes are periodically sleeping. It causes an extra delay. That is called sleep delay defined as the amount of time a sender waits until a sleeping receiver wakes up.

IV.IEEE802.15.4 MAC Protocol

802.15.4 Standard was created for small devices that consume low power and require lower data rates by IEEE. In every IEEE802.15.4 Personal Area Network (PAN) a single device acts as the PAN coordinator to control device association with in the network. In the star topology all communication and resource reservation occur through the PAN coordinator. Within the peer-to-peer topology, devices operate independently and need not communicate through the PAN coordinator, but all devices must associate with the PAN coordinator prior to participating in the network [8].

Devices in an IEEE 802.15.4 network may operate in a beacon-enabled mode, where the PAN coordinator periodically broadcasts a beacon for synchronization and management purposes, or in an unsynchronized mode without beacons. Beacon-enabled PANs utilize the synchronization provided by the beacon to perform slotted channel access while PANs without beacons use unslotted access. IEEE 802.15.4 uses a slightly modified CSMA/CA algorithm to access the wireless channel. First, the device performs a random back off before sensing the channel. If the device does not detect activity on the channel, and uses unslotted CSMA/CA, then it transmits the frame immediately. Devices using slotted CSMA/CA wait until the next slot and check the channel availability again. If a slotted CSMA/CA device detects no activity on the channel for two consecutive slots after the initial back off period, then it transmits the message. Any time a device detects channel activity during the contention procedure, it performs the back off algorithm and begins the process again at a later time. Devices only back off a limited number of times before giving up on transmitting a message. Since IEEE 802.15.4 focuses on energy constrained devices, the PAN coordinator does not initiate any data transfer.

Figure 3 shows how data transfers occur within IEEE 802.15.4. Devices with data for the PAN coordinator transmit it according to the channel access mechanism described previously. The PAN coordinator may send an optional acknowledgment upon successful data reception. Data transfer from PAN coordinator to device uses more messages, but the receiving device still initiates the transfer. The device first sends a data request command to the PAN coordinator indicating that the data transfer may occur. If desired, the PAN coordinator may transmit an acknowledgment indicating it received the command successfully. The PAN coordinator then transmits the data message according to the channel access mechanism described previously. Finally, an optional acknowledgment lets the PAN coordinator know the device received the data. Beacon messages may include addresses of devices with pending data to signal the devices to begin a data exchange. PANs operating without beacons require devices to poll the PAN coordinator for data [9].

The IEEE802.15.4 MAC can be operated in two different modes one is beacon enabled mode and the other is non-beacon enabled mode. The non-beacon enabled provides the better performance in terms of latency and energy consumption compared to beacon enabled mode. On the other hand, the beacon enabled mode offers high PDR [10].

Network topology considerably affects the overall power consumption of the system. An extended network configuration connection requires some nodes for relaying of messages coming from other nodes. This shows a higher duty cycle to monitor these messages. A well-designed synchronization strategy is required to alleviate this [11].

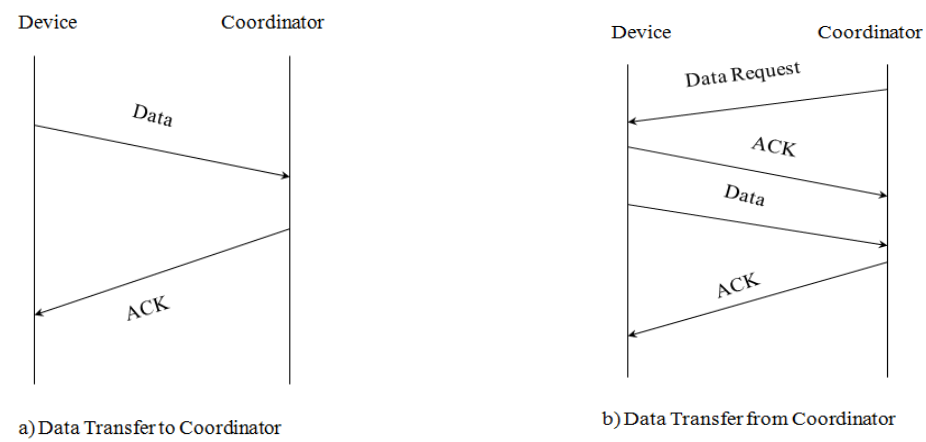


Fig. 3- IEEE802.15.4 Data Transfer

V. Simulation and Results

A. Simulation Parameters:

For the experimentation we have used the Network Simulator tool NS2 (NS2.35) [12]. In this, using the tcl (Tool Command Language) scripts we have created five different wireless sensor network topologies and we have tested the simulation results for S-MAC and IEEE 802.15.4 MAC Protocols. The five topologies are started with a simple 11 nodes to 50 nodes topology. In all the topologies the nodes are randomly deployed as the sensor nodes in a sensor network are random. The simulation parameters include, channel is wireless channel, antenna model is Omni antenna and its height is 1.5m, radio propagation model is two ray ground, network interface type is wireless physical and routing protocol is Ad hoc On demand Distance Vector Routing Protocol (AODV), transport layer protocol is Transmission Control Protocol (TCP), application protocol is File Transfer Protocol (FTP). The simulation is run for 100 seconds.

Table 1. Simulation Parameters

Channel	Wireless Channel
Radio Propagation Model	Two-ray Ground
Network Interface type	Wireless PHY
MAC Protocol	S-MAC, IEEE802.15.4
Interface Queue Type	Drop Tail/PriQueue
Link Layer Type	LL
Antenna Model	OmniAntenna
Max Packet in Queue	50
Routing Protocol	AODV
Transport Protocol	TCP
Application Protocol	FTP
Simulation Time	100 ms

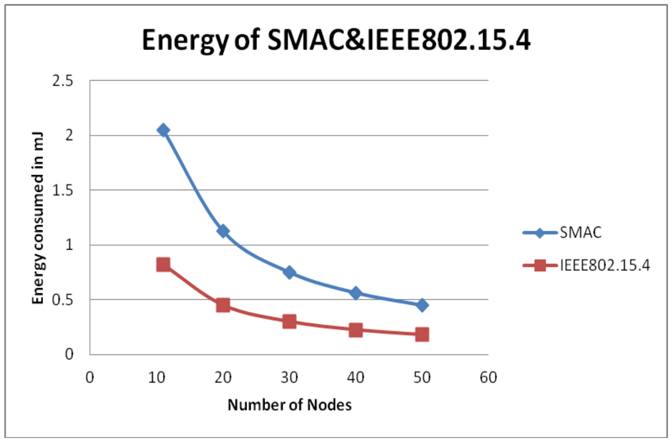
B. Simulation Results:

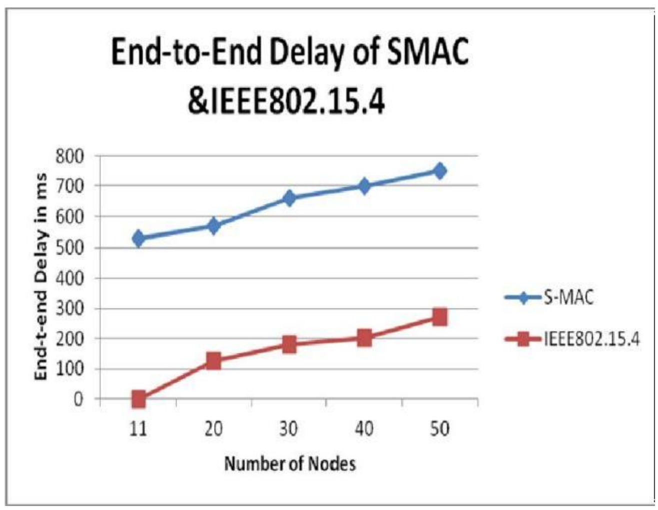
In sensor networks, all nodes cooperate for a single common task. At any particular time, one node may have dramatically more data to send than other nodes. Thus rather than treating each node equally, success is measured by the performance of the application as a whole and performance per node/per user is denied.Various parameters of a typical wireless sensor network are calculated for the same network for two different MAC Protocols and plotted. The parameters for which the performance is evaluated are Packet Delivery Ratio (PDR), Throughput (S measured in kbps), Average end-to-end delay (measured in ms), Average Energy consumed (measured in mJ), Network overhead (in terms of number of packets), and packet loss.

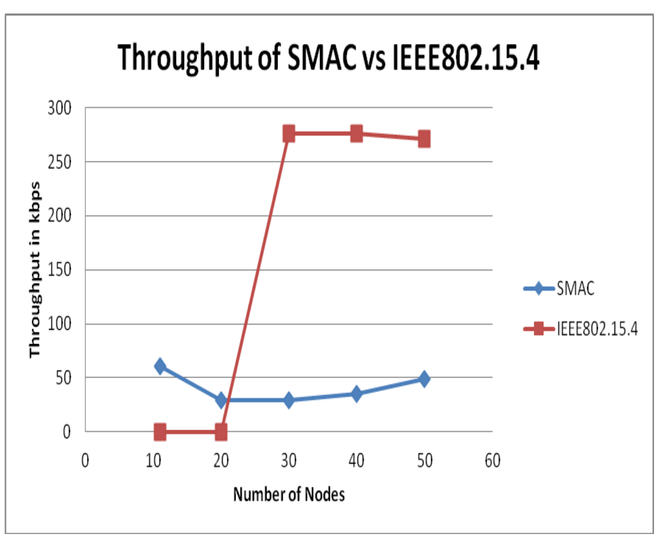
C. Result Analysis:

Energy consumed by the entire network is calculated. It shows that the energy consumption in S-MAC is more than that of IEEE802.15.4. The Packet Delivery Ratio, Throughput is high for S-MAC for smaller topologies and it is increased for higher networks where as for IEEE802.15.4 lower networks offered low PDR and Throughput and higher networks offered higher PDR and throughput. The end-to end delay of S-MAC is high for all types of networks compared to IEEE802.15.4. This is because of the longer sleep states maintained by the S-MAC protocol. The network overhead is increasing as the size of the network increases for both the protocols. But comparatively IEEE802.15.4 MAC Protocol has more network overhead.

The average energy consumed by the Network at MAC level using IEEE802.15.4 is less compared to SMAC because the former is designed for Low Rate Wireless Personal Area Networks (LR-WPAN) so as to consume low energy. In this MAC Protocol the data transfer is taking place with less number of messages and also less number of Control packets involved.



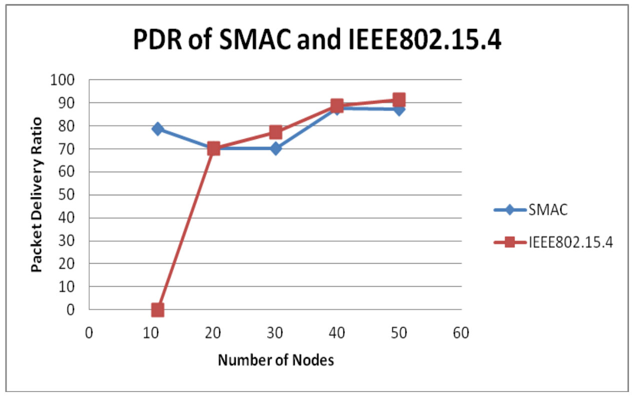




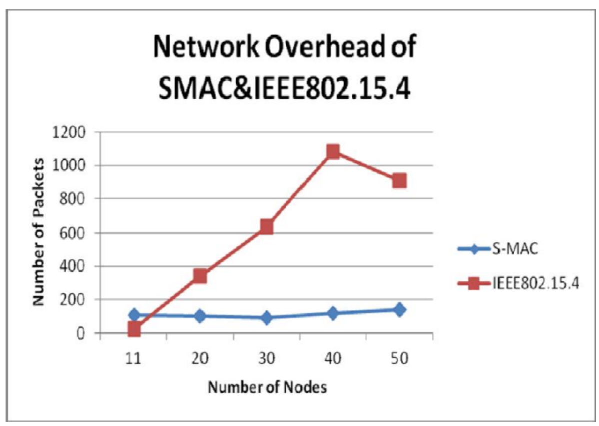
As there are number of sleep states involved in the protocol S-MAC the average end-to-end delay is more compared to the IEEE802.15.4.

The Network Overhead is the transmission of Control packets i.e., other than data packets. The network Overhead is high for the IEEE802.15.4 MAC Protocol. The network overhead is more for the IEEE802.15.4 because in the initial stage it has to coordinate for the formation of PAN coordinators. Apart from its well defined star topology for 802.15.4 here, a random network topology is choosen.

VI. Conclusions and Future Work



After simulating the S-MAC and IEEE802.15.4Throughput and PDR are high for the IEEE802.15.4 because it is simple in operation and also designed to meet higher throughput with minimum energy consumption. Initially i.e., for smaller networks the PDR and throughput using IEEE802.15.4 is low because the formation of PAN coordinators has consumed higher energy. As the S-MAC is exclusively designed to meet the requirements of a typical Wireless Sensor Network it has shown better Throughput and PDR for the smaller networks.



MAC Protocols for different types of networks and analysing the results, following conclusions can be made. For smaller networks S-MAC has shown better performance in terms of energy consumed and throughput and for larger networks IEEE802.15.4 has outperformed the S-MAC.

The protocol S-MAC was initially suggested for WSNs. As the S-MAC consumes less energy it can be improved to adopt to the larger networks also. Future experiments may include improving performance of S-MAC protocol for larger networks that is with more number of nodes.

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