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Hybrid ET-MAC Protocol Design for Energy Efficiency and Low Latency-Cross Layer Approach

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Abstract: Hybrid MAC protocol design in wireless sensor networks becomes vibrant research field for the past several years. The ubiquitous plug and play characteristics of commercially available open source hardware paved way for the development of smart wireless sensor network. Wireless sensor networks can be termed as a new generation of distributed embedded systems that has a capability of meeting broad range of real-time applications. Examples includehome automation, industrial automation, power plant monitoring, radiation monitoring, fire monitoring, pipeline monitoring and control, border surveillance, medical care etc. Wireless sensor networks that are deployed in time critical or mission-critical applications with highlydynamic environments have to interact with the physical phenomenon under stringent timingconstraints and severe resource limitations. The proposed hybrid ET-MAC (Emergency Threshold MAC) protocol targets advanced home automation which require careful MAC protocol design for safety critical low latency, reliability and end to end delay as a primary concernand secondary concern can be given for parameters like residual energy, energy efficiency etc. Supportingreal-time QoS faces severe challenges due to the wireless nature, limited resource, low node reliability, distributedarchitecture and dynamicnetwork topology.This paper presents the design, implementation and performance evaluation of a hybrid ET-MAC protocol with prioritization of nodeswhich adopts a TDMA approach to schedule collision-free slots during emergency periodand CSMA/CA approach during normal operation conditions in time/mission critical applications to avoid collision andto have low latency. The proposed MAC protocol is simulated in NS2 environment and from the results, it is observed that proposed protocol performs better than conventional MAC protocols in terms of energy efficiency and offering low latency.

Key words: Hybrid MAC protocol, emergency, threshold, advanced home automation, switching, CSMA, TDMA, time crucial and energy efficiency

INTRODUCTION

Wireless sensor network is a great enabling technology that can revolutionize information and communication technology, it has the potential to change the way we live and communicate.Since a sensor node is a small, lightweight, un-tethered, battery-powered device, its energy is limited (Akyildiz *et al*., 2002; Ye *et al*., 2002, 2004; Van Dam and Langendoen, 2003). As a result, energy efficiency is a critical issue for sensor networks. Many researchers have focused on the development of power saving schemes for wireless sensor networks (Simon *et al*., 2003; Kim *et al*., 2006; Huang *et al*., 2013). Due to unique characteristics and technical challenges, developing a wireless sensor networks for advanced home automation requires a combination of expertise from different disciplines (Narayanaswamy *et al*., 2002). The MAC protocol can be delay tolerant during normal monitoring and designed for energy efciency. However, when an emergency event occurs, say for example set of smoke detectors deployed for detecting fire event failed to report in the stipulated time or important data may be lost half way or delayed which might cause serious damage to the people residing in a high-rise building. If this is the case energy efficiency is less important than high packet delivery ratio and low latency.

Wireless Sensor Networks for emergency applications such as fire, flood and volcano monitoring, must be trafic and topology adaptive (Chelliah *et al*., 2014). In the last decade Wireless Sensor Networks (WSN) have attracted increasing attention from not onlyresearchers but also industrial experts. Advancement in the level of integrated technique with necessary inbuilt functions like advanced communications and

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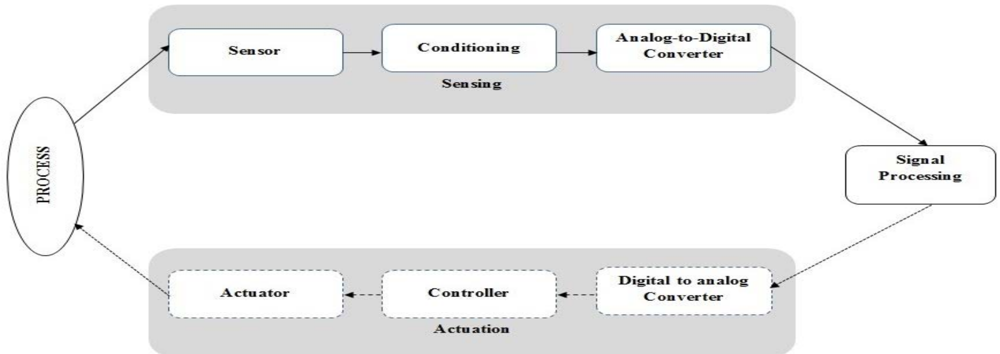

Fig. 1: Necessary components available in a mote for data acquisition and actuation task

signal processing capabilityinside a microcontroller paved the way for innovative distributed wireless sensor and actuator networks (Ye *et al*., 2002; Van Dam and Langendoen, 2003; Simon *et al*., 2003). Consequently, this led to the production of power constrained low cost tiny sensor nodes (Kim *et al*., 2006; Dargie and Poellabauer, 2010).

The human body is equipped with sensors that are able to capture optical information from the environment (wireless sensor eyes), acoustic information such as sounds (wireless sensor ears) and smells (wireless sensor nose). These are examples of remote sensors that is, they do not need to touch the monitored object to gather information (Dargie and Poellabauer, 2010). From a technical perspective, a sensor is a device that translates parameters or events in the physical world into signals that can be measured, analyzed and controlled.

Necessary components required for data acquisition and actuation task is shown in Fig. 1. A system which has direct or indirect contact with the parameter to be measured often referred to as a sensor device. The resulting electrical signals are oftennot ready for immediate processing, therefore they pass through a signal conditioning stage where variety of operations can be applied to the sensed signal to prepare it for making compatible to the succeeding stage. Signals often require amplication or attenuation to change the signal magnitude to better match the range of the following analog-to-digital conversion. Further, signal conditioning often applies filters to the signal to remove unwanted noise within certain frequency ranges high pass flters can be used to remove 50 or 60 Hz noise picked up by surrounding power lines. After conditioning, the analog signal is transformed into a digital signal using an Analog-to-Digital Converter (ADC). The signal is now available in a digital form and ready for further processing, by a programmable digital hardware like microprocessor or microcontroller.

Many wireless sensor networks also include actuators which allow them to directly control the physical world. An actuator can be a valve controlling the flow of hot water, a motor that opens or closes a door or window or a pump that controls the amount of fuel injected into an engine. Such a Wireless Sensor and Aactuator Network (WSAN) takes commands from the processing device or controller and transforms these commands into control signals for the actuator which then interacts with a physical process, thereby forming a closed loopcontrol.

The WSN is built of “nodes” fromfew to several hundreds or even thousands, where each node is connected to one or several sensors. Such sensor network node has typically several parts: aradiotransceiverwith an internalantennaor connection to an external antenna, amicrocontroller for processing sensed data, an electronic circuit for interfacing with the sensors and an energy source, usually abatteryor an embedded form ofenergy harvesting. Sensors have limited energy resources and their functionality continues until their energy is drained. Sensor networks are typically expected to last for several years and since the sensor nodes are battery powered, another challenge is to develop power efficient communication protocols (Simon *et al*., 2003).

Most sensor networks and sensing applications rely on radio transmissions in the unlicensed IndustrialScientific Medical band which may result in communications signifcantly affected by noise and interferences. Therefore there are some design principles challenges and technical approaches required for designing MACprotocol which has a direct effect on the reliability and efficiency of network (Gungor and Hancke, 2009). Due to the errors and interferences in wireless communications and other challenges such as the hidden-terminal and exposed-terminal problems, careful

MAC protocol design is required to reduce power consumption, latency and to overcome signal fading, simultaneous medium access by multiple nodes.

It is common for a MAC protocol in WSNs to trade energy efficiency for increased latency or a reduction in throughput or fairness. This proposed work reviews the responsibilities of the MAC layer in general, discusses the characteristics of MAC protocols for WSNs, describes the main classes of MAC protocols for wireless communication and provides descriptions of a selection of MAC protocols for WSNs. Therefore, communication protocols for WSNs should be carefully designed in order to guarantee the network's long-term effective running, the most important aim being maximizing the network lifetime and reducing the end to end delay in data exchange.

To design an energy efficient hybrid MAC protocol for the wireless sensor networks the following attributes has been considered. The first is the energy efficiency. Prolonging network lifetime for these nodes is a critical issue. Another important attribute is the scalability to the change in network size, node density and topology. Some nodes may die over time, some new nodes may join later, some nodes may move to different locations in order to cope up with these changes in network topologies a strategy need to be framed. A good MAC protocol should easily accommodate such network changes. Other important attributes include latency, throughput and bandwidth utilization.

MAC layer: In the OSI model of communication, the MAC layer is one of the two sub layers of data link control and is concerned with sharing the physical connection to the network among several computers. Each computer has its own unique MAC address. Ethernet is an example of protocol that works at the MAC layer level. The other data link control sub layer is logical link control layer.The medium access control (MAC) protocol layer exists just above the physical layer and the IEEE 802 reference model. It is designed to ensure orderly and fair access to a shared medium. It manages the division of access capacity among the different stations on the network. A good MAC protocol should be:

Fair: Each station should have equal access to the medium.

Efficient: There should be high data throughput and packets should not experience large transfer delays.

Simple: The implementation of the MAC protocol should not be so complex that it requires powerful hardware or long processing times that impair performance.

These conflicting requirements have been a challenge to MAC protocol designers ever since the development of the Aloha protocol in the 1960's (Akyildiz *et al*., 2002). A large amount of research has been performed in this area which has led to many solutions, implementations and standards (Radmand *et al*., 2010). Despite this extensive research effort, there is still a strong need for MAC research.The fundamental trade of between energy efficiency and delay has been analyzed and debated for the last thirty years. Traditionally, MAC protocols were designed to be simple. The need for speed and simplicity in the MAC layer outweighed the benefit of efficiency. However, with the incredible growth in computing speed, it is becoming plausible to design more complex MAC protocols in order to improve efficiency such as achieving better channel utilization and meeting Quality of Service (QoS) requirements (Rhee *et al*., 2008).

MATERIALS AND METHODS

Existing MAC protocols for WSN: A MAC in this scenario usually deals with latency, throughput and reliability after energy efficiency.Therefore, the main sources of power wastage in radio-basedcommunication are idle listening, collisions, overhearing andtraffic fluctuations define guidelines that are followed by virtually all MACs in this related work. Idle listening of the classical IEEE 802.11 MAC protocol for wireless local area network leads to a lot of energy wastes, since primary focus is not energy efficiency (Ye *et al*., 2004).

S-MAC is a MAC protocol for WSN based on time slots. Figure 2 and 3 shows the sleep and wakeup schedule of SMAC and T-MAC. It is also a CSMA-based protocol but it uses the RTS/CTS mechanism to avoid the hidden terminal problem. Neighboringnodes trade synchronization information in order to wake upsimultaneously to communicate. A major limitation with SMAC is that it does not allows any kind of configuration, neither static nor dynamic and thus have a fixed duty cycle which can lead to waste of energy (idle listening). T-MAC improvement of S-MAC, addresses problem dynamically adapts duty cycle through

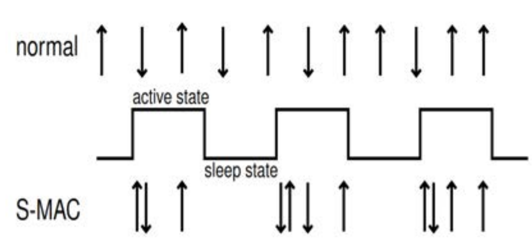

Fig. 2: SMAC duty cycle

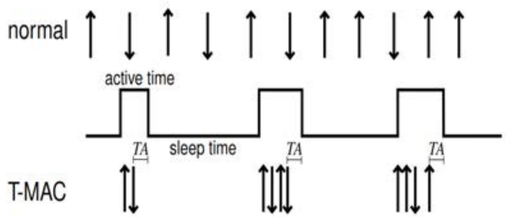

Fig. 3: T-MAC duty cycle

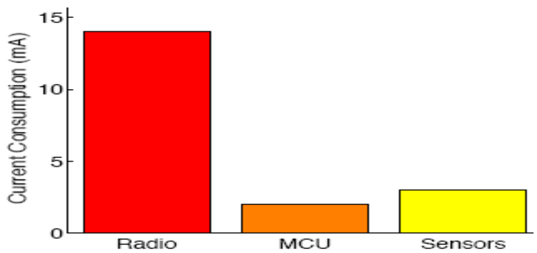

Fig. 4: Range of power consumed by motes for various operations

fine-grained timeouts. Although the RTS/CTS mechanism solves the hidden terminal problem, it introduces the exposed terminal problem, to which both these protocols are exposed. Also the information needed to keep neighboring nodes synchronized produces a certain amount of overhead (Simon *et al*., 2003).

B-MAC is a carrier sense MAC protocol for WSN. It provides an interface which enables on-the-fly reconfiguration, allowing network services to adjust their mechanisms. One limitation of B-MAC is that a receiver has to wait until the entire preamble is sent in order to exchange data, even if it was awake at the start of the transmission (Kim *et al*., 2005). This add to the overhearing problem, where receivers stay awake until the end of the preamble and find out that the packet was not addressed to them.

Both these limitations are solved by X-MAC which uses a short preamble and piggybacks the receiver address into it. Since a receiver can detect if the packet is destined to itself before actually receiving it, it can either turn off the radio or send an acknowledgment to the sender. In advance in the latter case the sender stops sending the preamble and starts to send the data. As both these protocols are CSMA-based, they suffer from the hidden terminal problem Fig. 3 .

Figure 4 shows Z-MAC is a hybrid MAC protocol which combines TDMA and CSMA. It uses a TDMA schedule but allows nodes to contend for other nodes slots using CSMA. Slots owner are given chances to transmit earlier, so a node can only steal slotsfrom nodes that would not use them. Z-MAC calculates the slot assignments at the time of deployment which introduces high overhead (Rhee *et al*., 2008).

T-MAC (Van Dam and Lanendoen, 2003) improves the energy efficiency of S-MAC by using a very short listening window at the beginning of each active period. With the same workloads, T-MAC and S-MAC perform equally, while T-MAC suffers from the same complexity, scaling problem and early sleeping problem of SMAC (Ye *et al*., 2002, 2004; Van Dam and Lanendoen, 2003).

ER-MAC is designed as a hybrid of the TDMA and CSMA techniques making it flexible to adapt to traffic and topology changes. Whereas ER-MAC uses two queues low priority and high priority queues, it operates in two modes no fire mode (normal mode) that uses CSMA/CA and in fire mode that uses TDMA (emergency mode). Priorities are based on their slack which means the time remaining until the global packet deadline expires. The main drawback of ER-MAC is high protocol overhead during the startup phase that is during the topology discovery and TDMA slot assignment phases. Traffic adaptability, energy efficiency, latency and end to end delay of ER MAC's no-fire mode and in-fire mode is similar to ZMAC's Low Contention Level (LCL) and whereas during High Contention Level (HCL) mode ER-MAC outperforms Z-MAC (Rhee *et al*., 2008; Sitanyah *et al*., 2010).

ADV-MAC (Ray *et al*., 2009, 2011) focuses on minimizing the energy lost in idle listening while maintaining an adaptive duty cycle to handle variable loads. Hence introduces an ADV period in its frame structure to intimate only the intended receiver to stay awake and allows all the other nodes to go to low power sleep mode. The ADV-MAC consists of a fixed length SYNC and ADV periods and variable DATA and SLEEP periods. During the SYNC period the nodes broadcasts synchronization message to bring its children nodes to the same clock as that of the parent. The Advertisement packet consists of the ID of the intended receivers and the time length of data transmission that is going to take place intimating the other unintended receivers go to sleep mode for that particular time length. The nodes whose ADV packets are successfully transmitted, transmits its data in the DATA period through a sequence of RTS/CTS/DATA/ACK hence the chance of collision is very less in data period.

ADV MAC supports good network lifetime but suffers from collision of advertisement packets, hence, if a collision occurs, the transmitter node will be awake without knowing about the collided packets and the receivers will be in sleep mode.If the ADV period is large, all the successfully transmitted ADV packets cannot be accommodated in the data period because it will affect valuable data transmission time.

Essential requirements of an efficient MAC protocol: An efficient MAC protocol for wireless sensor networks should have some good attributes to satisfy the needs of targeted application (Narain *et al*., 2011).

However, for industrial based applications or advanced home automationno need of treating equal priority for all nodes in the network. Some nodes may be time critical which should be given higher priority than the normal non time critical nodes.How to efficiently utilize the limited amount of energy has been the primary concern indesigning MAC protocols for WSNs.

In conclusion, the aim of a WSN MAC protocol design is to guarantee its longevity under the given energyand complexity constraints. The MAC plays a central part in this design since it controls the active and sleeping state of each node. The MAC protocols hence needs to trade longevity, reliability, fairness, scalability and latency, throughput is rarely a primary design factor. Since the radio is controlled by the MAC, the MAC is central in optimizing the WSN's lifetime.

Energy waste in MAC protocol: The reason of wastage of energy in a MAC protocol for wireless sensor networks are the following (Narain *et al*., 2011). When running a contention-based MAC protocol on an ad-hoc network with little traffic, much energy is wasted due to the following sources of overhead

Idle listening: Since a node does not know when it will be the receiver of a message from one of its neighbors, it must keep its radio in receive mode at all times. This is the major source of overhead, since typical radios consume two orders of magnitude more energy in receive mode (even when no data is arriving) than in standby mode. Extra energy is also consumed for Listening to receive possible traffic which is not sent.

Collisions: If two nodes transmit at the same time and interfere with each other's transmission, packets are collided and corrupted. Hence, the energy used during transmission and reception is wasted. The RTS/CTS handshake effectively resolves the collisions for unicast messages but at the expense of protocol overhead.

Overhearing: Since the radio channel is a shared medium, a node may receive packets that are not destined for it; it would have been more efficient to have turned off its radio.

Protocol overhead: The MAC headers and control packets used for signalling (ACK/RTS/CTS) do not contain application data and are therefore considered overhead, these overheads can be significant since many applications only send a few bytes of data per message.

Traffic fluctuations: A sudden peak in traffic density raises the probability of a collision, hence much time and energy are spent on waiting in the random back off procedure. When the load approaches the channel capacity, the performance can collapse with little or no traffic being delivered while the radio, sensing for a clear channel is consuming a lot of energy.

Control packet overhead: Energy is also required for Sending and receiving control packets due to these less useful data packets can be transmitted.

Problem statement: Designing MAC protocols for WSNs should efficiently utilize the limited amount of battery energy which has been the important concern (Chelliah *et al*., 2014). In typical sensor applications, the energy consumed by various modules for sensing, processing and communication is eventually different. In typical sensor applications, the energy consumption is dominated by the node's radio consumption. Figure 5 shows the power consumed by various subsystems of a mote which clearly indicates radio module power consumption is almost three times higher than sensing and processing module. Communication module consumes major source of power drain in WSN (Bachir *et al*., 2010).

From Table 1, It can be concluded that power consumption in sleeping mode is negligible to the power consumption in active mode. In addition, note that different node powering mechanisms are available such as non-rechargeable battery; rechargeable battery with regular recharging (e.g., sunlight); rechargeable battery with irregular recharging (e.g., opportunistic energy scavenging); capacitive/inductive energy provision (e.g., active RFID); etc. This has also an influence on the choice and design of the MAC protocol.

Hence by reducing the number of transmissions, power consumed by sensor node can be drastically reduced in turn longevity under the given energy can be significantly improved. The MAC plays a central part in

Table 1: Power consumed by radio modules of a mote in various states

Radio mode	Power consumption (mA)
Transmit (Tx)	14.88
Receive (RX)	12.50
Idle	12.36
Sleep	0.016

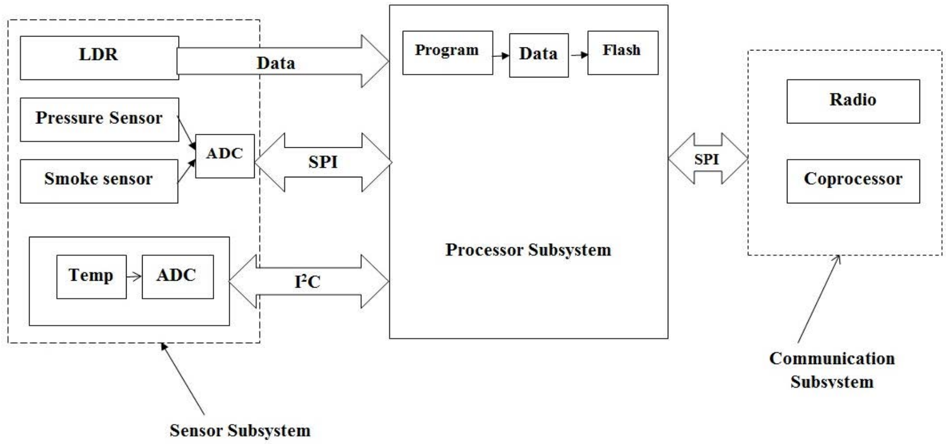

Fig. 5: Typical sensor node architecture

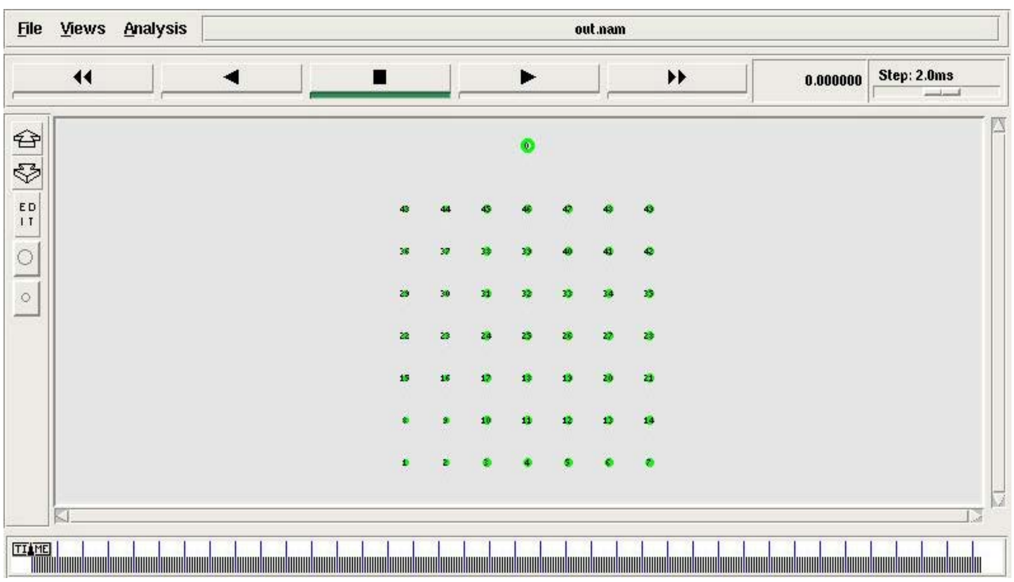

Fig. 6: Grid topology

controlling the radio's active and sleeping state thereby WSN's lifetime can be improved significantly (Akyildiz *et al*., 2002; Ye *et al*., 2002, 2004; Van Dam and Lanendoen, 2003).

Commercially available hardware for WSN is very costly as it has integrated all the necessary functionalities in one hardware module: sensing module, processing module, communication module and power module. Typical sensor node architecture is shown in Fig. 6. A simulator is a software tool that imitates selected parts of the behavior of the real hardware andis normally used as a tool for research and development.

For time critical applications based on latency isA SP 100.11A Working group classified industrial process control in to six different classes [ISA SP 100.11A STANDARD]

- Class 0: Emergency action (in terms of micro seconds)
- Class 1: Closed-loop regulatory control (in terms of milliseconds)
- Class 2: Closed-loop supervisory control (in terms of seconds)
- Class 3: Open-loop control (in terms of minutes)
- Class 4: Monitoring with short-term operational consequences (in terms of hours)

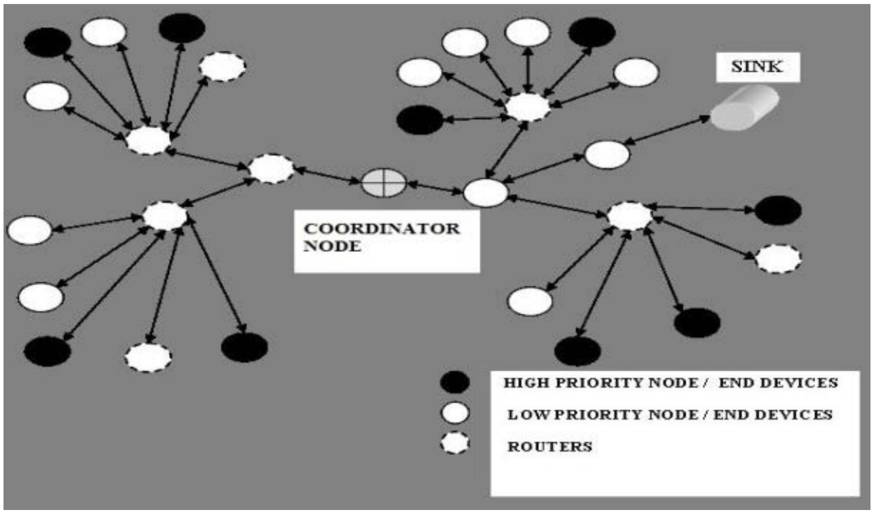

Fig. 7 : Random tree topology

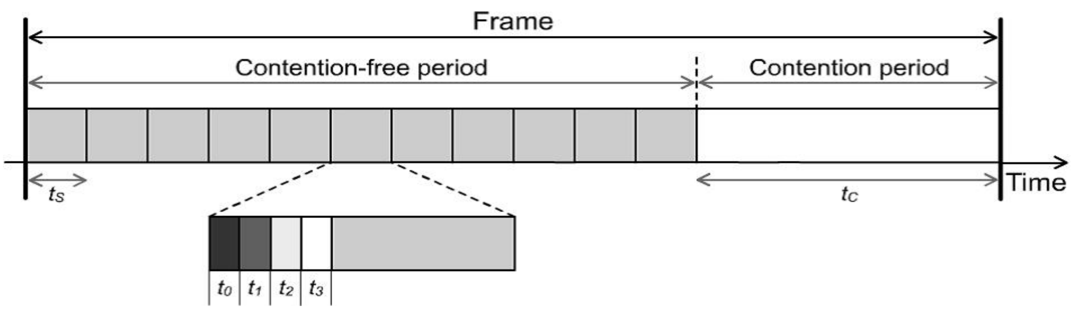

Fig. 8: MAC prioritizationframe structure

- Class 5: Monitoring without immediate operational consequences. (in terms of days)

Based on the above problem statement, it has been decided to develop ahybrid ET-MAC protocol which satisfies the needs of IWSN and Advanced home automation. Based on the literature it has been decided to develop a hybrid MAC protocol which addresses the needs of ISA Sp100.11A working group timing requirements for class2 based control strategy. The proposed work evaluates design, implementation and performance of a hybrid MAC protocol with prioritization of nodes which adopts a TDMA approach to schedule collision-free slots during emergency period and CSMA approach during normal operating conditions to avoid collision and to have low latency.

Proposed hybrid ET-MAC: The basic network scenario is shown in Fig. 7. The network scenario can be varied dynamically between grid and random topology this enables us to view the hybrid protocol working in both the topology ensuring that this protocol has the capabilities of both the Z-MAC (Rhee *et al*., 2008) and ER-MAC (Sitanayah *et al*., 2014). The network grid is 1000 m by 1000 m in dimension and a total of 20-200 nodes have been assumed as in a real time scenario the number of nodes would vary depending upon the size of the industry or the number of instruments in use. These nodes are deployed in two ways:

- Grid topology
- Random topology

The proposed Hybrid-MAC frame consists of contention-free slots with duration t_S each and a contention period with duration t_C as depicted in Fig 8. In each contention-free slot, except for the synchronization slot, there are sub slots t_0, t_1, t_2 and t_3 which only appear in emergency mode for contention. Note that in the emergency mode, the period of t_S - $(t_0 + t_1 + t_2 + t_3)$ is

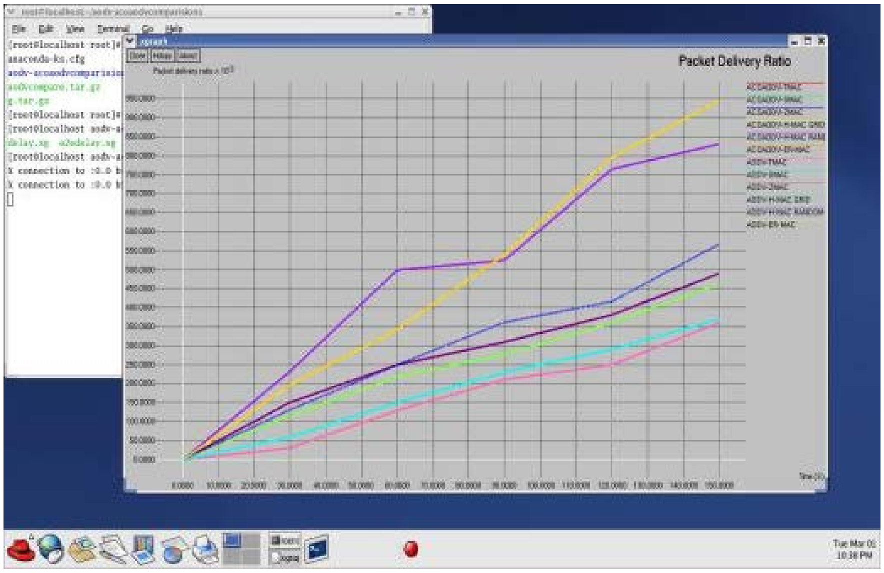

Fig. 9: Comparision of packet delivery ratio forvarious protocols

sufficient to carry a packet and a sub slot is big enough to carry a MAC header (a source, a destination and a flag).

Decision on threshold value: In the ET-MAC protocol the packets are transmitted only when the height of the buffer exceeds the specified threshold value. This can assure the energy efficiency. Each node switches to the sleep mode if the number of packets in the buffer is smaller than the specified threshold value or an RTS packet has not been received when the timer is on.

$$Tout = C + R + T \quad (1)$$

C is the contention interval, R is the length of RTS packet and T is a very short time interval between RTS and CTS.

$$Qthreshold = [(\lambda - \alpha)*10] \alpha < \lambda \quad (2)$$

$$Qthreshold = [\alpha *10] \quad \alpha = \lambda \quad (3)$$

Equation 2 considered for nodes that are except for the last node in the network towards the sink. And the Eq. 3 is used for the node that was left in the first. Thus we save energy by the varying buffer level.In the above two equations, α is the current node in the multihop, while λ is the total number of nodes in the sensor network. If there are 10 nodes then λ is 10, then the 10th node or first node from sink then it will have 100 has its threshold level. If current node α is 8 or the third node from sink, then $Q_{threshold}$ for λ of 10 will be 80.

Figure 8 and 9 In the normal mode, a transmitter occupies a slot from the beginning of the slot and sleeps after transmitting a packet. We include a contention period at the end of a frame to support new node addition. In normal monitoring, communication follows the nodes' schedules. To further conserve energy, a sender turns off its radio if it has no data to send and a timeout forces a receiver back to sleep if it does not receive any packets. In the proposed approach it is decided priorly the time criticality or safety criticality of nodes emergency. If any abnormality or emergency activityis detected by emergency nodes only nodes affected by the emergency activity change their MAC to emergency mode. Transmission is decided based on two conditions, either nodes wait for threshold value to reach or for emergency flag to rise. These nodes are nodes which detectemergency messages, their one hop neighbors that receive the messages, their ancestors toward the base station that receive data packets with an emergency flag and the ancestors' one-hop neighbors while other nodes remain in the normal mode.

Algorithm:

Proposed ET-MAC algorithm steps: A node changes the MAC with following rules

Initialization
If this.id = sourceThen send RT-REQ
If the channel is free the source precedes further when ACK received from next node Thensink send RT-REP

If channel is freeThen send RT-REP to source
If source received RT-REPThenstart sending queue of data
If node is source node Thencreate data packet and context information priority
If received packets >queue threshold ‖packet is high priority Then send RT-REQ for data
IfNext hop neighbor receive RT-REQ and send RT-REPThen current node receive RT-REP and send queue of data
RT-REQ, RT-REP, DATA process repeated till data reach the sink.
During emergency period the non-prioritized nodes stop communicating and pave way for prioritized node to communicate using TDMA and schedule the task in queue.
After emergency period the nodes switch to CSMA and operate in normal mode.

RESULTS AND DISCUSSION

Simulated output: The Network Simulator (NS2) comes along with an interesting tool, called the Network Animator (NAM). Nam is a Tcl based animation tool for viewing network simulation traces and real world packet trace data. In order to handle large animation data sets a minimum amount of information is kept in memory. Event commands are kept in the file and are read from the file whenever necessary.The Table 2 shows the essential parameters to measure the performance of ET-MAC.

It has been configured Z-MAC according to the default settings in (Rhee *et al*., 2008). All the protocols performance like Packet delivery ratio, Routing overhead, End to End delay, Packet drop, Residual energy has been tested for grid as well as random topology. ET-MAC conguration is shown in the simulation parameter's table. In addition, it is tested the performance of all the protocols for AODV (AdhocOndemand Distance Vector routing) and ACOAODV (Ant Colony Optimization Adhoc On demand Distance Vector routing). In each experiment data gathering analyzed for 150 sec and plotted the performance of all the protocols for two different routing strategies.

The performance of ET-MAC is compared with many similar hybrid protocols namely ZMAC, HMAC, ER-MAC and contention based protocols like SMAC, TMAC etc. Hence performance comparison study is made among them. Switching between TDMA and CSMA in hybrid designs allows contention in TDMA slots when the traf?c load increases to adapt for priority. And when traffic load decreases the proposed protocol looks for energy efficiency in CSMA.

Average end to end delay: The average end to end delay is delay between the data transmitted and received by the destination is shown in Fig. 10.

Table 2: Essential parameters to measure the performance of ET-MAC

Parameter	Value
Number of nodes	Varied between 20-200
Transmit(Tx)	14.88 mA
Receive(RX)	12.50 mA
Idle	12.36 mA
Sleep	0.016 mA
Frame time	100 m sec
Data packet	100 bytes
Sync packet	10 bytes
Priority nodes	4
Control packet	8 bytes
Contention period	8 ms
Coordinator node	1

ET-MAC has the least end to end delay, while the standard protocols such as S MAC or T MAC have a greater delay. The information being transferred in the existing protocols had to either transfer data only in the next wake up cycle or only by informing the other nodes in prior, however in ET-MAC average end to end delay is found to be minimal in both random and grid topology.

Packet delivery ratio: The ratio between the number of packets received and the number of packets sent. The packet delivery ratio, being one of the crucial factors in wireless sensor network, where the ratio indicates the amount of data received successfully in comparison with the generated by the source node during the lifetime of network. From the results the proposed ET-MAC has higher packet delivery ratio compared to other protocols.
understood that the ET-MAC is being capable of separating the high priority information.

Throughput: Network throughput is the rate of successful message delivery over a communication channel is shown in Fig. 11. The proposed ET-MAC has highest throughput.

Routing overhead: The routing overhead is the measure of the total number of control packets sent and received in the network. It is apparent that routing overhead for the proposed ET-MAC is marginally high, since it uses more number of control packets

Packet drop: Packet drop is an undesirable characteristics or a type of attack in a typical wireless sensor networks. Packet drop for proposed ET-MAC is very low compared to conventional SMAC and TMAC is shown in Fig. 12-16. Whereas the performance of ZMAC and ER-MAC is medium.

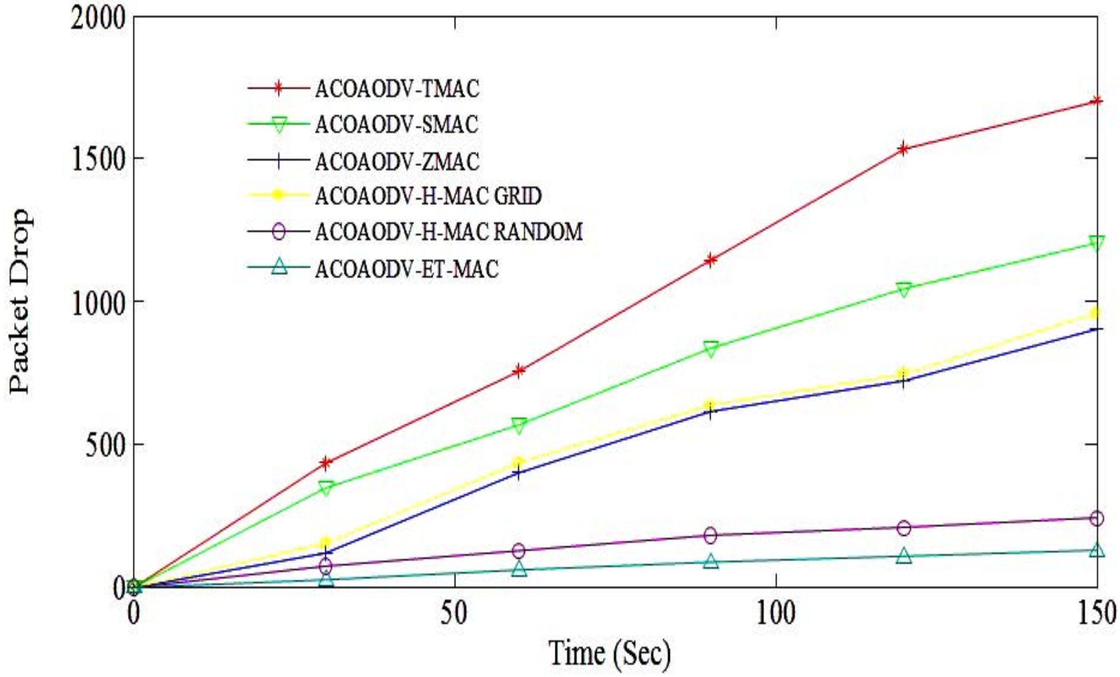

Fig. 10: Comparison of packet drop for various protocols

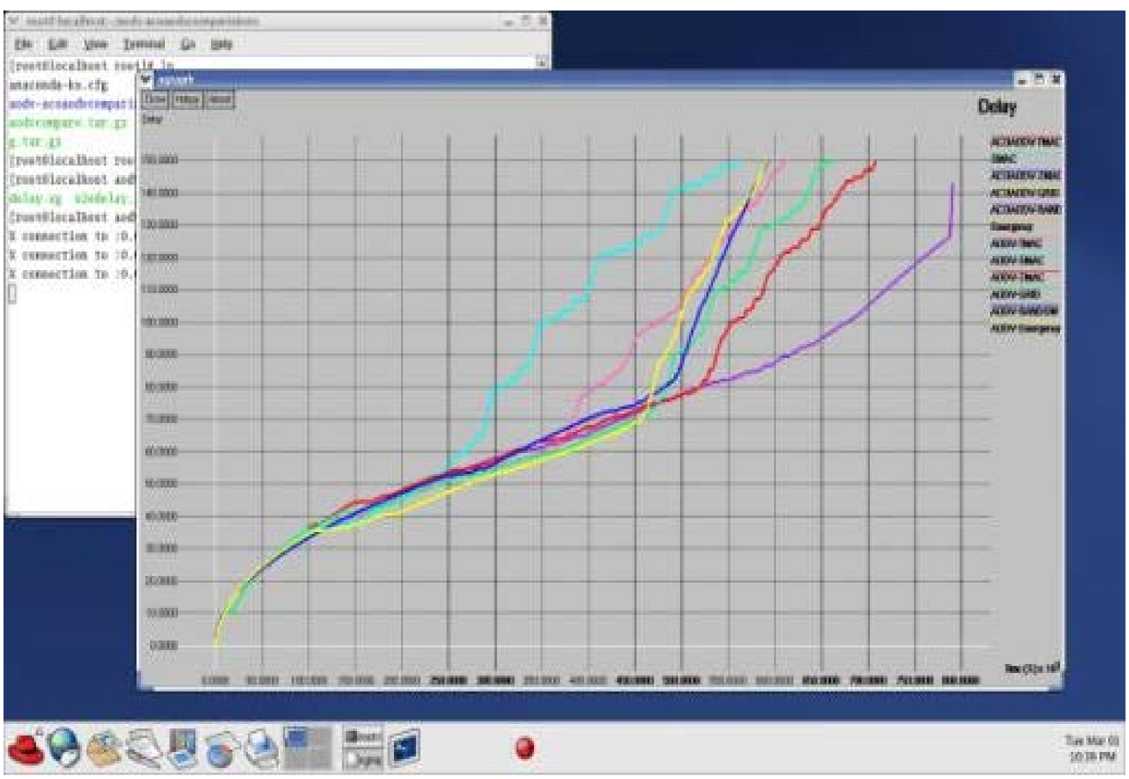

Fig. 11: Comparision of Xgraph view of average delay for various protocols

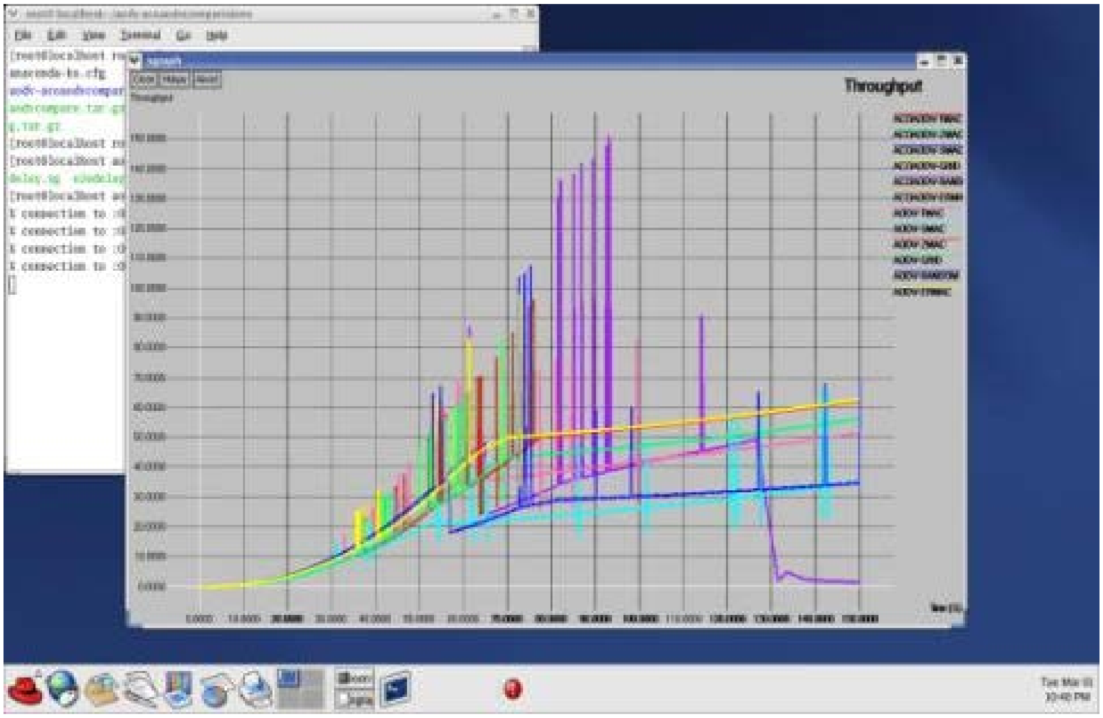

Fig. 12: Comparision of xgraph view of throughput for various protocols

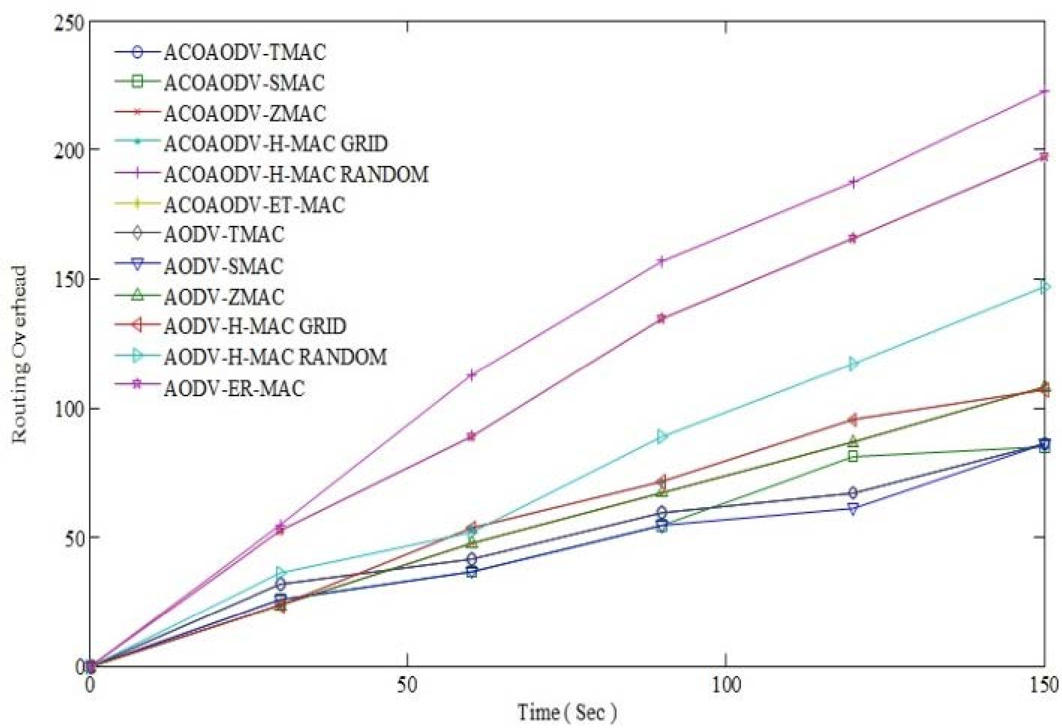

Fig. 13: Comparison of routing overhead for various protocols

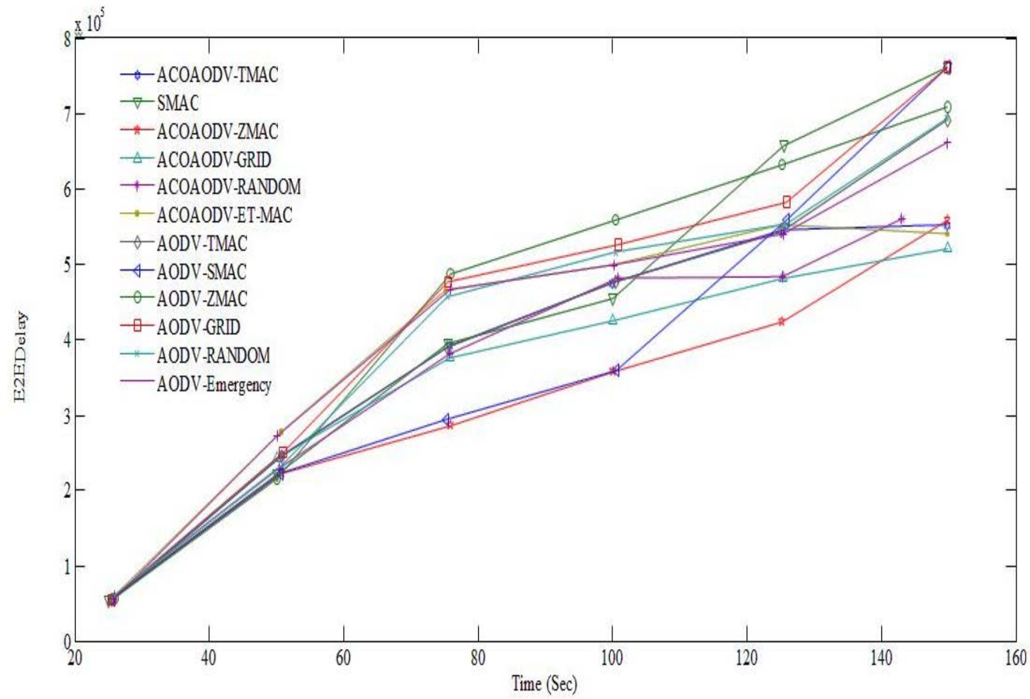

Fig. 14: Comparison ofaverage end to end delay for various protocols

Fig. 15: Random tree topology (20 nodes)

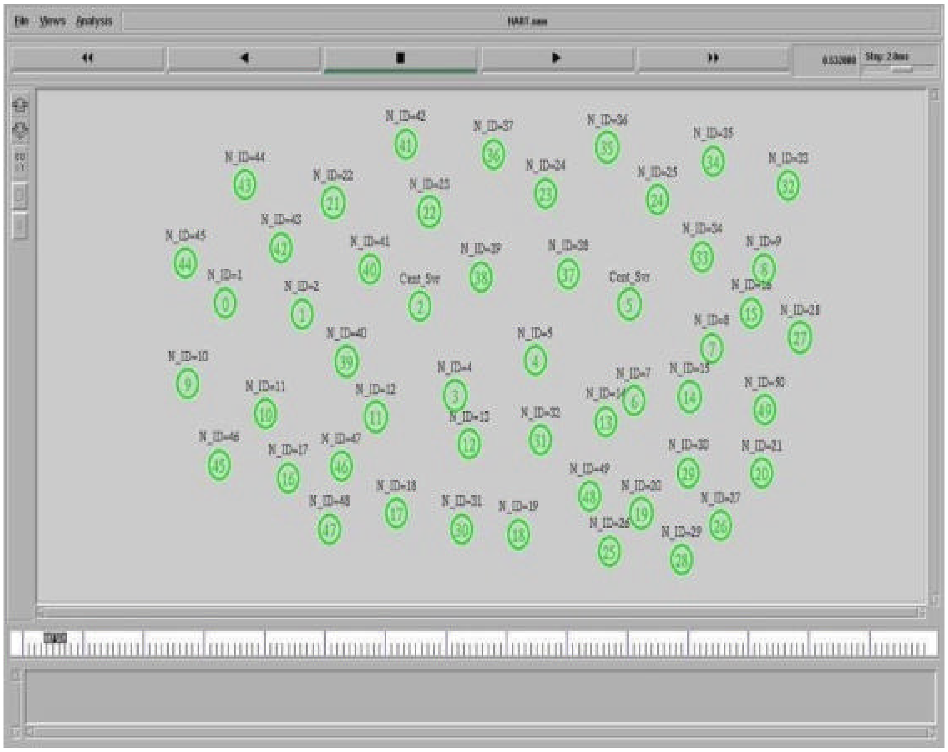

Fig. 16: Random tree topology (100 nodes)

CONCLUSION

The proposed hybrid ET-MAC shows high packet delivery ratio, low energy consumption, least end to end delay with flexibility to adapt traffic and topology changes. It involves prioritization of nodes which helps guaranteed transmission during emergency situation. Thus the emergency situation in the home automation or industrial automation scenario can be attended immediately by taking immediate control action. It is planned to verify the functionality proposed in the present work with commercially available real time hardware using contiki OS.

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