I J C T A, 9(20), 2016, pp. 245-257

Judicious Energy Management in Wireless Sensor Networks

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ABSTRACT

A Wireless Sensor Network (WSN) uses battery operated computing and sensing nodes which may lose its energy after certain amount of lifetime within the network. Papers so far dealing with the outdoor wireless sensor networks consider the battery included in the sensor node to be of photovoltaic nature which may recharge itself with the solar energy medium but do not guarantee the upliftment of energy level up to hundred percent every time, as a number of environmental factors may also participate during this activity. Besides the availability of solar rechargeable batteries, a major part of the research in wireless sensor networks so far emphasizes the procedures to improvise the energy efficiency among the data centric nodes in the network. But, it would be much advantageous if the research so far steered towards the provision of continuous energy within the sensors through passive medium and outperform throughout the lifetime as in the wired networks. The paper intends to model a new framework which involves improvising the energy level of each sensor node within the network by providing an algorithm for intelligent energy utilization and monitoring the levels of sensor node energy with a provision for passive charging system for each sensor node in the deployment area.

Keywords: wireless sensor network; sensor nodes; base station; energy efficiency; judicious energy management; power supply model; energy balancing model

1. INTRODUCTION

With the recent advances in the wireless communication technology, wireless sensor networks are marking their importance with their small size and low cost sensor nodes connected by wireless media to form a new class of communication network in which various small size nodes can be used to sense the environment, collect data from the environment and forward to the end user through base stations. The data may include environmental measurements of sound, light, moisture, temperature or other relevant parameters. Covering these or other parameters, wireless sensor networks are finding their importance in various applications like home application, health monitoring, biological detection, surveillance of remote or hostile or battle area, inventory tracking, national security, smart spaces, disaster relief, military surveillance, habitat monitoring, target tracking, sick building syndrome etc. [1-6]. In all these wireless sensor networks applications, network lifetime has remained a critical aspect as power resources small sized due to weight limitations.The network lifetime in general referred to as the time interval within a network is able to sense the data as well as transmit the sensed data. To enhance the lifetime of the network, two primary techniques of energy conservation are always focused: adjusting the coverage area i.e. sensing and/or transmitting range of these nodes and alternating the sensor nodes scheduling between sleep and active mode.Such energy conservation techniques play a vital role where the sensing is being done in the hostile environment. Optimal sensor deployment strategy in the hostile environment aims to save energy and enhance the lifetime of the network. Due to huge number of sensors in wireless sensor

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networks, the total cost will be high for entire network, though cost of the individual sensor is very low. Therefore, it is essential to identify minimum number of nodes that needed for wireless sensor networks to achieve uplifting of energy. Since, the coverage area of each sensor node can be adjusted so, it is always preferred for hostile environment that the sensor nodes perform for maximum period in response of adjusting the range of each sensor node to low coverage area and switching their lifecycle to sleep and active modes. Many of the papers [7-9] have suggested energy efficient coverage techniques but each one of them prolong the life time or coverage area rather than an approach in which energy efficiency may extend the coverage of a node or whole network to maximum till the user wants to sense the data independent of the sensor life or without replacing them physically. It would always be appreciable if each one of the sensor node in the deployment area outperform in terms of coverage i.e. each node covers maximum area, as this would reduce the demand of number of redundant sensor nodes in the area and thus decreasing the overall physical structure cost of the network. This paper aims to provide a clear overview about uplifting the energy in wireless sensor networks. This paper will help the future researchers to know about uplifting energy in wireless sensor networks through a passive energy recharge model, in which sensor nodes are recharged explicitly, working in co-ordination with a judicious model for energy management that will balance the energy level among the sensor nodes dynamically in the deployment area.This will also affect the energy aware coverage problems in wireless sensor networks that are attracting lot of research interest these days. The network coverage is one of the most critical issue to implement WSNs due to limited resources in each sensor node, hence it is critically important to provide required energy in an energy efficient way.To fix energy aware network coverage issues in wireless sensor networks, mostly models adopt boolean sensing model to meet the coverage requirements in which a subset of sensor nodes with minimum weights is selected, termed as Minimum Weight Sensor Coverage Problem (MWSCP) in which the sensor nodes with more residual energy are activated to balance the energy consumption and extend the network life [23].

2. MOTIVATION

In providing various applications, wireless sensor networks may find challenges in maintaining the energy efficiency among nodes, security in the network, making the system to be fault tolerant, dissiminating the data throughout the network, connecting to the neighbor nodes or managing the coverage of sensor nodes within the network. In each one of the challenge, another challenge is always associated either actively or passively, that is; the small sized battery limitation. This small sized battery of the sensor nodes is founding direct or indirect involvement of energy efficient system. Many researchers have proposed a number of algorithms or protocols to make the system energy efficient but an energy efficient system can uplift the lifetime of the network to some extent and can never make it working permanantly as with the fixed or wired system that has always an external and continuous power supply.Somehow, a ray of light is directed when a thought of implementing the concept of wireless electricity transmission over the field of wireless sensor network stiked. Wirless electricity is becoming a hot and demanding topic in the research day by day. The evolution started with the solar charging [18] follwed by charging models of space crafts and wireless power transmissions [12-15], then focussed to UAV chargings [16] and now in domestic applications as well. Though the feature was introduced in wireless sensor networks [17] and later in [11] but the bottleneck in this part was the usage of power beams which may be harmful for humans or any living obstruction that may come in the between the source and the destination. The main crux of this model was the rise in the cost of the network due to the involvement of extra hardware. So, to reduce the cost to some extent, the number of nodes have been reduced to 60%, as in generic techniques the remaining 40% of the nodes generally either provide duplicate information or may provide redundancy. Since, the more is the number of nodes more will be latency time, whether it be in micro seconds or a few seconds, for a node to get itself charged.

3. THE PROPOSED MODEL

The paper proposes a Judicious Energy Management (JEM) model which is divided into two main components:

A. Power Supply Model (PSM)-that will provide the provision for recharging sensor nodes with passive energy i.e. other than the solar energy.

B. Energy Balancing Model (EBM)-that will balance the energy level of all the sensor nodes in the network and allow the PSM to recharge the sensor node if its energy performance is below the scale.

In Judicious Energy Management, both the components will work in co-ordination with each other throughout the network lifetime in order to enhance the network efficiency, as shown in Figure 1.

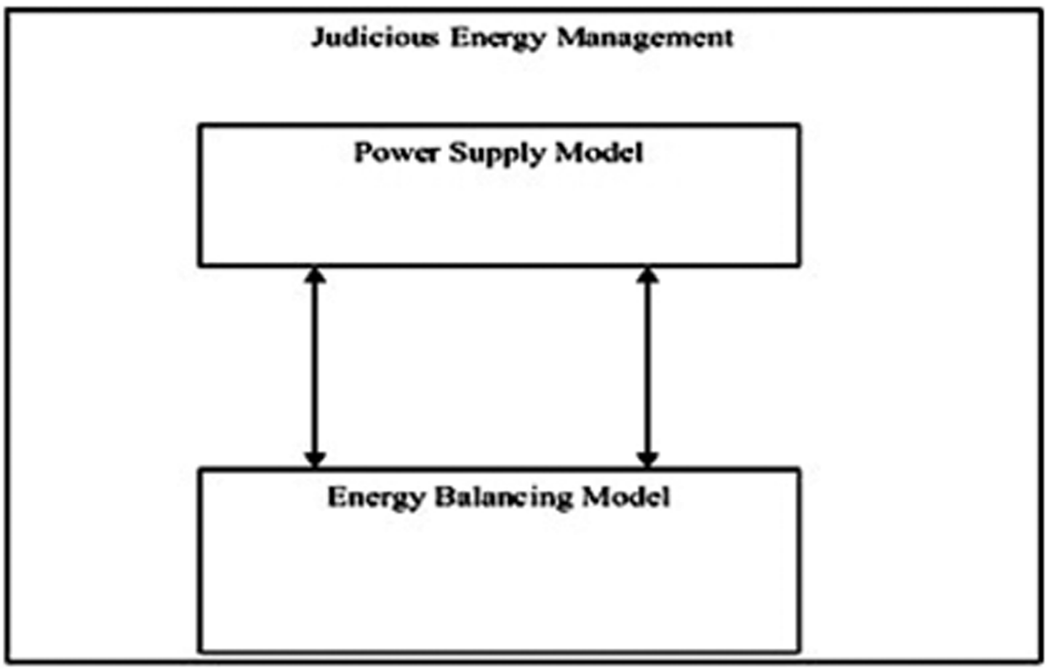

Figure 1: Block Diagram of Judicious Energy Management

3.1. Power Supply Model

The Power Supply Model (PSM) considers a wireless sensor network to be deployed in a hostile environment with fixed position of sensor nodes for long term sensing requirement of the field. PSM constitutes some

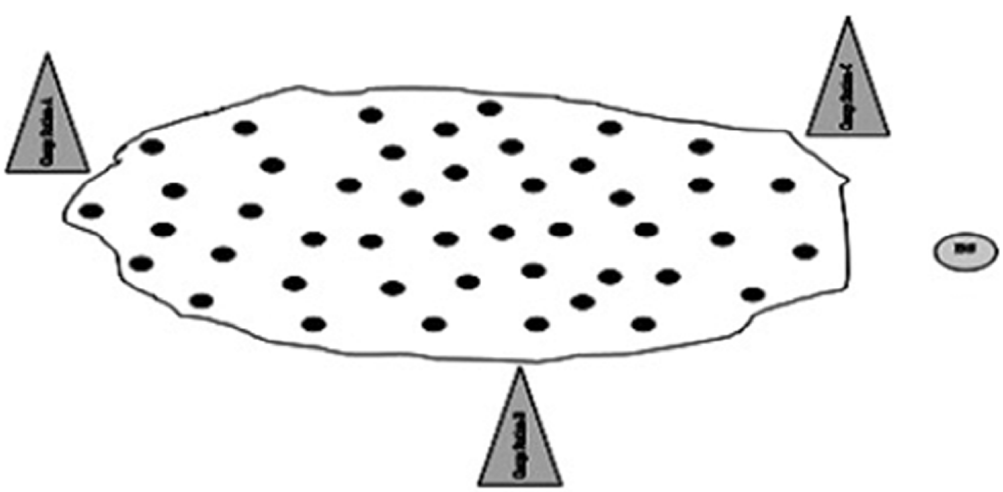

Figure 2: (a) Network arrangement at abstract level

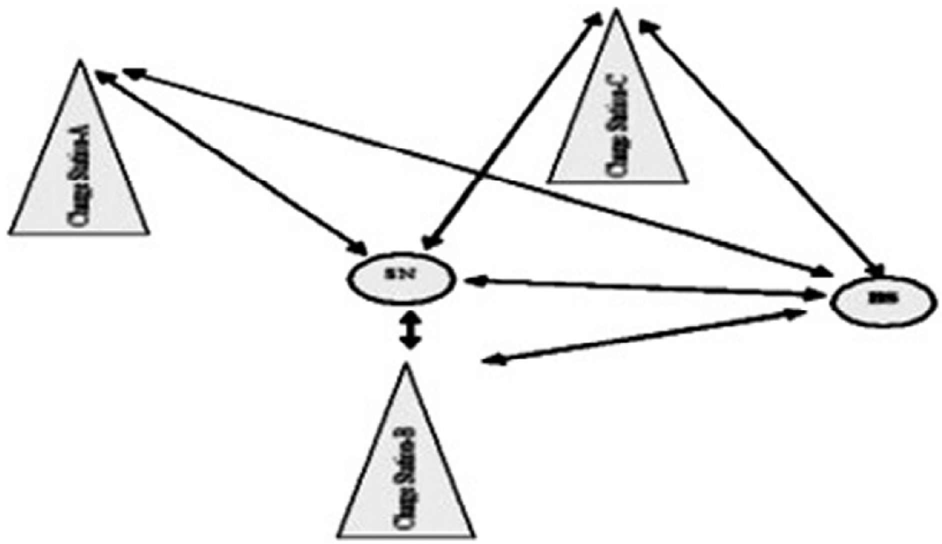

Figure 2: (b) Two-way communication for charging the network nodes

extra infrastructure including three charging stations and a different kind of power unit in the sensor node; inspired by [10].

The model constitutes of three charging station A, B, C, placed on three different sides of the deployment area, a base station and a deployment area constituting sensor nodes, as shown in Figure 2 (a). The charging stations constitutes an adaptive-phased array microwave emitters and they form a two way communication with the Base Station (BS) and the Sensor Nodes (SN) in the deployment area, Figure 2(b) shows the microwave charging procedure of the sensor nodes and the base station. The Figure3 shows the elaborative working of the model with the help of block diagram. The charging station and the sensor nodes constitute the following main components:

- Adaptive Phased Array- The power transmitter portion contains one or more number of adaptive-phase array emitters which can focus on the sensor nodes or the base station to be charged. The adaptive-phased arrays normally operate between the frequency range of 2 GHz to 10 GHz, however higher frequencies can also be employed which may be in lower in efficiency [10].
- Pilot Beam Detector- Its role is to detect a locator signal emitted by a pilot beam emitter in the sensor node.
- Backscatter Sensor- It is associated with the adaptive phase arrays of the charging station and detects any obstacle entering in the path of microwave beam sent through the charging station. The obstruction may be some human interference or in any other way. If the backscatter sensor senses some interference in the beam path then the adaptive-phased array associated with it will either turned off or reduce the beam concentration. The process preevents wastage of the microwave power which is not reaching its destination and damage to humans or any other interference within the path. The beam transmission will be held until the obstruction is removed from the beam path.
- Location Beam Detectio- It helps in detecting the location of sensor nodes in the deployment area. In this model, virtual and local co-ordinates are obtained with respect to three charging stations using triangulation technique [19].
- Control Logic- It controls the beam intensity if any obstruction arises while transmitting the beam.
- Energy Source- It is the power genrator that may contain AC or DC supply and helps the charging station to convert this electric power into microwave power that is to be further supplied to charge the nodes in the network.

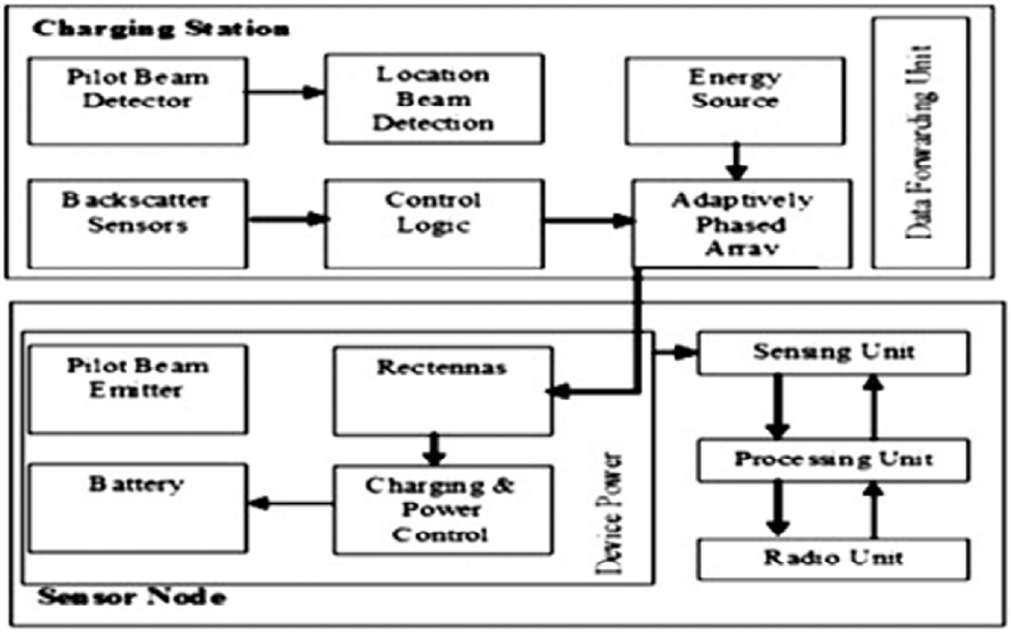

Figure 3: Block diagram of Power Supply Model

- Data Forwarding Unit- Besides the involvement of charging the nodes in the network, the charging unit also contains a modulator that will modulate the data onto the charging beams, thus acting as a gateway. This data can then be demodulated in the sensor components. The data transfer in this model is a multi-hop technique where the data from the sensing nodes is transferred to cluster heads at ground level and then is forwarded to the charging stations that are acting as gateways and forwards data with the help of data forwarding unit to the base station and vice versa.
- Rectenna- Rectenna within the sensor node can be used to receive and rectify the microwave beam sent by the charging station, which can be further used for primary power directly or for charging battery of the sensor node.

As can be seen in Figure 3, the power supply model is divided into two components one is the charging station and other is the sensor node that is part of the network. Besides the regular structure of sensor nodes, the node contains the rectennas that absorb the energy supplied from the charging station and provides supply to the charging and power control unit which helps in charging the photovoltaic battery attached here with. The charging station can be managed at base station end as well in which a pilot beam detector detects the location of any sensing unit by the additional emitter involved in the sensing unit. The detector helps to navigate the direction of the charging station through location beam detector; though the unit is independent but it will help in redirection of charging station.The charging station also consists of an energy source unit that gathers power either through photovoltaic mode or direct supply mode; this energy is then gathered in adaptive phased array which can supply wireless power to the sensing unit with the help of detector. The intensity of wireless power supply is controlled by the control logic and refined by the detection of obstacles through backscatter sensor.

3.2. Energy Balancing Model

Though the power supply model is capable enough to uplift the energy level of the nodes with low battery performance, but still it would always be in good practice if we reduce the number of nodes as in this working scenario the network outcome can be achieved with fewer population of nodes in the deployment area, each one of them is outperforming in terms of energy efficiency. Still the overhead may arise on the charging station if it would be called for charging different sensor nodes in the network in short time intervals. So, it would always be in good practice to balance the energy level of the nodes in the network otherwise a few nodes which found often invitation to perform their activities will be charged again and again while the others will not remain active all the time in the network.

After the successful setup of the network, this model comes into existence. This model constitutes two main algorithms in order to uplift energy level in wireless sensor networks and they are:

- Algorithm for head selection in cluster
- Dynamic sleep time algorithm

4. HEAD SELECTION ALGORITHM

Judicious Energy Management (JEM) follows the procedure of head selection algorithm which helps to separate entire network into number of clusters. Here, each and every node will be a part of cluster and have a cluster head (CH).The main objective of the cluster formation in the proposed approach is to balance the energy loads of cluster heads. Each and every cluster head in the network is responsible only for the received data from the cluster members and it performs aggregation process on the received data and also then to the base station (BS). The base station chooses the CH (cluster head) at the very beginning of each and every round based on the current information of the nodes.Each cluster is termed as Ci and one of the nodes in the cluster Ci is selected as the cluster head, CHi. The cluster head is responsible for only receiving and routing sensed data of other sensor nodes which belongs to the cluster and also to the base station. The round by round process is performed in order to select the cluster head (CH) from the sensor nodes which are in the same cluster. In general, energy consumption of the cluster head (CH) is higher while comparing with the other nodes. The cluster head (CH) in the cluster is considered as the alternate among the sensor nodes in order to balance the consumption of energy for extending the lifetime of the wireless sensor networks (WSNs). Therefore, it is clearly understood that, the selection manner of cluster head (CH) can have capacity to affect the lifetime of entire network (wireless sensor networks).When the threshold value is higher than the residual energy of cluster head (CH) node, it triggers new cluster head (CH) candidacy event by reporting the base station that it was not able to perform its functions as a cluster head (CH) any more. Afterwards, the base station will inform this to all other cluster heads thus by taking action on a cluster head rotation phase. In order to avoid deadlock when the older cluster head(CH) dies, the next round CH will be selected in advance.The proposed algorithm recommends associated cluster head array that contains Location-ID and Node- ID and also suggests decreasing the residual energy of the sensors. Cluster nodes are mainly used to collect the data from environment and then send it to the cluster head. While processing of the head node of the cluster, the energy level is reduced. If the energy of cluster head becomes lower to then the energies of the non-CH (cluster head) nodes, then it is essential to process the next round. At that period of time, the proposed algorithm calls the next cluster head for each cluster in order to start the process of new round.

In the proposed algorithm, physical clusters are assumed i.e.the formation of cluster and members of each and every cluster are fixed. So, it does not need any re-clustering process.Following are the sequence of steps followed for header selection in each cluster:

1. for node := 1: n //n is the total number of nodes

1.1. RADIOnode := 1

1.2. Broadcast locationnode to the BS

1.3. Add node to the cluster Ci based on its location.

2. fori := 1:p //p is the total number of physical clusters

2.1. for node := 1:q //q is the total number of nodes inside ith cluster

2.1.1. TRANSMISSIONnode := 0

2.1.2. RADIOnode := 0

2.2. for node := 1:q

2.2.1. Send information containing energy level to the BS

2.2.2. Find node with Maximumenergy in Ci and mark node as Xi; mark all remaining member nodes in Ci as Y.

2.2.3. Assign Xi as Cluster Head (CH).

2.3. for node:= 1:q

2.3.1. if node != Xi

2.3.1.1. TRANSMISSIONnode := 1

2.3.1.2. RADIOnode := 1

2.3.1.3. Aggregate the data received by Xi and unicast to BS.

3. if Xi-residual_energy<Energythreshold

3.1. goto step 2.

Implementation of cluster formation algorithm has several steps. First step is to setup the process and broadcast the information about the existing location of sensor nodes to the base station (SINK). The next step is to determine good clusters. Then in each and every cluster, all the sensor nodes sent its energy level to base station. If the sensor node has highest energy level then allows it choosing as cluster head and broadcast the information to its member nodes, otherwise, it chooses the nodes as the member nodes. As a next step, nodes send data to cluster head (minimal energy is used for transmission) and then the radio of each non cluster head can be turned off up to transmission time is allocated by the nodes. As a next step, cluster head performs data aggregation. Then aggregated data will be sent to base station (here transmission requires high energy). Then if the residual energy of cluster head (CH) node is less than the threshold value, then it allows selecting the new cluster head. Then the process of new round will be started and this is to choose next Location-ID and Node- ID.

5. DYNAMIC SLEEP TIME ALGORITHM

Initial phase of the dynamic sleep time algorithm performs three main tasks such as: each and every sensor node will receive neighbor information; finding all the possible routes to the destination; and position of base station (sink). Each and every node may send hello message in order to revise their routing table and also it may contain the information about the neighbor hop count from BS (base station).

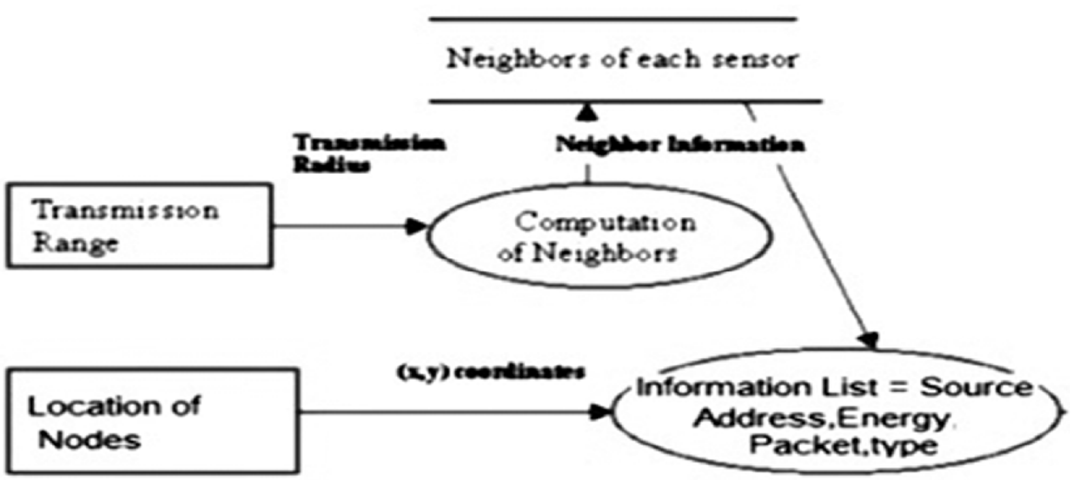

Figure 4: Performances of each sensor with its neighbor

To perform this task, it is essential to check the information about the packet, its energy level and also about the type of the packet. Afterwards, it is essential to add information about the list along with the routing header x, y coordinate and energy. The Figure4 illustrates the performances of each sensor with its neighbor in the proposed algorithm.

The proposed protocol assumes, the nodes which operate in the periodic sleep schedule where each node contains sleep interval and then wake-up interval. Generally, sleep interval is the duration of time taken when the node's radio is in the off state. At the same time, the wake-up interval is calculated as the duration of time, when the node is in on state in order to transmit packet. As well as, if the sleep and wakeup interval becomes dependent on the factors that measures the critical requirements of the network i.e. number of dependent point of interests on a single sensor node, it would be more beneficial. The sensor nodes calculate the distance from the point of interest (POI) by detecting the occurrence of any event at a point of interest (POI) based on the RSSI. Since, Boolean Disc Model facilitates the analysis and takes into coarse approximation to practical sensing model that leads to uncertainty of signal detection problem whereas the Probabilistic Disc Model works on the assumption that detection probability is a continuous decreasing function of the distance to be measured. Hence, a more realistic approach is to presume that the occurrence of the events can be detected by the sensor nodes with certain probability if the distance between the POI and the sensor node exceeds beyond the sensing radius in Boolean Disc Model.

For a given deployment area, let N be the set of sensor nodes and wi be the set of weight coefficients, where, $i = 1, 2, 3, \ldots, N$; $\lambda i(j)$ denotes the probability detection of sensor node i of events at POI (j), then the exponential attenuation probabilistic model [24] is given as:

$$\lambda i(j) = \begin{cases} 1 & if \quad d(i, j) \leq rs \\ e - ka \wedge m & if \quad rs < d(i, j) \leq ru \\ 0 & if \quad ru < d(i, j) \end{cases} \tag{1}$$

The probability of the events at POI (j) will be surely if the target is within the sensing range, rs of the sensor, as represented by the boolean disk model as well and the probability of detecting the target decreases exponentially when the distance exceeds rs, with the increase in Euclidean distance between the POI (j) and the sensor node i; however if the distance exceeds ru, then there is no scope of detection as the received signal will be contaminated by noise.

The algorithm starts in order to calculate data aggregation time. It calls three major functions: dataTime; time2listenTime; and time2sleep. If the Tagg = 0, then listen Period and status is considered as sleep. If Tagg = time2listenTime plus cycleTime, then listen Period and status is considered as listen. At the same time, if Tagg = time2listenTime, then listen Period and status is considered as listen.

Pseudo Code for Dynamic Sleep -

1. while termination conditions not met do
2. Check packet information, its type and energy.
3. Add that information in list along routing header x, y cordinate and energy.
4. Call sleep_duty_processing()

4.1. while routing queue length !=0

4.1.1. nodei->energy_model()->set_node_sleep(0);

4.2. End the loop

4.3. $\forall$ i$\in$N if (((j) 0)||(last_data_duration + DATA_INTERVAL < CURRENT_TIME))

4.3.1. nodei->energy_model()->set_node_sleep(1);

4.4. Elsenodei->energy_model()->set_node_sleep(0);

5. return

Here, the proposed algorithm checks the information about the packet, its energy level and also about type of the packet. Afterwards, it is essential to add information about to the list along with the routing header x, y coordinate and energy.Once this process is completed in the information list, then it is essential to call the function sleep_duty_processing(). This function can have capacity to save the energy by making the node to sleep when it is not in the use. Here, if the node has data to send, it will switch to wake up state. A default value of 5.0 has been assigned to DATA_INTERVAL. If the data duration does not hit the current time interval, it will move to switch mode else it will remain in wake up mode during data processing phase.

Implementation of NS-2 to uplift energy level can be achieved by performing various functions. Here, thefunction send_info( ) is taken to describe about uplifting energy level in the wireless sensor networks.

The following part shows how the information is added to the list:

$$rh \rightarrow type = type;$$
$$rh \rightarrow energy = node \rightarrow energy\_model() \rightarrow \ energy();$$
$$info\_list\_.add(ih \rightarrow saddr(), rh \rightarrow type, rh \rightarrow energy);$$
$$node\_list\_.add(ih \rightarrow saddr(), rh \rightarrow X, rh \rightarrow Y, rh \rightarrow energy);$$

Where, rh stands for routing header, and ih represents IP header.

Here, the packet information is checked with its type and energy. Then, information should be added as list along with the routing header x, y co-ordinate and energy.

Once the information is identified, then it is essential to call the function *sleep_duty_processing*(). This function is used to save the energy by making sensor node to sleep mode when it is not in use.

$$When\ routing\ queue\ length\ != 0$$
$$node\_ \rightarrow \ energy\_model() \rightarrow \ set\_node\_sleep(0);$$

Then it is essential to process the function *sleep_duty_processing*(). The loop inside this function performs in order to identify the sleeping node based on the data interval between last data duration and current time.

The header selection and dynamic sleep part of the Energy Balancing Model enhances the lifetime of the network. But, it is essential to further extend it to maximum i.e. till the physical life of the nework rather than the battery life. Hence, the Power Supply Model will always work in co-ordination with the Energy Balancing Model, as shown in Figure 1, so that the network always outperform and its coverage and connectivity don't get disturbed with decreasing battery level of the wireless sensor nodes.

6. RESULTS AND DISCUSSIONS

In wireless sensor networks, each and every sensor node is equipped with the limited energy battery and at some point of time or stage, the lifetime of the sensor network are expected to last their energy. At that stage, coverage and connectivity of the sensor node will start to get affected due to the energy lost. The stage where sensor node lost its energy level is called as the minimum threshold energy level. Then it needs to get charged to 100% explicitly.So, it is essential to compare energy uplifting method with generic technique in which sensor nodes last their energy at some point of time.

The model has been simulated with NS2 considering the following parameters:

Figure 5, below shows the performance evaluation of JEM in terms of energy parameter. In this figure, an outcome has been taken in respect to the average energy consumption of the nodes in a cluster with a

Table 1

Parameters	*Values*
Total Nodes	100
Deployment Area	500 × 500 m2
Simulation Time	100
Initial Energy	100 Joules
Receive Power	10 nJ/bit
Transmission Power	10 nj/bit
Program Flash Memory	128K bytes
Current Drawn During Transmission Mode	17.4 mA
Current Drawn During Receive Mode	19.7 mA
Current Drawn During Sleep mode	1 μA
rs	3 m
ru	12 m
K	m = 0.5

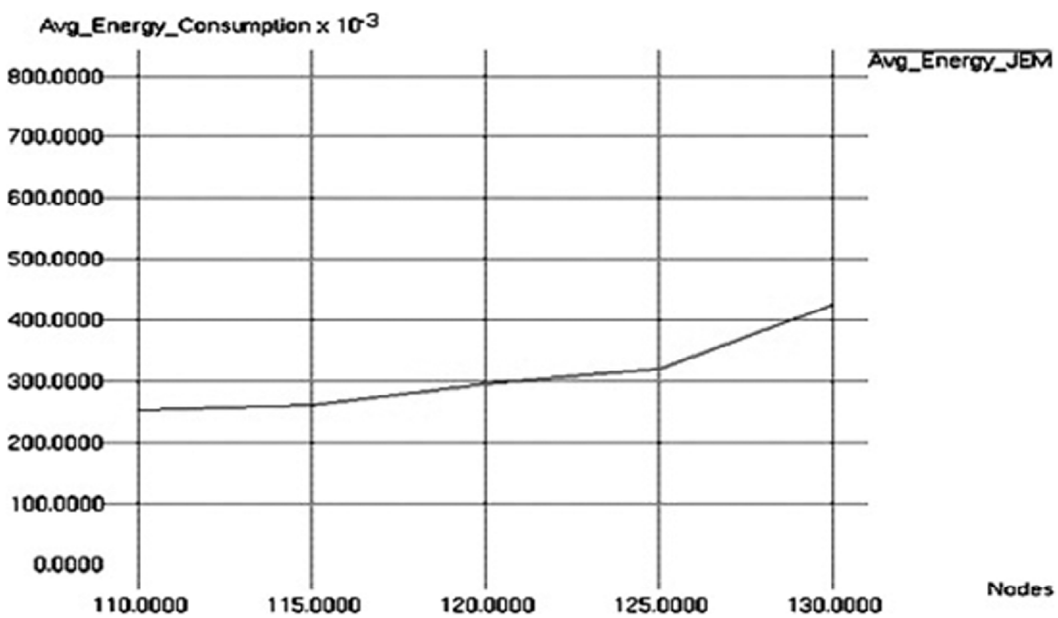

Figure 5: Nodes versus Average Energy Consumption

uniform span of time without any change in cluster head. Initially the nodes in this model were considered to be completely charged and the energy consumption of the cluster observed rise with the increase in the number of nodes.

Also, Figure 6 shows the performance evaluation of JEM in terms of control overhead instead of energy parameter. The figure shows the behavior of control overhead with respect to the number of nodes in JEM. Control overhead is referred to as the number of control packets sent to the number of data packets received. A few common control messages include request to send (RTS), clear to send (CTS) and acknowledgement of packet reception (ACK). JEMobserves the effect on this ratio with respect to the increase in number of nodes in the deployment area.

Figure 7 shows the comparative analysis. This figure focuses on the routing parameter affected by the shifts in network topology during EBM.

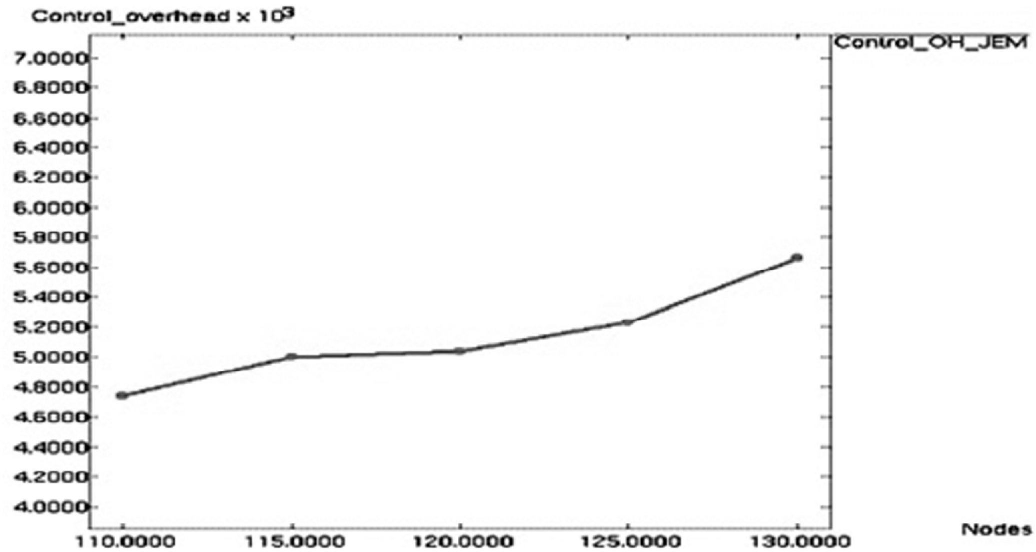

Figure 6: Nodes versus Control Overhead

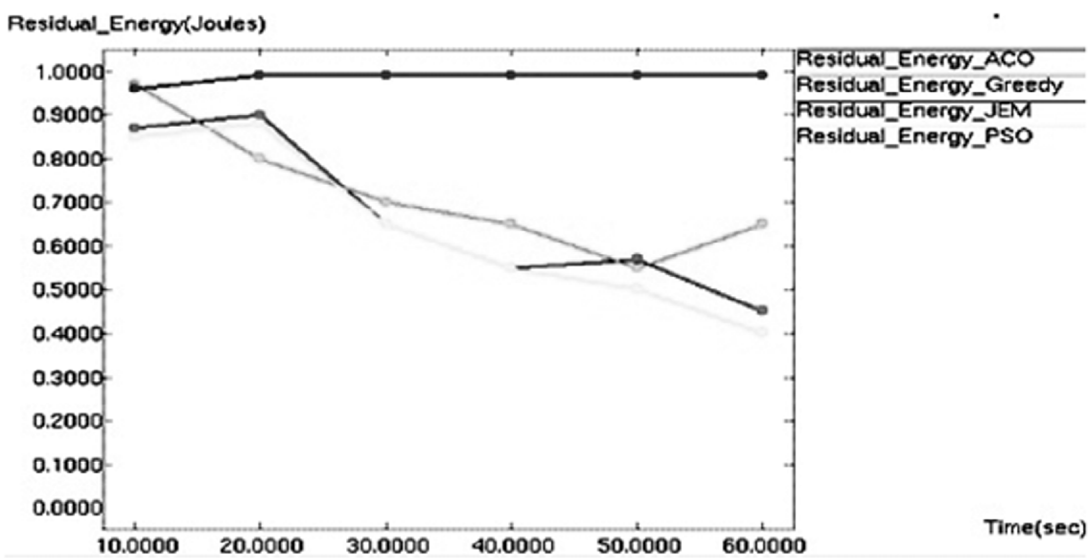

Figure 7: Residual Energy Versus Time

Judicious energy management has been applied to address various critical issues of wireless sensor networks like localization, clustering and data aggregation.In comparison to generic algorithms; ant colony optimization [21], greedy algorithm [22] and particle swarm optimization [20] which are considered best of our knowledge to solve the MWSP problems, judicious energy management outperform in network performances due to the involvement of PSM and EBM.The simulation analysis of judicious energy model, ant colony optimization [21], greedy algorithm [22] and particle swarm optimization [20]is taken under the same experimental settings. The average residual energy is considered as important criteria to evaluate the performance of JEM over the others. In the simulation, the primary focus was on the performance of lifetime of the network. In this course the results were obtained after certain time slots; at the beginning of every time slot a set of sensor nodes is selected with minimum aggregated weight from the set of nodes that are not in sleep mode. With the course of simulation, as the sensor node started consuming energy, the weight associated with it also increases.

7. CONCLUSION AND FUTURE WORK

Focusing on the critical issue of coverage and connectivity among the nodes may be harmed during the increased lifetime of the network in which the network nodes lost their efficiency caliber due to low energy levels in future time of the network. Energy models so far developed focused on the criteria to use less energy for enhancement of network lifetime but no one among all guarantees the working of network till infinite period of time. Though an effort by [11] was an initiative to overcome this drawback but the use of harmful power beams restricts the use in hostile environment as it may be harmful for living beings. Judicious Energy Management (JEM) is trying to overcome the drawbacks of all the previous models so far which contributed in maintaining the energy level as well as those used the power beams. In JEM, two sub models: PSM and EBM works in co-ordination with each other. The former is used to provide passive energy to the network besides the solar energy without affecting the health of any human intervening within the network while the later provides the energy efficiency so that the PSM don't get over burdened in its job all the time.JEM can be considered as an ideal model for future implementations. As the energy model which it commits may provide a new research horizon in other aspects of the wireless sensor networks technology because the future models can be developed independent of the energy efficiency factor and the coverage and connectivity performance can be delivered at constant rate throughout the lifetime of the network.

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