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Reduction of Energy Consumption in Dynamic Spectrum Access inWireless Sensor Networks using S-MAC

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***Abstract*:**This paper presents a simulation study of energy efficientWSNETs under Dynamic Spectrum Access. In wireless networks, a lot of bandwidth owned by the primary users goes unutilised. To acknowledge this problem, WSNETs can be implemented with dynamic spectrum allocation to use unutilised bandwidth opportunistically. We implemented and simulated a Time Division Multiple Access based energy efficient cognitive radio multichannel medium access control (MAC) protocol called S-MAC. A single channel Medium Access protocol does not perform well because of the multichannel hidden terminal problem. The S-MAC protocol handles this problem efficiently and allows secondary users to sense and utilise unused bandwidth. The proposed model is compared with IEEE 802.11 DCF. Extensive simulation results show that the model has a high network throughput and is energy efficient. The entire model is developed over Network Simulator 2.

***Keywords*:**WSNET, Dynamic Spectrum Access, Network Simulator 2.9, S-MAC

I. INTRODUCTION

Wireless Sensor networking is an emerging technology that has a wide range of potential application including monitoring, smart spaces, medical systems and robotics exploration such network will consist of large numbers of distributed nodes that organize themselves into multihop wireless network. Each node has one or more sensors, embedded processors and low-power radios.

The spectrum allotment in today's wireless network is control and regulated by the government organization in which fixed spectrum policy is followed. In wireless network the spectrum is broadcast to every node where a very small portion of spectrum is utilized as most portion of spectrum gets wasted. The variation of the spectrum utilization is shown in Fig.1.

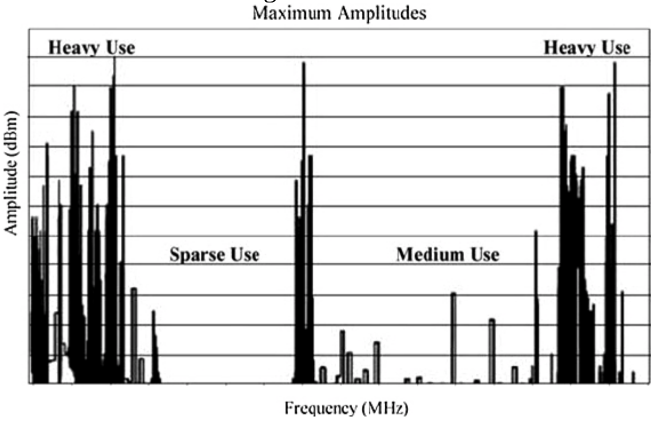

Fig.1. Spectrum utilization

Fixed spectrum allocation would be so unfit because of underutilization as availability of free channel. The solution of this problem is dynamic spectrum access (D&A). Which is new communication paradigm to cope with underutilization problem of fixed spectrum allocation in wireless network.

Dynamic spectrum access techniques allow the cognitive radio to operate in the best available channel. Cognitive radio (CR) is the enabling technology for Dynamic spectrum access in networks. It was proposed by Joseph Mitola III. More specifically, the cognitive radio technology enables the users to determine the portions of the spectrum available for usage.

CR also authenticates the license users when a user operates a licensed band this is known as spectrum sensing. Other characteristics of CR include spectrum sharing when it coordinates the access to its channel with other users and vacate the channel when a licensed user is detected also called spectrum mobility [4].

Wireless sensor network exhibit characteristics like dynamic topologies, bandwidth constraints, energy constraints and link instability. These characteristics pose critical challenges while providing communication for wireless sensor networks. Above all the energy consumption is most important factor. So due to the limited battery resources owned by nodes in wireless sensor network, its energy consumption should be analyzed properly and conserved accordingly. Sensor node in wireless network will get active when it needs to transmit the sensed data. Also it will become difficult to synchronize with other needs and to acquire the channel a MAC protocol for wireless sensor network called S-MAC protocol is used for communication where there is need of central authority.

S-MAC uses three novel techniques to reduce energy consumption and support self-configuration. To reduce energy consumption in listening to an idle channel, nodes periodically sleep. Neighbouring nodes form *virtual clusters* to auto-synchronize on sleep schedules. Inspired by PAMAS, S-MAC also sets the radio to sleep during transmissions of other nodes. Unlike PAMAS, it only uses in-channel signalling. Finally, S-MAC applies *message passing* to reduce contention latency for sensor-network applications that require store-and-forward processing as data move through the network.

As wireless network need to fully exploit the spectrum opportunities, the SMAC layer should be design keeping in mind its requirement to utilize multi-channels in parallel. The utilization of multiple channels enables multiple transmissions on different channels thereby improving overall network throughput. Thus, multichannel MAC protocols are a practical choice over multiple channel MAC protocols. Also, they offer reduced interference among users and a reduction in the number of nodes affected by the return of a licensed user. The current IEEE 802.11 devices are equipped with half-duplex transceivers. As a result, the devices are not able to hear to more than one device at a time leading to multichannel hidden terminal problem as shown in Fig.2. This problem is rectified by the multichannel S-MAC protocol.

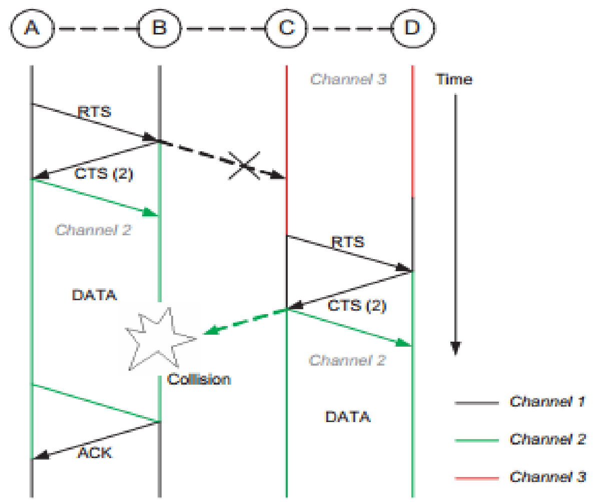

Fig.2.Multichannel hidden terminal problem. Channel is the control channel.

Dynamic Spectrum Access (DSA) has emerged as a new communication paradigm to cope with improper utilization problem of fixed spectrum allocation in wireless networks. Dynamic spectrum access techniques allow the cognitive radio to operate in the best available channel. Cognitive Radio (CR) is the enabling technology for Dynamic spectrum access in networks. It was proposed by Joseph Mitola III [3]. A “cognitive radio” is a radio that can change its transmitter power based on the environment in which it operates. More specifically, the cognitive radio technology enables the users to determine the portions of the spectrum available for usage.

Each node in a WSNET may have more than one available channel for communication. The distributed nature of control in WSNET makes it difficult in synchronising the different nodes to use a common channel. Hence, a MAC protocol has to be used for communication where there is no node of a central authority.

As WSNETs need to fully exploit the spectrum opportunities, the MAC layer should be designed keeping in mind its requirement to utilize multi-channels in parallel. The utilization of multiple channels enables multiple transmissions on different channels thereby improving overall network throughput. Thus, multichannel MAC protocols are a practical choice over single channel MAC protocols. Also, they offer reduced interference among users and a reduction in the number of nodes affected by the return of a licensed user.

The current IEEE 802.11 devices are equipped with half-duplex transceivers. As a result, the devices are not able to hear to more than one device at a time leading to multichannel hidden terminal problem. This problem is rectified by the multichannel S-MAC protocol. We study and simulate the S-MAC protocol as suggested in [2] to ultimately improve energy efficiency of WSNETs in a dynamic spectrum access. The results of the S-MAC will be compared with IEEE 802.11.

ECR-MAC utilises the multi availability of channels efficiently. It successfully manages multichannel hidden problems as discussed later by slotting time into beacons. It borrows the distributed coordination function (DCF) of IEEE protocol for avoiding collisions. It also addresses the overhearing problem of inactive nodes. The above mentioned protocol provides energy saving by enabling the nodes not involved in the communication to go to sleep mode. Also, the S-MAC protocol enables secondary users in a WSNET to utilise unused frequency spectrum of the primary users also called as the multichannel utilization. Thus, the S-MAC protocol also results in a significant increase in network throughput.

In this paper we use Network Simulator 2, which is a discrete simulation model for wireless sensor networks [5]. This model effectively captures the physical layer level dynamics. The model implements S-MAC protocol on the higher level having features such as spectrum sensing, multichannel utilization etc. It effectively manages the multichannel hidden terminal problems and handover features together with a node architecture designed to operate in wireless sensor networks.

The paper is divided into five sections. The second section discusses the reasons of energy wastes in WSN. The third section proposes a SMAC design overview to provide dynamic spectrum access to WSNETs in an energy efficient way. Section IV presents the simulation tools, environment and the result. Section V concludes the paper.

II. REASONS OF ENERGY WASTE IN WIRELESS SENSOR NETWORK

In this section, we describe four major problems that leads to energy wastes that may exist in a wireless sensor network. Firstly, if a node which is receiving data receives more than one packet simultaneously, these packet are called "**collided packets**". Even if they collide partially all packets that cause the collision are discarded and the retransmission needs more energy consumption. Other reason contributing to energy waste is overhearing, which means that a receiver gets the packets that are actually meant for other nodes [1].

Third reason contributing for energy waste occurs in form of control packet overhead. As we know that overheads are the control packets needed to deliver a particular message or to maintain the transmission. Protocol having minimum number of overhead or header packets betters the bandwidth and energy consumption. Another big source of energy waste is idle listening, i.e., listening to an idle bandwidth to receive possible traffic. Final reason for energy wastage is over emitting, which comes in to role play when a packet is transmitted by transmitter when receiver is not ready [6][7].

III. S-MAC DESIGN OVERVIEW

S-MAC incorporates strategies to reduce energy consumption in a wireless sensor node during idle listening, overhearing, and control overhead and overhearing. Before elaborating the S-MAC components, we first summarize our assumptions about the wireless sensor network.

A. Periodic Listen and Sleep

Asmentioned above, inalmost all the wireless sensor networks applications,nodesremain idle for longer interval of timeif noneighboring sensor node senses the channel during this interval.Considering thefactthatthedatarateduring thisperiod is low,it isnotnecessarytokeepthe nodesin listen modeduring this time interval.S-MAC proposes to reducethelistentimebyswitching the nodesintoperiodicsleep mode.

The basic architecture is shown in Figure 3. Each node sleeps for some time, and then wakes up and listens to see if any other node wants to talk to it. During sleeping, the node turns off its radio, and sets a timer to awake itselflater.

Fig. 3. Periodic listen and sleep.

We call a complete cycle of listen and sleep a *frame*. The listen interval is normally fixed according to physical-layer and MAC-layer parameters, *e.g.*, the radio bandwidth and the contention window size. The *duty cycle* is defined as the ratio of the listen interval to the frame length. The sleep interval can be changed according to different application requirements, which actually changes the duty cycle. For simplicity these values are the same for all nodes.

B. Collision Avoidance

If multiple neighboring nodes wants to communicate to a node at the same time, they tries send when the node starts listening. In this case, they need to compete to acquire the medium. Among the contention free protocols, the 802.11 does a considerable job to avoid the collision. Sensor-MAC follows the same principle, including virtual and physical carrier sense, and the RTS/CTS exchange for the hidden terminal problem.

The remaining transmission time of current packetis indicated by the duration filed which holds in every transmitted packet.From this field, a node knows how long it needs to keep silent if it receives a packet destined to another node. The value is recorded by this node in a variable known as the network allocation vector (NAV) and sets a timer for it. The node decrements its NAV every time when the timer fires until it reaches to zero. The node first looks at its NAV before starting a transmission. The node determines that the medium is busy, if its value is not zero. This whole process is known as virtual carrier sense.

At the physical layer, physical carrier sense is performed by listening to the channel for any possible transmissions. To avoid collisions and starvations carrier sense time is randomized within a contention window. The medium is declared as free if both physical and virtual carrier sense indicates that it is free.

C. S-mac implementation

SMAC is a protocol known as Sensor MAC. It is applied to minimize the use of energy while overhearing, collision and idle listening. The protocol divides each node in two states, sleep and active state. Unlikely of the STEM protocol which divides in two channels, SMAC don’t follow this procedure of division of channels. During the listen period a node can receive and transmit data.It follows a periodic wake up strategy. SMAC targets the synchronization of listen periods of neighboring nodes. The listen period of a node is divided into three phases as shown below in Fig. 4. A node is in awake condition during the listen state, the node goes to sleeping rest of the time. The S-MAC proposes fixed intervals for listen and sleep period.

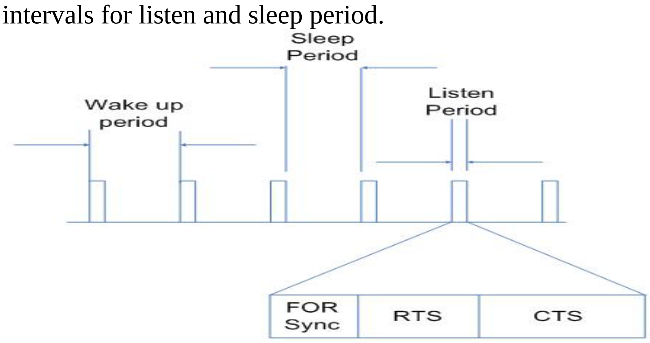

Fig.4. Three phases of listen period.

During the sync phase a table of the synchronized listen periods of the neighboring nodes is maintained. All nodes who wish to transfer data sends RTS in CSMA mode only during RTS phase with additional back off. It only acknowledges during the CTS period and communication between the two nodes starts and proceeds even in their sleep periods. All the neighboring nodes periodically synchronize. For the periodically synchronization SYNC packets are used. These packets holds address of the sender and time of its next sleep. The receiver adjusts its timers after receiving the SYNC packet and updates the neighbor’s schedule.The next sleep time decided according to the sender.The SMAC proposes the fragmentation of long data messages and then sent form transmitter to receiver. The receiver is supposed to acknowledge each and every fragment, otherwise it should be retransmitted. The message passing[7] method is used to send a series of fragments with only one CTS and RTS message. A variable Listen and Sleep periodsprotocol is also proposed known as T-MAC which is similar to S-MAC in functionality.It helps to reschedule the listen and sleep periods according to the network traffic.The exclusive feature of SMAC is that, all the neighboring nodes synchronize their sleep and listen periods and form virtual clusters. These nodes transfer data only during their listen periods and sleep for the remaining time. A longer than permissible message is divided into many shorter fragments and all these fragments are sent as burst. The contribution of S-MAC in this whole process; minimization of idle listening(as nodes sleep and are not in idle listening mode),avoidance of collision and overhearing by using RTS and CTS, and reducing energy consumption and time taken, by transmitting a series of fragments of a long message together, and not going for contention after sending each fragment [8].

IV. SIMULATION RESULTS

In this section of the simulation results of the model are implemented. This section explains the simulation environment, performance metrics and simulation results.The result of this model is compared with IEEE 802.11

A.Network Simulator 2

Network Simulator version 2.9is used to evaluate the performance of the proposed S-MAC protocol. NS2 provides several advantages which makes it a clear choice in simulating this model [9]. The implementation of S-MAC is one of them. The isolation of operations implemented in AWK from the design of nodes and networks NS2 is very suitable for developing generic models for networking research. This model is highly scalable as several protocols can be implemented on the higher levels without changing the basic architecture of the model.

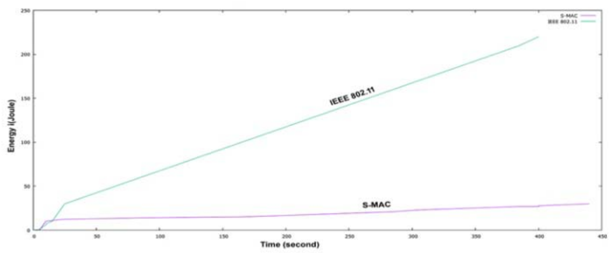

Fig.5. Energy Consumption at Intermediate Mode

B. Simulation Environment & Results

Topology: In this simulation we have used a 2 node topology one is source and another is sink.
Traffic pattern: We attached the UDP agent and CBR Traffic source to the source node [10].
In this simulation we have compare the IEEE 802.11 and S-MAC protocol. Both are same except S-MAC having the some differences from 802.11 [11].
Wireless sensor networks uses a specially designed protocol S-MAC (Sensor MAC). Mobile devices which are capable of computing and sensing are known as Wireless Sensor Devices. A network of such devices will be established for some applications like environmental monitoring. We expect from these networks to be installed in such a way that they remain inactive for longer period of time, but suddenly gets active when senses something [13]. These are the characteristics of S-MAC that makes it different from traditional wireless MACs such as IEEE 802.11 in almost every way: reduction of energy consumption and self-configuration are primary goals, while the other parameters like latency and per-node fairness are less important. S-MAC protocol proposes three techniques to minimize energy consumption and self-configuration of nodes. To minimize the energy consumption in idle listening channel, nodes goes to sleep state. Neighbouring nodes synchronize the sleeping schedules of these nodes. Inspired by other protocols like PAMAS, S-MAC also allows the sleeping of nodes when other nodes communicates. Itpropose to use the in-channel signalling which is different from PAMAS. Lastly, S-MAC for the reduction of contention latency in sensor-network applications message passing is used that require store-and-forward processing as data move through the network [12].

C. Energy consumption at Intermediate node

Herewedesigna3nodetopology1node is senderand1node is sinkand1isrouter. In this wecomparetheidealenergystateoftheintermediatenode.For S-MAC variationofenergyconsumptionatanintermediatenodeisveryle sswhilefor802.11itis having a largevariation. This isshownintheGnuplot Fig.5. Also if we change the listen period of the program by changing the duty cycle. We get the result that as listen time is small energy consumption is less and delay is more.
Also if we take data of Link BW and Efficiency we get the Gnuplot as shown in Fig. 6.

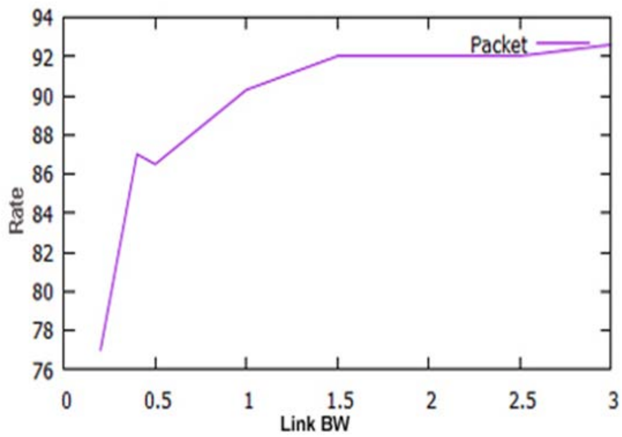

Fig.6. Link BW and Rate

V. CONCLUSION

The aim of this paper was to simulate an energy efficient Wireless SensorNetwork under dynamic spectrum access. To generate the given scenario, we used a Network Simulator 2 to create a network having features such as spectrum sensing. The model was further developed by implementing the S-MAC protocol. The results of the S-MAC protocol was compared with the IEEE 802.11 protocol.
Results from the simulation shows that the S-MAC protocol has a much higher network throughput as compared to IEEE 802.11. Clearly, the S-MAC protocol exploits multiple channels simultaneously to improve network throughput.WelearnNS2.9 thensimulateS-MACin NS 2.9 andfoundouthowS-MACworks.Wehavecomparethe S-MAC protocolwiththeIEEE802.11.Throughanalyzingthesimulation results,wehavethefollowingconclusions:
S-MACwithperiodicsleepefficientlyreducestheenergyconsumptionsduetoidlelistening.However,periodicsleepingincreaseslatencyandreducesthroughput. So, S-MAC isatradeoffbetweenenergyanddelay.

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