Game Theory and Wakeup Approach Scheduling in Wireless Sensor Network for Energy Efficiency

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Abstract: To examine data collection, communication and physical situations, a network with huge sensor nodes called Wireless Sensor Network (WSN) is used. For distributing sensor nodes data, they communicate with base station and it used for storage and remote process. While data transmission, there is a chance for energy problem. In this work, sender is enabled use a reinforcement learning method for predicting receivers' wake-up times. If sender has a packet for transmission, before receiver's wake-up time, senders can wake up shortly. This saves the energy used by senders for idle listening. In this condition, trade-off should not be made by senders as its wake-up times are entirely based on wake-up times on receivers. However, trade-off is faced by received. Our proposed technique defines the receiver's wake-up time for scheduling function and various wake-up intervals are produced due to various parameter selection. In addition, in receiver's wake-up scheduling function, sender must request parameters before sender making a prediction regarding receiver's wake-up time.

Keywords: Wireless Sensor Network, Energy Efficiency, Sleep / Wakeup Scheduling.

I. Introduction

A wireless network with spatially distributed autonomous devices is called wireless sensor network (WSN). Sensors are used for cooperatively monitor environmental or physical conditions like motion pollutants, pressure, vibration, sound, temperature at various locations (Karthik & Kumar, 2015).

Various unique characteristics like unattended operation, large scale deployments, mobility of detected events, energy harvesting, mobility of nodes, node failures, harsh environmental conditions, limited power supply, dynamic network topology, small-scale sensor nodes, are shown by Wireless Sensor Networks (Zhang et al., 2017). In WSNs, rechargeable power sources like batteries are used in majority of sensor nodes for providing necessary power.

In most cases, especially in outdoor monitoring, it is highly challenging to replace or charge batteries. This makes power management is a crucial task. WSNs applications are development are restricted by a bottleneck called energy storage. For equipment's like electric motor, pumps and air-conditioning compressor's energy saving and lifetime prolonging, in various devices, duty cycling or sleep scheduling are used in engineering practices (El Barachi et al., 2008).

In sensor resources, very scarce resource is energy. During the mission period, for extending sensor node's life, energy must be managed. Most complex as well as challenging problem is sensor node's lifetime maximization. In a sensor node, there are two energy consumption types, it could be either "wasteful" or "useful". Useful energy consumption occurs during data transmission and reception.

Process manager performs process scheduling which handles running process removal from CPU and another process selection according to strategy. In Multiprogramming operating system, an essential part is process scheduling. An effective process is Sleep/Wake scheduling which is used for saving network's energy in a maximum extent. After cluster formation in network, sleep/wake scheduling process is applied by every cluster (Ye & Zhang 2017).

For saving energy, in every cluster, only one or two nodes having highest residual energy are kept active and other nodes are maintained in sleep mode. For analysing residual energy, all nodes in cluster are maintained in action position during the beginning of scheduling process. In a cluster, an active node having high residual energy are selected using this analysis. In a cluster, sensing task is handled by this active node. Cluster head decides which node should handle this sensing task.

TA WORK message is send by cluster head for directing selected node for performing its duty as active node. In next period, one of this node will be a cluster head. To all other nodes, SLEEP message is send by cluster head. Using a reinforcement learning method, senders are enabled to predict receivers' wake-up times.

If sender has a packet for transmission, before receiver's wake-up time, senders can wake up shortly. This saves the energy used by senders for idle listening. In this condition, trade-off should not be made by senders as its wake-up times are entirely based on wake-up times on receivers. Figure 1 shows the WSN architecture.

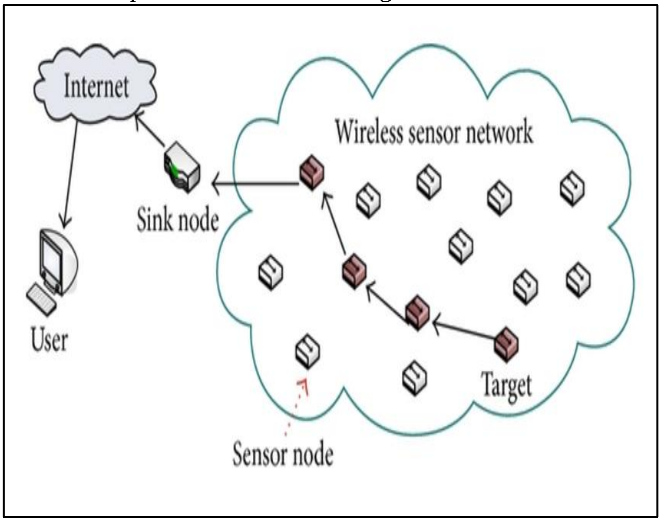

Figure 1. WSN Architecture

II. Literature Review

Sleep scheduling called as duty cycling is proposed by (Zhen et al., 2014). In required time slot, sensor nodes are turned on and off. This is a common method for saving energy. For prolonging WSNs lifetime, a significant mechanism is sleep scheduling. In recent years, various related techniques are proposed, which has diverse application and emphases areas.

In various taxonomies, those techniques are classified in this paper and deep insight into them are provided. When compared with synchronous wake-up techniques, sensor nodes needs to wake up more frequently for satisfying those requirement.

Small devices are used for making Wireless Sensor Networks (WSN) for sensing context information like environment, physiology and space as shown by (Wan & Xiong 2018). Cellular and internet networks convergence are focused by IP Multimedia System (IMS). Multimedia services delivery to end-users are enabled using this. An opportunities for providing wide range of novel multimedia services is created by integrating WSN's sensing capabilities in IP multimedia.

For integration, a presence based architecture is proposed in this paper, which focuses on information conveying to presence infrastructure called inbound interface from WSN. An IMS's integral part is presence. End-user presence information like availability, location and context information sub-set are distributed using this to interested parties called application. For 3GPP presence service, some required extensions are elaborated and architecture is introduced. It also describes concept prototype proof.

In wireless sensor networks, a fundamental problem is Sleep/wake-up scheduling as illustrated by (Wu et al., 2009). There is a limited energy in sensor nodes and they can be recharged. In sleep mode, every node's energy are saved by keeping them in sleep by using sleep/wake-up scheduling. This ensures packet delivery efficiency and maximizes lifetime.

A self-adaptive sleep/wake-up scheduling is proposed in this work. Other related techniques are outperformed by proposed technique's performance using these techniques. Duty cycling methods are used in various available approaches and for enhancing these approaches performances, much efforts are taken by various researchers. Thus, for sleep/wakeup scheduling, an efficient and a mature technique is duty cycling. Duty cycling method is not utilized in this paper. In a timeslot, transmit, listen or sleeping action of node is decided autonomously by every node.

Thus, every time slots are independent and there is no cycle in proposed technique. There is a predefined sleep/wake-up patterns of nodes in available sleep/wake-up scheduling technique. using learning methods, sleep action of nodes are decided dynamically as well as autonomously. In different circumstances, better performance is shown by proposed techniques are demonstrated in simulation results.

In wireless sensor networks (WSNs), paramount concerns are synchronization and energy-saving issues, which are analysed. An acoustic positioning applications based efficient as well as simple WSN is proposed in this paper and an on-demand sleep/wake scheduling synchronization protocol is presented. This design considers three aspects namely, high synchronization accuracy, energy efficient and power control.

Based on demand and environments, power supply is controlled and energy saving is maximized in this work. An energy consumption model is established and enhanced using on-demand synchronization and power control.

In sensor nodes, implemented an on-demand synchronization protocols and in a test-bed, they are evaluated. Energy consumption is reduced significantly using proposed protocol as confirmed in performed simulation and analysis. Effective and accurate platform is formed by this as demonstrated in experimentation.

For wireless sensor networks (ESSM), with similarity measure, an energy-efficient sleep scheduling mechanism is analysed. For effective energy consumption minimization, sensor nodes are scheduled to sleep or active node using this. At first, for organizing all sensor nodes as various clusters, estimated the optimal competition radius and it also balances energy consumption.

Then, for measuring similarity degree, a fuzzy matrix is obtained based on data collected using member nodes. For splitting sensor nodes as various classes, fuzzy theory based correlation function is defined. Under the premises of entire network's data integrity assurance, in next round, redundant nodes are put into sleep state.

With respect to network's proper cluster distribution and energy efficiency enhancement, better performance is achieved by proposed method as illustrated in simulation results with data accuracy guaranteeing.

III. Problem Statement

Time axis is split as periods in majority of available sleep/wake-up scheduling techniques based on duty cycling. There are various time slots in every period. Wake up and sleep time of nodes are adjusted in every period, i.e., duty cycle adjustment, where, in some time slots, every node keeps awake and in other time slots, they will sleep.

A self-adaptive sleep/wake-up scheduling is proposed in this work. Duty cycling technique is not used in this technique. In this technique, various time slots are formed by diving time axis. In a timeslot, transmit, listen or sleeping action of node is decided autonomously by every node.

Thus, every time slots are independent and there is no cycle in proposed technique. There is a predefined sleep/wake-up patterns of nodes in available sleep/wake-up scheduling technique. using learning methods, sleep action of nodes are decided dynamically as well as autonomously. Thus, when compared with majority of available techniques, nodes in this method are smarter.

IV. Proposed System

A self-adaptive sleep/wake-up scheduling is proposed in this work. Duty cycling technique is not used in this technique. In this technique, various time slots are formed by diving time axis. In a timeslot, transmit, listen or sleeping action of node is decided autonomously by every node. Based on neighbour's situations approximation and its current situation, decisions are made by every node. Communication with neighbours are not required for making such approximations.

Other related techniques are outperformed by proposed technique's performance using these techniques. Duty cycling methods are used in various available approaches and for enhancing these approaches performances, much efforts are taken by various researchers. Thus, for sleep/wakeup scheduling, an efficient and amature technique is duty cycling. Duty cycling method is not utilized in this paper.

Instead, game theory base technique is proposed in this paper as an alternative and it uses inforcement learning method. Comparison is made between available and proposed technique. In WSNs, new way for sleep/wake-up scheduling is provided using this proposed method as indicated in comparison. Theoretical study is mainly focused in this paper and various assumptions are made (Zhang et al., 2017);(Rachelin Sujae & Arulselvi, 2019). This approach's discussion are simplified using these assumptions.

This technique's discussion is made more complex without these assumptions. For this paper's readability, this makes more harmfulness. This paper addresses this problem, these assumptions are not simplifying these problems.

Under these assumptions, this problem is general. An energy-efficient medium access solution is achieved using wake-up radios (Aggarwal & Gupta, 2016). Sensor node's on-demand activity is enabled using this wake-up radio, so until its requirement, node may be in sleep position.

At the same time, at low sampling rates, energy is saved using this on demand capability. For on-demand and event based applications, highly effective utilization is enabled by this technique. Continuous communication is not required for this. There exist a wake-up transmitter as well as receiver in wake-up system.

A specific packet routing protocol is not incorporated for designing proposed technique. This is due to the fact that, with a specific packet routing protocol incorporation, sleep/wakeup scheduling technique is designed. With this routing protocol, better performance is shown by scheduling technique. With other routing protocols, it efficiency is degraded. With a packet routing protocol incorporation, designed a sleep/wake-up scheduling technique.

For data propagation, for creating unidirectional delivery paths, staggered wake-up schedules is used in this scheduling technique (Niewiadomska-Szynkiewicz, 2012). Data collection process's latency is reduced significantly using this technique. If packets are delivered in designated direction, better performance is shown using this technique, but, it is not effective, of packets are not delivered in designated direction. This thesis contribution is summarized as,

1) Duty cycling method is not used in this technique, which is a first technique to do so. This technique avoids, trade-off between packet delivery delay and energy saving, which are incurred in duty cycling. Both packet delivery delay and energy consumption are reduced using this technique.

2) In different circumstances, high packet delivery ratio can be achieved using this technique when compared with other benchmark methods.

3) Without requesting information from neighbours, neighbour's situation are approximated by nodes in this technique, where in recent technique based on predictions, information must be exchanged between each other. This saves the huge energy required for exchanging information.

Thus, in WSNs, among sensors, for dealing with sleep/wake-up scheduling problem, game theory is used. A payoff matrices pair is used for defining game.

$$R = \begin{pmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{pmatrix} \text{ and } C = \begin{pmatrix} c_{11} & c_{12} & c_{13} \\ c_{21} & c_{22} & c_{23} \\ c_{31} & c_{32} & c_{33} \end{pmatrix}$$

Where, for row player, payoff is specified as R and for column player, payoff is specified as C. From three available actions, an action is selected by every one of two players. Based on players payoff matrices, players joint action is determined by its payoffs. If action i is selected by row player and j is selected by column player, payoff rij is received by row player and cij is received by column player.

According to probability distribution over player's available actions, actions are selected stochastically by players. Probability of row player for selecting actions 1-3 is represented as α1–α3 and α1+ α2 + α3 =1. Probability of column player for selecting actions 1-3 is represented as β1–β3 and β1 +β2 + β3 =1. Expected payoff of row player is expressed as,

$$P_r = \sum_{1 \le i \le 3} \left(\sum_{1 \le j \le 3} r_{ij} \alpha_i \beta_j \right)$$

And column player's expected payoff is

$$P_c = \sum_{1 \le i \le 3} \left(\sum_{1 \le j \le 3} c_{ij} \alpha_i \beta_j \right)$$

Sleep, listen and transmit are denoted using above mentioned expression. In payoff matrices, node's energy consumption is used for defining those payoff values, which is a negative one. A positive constant U with a value 98 is added with an energy used for transmitting or receiving packet for computing receiver or transmitters payoff, if packet is transmitted successfully. Only during the successful packet transmission, energy consumption is added with constant U.

For action sleep, payoff is −0.003 which indicates, energy consumption in sleep period, and it is defined irrespective to opponent's action, where, energy consumption is indicated using negative sign. For packet transmission or reception, used energy is lesser than constant U's value. For instance, listen action is selected by column player, if row player has a packet for transmission. This makes successful packet transmission.

For both players, pay offs are positive, constant U and energy required for packet transmission and reception are used for computing this. Then, payoff −81+98=17 is received by row player and payoff −30+98 = 68 is received by column player, where, energy consumption for packet transmission is 81and packet reception is 30. Energy consumption is indicated using a negative sign.

However, packet is not transmitted successfully, if sleep action is selected by column player. Then, payoff-0.003 is received by column player which indicates, energy of sleep action and payoff-81 is received by row player, which indicates energy used for packet transmission. A transmit action is not selected by a node, if it is not having any packets for transmission. In a timeslot, every node will be in one of various states. Buffer state is indicated using this.

For instance, if three packets can be stored in node's buffer, it may have four possible states namely s0-s3, this indicates that, node is having 0-3 packets in buffer. Every node concentrates to compute a policy π for mapping state with action which maximizes node's long-run payoff. In specific, based on a probability π(s,a), in current states, its actions is selected. In current state s, over available actions, probability distribution is represented using a vector π(s), which makes policy π as a matrix. For example, node will have four states namely s0–s3 as mentioned above, if three packets can be stored in its buffer.

There are three actions in node namely, sleep, listen and transmit. They are represented as 3,2,1. Hence, node's policy is expressed as,

$$\pi = \begin{pmatrix} \pi(s_0,1) & \pi(s_0,2) & \pi(s_0,3) \\ \pi(s_1,1) & \pi(s_1,2) & \pi(s_1,3) \\ \pi(s_2,1) & \pi(s_2,2) & \pi(s_2,3) \\ \pi(s_3,1) & \pi(s_3,2) & \pi(s_3,3) \end{pmatrix}$$

At first, in every state, every action is given with equal importance as node does not have any prior knowledge. In π, every element is assigned a value 1/3 for making $\sum_{1\leq i\leq 3} \pi(s,i)$ as 1 for every state. Then, in π, every elements value is adjusted by node through learning. In following sections, their details are specified. An action's selection probability is represented using π(s,a) and α, β. States are considered in π(s,a) and in α and β, they are not considered. For algorithms and model's convenient description only, α and β are used.

In time slot, packet transmission time should be decided by nodes, if transmit action is selected. A payoff is received by node and new state is reached. According to new state's maximum Q-value (line 7) and received payoff, selected action's Q-value is updated by node in its current state. In states, selected action's reinforcement is represented using Q-value, Q(s,a). Learning process is reinforced using this information.

Value iteration update is expressed in line 7 of this expression. At first, designer specifies the Q-value arbitrarily. Addition of learned knowledge, $\xi(p+\gamma \max_a Q(s,a))$ and current Q-value, $(1-\xi)\, Q(s,a)$ is used for updating Q-value. Payoff computed using node by considering optimal future value's estimation and action $p+\gamma \max_a Q(s,a)$, are used in learned knowledge.

In lines 8-10, over neighbour's available actions, probability distribution is approximated by a node, if sleep is not taken as an action. Node which is received a packet from a node or transmitted a packet to a node in current time slot is termed as neighbour node which is had an interaction with that node.

V. Experimental Result

The proposed algorithm is tested using a simulation platform called Network Simulator-NS2. In the below mentioned table, results are tabulated. According to proposed algorithm, SA-MECH algorithm's performance and effectiveness, these results are declared. Comparisons are made between EM-MAC and SA-MECH algorithm and represented in following graphs (Kokila & Sarawady, 2018) ;(Hsu et al., 2012). Table 1 shows the simulation parameters.

Table 1. Simulation Parameters

PARAMETER	VALUE
Simulator	NS-2.34
Topology	grid
Nodes count	49,81,121,169
Sink nodes	5
Grid distance	200m
Simulation time	100s
Traffic type	CBR, UDP
Transmission range	200m

EM-MAC: A pseudorandom number generator is used by every node in EM-MAC: Xn+1 = (aXn + c) mod m for computing its wake-up times, where m > 0 is modulus, multiplier is represented as a, increment operator is expressed as c, current seed is givne by Xn and next seed is given by Xn+1. In this simulation, m = 65536, based on principles given by Kunth, every node's Xn, c and a are selected independently.

Receivers future wake-up times can be predicted by a sender by requesting parameters Xn, c, a, and m from receiver. Based on this prediction, data are prepared to send. Synchronization is not required in EM-MAXC, but before making prediction, information should be exchanged by nodes.

Three quantitative metrics are used for measuring the performance:

1) Average packet delivery latency;

2) Packet delivery ratio;

3) Average energy consumption.

Around 2 ms is required as a minimum time for transmitting or receiving a packets by nodes (Tang et al., 2011), e.g., radio chip Chipcon CC2420 usage. Following describes three metrics.

1) Average time required for transmitting every packet to destination from source defines Packet delivery latency. For this computation, packets which are not reached the destination successfully must also be considered. In network, their delivery latency corresponds to the time interval in which they available.

2) Packets percentage which are delivered successfully to destination from source defines packet delivery ratio. In every packet, there exist a parameter called time-to-live (TTL), which is a positive value. If the packet is transmitted to receiver from sender irrespective of its delivery condition either unsuccessful or successful, this packet's TTL is subtracted by 1. If packet TTL is zero and it is not reached its destination, then this packets delivery is said as a failure one.

3) Ratio between total energy consumption and nodes count n in network during simulation defines average energy consumption.

Simulation Results in Grid Networks:

As described in previous section, grid computing topology is similar to chessboards. There are three rules in grid networks.

1) There are two neighbors for every one of four nodes which are located at four corners.

2) There are three neighbors for nodes on edges.

3) There are four neighbors for all other nodes.

Moreover, at network center and four corners, five sinks are located in this simulation, which makes highly regular grid networks. Reinforcement learning forms base for this proposed SA-Mech. Because of this better performance is exhibited by proposed SA-Mech. Technique. Easily learning of something with high regularity can be done using this.

In grid networks, to center and four corners, all packets are transmitted, where sinks are located. As time progresses, under SA mechanism, nodes can understand this regularity easily. Node's neighbors' situations can be approximated precisely by them using learned knowledge. Following section provides detailed simulation results analysis. Figure 2 shows the average delivery latency (ms).

1) In various Grid network scales, proposed techniques performance are illustrated as below,

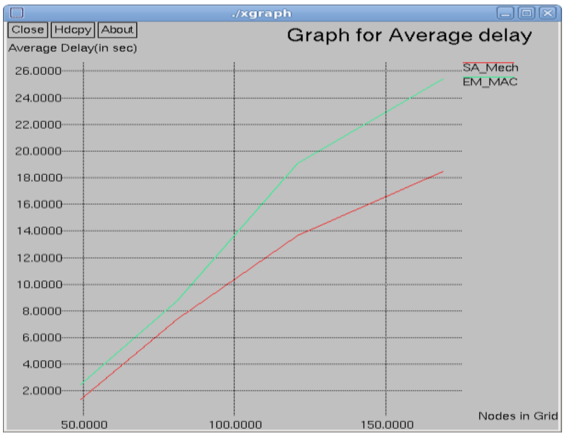

Figure 2. Average Delivery Latency (ms)

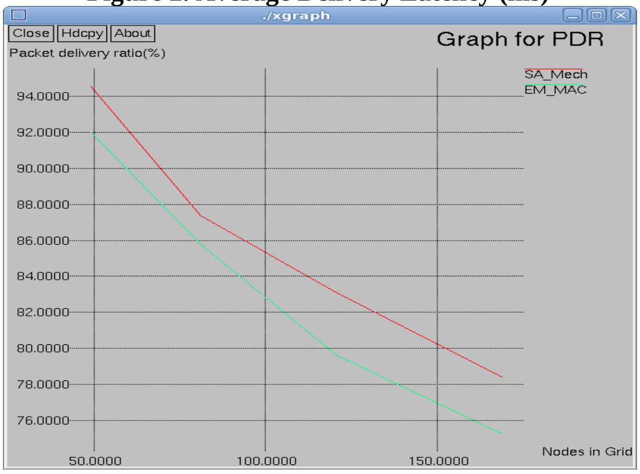

Figure 3. Packet Delivery Ratio (%)

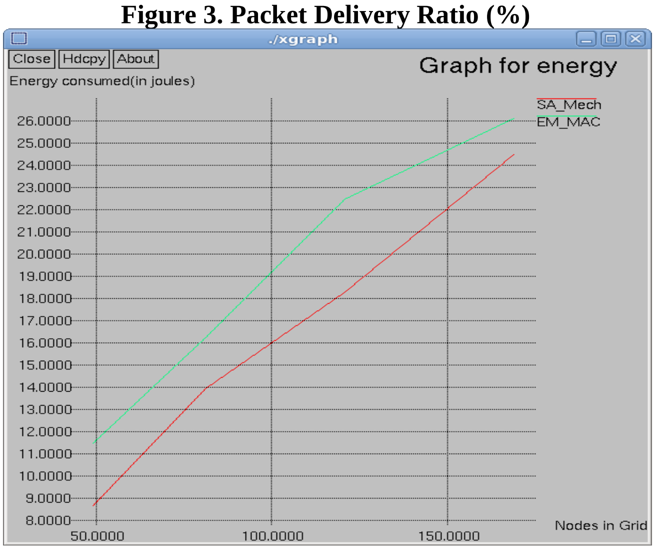

Figure 4. Average Energy Consumption (mW)

In various grid network scales, these techniques performance are demonstrated above. Packet generation probability is assumed as 0.2. There is an increase in average delivery latency of all techniques with an increase in network scale as illustrated in figure 4. If there is an increase in network scale, more steps are required for transmitting every packet to its destination and steps are defined according to used routing technique in simulation.

Thus, in EM-MAC, there is around 5% enhancement in average delivery latency as indicated. For future wake-up prediction, nodes need to know its neighbor's information. This is done on demand and only once. Figure 5 shows the average delivery latency (ms).

In Grid networks, under various packet generation probabilities, performance proposed technique is illustrated in the below figures. Figure 6 shows the packet delivery ratio (%).

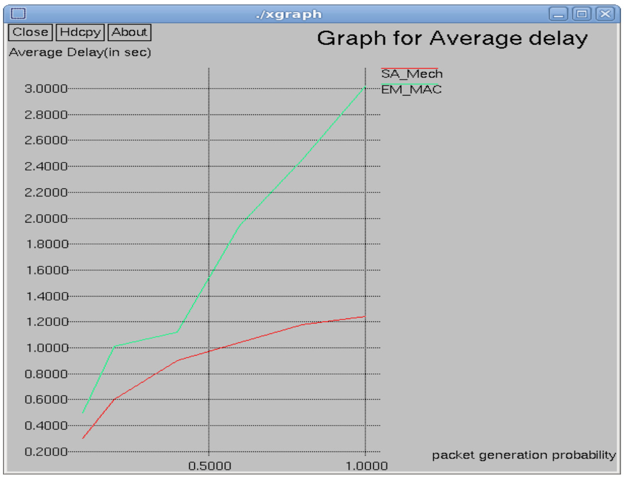

Figure 5. Average Delivery Latency (ms)

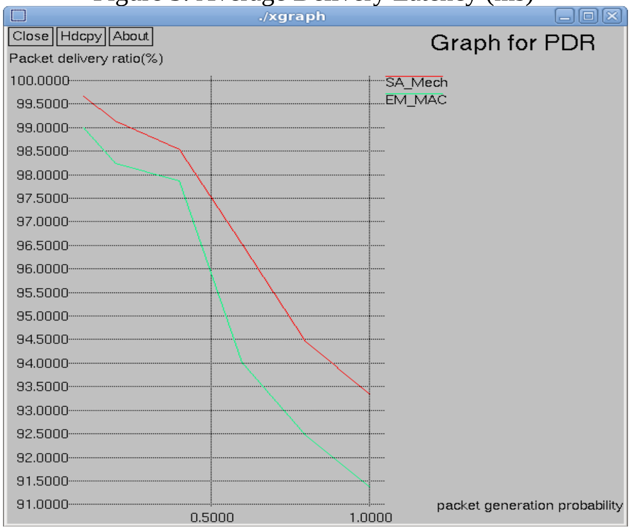

Figure 6. Packet Delivery Ratio (%)

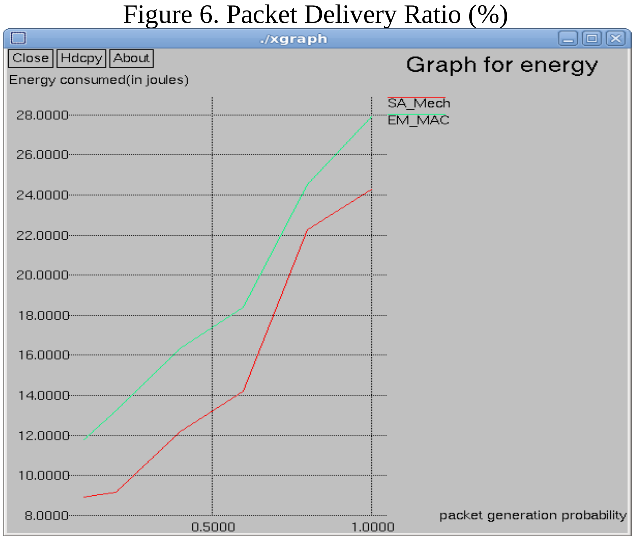

Figure 7. Average Energy Consumption (mW)

There is substantial energy consumption due to large packet delivery failures as illustrated in figure 7. Therefore, in EM-MAC, there is a significant increase in energy consumption with respect to the increase in packet generation probability, whereas in other techniques, there is a steady rise in energy consumption with respect to the increase in transmitted packets count in network.

VI. Conclusion

With high densities of around 20 nodes/m3, sensor networks are deployed for enhancing its longevity and reliability. However, excessive amount of energy will be consumed if all sensor nodes in that dense condition operates at the same time. Also, in network, due to the forwarding to large packets count, there will be an increase in packet collisions. In addition, in network, majority of forwarded data will be redundant and there will be an overlapping of node's sensing regions if node density is high. There exists a high correlation among adjacent sensor nodes data. In summary, by avoiding redundant data's transmission, network traffic and energy consumption are reduced using sleep scheduling. A self-adaptive sleep/wake-up scheduling technique is introduced in this thesis. Duty cycling technique is not used in this approach. Instead, time axis is split as various times slots and in a time slot, transmitting, listening or sleeping nature is decided autonomously by every node. According to every node's current situation and its neighbor's situation's approximation, they make its decision. Communications between neighbors are not required for making such approximation.

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