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Study of Different Wireless Sensor Network MAC Protocols

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Abstract: Wireless sensor network (WSN) gives a vast area for researchers due to its extensive range of applications such as in healthcare system, environment, military, commercial and structural monitoring etc. The MAC protocols of WSN attract the researcher in the last two decades due to its significance role in the power saving and increase the lifetime of WSN. As WSN is built from a large number of sensors node which operated on batteries, replacing those batteries or recharging them is not cost effective. A lot of work is going on to increase the lifetime of sensor nodes and decrease the power consumption. This survey paper proposed different type of MAC protocols, their behaviour, used strategy and lacking area. After that, we discussed few typical power saving MAC protocols and compare the performance as well. Performance comparing of such protocols gives idea for taking the suitable strategy and protocol for new researcher to take a right direction. Finally, we introduce the Network Simulator version 2.0 (NS-2), using NS-2 we simply analysis the throughput, jitter and delay of simple 6 node mesh topology.

Keywords: WSNs, MAC protocols, NS-2

I. INTRODUCTION

Wireless Sensor Networks have come-up as one of the attractive technology for researches due to its usage in various applications. A WSN is made-up of large number of sensors node which consists a microcontroller or micro embedded processor, a transmitter/receiver wireless communication circuitry with moderate memory.
As sensors nodes are battery operated so efficient usage of battery power is very important constrain in WSN. Medium Access Control (MAC) play a significance role in successful operation of the sensors network.

A significant energy is loss in MAC so, many researchers work on MAC protocol to achieved better efficient usage of energy in network, collision, idle listening, latency, overhearing, over emitting, and control packet overhead. The main objective of this paper is increasing the life time of network. This survey paper is the proposed the necessity of MAC, design challenge, attribute of MAC protocol, cause of energy loss and performance matrices of good MAC protocols, then discussed the different types of energy efficient MAC protocols with their advantages and disadvantages. Thereafter, we discuss the NS-2 and the future scope for new researchers.

II. WHY MAC?

Medium access control (MAC) is responsible for successful network operation because it is an important technique as nodes used shared wireless medium to exchange the information. As nodes are used shared wireless medium [1]. MAC protocol is to avoid collisions from interfering nodes.

The typical IEEE 802.11 MAC protocol for wireless local area network wastes major part of energy due to idle listening. Main objective of designing power efficient MAC protocol is to enhance the lifetime of the network.

III. MAC LAYER PROPERTIES FOR WSN

As sensors nodes are battery operated so the main objective of sensors networks study is to maximizing the lifetime of the WSN. Designing a power efficient MAC protocol following properties should be considered [2][3].
i. **Delay**: - Delay refers to the amount of time spent by a data packet in the MAC layer before it is transmitted successfully. Delay depends network traffic load as well as MAC protocol design.

ii. **Throughput:** - Throughput is the rate of information or message transferred per second. It is usually measured either in messages per second or bits per second.

iii. **Robustness**: - It is the combination of availability, reliability and dependability requirements, reflects the degree of the protocol insensitivity to errors and wrong information.

iv. **Scalability**: - It refers to the ability of a communications system to meet its performance when the size of a network is not fixed. In WSNs, the number of sensor nodes may be very large, exceeding thousands and in some cases millions of nodes. In these networks, scalability becomes a critical factor.

v. **Stability**: - It refers to the ability of a communications system to handle the variable traffic load over specific periods of time.

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vi. **Fairness**: - A MAC protocol is called to be fair if it allocates channel capacity evenly among the communicating nodes without reducing the network throughput.

vii. **Energy Efficiency**: - A sensor node is made up with one or more integrated sensors, embedded processors with limited capability, and short-range radio communication ability. As WSN is built from a large number of sensors node which operated on batteries, replacing those batteries or recharging them is not cost effective. Furthermore, recharging sensor batteries by energy scavenging is complicated and volatile. As a result, energy conservation becomes of most importance in WSNs to increase the lifetime of sensor nodes.

IV. MAJOR CAUSE OF ENERGY WASTE

Major sources of energy waste in wireless sensor network are basically of four types [2][3].

i. **Collision:** - Collision is occurred when a transmitted packet is corrupted due to interference, it has to be discarded and the requirement of re-transmissions increases energy consumption. Collision increases latency too.

ii. **Overhearing:** - Overhearing defines as a node picks up packets that are destined to other nodes.

iii. **Packet Overhead**: - Sending and receiving control packets consumes energy too and less useful data packets can be transmitted. It is necessary to control the packet overhead.

iv. **Idle listening**: - The last major source of inefficiency of WSN is idle listening i.e., listening to receive possible traffic that is not sent. This is occurred in many sensor network applications. If nothing is sensed, the sensor node will be in idle state for long time. The main motive of any MAC protocol for sensor network is to minimize the energy waste due to idle listening, overhearing and collision.

v. **Over emitting**: - It is occurred when destination node is not ready to receive any packet or information massage and transmission node sending the information.

V. MAC LAYER PROTOCOLS

There are main two category of WSN MAC protocol as follow:

i. **Contention-Based MAC Protocols**

The contention based protocols is independent of time synchronization requirements and can easily adjust to the topology changes as some new nodes may join and others may dead after battery drain completely. These protocols are based on Carrier Sense Multiple Access (CSMA) technique and it have higher costs for message collisions, overhearing and idle listening.

PAMAS: Power Aware Multi-Access (PAMAS) [4] is one of the oldest contention based MAC protocol designed with energy efficiency is the main object. In this protocol nodes which are not transmitting or receiving are in sleep mode to conserve energy.
It uses two separate channels one for the data and second for control packets. It requires two radios in the different frequency bands at each sensor which increase in the sensors cost, size and design complexity. So, there is optimal power consumption because of addition switching between sleep and wake-up states.

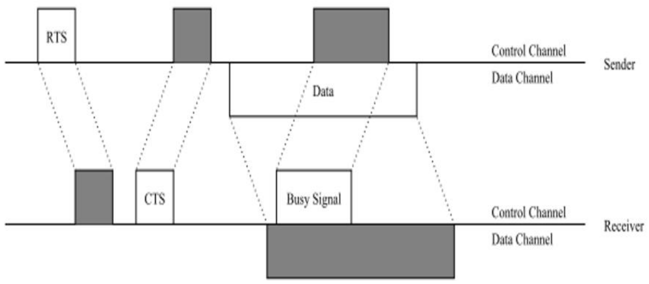

Fig 1. PAMAS

SENSOR- MAC(S-MAC): S-MAC [2] was based on IEEE 802.11. The function of SMAC is to save energy. In S-MAC time divided into frames. S-MAC protocol uses the method of periodic sleep-listen schedules, two stages, sleep stage and wake-up stage. Neighbouring nodes set-up as to follow common sleep schedule from virtual cluster. When two neighbouring node present in two different virtual clusters they will active in the listen period of wake-up stage of these two clusters which gives result in more energy consumption by idle listening and overhearing.

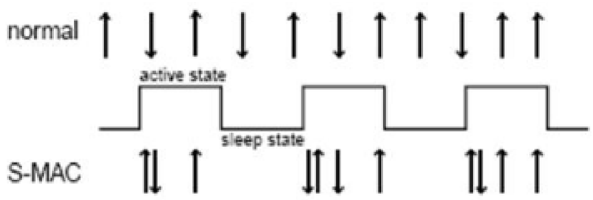

Fig 2. S-MAC

Timeout-MAC (T-MAC): Overcome the drawback of S-MAC protocol is improved by T-MAC [3]. It reduces energy consumption on idle listening. It uses of adaptive duty cycle concept in which messages are transmitted in different length of bursts and the lengths of bursts is determined dynamically. As in S-MAC protocol, there are two time frame has two types of periods which are active and sleep periods.

In a fixed time period Ta if there is no activity occurs between nodes than active period ends. The time- frame Ta represents the smallest listening time.

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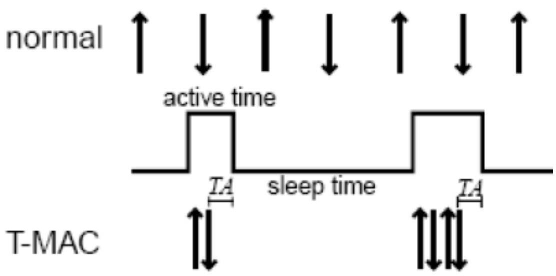

Fig 3. T-MAC

TRAMA: Traffic Adaptive Medium Access protocol (TRAMA) [5], it determines a collision-free scheduling and performs link assignment according to the predicted traffic. This protocol contains two phases namely localized topology formation and scheduled channel access. The channel access schedules as each node to wake up only to transmit or receive, which reduces idle listening and overhearing to zero. Drawback of it is its complexity and the assumption that nodes are synchronized.

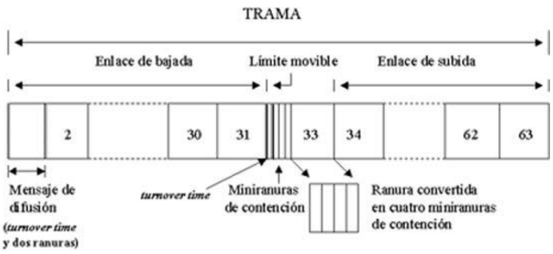

Fig 4. TRAM

SMACS: Self-organizing Medium Access Control for Sensor networks (SMACS) [6], it allows nodes to establish a communication infrastructure between neighbouring nodes by defining transmission and reception slots. It is localized and distributed, so, there is no requirement for a master node in a cluster. It consists two phases namely neighbour discovery and channel assignment.

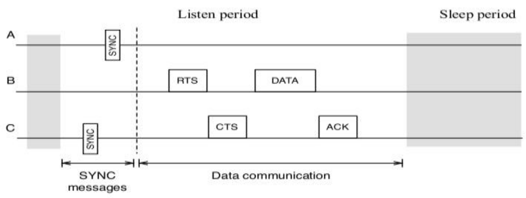

Fig 5. SMACS

Preamble-Sampling ALOHA: Aloha with Preamble Sampling is proposed in [7] where the ALOHA protocol [8] has been combined with the preamble sampling technique. It does not use common active/ sleep schedules instead it they let each node choose its active schedule independently to neighbouring nodes. In preamble sampling protocols, a node spends most of the time in sleep mode. It wakes up only for a short duration to check channel. To avoid deafness, each data frame is preceded by a preamble that is long enough to make sure that all important receivers detect the preamble and then get the data frame.

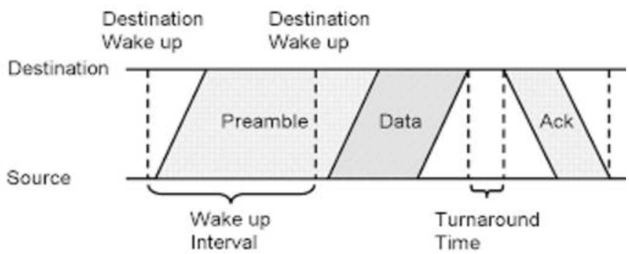

Fig 6. Preamble-Sampling ALOHA

Wise MAC: It stands for "Wireless Sensor MAC" [9], it uses short preambles for some unicast transmissions. To reduce the transmitter overhead it uses a full length preamble, Wise MAC aims at letting each node learn about its neighbours' wakeup times, if the transmitter aware with wakeup time of the receiver, then it can timely start its transmission only to meet the receiver wakeup.

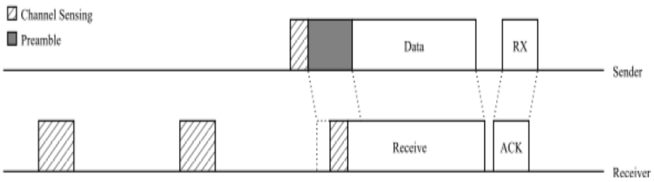

Fig 7 Wise MAC

BMAC: It stands for "Berkeley MAC" [10], this protocol uses a technique based on outlier detection to improve the quality of CCA. In which a node searches for outliers in the received signal such that the channel energy level is below the noise floor. If the node detects an outlier in between the channel sampling, then it declares the channel is clear. If the node does not find any outlier within five samples, then it declares the channel to be busy.

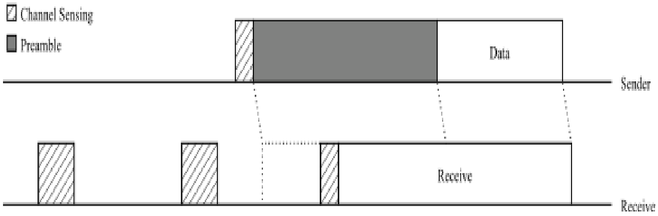

Fig 8. BMAC

DMAC: It stands for "Data-gathering MAC" [11], it based on the situation where many sources nodes send data to a sink node through a unidirectional tree, known as converge cast communication. Nodes exploit this tree to determine their active schedules. A node checks its active schedules based on the media traffic load and the depth of that tree. The active periods of DMAC are similar to FPA. It mainly targets is stationary networks as it does not envisage common global active periods. Hence, randomly may decrease DMAC's performance.

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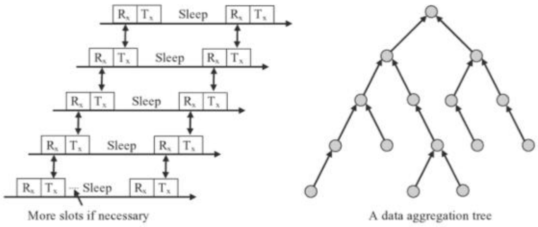

Fig 9. DMAC

Table 1.1 Comparison of Different Contention-Based MAC Protocols

PROTOCOLS	MODEL	PARAMETERS	GAP
PAMAS	Separates channels and frequency bands to send and receive data	Energy efficiency, avoid overhearing by putting node into sleep	Nodes are power off when is blocked from transmitting and receiving. The delay characteristic is not change because it has not any concept of delivering the packets from sender to receiver or vice versa
SENSOR-MAC(S-MAC)	Fixed duty cycle, virtual cluster, CSMA	Power savings over standard CSMA/CAMAC.	It has only static sleep-awake schedule. Static sleep- listen periods of S-MAC result in high latency and lower throughput as indicated earlier
Timeout-MAC (T-MAC)	Adaptive duty cycle, overheari-ng	Uses 20% of energy used in S-MAC	The major disadvantage with this technique is "The early sleep problem". i.e. the node goes to sleep mode even if it its neighbouring node have something to send to it
TRAMA	TDMA	Utilization of classical TDMA	TRAMA has higher queuing delays This protocol may be suitable for applications which are not delay sensitive but require higher energy efficiency and throughput
SMACS	This MAC protocol uses a combination of TDMA and FDMA or CDMA for accessing the channel.	Used master slave concept and used less power to connect all nodes in a large network.	The major drawback of this protocol is its super frame length, if the length of super frame is too short then all neighbour node visible. Another is network load and number of node in a WSN, if network load is low and number of nodes is high then nodes will be awake to check any transmission in channel which consume lots of power
Preamble-Sampling ALOHA	Fix duty cycle and nodes independent to choose active/sleep schedule	Idle listing and node deafness	The basic preamble sampling technique lacks traffic load adaptability because the duty cycle is fixed for all of the sensor nodes independent of their traffic load requirements
WiseMAC	Minimized preamble sampling, schedule	Better than SMAC and Low Power Listening.	It conflict when one node starts to send the preamble to a node

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			that is already receiving another node's transmission where the preamble sender is not within range
BMAC	LPL (Low Power Listening), channel assessment software interface	Better power savings, latency, and throughput than S-MAC	It has long preamble which creates large overhead in network
DMAC	Converge cast commu-nication	Low latency	It has long idle listening and contention may be occur at receiver nodes

ii. **Contention-Free MAC Protocols**
A MAC protocol is known as contention-free when it does not allow any collisions in channel. All contention-free MAC protocols uses the concept that the sensor nodes are time-synchronized in a way that there is no chance for packet collision.

DEE-MAC: It uses the concept of synchronization, at cluster head in which energy is reduced by forcing the idle listening modes to sleep mode [12]. It consists of two phases which is cluster formation phase and a transmission phase.

Cluster formation phase, it used to decide that which node become the cluster head or not and it is also based on remaining power. Transmission phase have different types of sessions and every session consists of two type of period a data transmission period and contention period.

SPARE–MAC: It is used to reduce the power consumption with the help of minimizing the causes of overhearing and idle listening[13]. It is used data diffusion and distributed scheduling solution, in which each sensor node has a fixed time slots. It minimize the problem of collisions and idle listening.

μ-MAC: High sleep ratios are obtained by μ-MAC [13] which is retaining the message reliability and latency. It is based on a schedule-based approach by which shared medium is accessed, which is predicted by behaviour of traffic. It used single time-slotted channel. Function of this protocol alternate between a contention-free period and contention period.

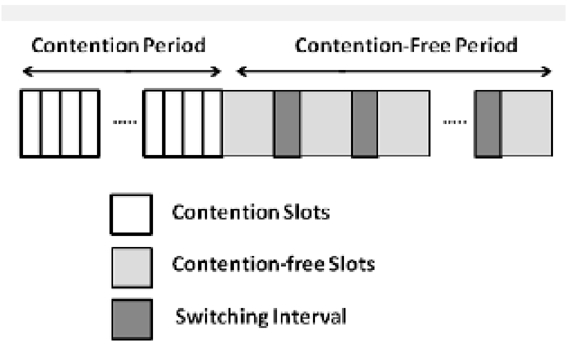

Fig 10. μ-MAC

IEEE 802.15.4: It is a low-data rate Wireless Personal Area Networks (WPAN) [14]. It used coordinators to maintain the synchronization of time-frames which is operating in the beaconed mode. It based on super frame structure which uses in TDMA style period for access, and a contention-based period for non-guaranteed access. When nodes are not in used then they undergo in sleep mode and also work in ad- hoc based mode. Typical duty cycle controlling scheme is used for energy conservation.

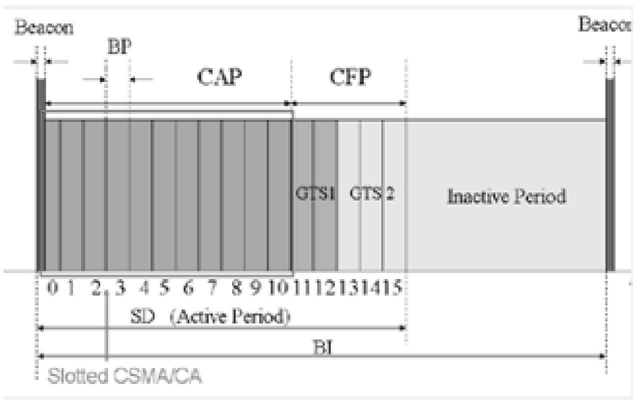

Fig 11. IEEE 802.15.4

A-MAC: This protocol is used for reducing overhearing, collision and fewer idle-listening. It is used in the applications which are long-term surveillance and monitoring [15]. A-MAC is based on the concept of node notification in advanced when any receivers wants to receive the packets nodes. By this method Wastage of energy is unseen on idle listening and overhearing. It is also enhancing the availability and accessibility of the channel.

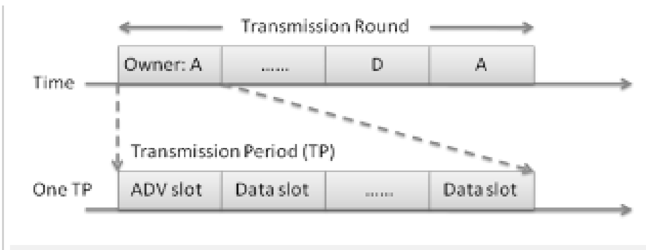

Fig 12. A-MAC

Z-MAC: It improves contention resolution by integrating TDMA and CSMA. Z-MAC [16] is based on the concept of owner slot.

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In this protocol only owner slot is accessed as TDMA style and other slots are access as CSMA style. Z-MAC has two basic components. First is called neighbour detection and slot assignment, and the other one local framing and synchronization. By this, collisions are reduced and decrease the energy conservation.

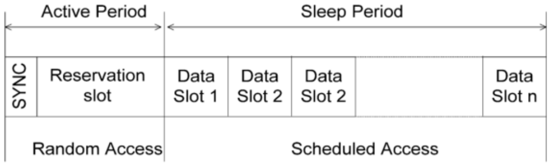

Fig 13. Z-MAC

Table 1.2 Comparison of Different Contention-Free MAC Protocols

PROTOCOLS	MODEL	PARAMETERS	GAP
DEE-MAC	DMAC used Slotted Aloha algorithm	Low latency and low power consumption	The DEE-MAC also used in event-driven applications. Additional power saving may be obtained by analysing the error possibility in a packet in the contention period, and by employing inter-cluster communication through nodes instead of only through the cluster heads.
SPARE–MAC	SPARE MAC used TDMA based MAC scheme for data diffusion in WSNs.	Limiting the impact of idle listening and traffic overhearing.	The control packet overhead is very large, and the data delay is very large too.
µ-MAC	Time slotted channel	Reliability and latency.	In this protocol, the contention period has large overhead to take place frequently. So, it is impossible to adapt it to frequent network organization changes. Furthermore, the knowledge of the traffic pattern has to be available.
IEEE 802.15.4	Used Beacons with super-frame	Low duty cycle, low idle listening, CSMA/CA with optional ACKs on data packets.	In IEEE 802.15.4, the end-to-end reliability or security are not specified in the current version of the standard.
A-MAC	Node notification in advanced.	Overhearing, collision and idle-listening	In A-MAC, some additional latency will be introduced.
Z-MAC	Slot Stealing.	Possesses high throughput under low contention.	It add additional overhead to detect abandoned slot.

VI. NETWORK SIMULATOR

Network Simulator (Version-2), known as NS-2, it is useful for those researchers who works in the communication domain and the best part of it is that free open source, a user can modify parameters at different layers, create his or her own applications, and develop new protocol.

It is an event driven and packet level simulator tool which is used for both types of networks either wired or wireless. It provides user to work on a specific protocol and simulate the behaviour of that protocol and analyse the effect on the overall performance of any network. NS-2 was developed in the year of 1989, after that it gained the rapid popularity in the field of communication networks and now it's very fascinating tool among researchers who work on communication networks due to its modular nature and flexibility. It has a very useful component known as NAM (Network Animator), it gives the visualize output, NAM editor, we can analyse output using trace file it is a GUI interface to generate NS script. NS-2 is written in C++, with an Otcl interpreter as a frontend.

Example: - We have taken a simple scenario of a simple wireless network topology with 6 wireless nodes. Node N0 is the source node with TCP (Transmission Control Protocol) agent and FTP (File Transfer Protocol) application, node N5 is sink node for N0. Similarly, node N3 is source node with UDP (User Datagram Protocol) agent and CBR (Constant Bit rate) application, node N5 is sink node fir it.

When we run above topology TCL (Tool Command Language) script in NS2 then it generate the two output file namely wireless.tr and wireless.nam, .tr extension for trace file and .nam for network animator file output. When we run this wireless.tr file in XGRAPH or TRACEGRAPH then we are able to evaluate the following parameter of this network:

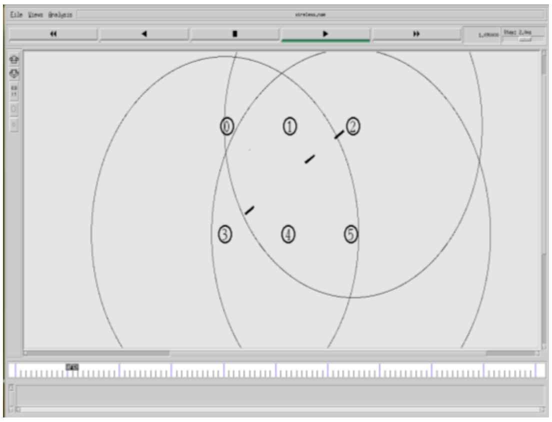

Fig 14. Sensors Node Mesh Topology using 6 nodes

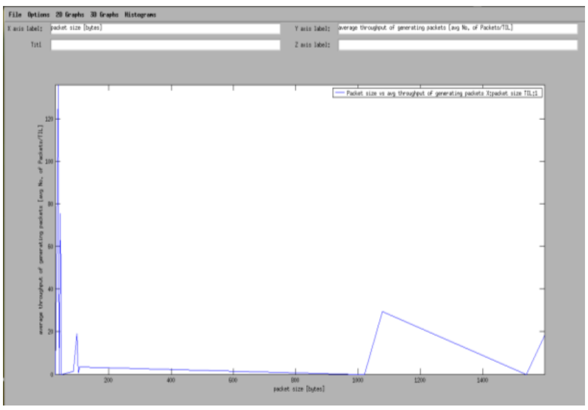

Fig 15. Throughput of Packet Generated Node

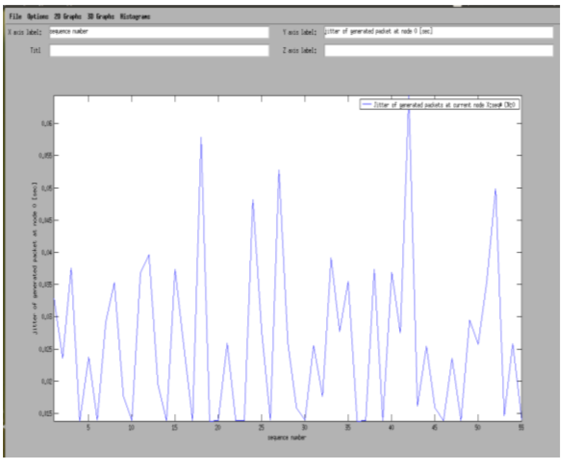

Fig 16. Jitter of Generated Packet of Source Node

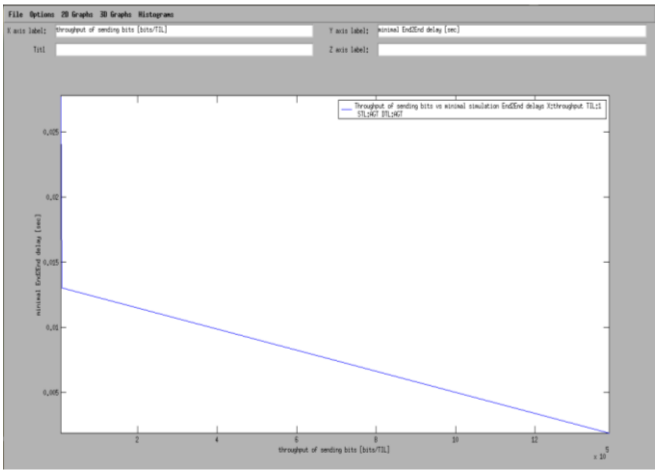

Fig 17. Minimum End-to-End delay

VII. CONCLUSION AND FUTURE WORK

This paper reviewed MAC protocol for WSNs, sources and causes of energy loss and the effects of energy loss on the network. It also discusses the NS2 tool with basic topology and analysis of different parameters i.e. throughput, delay and jitter. WSNs need to enhance MAC protocols because of their energy constrains which is not as much an issue with other wireless networks. To increase the life time of WSN through energy proficient MAC protocols by editing the MAC protocols. From the available literature, MAC protocols have fixed duty cycle or contention windows to, flexible, dynamic and adaptive protocols. This has greatly enhanced energy efficiency especially when different protocols are merged in hybrid algorithm.

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BIOGRAPHY

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