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Techniques to Enhance Lifetime of Wireless Sensor Networks: A Survey

By Jyoti Saraswat, Neha Rathi & Partha Pratim Bhattacharya

Mody Institute of Technology & Science (Deemed University), Lakshmangarh, Dist. Sikar, Rajasthan, India

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TECHNIQUES TO ENHANCE LIFETIME OF WIRELESS SENSOR NETWORKS A SURVEY

Strictly as per the compliance and regulations of:

Techniques to Enhance Lifetime of Wireless Sensor Networks: A Survey

Jyoti Saraswat [α], Neha Rathi [σ] & Partha Pratim Bhattacharya [ρ]

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Keywords : Wireless sensor network, energy efficient routing, asleep protocol, photovoltaic cell, battery lifetime modeling.

I. Introduction

Wireless sensor network (WSN) consists of a large amount of small battery powered devices which perform tasks like processing, radio transmission-reception, sensing and actuating. Wireless sensor network devices have limited energy to complete large tasks. Energy consumption still remains the limitation of this field.

Wireless sensor network comprise of thousands of motes which are used to exchange information with the user either directly or through the external base-station (BS). Each of these sensor nodes sense data from environment surrounding the sensors and send it to the outside world through the external base station. A base station is a mobile node or may be a fixed node which has a capability of connecting the sensor network to an existing communications infrastructure or to the internet [1].

An ordinary node performs two major tasks. Firstly, it senses physical phenomenon and performs some computation and forwards it to other nodes, if necessary. Secondly, it also acts as relay point for other sensor nodes to route the data [2]. Sensor nodes have many applications such as target field imaging, intrusion detection, weather monitoring, security and tactical surveillance, distributed computing, detecting ambient conditions (e.g. temperature, movement, sound, light) or the presence of certain objects, inventory control, and disaster management. Placement of the sensor nodes in these applications is random in nature or these can be placed manually. For example, in a disaster management application, a large number of sensors can be dropped from a helicopter. These sensors nodes can assist rescue operations by locating survivors, identifying risky areas, and making the rescue team more aware of the overall situation in the disaster area.

The structural view of sensor network is shown in figure 1. Sensing unit, processing unit, transmission unit, and power unit are the four major constituent of sensor nodes assigned with dissimilar jobs. Sensing unit is used to trace the physical environment and tells the CPU to compute and store the data it sensed. Transmission unit is tasked to receive the information from CPU and transmit it to the outside world. Power unit regulate battery power to sensor node.

There are different ways to achieve better lifetime which include energy efficient routing, battery characteristics etc. Routing in wireless sensor networks is very challenging due to several characteristics that distinguish these networks from other wireless networks like mobile, ad hoc networks or cellular networks. These include dense deployment of sensor nodes, significant data redundancy, limited bandwidth and limited transmission power, etc. In section 2, the energy efficient routing techniques are discussed which helps in raising the energy efficiency of the node. In section 3, different characteristics of the batteries are discussed which helps in enhancing the battery backup. The battery discharge characteristics, which are used to increase the lifetime of the battery is discussed in section 4.

Author α σ ρ : Department of Electronics and Communication Engineering, Faculty of Engineering and Technology, Mody Institute of Technology & Science (Deemed University), Lakshmangarh, Dist. Sikar, Rajasthan, Pin – 332311, India.
E-mail α : jyotisaraswat.mit@gmail.com
E-mail σ : neharathi17@gmail.com
E-mail ρ : hereispartha@gmail.com

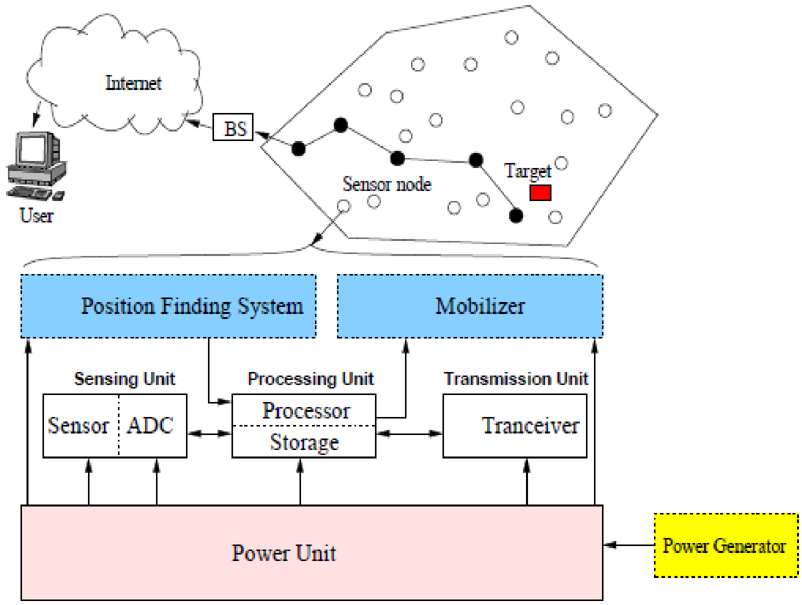

Figure 1 : Structural view of sensor network

II. Energy Efficient Routing

The sensor nodes are constrained to limited resources itself, so the main target is how to design an effective and energy awareness protocol in order to enhance the networks lifetime for specific application environment.

Routing protocols are classified into three categories: Flat-based routing (Flooding), Hierarchical-based routing (Clustering) and Location-based routing (Geographic), depending on the network structure in WSNs.

a) Flat Based Routing

In flat-based routing, all nodes are typically equal and act the same functionality. It is not possible to assign global identifiers to each node in wireless sensor networks because of dense deployment and dynamic environment of sensor nodes.

In data-centric routing [3], sinks send queries to certain regions and waits for data from sensors located in the selected regions. To facilitate data-centric characteristics of sensor queries, an attribute-based naming scheme is used to specify the properties of data.

i. *Flooding and Gossiping*

Flooding and gossiping [4] are the most traditional network routing. In flooding mechanism, each sensor receives a data packet and then broadcast it to all neighboring nodes. When the packet arrives at the destination or the maximum number of hops is reached, the broadcasting process is stopped. Although flooding is very easy, it has several drawbacks like implosion, overlap and resource blindness problem.

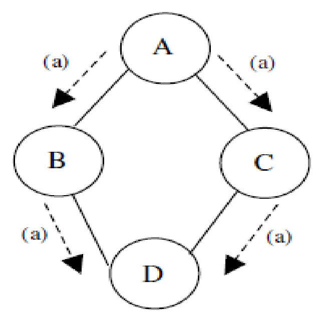

Figure 2 : The implosion problem

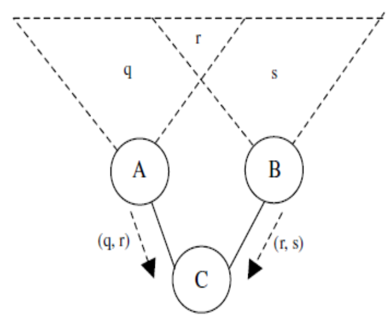

Figure 3 : The overlap problem

Implosion is caused by duplicate message sent to same node as shown in figure 2. 'A' starts by flooding its data to all its neighbors. Two copies of data eventually end at node 'D' due to this system wastes energy and bandwidth.

Overlap occurs when two nodes sensing the same region send similar packets to the same neighbor and resource blindness by consuming large amount of energy without consideration for the energy constraints. Overloading problem shown in figure 3.

Gossiping avoids the problem of implosion by sending information to a random neighbor instead of classical broadcasting mechanism sending packets to all neighbors.

ii. *SPIN*

Joanna Kulik *et al.* in [4] proposed a family of adaptive protocol, called SPIN (Sensor Protocol for Information via Negotiation) that efficiently disseminates information among sensors in an energy-constrained wireless sensor network and overcome the problem of implosion and overlap caused in classic flooding. Nodes running a SPIN communication protocol name their data using high-level data descriptors, called metadata. SPIN nodes negotiate with each other before transmitting data. Negotiation helps to ensure that the transmission of redundant data throughout the network is eliminated and only useful information will be transferred.

The disadvantage of SPIN [5] protocol is that it is not sure whether the data will certainly reach the target or not and it is also not good for high-density distribution of nodes. Other drawback is that if the nodes that are interested in the data are far away from the source node and the nodes between source and destination are not interested in that data, such data will not be delivered to the destination at all. Therefore, SPIN is not a good choice for applications.

iii. *Directed Diffusion*

A popular data aggregation paradigm for wireless sensor networks called directed diffusion is proposed by Ramesh Govindan *et al.*[6]. Directed diffusion is data-centric and all nodes in a directed diffusion-based network are application-aware. This enables diffusion to achieve energy savings by selecting empirically good paths and by caching and processing data in-network (*e.g.,* data aggregation).

SPIN protocol allow sensors to advertise the availability of data and the nodes which are interested, query that data but in Directed Diffusion the sink queries the sensor nodes if a specific data is available by flooding some tasks.

The main advantages of directed diffusion are:

1) Since it is data centric, all communication is neighbor-to-neighbor with no need for a node addressing mechanism. Each node can do aggregation and caching, in addition to sensing. Caching is a big advantage in terms of energy efficiency and delay.
2) Direct Diffusion is highly energy efficient since it is on demand and there is no need for maintaining global network topology.

Directed Diffusion is not a good choice for the application such as environmental monitoring because it require continuous data delivery to the sink will not work efficiently with a query-driven on demand data model.

iv. *Energy-Aware Routing*

Energy aware routing protocol is efficient method to minimize the energy cost for communication and can increase the network lifetime. Unlike directed diffusion, data transmission is done through several optimum paths at higher rates instead of transmitting through one optimal path. The transmission path selection is done by choosing a probability value of each path. The probability value balanced the initial network load and enhanced the network lifetime.

The disadvantage is that energy-aware routing needs to exchange local information between neighbor nodes and all nodes have a unified address, which enlarges the price of building routing paths.

v. *Fermat Point Based Energy Efficient Geocast Routing Protocol*

Geocast routing protocol is used to deliver packets to a group of nodes that are within a specified geographical area, i.e., the geocast region. Fermat point based protocols are adapted for reducing the energy consumption of a WASN by reducing the total transmission distance in a multi hop-multi sink scenario. Congested environment around a WASN expand the chance of multipath propagation and it in turn acquaint multipath fading. In [7], the effects of both of these factors are considered on the performance of I-Min routing protocol designed for WASNs. Both these parameters are considered to find out the degree of variation on the performance of a protocol that doesn't consider either of these two parameters. Here, the geocast routing protocol under consideration is the I-MIN protocol. I-MIN has been discussed in [7].

I-MIN is the energy efficient scheme as it increases the probability that a node with higher residual energy is selected even if its distance from destination is somewhat more as compared to that for another node with a lesser value for residual energy.

After modifying the radio model of with considerations for changed propagation environmental effects and multipath fading, the consumption of energy in a geocast routing protocol will vary considerably [7]. Higher the number of geocast regions, larger is the total distance that a data packet has to travel and thereby greater is the effect of propagation environment combined with the effect of multipath fading on the performance of an energy aware algorithm.

vi. *Gradient-Based Routing*

The algorithm makes an improvement on Directed Diffusion, in order to get the total minimum hop numbers other than the total shortest time. In the traditional gradient minimum hop count algorithm, hop count is the only metric, which measures the quality of route. Li Xia *et al.* [8] proposed a new gradient routing protocol which not only consider the hop count but also use the remaining energy of each node while relaying data from source node to the sink. This scheme is helpful in handling the frequently change of the topology of the network due to node failure.

b) Hierarchical-Based Routing (Clustering)

Hierarchical routing is a guarantee approach for point-to- point routing with very small routing state [9]. It is well known technique with special advantage of scalability and efficient communication. Nodes play different roles in the network. Hierarchical routing maintains the energy consumption of sensor nodes and performs data aggregation which helps in decreasing the number of transmitted messages to base station. The whole wireless sensor network is divided into a number of clusters in term with the specific rules. Some hierarchical protocols are discussed here.

i. *LEACH*

LEACH [10] stand for Low-Energy Adaptive Clustering Hierarchy and was one of the first hierarchical protocols. When the node in the network fails or its battery stop working then LEACH protocol is used in the network. Leach is self-organizing, adaptive clustering protocol in which sensor nodes will organize themselves into local clusters and cluster members elect cluster head (CH) to avoid excessive energy consumption and incorporate data aggregation which reduces the amount of messages sent to the base station, to increase the life time of the network. Therefore this algorithm has an effect upon energy saving.

Two-Level Hierarchy LEACH (TL-LEACH) is a modified form of the LEACH algorithm which consists of two levels of cluster heads (primary and secondary) instead of a single one. The advantage of two-level structure of TL-LEACH is that it reduces the amount of nodes that transmit information to the base station, effectively reducing the total energy usage.

ii. *PEGASIS and Hierarchical-PEGASIS*

PEGASIS (Power-Efficient Gathering in Sensor Information Systems) is optimal chain-based protocol that is an improvement over LEACH. Instead of forming multiple clusters, PEAGSIS construct a node chain when nodes are placed randomly in a play field then each node communicates only with a close neighbor, take turns and transmit data to the base station, thus reducing the amount of energy spent per round [11]. The chain construction is performed in a greedy way. Figure 4 shows node 0 connected node 3, node 3 connecting to node 1, and node 1 connecting to node 2. When a node fails, the chain is reconstructed in the same manner by avoiding the dead node. For gathering data in each round, each node receives data from one neighbor, aggregates with its data, and transmits it to the other neighbor in the chain.

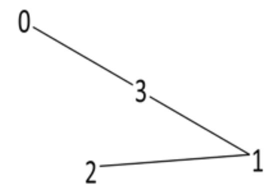

Figure 4 : Chain construction using the greedy algorithm

Although PEGASIS performs better than LEACH by eliminating the overhead of dynamic cluster formation, because transmission is asynchronous, the time of transmission will be prolonged too much. Hierarchical-PEGASIS makes a further improvement; it allows concurrent transmission when the nodes are not adjacent.

Compared with LEACH, the two algorithms eliminate the overhead of forming cluster, but both of them do not take the energy condition of next hop into consideration when choosing a routing path, so they are not suitable for heavy-loaded network. When the amount of nodes is very large in WSNs, the delay of data transmission is very obvious, so they do not scale well and also are not suitable for sensor networks where such global knowledge is not easy to obtain.

iii. *TEEN and APTEEN*

TEEN stands for Threshold sensitive Energy Efficient sensor Network protocol and it is the first protocol developed for reactive networks [12]. It is used in temperature sensing application. Based on LEACH, TEEN is based on hierarchical grouping which divide the sensor nodes twice for grouping cluster in order to detect the scene of sudden changes in the sensed attributes such as temperature. After the clusters are formed, TEEN separates the Cluster Head into the second-level Cluster Head and uses Hard-threshold and Soft-threshold to detect the sudden changes. The model is depicted in Figure 5.

Thus, the hard threshold tries to reduce the number of transmissions by allowing the nodes to transmit only when the sensed attribute is in the range of interest. The soft threshold further reduces the number of transmissions by eliminating all the transmissions which might have otherwise occurred when there is little or no change in the sensed attribute once the hard threshold.

The main drawback of this scheme is that it is not well suited for applications where the user needs to get data on a regular basis. Another possible problem with this scheme is that a practical implementation would have to ensure that there are no collisions in the cluster. TDMA scheduling of the nodes can be used to avoid this problem but this causes a delay in the reporting of the time-critical data. CDMA is another possible solution to this problem. This protocol is best suited for time critical applications such as intrusion detection, explosion detection etc.

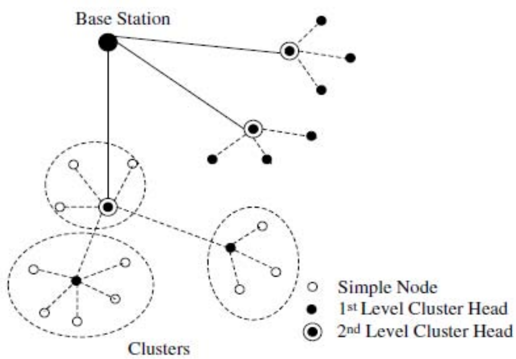

Figure 5 : Hierarchical clustering in TEEN and APTEEN

The Adaptive Threshold sensitive Energy Efficient sensor Network protocol (APTEEN) is an extension to TEEN and aims at both capturing periodic data collections and reacting to time critical events. The architecture is same as in TEEN. In APTEEN once the CHs are decided, in each cluster period, the cluster head broadcasts the parameter such as attributes, threshold and count time to all nodes [13].

The performance of APTEEN lies between TEEN and LEACH in terms of energy consumption and longevity of the network. While sensing the environment, TEEN only transmits time critical data. APTEEN makes an improvement over TEEN by supporting periodic report for time-critical events. The main disadvantages of the two algorithms are the overhead and complexity of forming clusters.

c) *Location-Based Routing*

Most of the routing protocols require location information for sensor nodes in wireless sensor networks. Location information is required to calculate the distance between two particular nodes on the basis of signal strength so that energy consumption can be estimated. It is also utilized in routing data in energy efficient way when addressing scheme for sensor network is not known. It is worth noting that there have been many location-based protocols in Ad Hoc networks and it makes great effects when we transplant those research achievements for wireless sensor networks in some ways.

i. *MECN and SMECN*

Minimum energy communication network (MECN) [14] sets up and maintains a minimum energy network for wireless networks by utilizing low power GPS. Although, the protocol assumes a mobile network, it is best applicable to sensor networks, which are not mobile. MECN assumes a master site as the information sink, which is always the case for sensor networks.

MECN identifies a relay region for every node. The relay region consists of nodes in a surrounding area where transmitting through those nodes is more energy efficient than direct transmission. The relay region for node pair (*i, r*) is depicted in Figure 6.

The enclosure of a node *i* is then created by taking the union of all relay regions that node *i* can reach. The main idea of MECN is to find a sub-network, which will have less number of nodes and require less power for transmission between any two particular nodes. In this way, global minimum power paths are found without considering all the nodes in the network. This is performed using a localized search for each node considering its relay region.

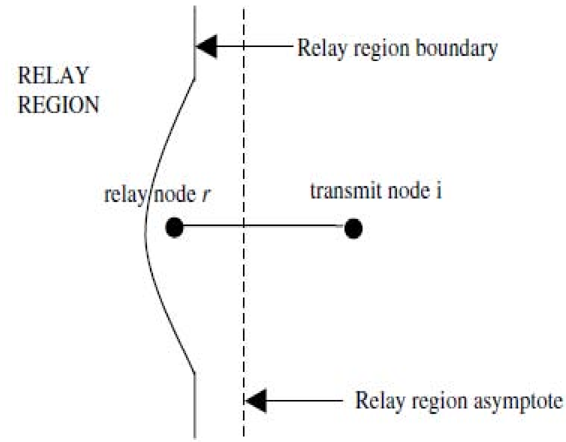

Figure 6 : Relay Region of transmit relay node pair (*i, r*) in MECN

MECN is self-reconfiguring and thus can dynamically adapt to nodes failure or the deployment of new sensors. Between two successive wake-ups of the nodes, each node can execute the first phase of the algorithm and the minimum cost links are updated by considering leaving or newly joining nodes.

The small minimum energy communication network (SMECN) [15] is an extension to MECN. In MECN, it is assumed that every node can transmit data to other nodes, which is not possible every time. In SMECN possible obstacles between any pair of nodes are considered. However, the network is still assumed to be fully connected as in the case of MECN. The sub-network constructed by SMECN for minimum energy relaying is probably smaller (in terms of number of edges) than the one constructed in MECN if broadcasts are able to reach to all nodes in a circular region around the broadcaster. As a result, the number of hops for transmission will decrease. Simulation results show that SMECN uses less energy than MECN and maintenance cost of the links is less. However, finding a sub-network with smaller number of edges introduces more overhead in the algorithm.

ii. *GEAR*

The aim is to reduce the number of Interest in Directed Diffusion and add geographic information into interest packet by only considering a certain region rather than sending Interest to the whole network by

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means of flooding. GEAR uses energy aware and geographically informed neighbor selection heuristics to route a packet towards the target region [16]. Therefore, GEAR helps in balancing energy consumption in this way and increase the network lifetime. When a closer neighbor to the destination exists, GEAR forward the packet to the destination by picking a next-hop among all neighbors that are closer to the destination. When all neighbors are far away, there is a hole then GEAR forward the packet by picking a next-hop node that minimizes some cost value of this neighbor. Recursive Geographic Forwarding algorithm is used to disseminate the packet within the region.

GEAR is compared to a similar non-energy aware routing protocol GPSR, which is one of the earlier works in geographic routing that uses planar graphs to solve the problem of holes. The simulation results show that for uneven traffic distributions, GEAR delivers 70% to 80% more packets than GPSR. For uniform traffic pairs, GEAR delivers 25 - 35% more packets than GPSR.

iii. *GAF and HGAF*

GAF [17] is adaptive fidelity algorithm in which large numbers of sensor nodes are placed in observed area and only few nodes in the observed area are selected to transmit messages, while the other nodes sleep. In this way, GAF reduces the number of nodes needed to form a network and saves node battery.

Hierarchical Geographical Adaptive Fidelity (HGAF) saves much more battery by enlarging the cell of GAF by adding a layered structure for selecting an active node in each cell. GAF saves battery power by enlarging the size of the cell. The connectivity between active nodes in two adjacent cells must be guaranteed because active nodes works as cluster heads to deliver packets between cells. Because of this limitation, GAF needs an active node in every area whose maximum size is $R^2/5$.

HGAF limits the position of active node in a cell and synchronizes the position in each cell among all cells. Through this modification, the connectivity between active nodes in two adjacent cells can be guaranteed for a larger cell than in GAF.

Simulation result shows that HGAF outperforms GAF in terms of survived nodes and the packet delivery ratio when the node density is high. The lifetime of dense and randomly distributed networks with HGAF is about 200% as long as ones with GAF.

III. Efficient Battery Usage for Wireless Sensor Network

Wireless sensor network consist of a large number of small batteries. By nature wireless sensor network devices have limited available energy to perform a wide range of demanding tasks. In order to maximize their operation lifetime, optimal resource management is an important challenge and its success requires methodical modeling of the factors contributing to the overall power consumption. Therefore, it is necessary to study the discharge rate of battery taking into consideration the battery type, capacity, discharge pattern and other physical parameters.

a) *Battery Lifetime Prediction Model*

Fotis Kerasiotis *et al.* [18] mainly focus on the issue of battery lifetime prediction which is addressed for a WSN platform, namely the TelosB .The main advantage of this approach is that it follows a structured methodology for modelling the battery lifetime of TelosB. This is done by decomposing the operation pattern in time periods of discrete elementary power consumption levels.

i. *Battery Energy and Lifetime Modelling*

A battery depletion profiling approach based on discrete basic operation which can be performed by a wireless sensor network (WSN) device. The behavior of battery depends on the corresponding average current drawn, where each HW module [18] is uniformly utilized during the lifetime duration of node in a wireless sensor network. Therefore, the aim is to express the relation of the battery depletion with the imposed load in terms of lifetime and capacity characterizing a common AA alkaline battery.

ii. *Battery Characteristics*

The actual energy and the capacity that the battery can provide depend on the discharge rate. A specific discharge rate defined by the value of current in mA is the nominal capacity given by the constructor.

Here the various loads are considered and converted it into average current drawn. The time interval required for the battery to finally deplete varies inversely proportional to the applied load. Some other parameters that affect battery capacity are temperature, self discharging effect and recovery effect but they are less important factors under common conditions, because of the low currents flow by the low power HW modules of most of the wireless sensor network devices.

iii. *TelosB Platform Radio Supply Schematic*

The experiment consists of CC2420 radio module which is the most consuming component of the TelosB platform which draws current approximately up to 20mA. The accurate and the robust operation are needed from the radio point of view. Figure 7 shows the voltage regulator which provides voltage stability of 1.7 to 1.9 V and is used by the particular radio module. It is translated to highly stable power consumption despite the variation of the voltage as the batteries deplete.

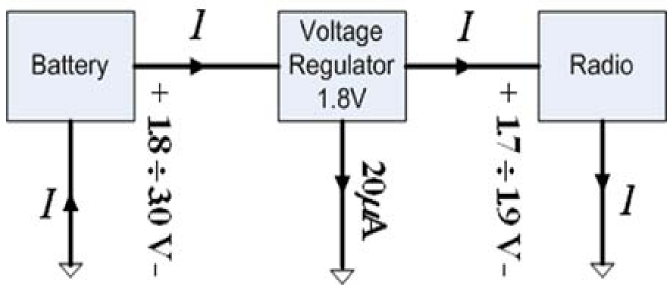

Figure 7 : Current drawn by the radio module and the voltage regulator

The topology used for the experiment consists of two motes, one connected to a PC receiving the available information from the second one, which is configured with the operation examined each time and powered either by a power supply generator or batteries. All the operations include CPU at LPM0 state as well as use of AD converter channel for the battery voltage measurement, which helps to increase the current drawn by almost 2.3 mA at 3V.

The battery lifetime can be estimated by incorporating the coefficient *DCx*, which represents the time proportion, where x current demand, is enabled .The proposed formula is presented in (1), where $E_{offered}$ is the energy capacity offered by the batteries, t_{max} is the battery lifetime, $I_{average}$ is the average current drawn corresponding to the node's lifetime [18]:

$$t_{max} = \frac{E_{offered}}{I_{average}} \quad (1)$$

$$= \frac{E_{offered}}{\sum_{x=1}^{x=number\ of\ different\ current\ demands} DC_x \times I_{x\_average}}$$

Let a node configured with radio on RX operation and assuming that low power operation is enabled, the measurable lifetimes estimated by t_{max} for duty cycles of 80%, 67% and 40%, respectively, are very close to the experimental results shown in figure 8(a), despite the estimated of the battery energy recovery effect. The estimated error for the three respective duty cycle configurations is given in eqn. (2), (3), (4) [18], where I_{ADC} is the current drawn by AD converter, I_{CPU_LPM3} is the current drawn by CPU in LPM3 mode :

$$t_{max\ 80\%\ DC} = \frac{E_{offered}}{DC_{80\%} \times I_{RX\_average} + I_{ADC} + I_{CPU\_LPM\ 3}}$$

$$= \frac{3100\,mAh}{15.36\,mA} = 201.8h \rightarrow \text{error}: 2\% \quad (2)$$

$$t_{max\ 67\%\ DC} = \frac{E_{offered}}{DC_{67\%} \times I_{RX\_average} + I_{ADC} + I_{CPU\_LPM\ 3}}$$

$$= \frac{3100\,mAh}{12.95\,mA} = 239.1h \rightarrow \text{error}: 2.6\% \quad (3)$$

$$t_{max\ 40\%\ DC} = \frac{E_{offered}}{DC_{40\%} \times I_{RX\_average} + I_{ADC} + I_{CPU\_LPM\ 3}}$$

$$= \frac{3100\,mAh}{7.95\,mA} = 390h \rightarrow \text{error}: 3\% \quad (4)$$

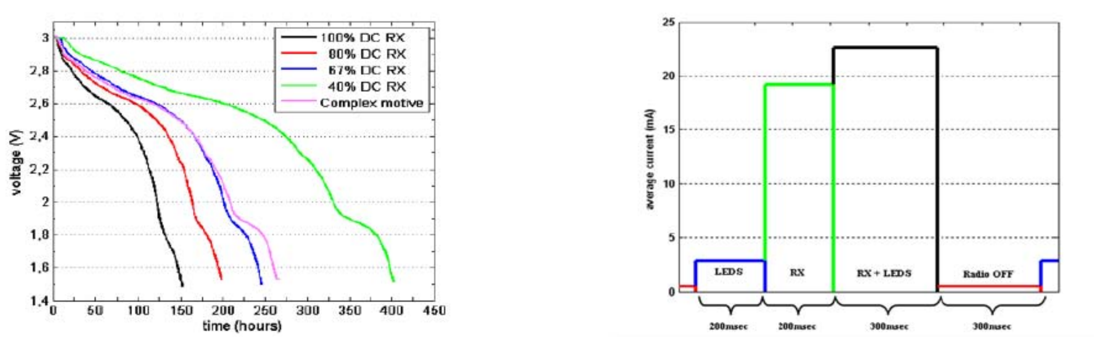

Figure 8 : a) Experimental results of validation experiments b) complex operation motive

At last, the periodic interchange among four different operations corresponding to four different current demands. The pattern recorded is similar as in figure 8(b). In this, equation (5) produced a small estimated error of 2.7% [18], which proves the significant accuracy of the equation (1) used in predicting the battery lifetime.

$$t_{max\ oper} =$$

$$= \frac{E\ offered}{(I_{LEDS\_average} + I_{RX\_average})20\% + (I_{RX+LEDS\_average})30\% + I_{ADC} + I_{CPU\_LPM\ 3}}$$

$$= \frac{3100\,mAh}{11.29\,mA} = 274.5h \rightarrow \text{error}: 2.7\% \quad (5)$$

IV. Battery Discharge Characteristics

In order to maximize the operating life of battery-powered systems such as sensor nodes, it is important to discharge the battery in such a way that maximizes the amount of charge extracted from it. A systematic experiment is conducted to quantify the impact of key wireless sensor network design and environmental parameters on battery performance [19]. Test bed on which this experiment is conducted consists of MICA2DOT nodes, a commercial lithium coin battery, and techniques for measuring battery performance. For many electronics systems, achieved battery life is not only the function of the energy consumed by the system, but also the manner in which the system drains the battery, and battery specific characteristic.

Many techniques have been proposed in recent years for estimating battery lifetime. A variety of strategies is used to exploit battery characteristics for designing more "battery friendly" systems and communication. In addition, most work in this area relies on simulation of generic battery models and does not place emphasis on quantitative results about actual hardware platforms and batteries. Chulsung Park et al. [19] conducted an experiment with a commercial lithium-ion cell in which fixed transmission power levels are assumed and the influence of temperature is not considered. Secondly, they did not calculate the impact of battery characteristics on network-level trade-offs. One of their findings was that the capacity extracted from the battery is significantly degraded by the voltage converter that is typically used to supply power to the sensor node.

a) *Factors Affecting Battery Discharge*

Lithium-ion batteries are considered here because they are commonly used in the scope of portable electronics, including sensor networks. Simplified view of a lithium/thionyl chloride battery is shown in Figure 9. The battery consists of an anode (*Li*), a cathode (carbon), and an electrolyte. During discharge, oxidation at the anode (*Li*) releases electrons, which flow through the load system, and positively charged ions (*Li*+), which migrate through the electrolyte flow towards the cathode by diffusion. At available reaction sites in the cathode, Li^+ ions combine with negatively charged ions (Cl^-) to create an insoluble compound, *LiCl*. Cathode sites where *LiCl* is deposited become inactive, or unavailable for further reaction. As discharge proceeds, more reaction sites become unavailable, eventually leading to a state of complete discharge.

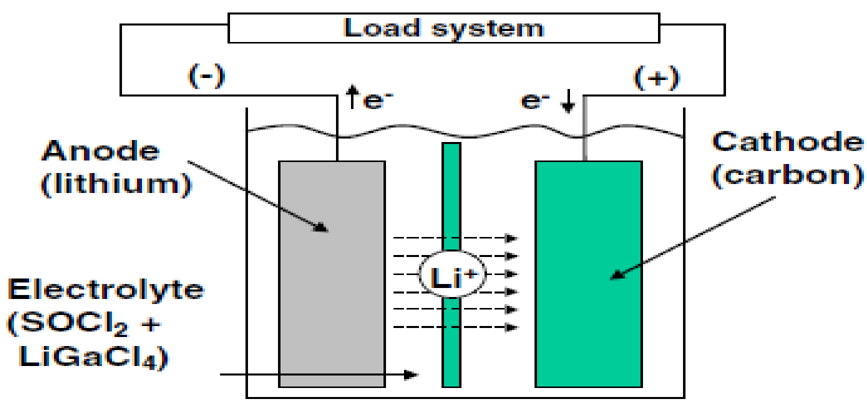

Figure 9 : Simplified view of a lithium/thionyl chloride battery

The standard or rated capacity of a battery (usually expressed in current-time units, e.g. mAh) is a measure of the total charge that can be extracted from a battery when discharged under standard load conditions. Manufacturers may specify a rated current, a constant discharge rate that corresponds to the standard load conditions. For example, a battery may be rated at 500 mAh capacity under a rated current of 100 mA, at 25◦C. The delivered capacity of a battery is the capacity that the battery delivers under a given load and operating environment, and is an indicator (along with battery life) of the efficiency with which the battery is discharged. Capacity (usually expressed in mAh) and energy (expressed in Joules) are used interchangeably. Several electrochemical effects make the delivered capacity sensitive to the characteristics of the discharge profile and the environment. Hence, in practice, the delivered capacity may differ significantly from the rated capacity. Only those characteristics that have been demonstrated to play a significant role in affecting the efficiency of lithium-ion batteries are considered.

i. *Rate Capacity Characteristic*

Battery life depends largely on the availability of active reaction sites throughout the cathode. At low discharge current, throughout the volume of the cathode inactive reaction sites gets uniformly distributed. During interval when the discharge current is large, making many internal active sites unreachable, the outer surface of the cathode gets covered with inactive sites. These rate capacity effects lead to an overall reduction in battery capacity at higher rates of discharge.

ii. *Recovery Effect*

When current started flowing from the battery, the positively charged ions are consumed at the cathode-electrolyte interface, and are replaced by new ions that diffuse through the electrolyte from the anode. When the current drawn is large in amount, the rate of diffusion does not able to keep up with the rate at which ions are consumed at the cathode. As a result, the concentration of ions decreases near the cathode and increases near the anode, it decreases the battery output. If the battery is allowed to keep idle for some period of time, then due to diffusion the concentration gradient decreases, due to which charge recovery is taken place. As a result, the capacity and lifetime of the battery increases [19].

iii. *Thermal Effects*

The effect of ambient temperature on battery efficiency depends strongly on the specific battery chemistry being considered. Most batteries perform well at room temperature. Higher temperature allows for increased mobility of the electrolyte materials, which result in lower internal resistance. This has the effect of increasing the effective capacity of the battery. However, continuous exposure to elevated temperatures have other undesirable effects, such as shortened cycle life (the number of times the battery can be charged/discharged), and an increased rate of self-discharge (the irreversible loss of charge that occurs when no current is drawn from the battery). At lower temperatures, increased internal resistance of the battery leads to reduced capacity.

The disadvantage of lithium-ion batteries is that over time, the capacity of the cells diminished. The increase in internal resistance reduces the cells ability to deliver current. This problem is more pronounced in high-current applications. Due to this disadvantage the battery replacement and maintenance cost increases.

b) *Solar Cell Battery*

The method for achieving extended lifetime for a wireless sensor network is to exploit the possibility of energy harvesting from the environment, where energy harvesting from the sun gives the best performance which is proposed by L. Hanssen and J. Gakkestad [20].

i. *Power Model of a Wireless Sensor Network Node*

The block diagram of typical wireless sensor network node is shown in figure 10 which consists of microcontroller (MCU), a radio, a sensor block and a power module. When powered with a solar cell, a local charge storage or a battery is needed to store surplus energy for periods when sun irradiation is low or absent e.g. during the night, on overcast or rainy days.

The MSP430 MCU and the CC2420 radio from Texas Instruments are used in [20]. The MCU has certain sleep modes, but it is assumed that the real time clock (RTC) must be running in sleep mode in order to make the node wake up itself at given points in time. For such short range radios as the CC2420, the maximum power consumption is in the receive mode. The transmit power is programmable and the power output can be lowered for short ranges. The radio will be in listen or receive mode for network to operate where each node can hear many neighboring nodes. Three states for the node are defined as active, running and sleeping.

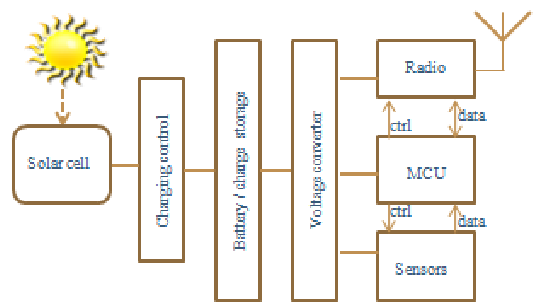

Figure 10 : Block Diagram of Typical WSN node

In active state the node can participate in networking. In sleep mode only the RTC in the MCU is running. Many wireless sensor network implementations are based on IEEE 802.15.4 and ZigBee. Here, super frame structure is used, and all local communication is performed within one frame.

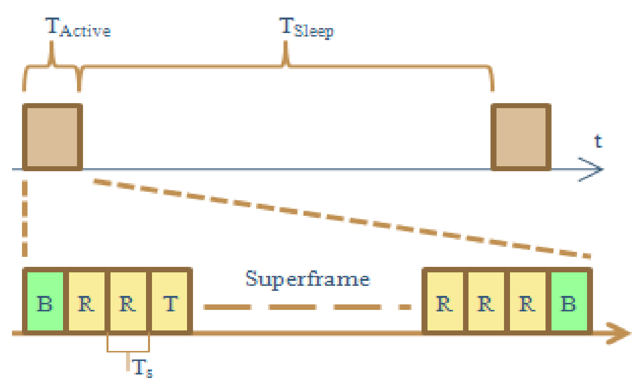

Figure 11 : Active sleep period with a super frame containing beacons (B),receive periods I and one transmit period (T)

One super frame consists of 16 slots (NF), and the length of one slot (TS) is determined by the number of bytes for address and data. This is shown in Figure 11 with one active and one sleep period. The active period consists of a super frame with beacons (B), receive (R) and transmit (T) slots.

ii. *Solar Battery Modeling and Analysis*

Alcaline and Li-Th-Cl are not chargeable, which means that a wireless sensor network equipped with such batteries has a limited lifetime. When the node is powered with a solar cell panel, a chargeable battery or another charge storage element is needed to average the energy received during daytime over the whole 24 hours. The charge storage capacity, i.e. the size of the battery, should be adapted to the 24 hours irradiance if we want to minimize it.

a. *Battery Mechanisms*

Two main mechanisms of batteries are considered, rate capacity effect and recovery effect [21]. These two mechanisms are dependent on the discharge profile of a specific battery. Discharge profile means the amount of time battery voltage fall to a certain threshold voltage, i.e. the amount of time the battery discharged or reaches "empty" state.

The battery is an electrochemical device which allows storage of energy using the battery's chemical characteristics to store the energy. During discharge of the battery, it is attached to some load which provides path to the charge to follow. In rechargeable type of batteries, an externally applied current can be applied to the battery to reverse the chemical process of discharging. The batteries are classified according to their rated capacity which is defined as the amount of charge a battery can store i.e. measured in A-hours (3600 coulombs). This capacity is dependent on the amount of current charge being supplied as well as in the current charge state of the battery. The capacity is not equal to the amount of charge delivered to the load. Self-discharge also occur which decreases the capacity of the battery. Rechargeable batteries exhibit more self-discharge rate than standard batteries (about 2-3% a day). That is why rechargeable batteries are not enough to replace a standard alkaline battery in a network environment. Rate capacity fading is also affect the capacity of the batteries.

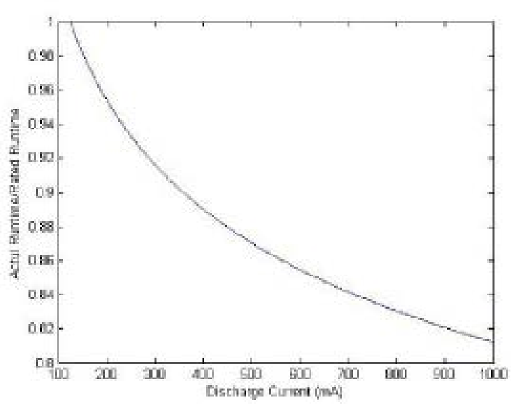

Figure 12 : Rate capacity fading

As the discharge current increases, the difference between the actual runtime and rated runtime also increases as shown in figure 12.

b. *Solar Energy*

The amount of solar energy which is provided by photovoltaic cell is depending on certain factors. Solar energy is a natural resource so it depends on the environmental condition. The dependence of solar energy on the temperature is neglected. The parameter on which John Paul M et al. focused is the relationship between time and the amount of energy provided by the photovoltaic cell. Here equation is considered that describes the flux intensity for photovoltaic cell. The flux intensity is defined as [21]:

$$I\,(z) = I_0\, e^{c\,(\sec z)\,s} \qquad (6)$$

Where

$I\,(z)$ = Flux Intensity in kW/m^2

I_0 = Exo atmospheric solar flux ($1.353\ kW/m^2$)

z = zenith distance

c = 0.357

S = 0.678

Solar flux intensity is a measure of the energy which is absorbed by a photovoltaic cell. S and c are empirical data numerical constants while I_0 is the flux intensity outside the earth's atmosphere. The solar flux intensity data can be used to know that how much energy is provided by the cells. At constant voltage, increasing the amount of solar flux intensity would also increase the amount of current supplied to the load. By knowing this one can determine the amount of current being supplied to charge a rechargeable battery.

The zenith distance is the angular distance from the position of the sun directly above a spectator. This parameter is dependent on day time.

$$\cos z = \sin \alpha . \sin \partial + \cos \alpha . \cos \partial . \cos t \qquad (7)$$

$$t = (360/24)\ T \qquad (8)$$

Z is the zenith distance, α is the latitude of the collector site and ∂ is the solar declination. Solar declination is angle between the earth-sun line and the equatorial plane. Due to a $23.45\ ^0$ tilt of the earth's equatorial line with earth's orbit, there would be variation of the solar declination throughout the year which causes seasons. The value of the declination angle can be at about approximate 25.50 during summer and -23.50 during winter.

V. Conclusion

In this paper, theoretical analysis of different ways by which we can improve the energy efficiency of the wireless sensor networks is presented. Routing is one of the most important ways that gives energy efficiency, and increases the network life. Routing protocols are based on three categories: Flat based routing, Hierarchical-based routing and Location-based routing on the basis of network structure. Many issues and challenges like effectiveness, scalability, adaptability etc. still exist that need to be solved in the sensor networks. Battery characteristics such as recovery effects, thermal effects, discharge characteristics etc. are the most important aspects for increasing the lifetime of the battery.

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