Energy Efficient Communication Protocol for a Mobile Wireless Sensor Network System

Hiren Kumar Deva Sarma[1] Avijit Kar[2] Rajib Mall[3]

1. Department of IT, Sikkim Manipal Institute of Technology, Sikkim, INDIA
2. Department of CSE, Jadavpur University, Jadavpur, Kolkata, INDIA
3. Department of CSE, IIT Kharagpur, Kharagpur, INDIA

Abstract
Wireless Sensor Network Systems can be applied to monitor different environments ranging from military to civil applications. It has been observed that different protocols required for smooth functioning of the network system are highly application specific. Another important fact is that the communication protocols have significant role in achieving right performance of the network system. In this paper we consider a highly dynamic wireless sensor network system in which the sensor nodes are mobile as well as the base station is also mobile. We propose a hierarchical energy efficient communication protocol for such type of a wireless sensor network namely wireless **S**ensor system for **H**ierarchical **I**nformation gathering through **V**irtual triangular **A**reas (**SHIVA**). Our approach considers a cluster head set in place of a single cluster head for a cluster. We also follow a novel approach for clustering process. Simulation results show the energy analysis in the system.

***Key Words*:**
Energy Efficient Routing, Wireless Sensor Networks, Base Station Mobility, Sensor Node Mobility

1. Introduction

Wireless Sensor Network (WSN) is becoming very popular area for research & development and has been a hot stuff for researchers and engineers in the current time. The wide varieties of the possible applications of wireless sensor networks have made researchers and engineers attracted towards it. Internetworking of unattended sensors wirelessly and making it possible to process the data sensed by the sensors in the sensor network system and finally communicating the data sensed by individual sensors in their locality to a powerful computer which is located far away from the sensor field make it possible to monitor events in an area of interest from a remote place.

The sensors are equipped with sensing, data processing and communication capabilities. Also these sensors are powered by battery. The sensing circuitry in the sensor node makes measurements of different parameters from the surrounding environment and transforms these into an electric signal. By processing of such a signal, some properties of the source objects located in the environment or some information about different events happening in the environment may be revealed.

Sensors can process the sensed data locally though each sensor is equipped with limited processing capability. And this local processing is important as this process may reduce the volume of data to be sent or communicated to the Base Station. The data sensed by the sensors are sent to the command center popularly known as Base Station / Sink usually via a radio transmitter. This communication may be direct i.e. directly from the sensor to the base station or indirect i.e. through some intermediate sensor nodes. This absolutely depends on the logical organization of the wireless sensor network (e.g. whether hierarchical or flat).

Since these types of network are battery driven, the sensors are always energy constrained. Also these systems are typically disposable and expected to last as long as they have energy or battery power. Therefore, wise management of energy is extremely important in such systems in order to get an extended life of the network for the duration of a particular mission.

Scalability is another important issue in the design of such networks. Any protocol designed for such networks should be scalable so that it can handle a larger network of thousand of thousands sensor nodes.

Most importantly any protocol designed for WSN is application specific. Different types of applications demand either the modification of the existing protocol or an entirely new protocol.

It has already been accepted that WSN may be deployed for military and civil applications e.g. combat field surveillance, security, environment monitoring, traffic monitoring on highways/roads, disaster management etc. Every application demands a particular model regarding

Manuscript received February 5, 2009
Manuscript revised February 20, 2009

the mobility nature of the sensors and also that of the base station.

Most of the cases regarding the applications of WSN considered so far by the researchers and engineers are basically of static nature in the sense that the sensors distributed in the field are static and also the base station is static. But the overall topology of the network is dynamic due to the sudden death as well as availability of the sensor nodes.

Therefore four possible models of Wireless Sensor Networks are as follows:

Model 1: Both the Sensor Nodes as well as the Base Station are static
Model 2: The Sensor Nodes are mobile but the Base station is static.
Model 3: The Sensor Nodes are static but the Base Station is mobile.
Model 4: Both the Sensor Nodes as well as Base Station are mobile.

It is unimportant to mention that all these models have applications in practical day to day life.

It is worthy to mention that as we move from one model to the other, the existing protocols require lot of modifications or entirely new protocols are in demand.
In this paper, we consider *Model 4* in which the sensor nodes have mobility as well as the base station is mobile.

A very simple example of this model may be - the base station is a high end laptop computer carried by a person in travel. Though the person is in travel basically he moves within a region with certain velocity. On the other hand, sensor nodes are also tied with some mobile objects may be some animals or birds moving within a certain geographic area. And the intention behind the application may be monitoring of these different mobile objects by a person who is also mobile. It is worthy to mention that at certain point in time some of the mobile sensor nodes may become static as well as the base station may be static. But most of the time the nodes as well as the base station will be in movement. So there is a probability that at some point in time the model may get reduced to any one of the other three models. This kind of model may be useful for wildlife protection in national parks or sanctuaries.

We consider the network layer issue called routing specifically in this work. We propose a framework for the routing problem in such type of a WSN model, namely wireless ***S****ensor system for* ***H****ierarchical* ***I****nformation gathering through* ***V****irtual triangular* ***A****reas* (**SHIVA**). We observe that the solution is energy efficient as well as scalable in nature. We focus on the routing issues only and we consider a hierarchical organization of the network. Our algorithm dynamically adapts to the topology changes as the topology change is very frequent under such type of circumstances. Our approach extends the life of the network without compromising with the performance of data transmission.

There are very limited literatures available which considers this model of WSN that we have considered here in this paper. Most of available work considers only the model in which both sensors and base station are static [2] [13] [15] [16] [17].

Rest of the paper has been organized as follows- Section 2 provides background. In Section 3, we describe the system model. We propose a routing protocol for WSN in Section 4 followed by Section 5 in which we report the Simulation Results. Finally in the Section 6 we conclude this work and mention about the future scopes of this work.

2. Related Works

In the case of wired networks more attention is towards maximizing end-to-end throughput and minimizing delay. In the area of routing in wired networks when routes are computed, main stress is on minimizing hop count or delay. In the area of wireless communication, signal interference and energy constraints become important apart from the above mentioned issues of wired networks [4][5][6][7][10]. Researchers are already focused into the signal interference issue may be due to the popularity of wireless consumer devices. Recent research focus is on energy efficiency in the wireless applications [1]. For application of wireless communication systems like unattended wireless sensor networks, energy efficiency issue has become a prime interest for the researchers [2].

Energy efficiency can be improved at various layers of the communication protocol stack. Most of the published works focus on lower layers of the communication protocol stack that is hardware related energy efficiency aspects of wireless communication [11]. Low power electronics, power-down modes and energy efficient modulation are few representative works in this category [12]. However energy efficiency issue can be also tackled in the higher layers of the protocol stack. Therefore energy efficiency also becomes a software level issue. In this work we focus on providing solutions at the network layer of the protocol stack.

Energy efficient routing in WSN has received significant attention in recent time. In the case of mobile networks, the overhead of maintaining a routing table is very high

(*the stability of a router becomes major concern*). Stable routers are supposed to be reliable and long living [8]. But the routing approach in WSN is different from the classical TCP/IP based networks, including mobile networks [3]. Therefore our protocol is different from stability based routing as stability based routing gives more emphasis on the routes (*that is why it is route centric*) but does not consider network-wide metrics. In the case of WSN, it is necessary to consider some network-wide metrics also.
There are different routing protocols already reported for WSN applications but mostly they are for static networks (*Model 1*). All major protocols may be categorized into following four categories:

Data Centric Protocols, Hierarchical Protocols, Location Based Protocols and Network Flow and QoS Aware Protocols [9].

Few representative works of these categories are given below-

Category	***Representative Protocols***
Data Centric Protocols	Flooding and Gossiping, SPIN, Directed Diffusion, Rumor Routing, Gradient Based Routing, Energy-aware Routing, CADR, COUGAR & ACQUIRE.
Hierarchical Protocols	LEACH, PEGASIS, H-PEGASIS, TEEN & APTEEN
Location Based Protocols	MECN & SMECN, GAF & GEAR
Network Flow & QoS Aware Protocol	Maximum Lifetime Energy Routing, Maximum Lifetime Data Gathering, Minimum Cost Forwarding, SAR & SPEED

In Network Flow Protocol route setup is modeled and solved as a network flow problem and QoS Aware Protocols consider end-to-end delay requirements during the setting up of the routes.

On observing the reported results we get a clear indication that traffic should be routed such a way that the energy consumption remain balanced among the nodes in proportion to their available energy.

Due to the even moderate mobility of the Sensor Nodes as well as the Base Station the topology change in the network becomes very frequent and this contributes towards a highly dynamic wireless sensor network. And this factor gives rise to the requirements of suitable routing protocols for such a highly dynamic network system which shall be able to handle such frequent topology changes.

3. System Model

The model of Wireless Sensor Network we have considered here is as follows:

The network may be composed of hundreds of sensor nodes. Sensor nodes are relatively inexpensive and are connected to many others wirelessly. Sensor nodes are also resource constrained as those are equipped with limited memory, limited processing capability as well as limited battery power. Radio is the medium of communication for the sensor nodes.

One powerful computer (may be a high end Laptop Computer) acts as the Base Station. The Base Station is considered to be resourceful and reliable. Even it is possible to recharge the battery of the Base Station if it becomes necessary.

There is no preexisting infrastructure in the system model. Sensors are deployed and then they form a network including the base station in a self organized manner. It has been assumed that it is possible to know the geographic location of each sensor by itself through a GPS free solution [14].

3.1 Mobility Model

The base station is mobile having moderate mobility. We consider that the zone in which the base station moves is known aprior. Also the location of the base station at a certain point in time is predictable with a certain value of probability. Therefore we may assume that the locus of the base station over a span of time is predictable which can be basically a good estimation of the actual.

Similarly the sensor nodes are also having moderate mobility. The sensor nodes can move in any arbitrary direction. But we assume that at a certain point in time the location of a particular sensor node is predictable with a certain value of probability. Therefore it is possible to know the locus of a sensor node over a span of time and this is again an estimation of the actual movement of the sensors.

Though these assumptions do not represent the actual picture of the practical field, this is basically to simplify the problem. Once we have solution to a simplified model, we may start removing the assumptions and enhance the original solution.

3.2 Topology Model

We consider a hierarchical logical topology. Sensors form clusters in association with the base station. Each cluster is controlled by a set of command nodes, which we may say as cluster head set. Ordinary sensor nodes are only capable of radio-based short-haul communication. They are responsible for probing the environment. The cluster heads are responsible for long-range communication as well as data fusion. The fused data is sent to the base station by the cluster heads sometimes directly and sometimes via some other cluster heads in multi-hop fashion. This decision is made dynamically based on the current status and configuration of the network.

Since all the nodes are dynamic, the topology of the network changes at a fast rate. But logical topology i.e. *clusters* are expected to be same for one session at least.

Such dynamics of the network system may cause even frequent network partition and also network join and the routing protocol has to take care of such events.

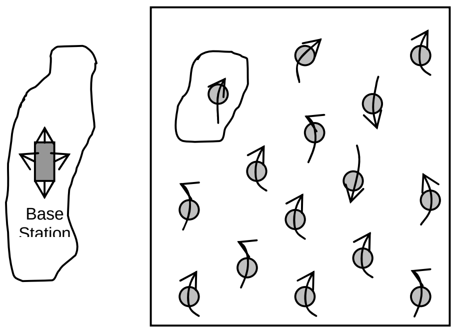
4. Proposed Protocol for Routing of Data from Sensor Node to Base Station

In this section we propose a communication protocol for routing of data from ordinary sensor nodes to the Base Station. We consider a logical hierarchical organization of the Sensor Network. The proposed protocol speaks about how the logical hierarchical topology is achieved in self organizing manner. The entire protocol namely wireless **S**ensor system for **H**ierarchical **I**nformation gathering through **V**irtual triangular **A**reas (**SHIVA**) is composed of many sub parts and those are summarized below:

4.1 Preprocessing of the Base Station Locality

We consider that the Base Station has a rough idea about its own movement profile during the next ***time interval***. One ***time interval*** may be defined as the maximum time period during which one round of the sensor network routing protocol may be expected to remain valid. The round may get finished before the time interval expires based on the state of the sensor nodes. Once one round is over, re-computation of different topological parameters like cluster and cluster head selection etc are required. The protocol has been designed keeping this concept of ***time interval*** in mind and since the base station as well as the sensor nodes are mobile (dynamic) it is difficult to elongate the time interval to a greater extent as well as keeping the overhead of computing different topological parameters in mind, it is desirable not to have a very short time interval too. Therefore the span of the time interval is basically a compromise between the above two contradicting issues. This time interval may be fixed based on trial and error method. Upon experimenting (*through simulation*) different arbitrarily chosen time values the optimum time value may be determined for a ***time interval***. It is important to note that for a particular ***time interval*** the movement profile of each sensor node & base station is predictable and based on this the topology of the sensor network is computable by the base station. This topology remains valid for the ***time interval*** under consideration. When the next round begins the topology has to be reconstructed.

As mentioned earlier, base station knows its movement profile for a particular ***time interval***. Therefore base station constructs a curve representing the mean value of its actual movement pattern. This newly constructed curve gives the position of the base station at a particular time instant with maximum accuracy. The base station may not physically be present exactly at that point P_{ib} indicated by the curve at a particular time instant t_i but it has to be actually somewhere in a nearby position to that point P_{ib}. This much of deviation from the exact location of the base station shall not disturb the performance of the routing protocol. We can go with this much of error with respect to the position of the base station. The Figure 1 describes this process.



Sensor Field

Fig 1: Mobility with Sensors as well as Base Station

4.2 Preprocessing of the Geometry of the Sensor Field:

It is possible to predict the movement of each sensor node by the base station over a time interval with greater accuracy. It is also assumed that the base station can know an estimation of the graphical location of a sensor node by a GPS free solution [14]. Therefore by doing some amount of preprocessing the base station can construct the topology of the sensor field as shown in Fig-2. Each sensor node is represented by a curve which is basically mean of the actual movement profile of the sensor node. Therefore every point (P_{is}) in a curve, representing a sensor node represents an estimation of the actual presence of the sensor node in the sensor filed during that *time interval* t_i. The base station maintains this topology (for a particular time interval) along with its own movement profile. The picture representing the topology of the sensor field as well as the movement profile of the base station is an important piece of information for the base station as the rest of the protocol works on this picture only.

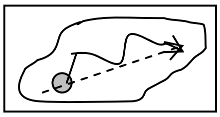


Fig 2: Mobility Profile of a Sensor Node

4.3 Cluster Setup:

We follow a non traditional and novel approach for clustering purpose. The base station is equipped with the picture representing the geometry of the sensor field (for a particular *time interval*) which we call as the ***sensor field map***. Sensor field map contains few curves as shown in the Fig 1 and each curve represents the mobility profile of a particular sensor over a particular *time interval.*

It is important to note that each sensor may start with non uniform energy level with respect to other sensor nodes in the field. During cluster formation phase we put more emphasis on the geographical position of a sensor than other parameters like distance of the sensors from the base station or energy level of the sensors. The base station throws some triangles of certain area to the sensor field as shown in Fig 3.

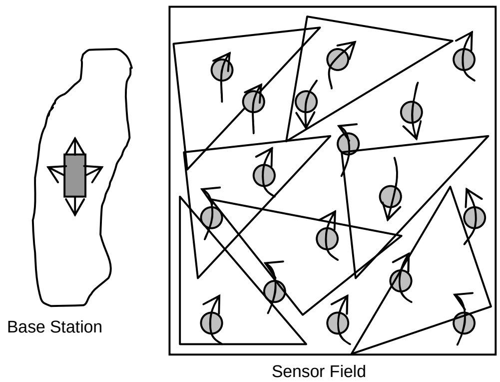


Fig 3: Clustering through Triangulation

In order to make clusters the base station performs the following steps –

Step1: Throw a certain number of triangles (n_i) of area (a_i) to the sensor field during the i^{th} iteration. [n_i is determined dynamically]. The moment all curves are under some triangles, the base station stops throwing any more triangles. The initial value of a_i is fixed arbitrarily.

Step 2: If any curve is under more than one triangle increase the area a_i by certain percentage and re-throw the triangles. Continue this until all curves are covered.

Step 3: Repeat Step 2 if required.
(*while throwing triangles, the area of the triangles is kept constant during a particular step but the orientation as well as the value of base and hypotenuse of the triangle may vary. And these triangles are generated randomly.*)

Step 4: After third iteration stop throwing of the triangles. Each triangle will now represent a cluster. In the event of multiple presence of a curve inside multiple triangles assign the curve to the triangle (*i.e., cluster*) having maximum percentage of presence of the curve.

Now the clusters are formed and the number of clusters is determined dynamically.

4.4 Cluster Head-Set Selection:

When a set of cluster heads is computed for a cluster the parameters under consideration are:

- *Average distance of each curve (sensor) to the base station.*
- *Remaining energy level of each curve (sensor).*
- *The curve nearest to all other curves inside the cluster (average distance is considered) is a potential candidate for becoming the head.*
- *Number of times the cluster headship responsibility already taken.*

If the sensor nodes cross a threshold value of the *eligibility scale,* all sensor nodes become eligible for headship and the cluster headset is formed.

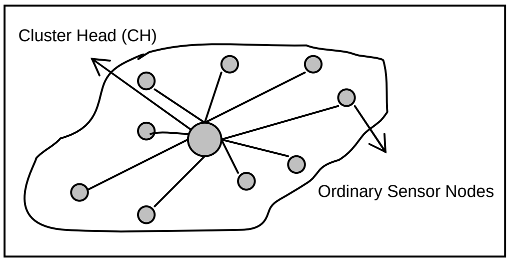


Fig 4: Inside a Cluster

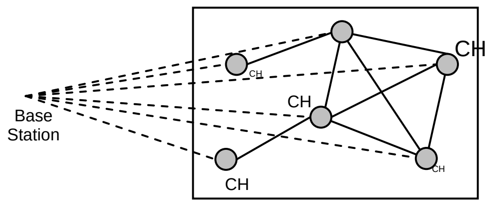


Fig 5: Cluster Head's communicating with Base Station

4.5 Schedules for Data Transmission:

Once clusters are formed and cluster heads are selected for each cluster the Chief Cluster Head (*which is the node having highest point in the eligibility scale*) takes the charge of the cluster. It gives a TDMA schedule to all the nodes inside its cluster. And according to this schedule all sensor nodes keep on sending data to the Chief Cluster Head.

4.6 Data Transmission to the BS:

Once the Chief Cluster Head gathers enough data it decides to transmit those to the Base Station. It is a long range communication which is expensive. The base station computes the path from a Chief Cluster Head to the Base Station based on the available image map for a particular time interval. This path may be a multi-hop or may be a direct one. This dynamic decision saves significant amount of energy since this is a high energy transmission as the BS is far away from the sensor field.

4.7 Role of other Cluster Heads in a Cluster Head Set:

The other Cluster Heads in a Cluster are supposed to assist the Chief Cluster Head. In presence of fault in the CCH the next head in the set takes the charge. Also if due to the mobility of sensor nodes some sensor looses connectivity with the CCH these sensors then send data to any one of the CH in the set. Eventually this CH in the set shall send these data to the CCH.

After the time interval is over the next round begins and a fresh computing of all metrics are required.

5. Simulation Results

Simulation of the proposed technique has been carried out through a simulation program written in C++. This simulation eliminates the effect of underlying MAC layer and solely focus in the routing technique used. And the proposed technique SHIVA describes a TDMA based schedule for data communication inside a cluster which has also been considered as the Medium Access Control information. We report the results of the simulation studies in this section.

We consider a rectangular 2-dimensional sensor filed where sensor nodes are deployed randomly. The Base Station is located far away from the sensor field.

Following is the radio model we used for the simulation purpose.

Radio Model- We use the first order radio model. The radios have power control and they can expend minimum energy to reach the intended recipients. Radios can be turned off to avoid receiving unintended transmissions. There is a loss of r^2 energy for channel transmission.

The equations for transmission costs and receiving costs for a k-bit message and a distance d are as follows:

Transmitting:

$E_{Tx}(k,d) = E_{Tx\text{-}elec}(k) + E_{Tx\text{-}amp}(k,d)$

$E_{Tx}(k,d) = E_{elec}*k + \epsilon_{amp}*k*d^2$

Receiving:

$E_{Rx}(k) = E_{Rx\text{-}elec}(k)$

$E_{Rx}(k) = E_{elec}*k$

In this radio model we consider,

$E_{elec} = 50$ nJ/bit (*energy dissipated for transmitting or receiving operation*) and

$\epsilon_{amp} = 100$pJ/bit/m^2 (*energy dissipated in the transmitter amplifier*)

Metrics Used- The proposed protocol tries to optimize the energy requirement in the sensor nodes. Our simulation is based on the analysis of the energy requirements by the sensor nodes in the network system under various circumstances as described through the graphs (*Fig 6 to Fig 9*).

We consider that the sensor nodes have data to transmit continuously. Data are sent by the sensor nodes in terms of reports. Each report constitutes of 32 bytes and such reports are being generated continuously by the sensor nodes. Whenever a node gets its TDMA based slot it transmits such reports.

Following metrics are used for energy analysis purpose-

Average Communication Energy: This is the total Communication Energy consumption, including transmission, retransmission, receiving, overhearing of both reports and control messages by the sensor nodes over the total number of reports received at the Base Station.

Average Energy: This is the ratio of the total energy consumption including communication energy and idle energy consumption by the sensor nodes, over the total number of distinct reports received at the Base Station.

Control Message Overhead: This is defined as the ratio between the total number of control messages received and transmitted by the nodes and the total number of distinct reports received at the Base Station.

Experimental setup: During simulation we used the following experimental setup-

Number of Sensor Nodes = 100-500;
Initial Energy of each Sensor Node = (0.5-1) J;
Data Report Size = 32 bytes;
Network Diameter = 200 m;

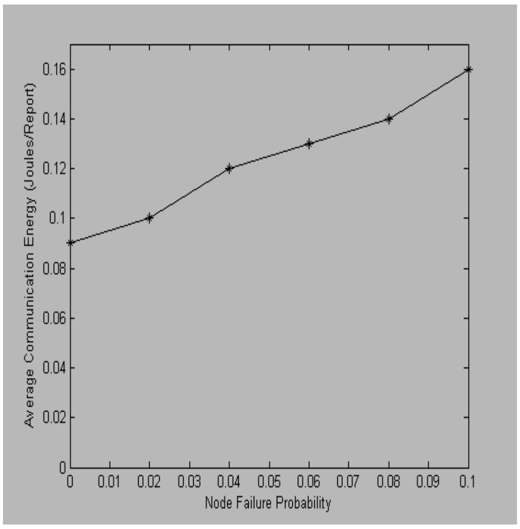


Fig 6: Average Communication Energy versus Node Failure Probability

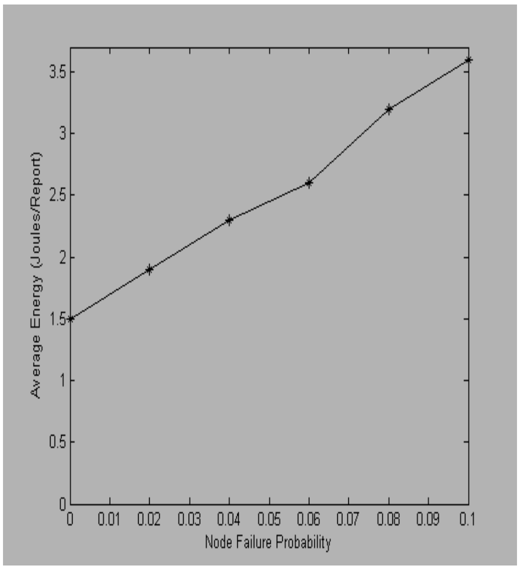


Fig 7: Average Energy in the Network versus Node Failure Probability

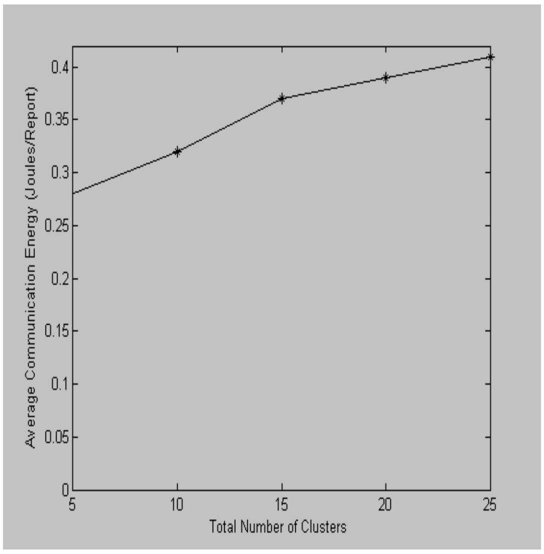


Fig 8: Average Communication Energy versus Total Number of Clusters

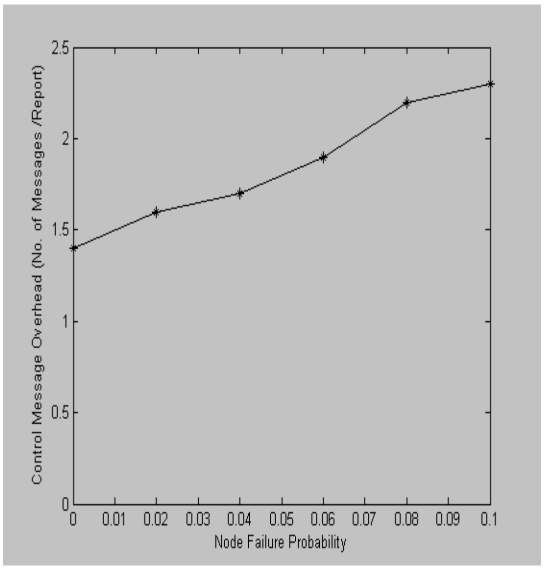


Fig 9: Control Message Overhead versus Node Failure Probability

Discussion: The graphs shown in the *Figure 6, 7 & 9* show that average communication energy, average energy as well as control message overhead increases with the increase in the node failure probability though it is not an abnormal growth. Moreover *Fig 8* shows that the average communication energy also increases with the increase in the number of nodes and that is why the number of clusters in the sensor filed. Here also the growth of energy consumption is not abrupt along with the increase in the number of nodes and it shows the scalability of the protocol.

6. Conclusion & Future Works

We have introduced an approach for energy aware routing for Wireless Sensor Networks in which base station and the sensor nodes are mobile. We name it as wireless **S**ensor system for **H**ierarchical **I**nformation gathering through **V**irtual triangular **A**reas (**SHIVA**). We consider the hierarchical architecture of the network and this facilitates us in providing a scalable solution to the routing problem.

Our clustering approach is novel. We also rely on a cluster head set to manage a cluster on contrary to the traditional concept of one cluster head in a cluster. This also gives robustness to the solution in the sense that if one cluster head looses connectivity to some of the subordinate sensor nodes due to the mobile nature of the sensor nodes as well as the Base Station then this cluster head can get connected to that through another cluster head in the set.

Our solution also tries to balance the load among the sensors by rotating the headship responsibility among the eligible sensor nodes in a uniform manner. This also contributes significantly in elongating the network lifetime.

In the proposed protocol the decision regarding the direct or indirect communication between cluster head and the base station is made dynamically based on the current status of the network topology. This saves siginificant amount of energy to be expended for communication.

As a future scope of the work, we shall try to remove the assumptions we have already made in providing this solution. Specially adding randomness to the movement of the sensor nodes, which will make the mobility profile of the sensor nodes unpredictable and then designing routing protocol for such type of a setup becomes a problem of fantastic complexity. Our future plan includes study of inter-cluster interaction and fault tolerant operation of the network emphasizing on energy conservation.

References:

[1] S. Singh, M. Woo, and C. Raghavendra. Power-Aware Routing in Mobile Ad Hoc Networks. In *the proceedings of the Fourth Annual ACM/IEEE International Conference on Mobile Computing and Networking (MobiCom '98)*, Oct. 1998.

[2] Wendi Rabiner Heinzelman, Anantha Chandrakasan, and Hari Balakrishnan. Energy Efficient Communication Protocol for Wireless Microsensor Networks. In the *proceedings of the Hawaii International Conference on System Sciences*, January 4-7, 2000, Maui, Hawaii.

[3] Feng Zhao, Leonidas Guibas. *Wireless Sensor Networks an information processing approach*, Morgan Kaufmann Publishers, An imprint of Elsevier, 2005, ISBN 81-8147-642-5.

[4] X. Lin and I. Stojmenovic. Power-Aware Routing in Ad hoc Wireless Networks. In *SITE*, University of Ottawa, Dec. 1998.

[5] Stephanie Lindsey, C S Raghavendra. PEGASIS: Power-Efficient Gathering in Sensor Information Systems.

[6] Arati Bhat Manjeshwar. Energy Efficient Routing Protocols with Comprehensive Information retrieval for Wireless Sensor Networks. Masters Thesis, Department of Computer Science, University of Cincinati, May 2001.

[7] Arati Bhat Manjeshwar, Dharma P Agrawal. APTEEN: A hybrid Protocol for Efficient Routing and Comprehensive Information Retrieval in Wireless Sensor Networks. *Proceedings of the IEEE International Parallel and Distributed Processing Symposium (IPDPS'02), 2002*.

[8] V. Rodoplu and T.H.Meng. Minimum Energy Mobile Wireless Networks. *IEEE Journal Selected Areas in Communications, vol. 17, no. 8, Aug 1999, pp. 1333-44*.

[9] Kemal Akkaya, Mohamed Younis. A survey on routing protocols for wireless sensor networks. Science Direct *Ad Hoc Networks* 3 (2005) pp. 325-349.

[10] P.g.M. Havinga and G.g.M. Smit. Design Techniques for Low Power Systems. *Journal of Systems Architecture*, 46(1), 2000.

[11] C-K. Toh. Maximum Battery Life Routing to Support ubiquitous Mobile Computing in Wireless Ad hoc Networks. *IEEE Communications Magazine*, June 2001.

[12] N. Bambos. Toward Power Sensitive Network Architectures in Wireless Communication: Concepts Issues and Design Aspects. *IEEE Personal Communications*, June 1998.

[13] A. Savvides, C-C Han, and M.Srivastava. Dynamic fine-grained localization in Ad-hoc networks for sensors. *Proceedings of the Seventh ACM Annual International Conference on Mobile Computing and Networking (MobiCom), July 2001. pp. 166-179.*

[14] A Caruso, S Chessa, S De, A Urpi. GPS Free Coordinate Assignment and Routing in Wireless Sensor Networks. available in *WWW*.

[15] O Younis, M Krunz and S Ramasubramanian. Node Clustering in Wireless Sensor Networks: Recent Developments and Deployment Challenges. *IEEE Network, vol 20, issue 3, May 2006, pp. 20-25*.

[16] C. Zhang, Y. Zhang and Y. Fang. Detecting coverage boundary nodes in wireless sensor networks. *In Proceedings of the IEEE International Conference on Networking, Sensing and Control, 2006. ICNSC '06, pp 868-873*.

[17] Ye, M.; Li, C.F.; Chen, G.; Wu, J. EECS: An Energy Efficient Clustering Scheme in Wireless Sensor Networks. Int. J. Ad Hoc Sensor. Network. 2007, 3, 99-119.