Energy-Efficient Cluster based Routing Schemes for Static and Mobile Sensor Networks

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by
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CERTIFICATE

Certified that the work presented in this thesis entitled **"Energy-Efficient Cluster based Routing Schemes for Static and Mobile Sensor Networks"** is a bonafide work done by Mr. Santhosh Kumar G., under my guidance in the Department of Computer Science, Cochin University of Science and Technology and that this work has not been included in any other thesis submitted previously for the award of any degree.

Kochi
April 11, 2011

Dr. K. Poulose Jacob
(Supervising Guide)

DECLARATION

I hereby declare that the work presented in this thesis entitled **"Energy-Efficient Cluster based Routing Schemes for Static and Mobile Sensor Networks"** is based on the original work done by me under the guidance of Dr. K. Poulose Jacob, Professor, Department of Computer Science, Cochin University of Science and Technology and has not been included in any other thesis submitted previously for the award of any degree.

Kochi
April 11, 2011

Santhosh Kumar G.

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Preface

Wireless sensor networks (WSNs) consist of a large number of sensor nodes that are densely deployed in a region of interest to collect data about a target or event, and to provide a variety of sensing and monitoring applications. However, these networks are characterized by limited amount of energy supply at sensor nodes and hence the energy optimization in sensor nodes becomes a very important design challenge for WSN. Clustering is a technique that can effectively reduce the energy consumption of sensor nodes and has been widely used in WSNs for data gathering and routing. A variety of clustering protocols have been proposed to address the energy efficiency problem in different network scenarios. Clustering protocols must be designed by appropriately selecting cluster heads to achieve load balancing and hence energy efficiency. Apart from static deployment scenarios of sensor nodes, mobile sensor networks are gaining significant attention recently. Most of the existing routing protocols are unable to support mobile sensor nodes because they do not consider the nodes' movements after clustering.

WSNs have the potential to interface the physical world with the virtual world on an unprecedented scale and provide practical usefulness in developing a large number of applications. However, effort needed to develop such applications is enormous due to the fundamental characteristics of sensor networks. There must be an elegant way to collect and use the data gathered by sensor networks without worrying about the underlying intricacies of the network.

The thesis, presented in eight chapters deals with the work carried out in designing and developing energy-efficient routing schemes for static and mobile sensor networks.

Chapter 1 introduces the area of wireless sensor networks, its applications and design challenges.

Chapter 2 is a systematic survey on existing routing protocols for static and mobile wireless sensor networks. LEACH protocol and various schemes based on this single protocol in the literature are also given. A taxonomy and a comparison based on various criteria of the surveyed hierarchical protocols are presented.

In **Chapter 3** power consumption by sensor nodes of the network for basic routing approaches is studied. The energy consumption statistics shows that cluster based routing schemes out performs the others. The basic clustering protocol is extended by introducing multilevel clustering and energy optimization in the clustering scheme. Energy savings by the proposed protocol is verified by simulation and comparison with the basic scheme.

Load balancing and multi hop communication can extend the lifetime of a sensor network. A new cluster based scheme for obtaining load balanced clusters by voting mechanism is proposed in **Chapter 4**. The algorithm for cluster set up and maintenance is discussed for static and dynamic cases. The scheme is found to be effective in energy savings, it is also validated by simulation and comparison with similar schemes.

Chapter 5 investigates the impact of node mobility on routing protocols across different set of mobility patterns. Routing behaviour is studied by observing the impact on various routing metrics. The important observation drawn from the investigation is mentioned.

In **Chapter 6** a cluster based scheme for mobile wireless sensor network is discussed. Cluster head election and durability of clusters during mobility is addressed here. The performance of the scheme is studied for various routing metrics and is compared with an existing routing protocol.

Chapter 7 details a Service Oriented Architecture using Web Services. The framework proposed facilitates an organization, with certain on site data acquisition capability, to publish that capability as a service on the Internet. The work also shows an experiment that was conducted as part of the study.

Chapter 8 recapitulates the thesis and mentions possible future research directions. Some of the results have been published in international journals and in the proceedings of various national and international conferences, the details of which are given in the following pages.

List of Publications

Papers in International Journals

1. Energy Aware Cluster-based Multihop Routing Protocol for Sensor Networks
   G Santhosh Kumar, Sithara A, K Poulose Jacob
   International Journal on Information Processing., **4(3)**, 11 - 19 (2010)

2. Service Oriented Architecture for Data Retrieval from WSNs
   G Santhosh Kumar, Sariga Raj, Vinu Paul M, K Poulose Jacob
   International Journal on Information Processing., **3(4)**, 33 - 44 (2009)

Papers in International Conferences

1. **G Santhosh Kumar**, Sithara A, K Poulose Jacob. *An adaptive cluster based routing scheme for mobile sensor networks*, **International Conference on Computing Communication and Networking Technologies**, Karur, Tamilnadu, India, July 29-31 (2010)
   http://dx.doi.org/10.1109/ICCCNT.2010.5592586

2. **G Santhosh Kumar**, Sithara A, K Poulose Jacob. *Voting based Clustering Scheme for Energy Efficient Routing in Sensor Networks*, **International Conference on Information Processing**, UVCE, Bangalore, Karnataka,, India, Aug 07-09 (2009)

3. **G Santhosh Kumar**, Vinu Paul M V, K Poulose Jacob *Mobility Metric based LEACH-Mobile Protocol*, **16th International Conference on Advanced Computing and Communication (ADCOM 2008)** Anna University, Tamilnadu, India, Dec 14-17 (2008) http://dx.doi.org/10.1109/ADCOM.2008.4760456

4. **G Santhosh Kumar**, Vinu Paul M V, K Poulose Jacob *Routing protocol enhancement for handling node mobility in WSNs*, **IEEE TENCON** University of Hyderabad, India, Nov 18-21 (2008) http://dx.doi.org/10.1109/TENCON.2008.4766540

5. **G Santhosh Kumar**, Sariga Raj, Vinu Paul M V, K Poulose Jacob. *Service Oriented Architecture for Data Retrieval from WSNs*, **International Conference on Information Processing**, UVCE, Bangalore, Karnataka,, India, Aug 08-11 (2008)

6. **G Santhosh Kumar**, Vinu Paul M V, K Poulose Jacob. *Impact of Node Mobility on the Performance of Wireless Sensor Networks*, **International Conference on Sensors and Related Networks (SENNET '07)**, VIT University, Tamilnadu, India, Dec 12-14 (2007)

7. **G Santhosh Kumar**, Lino A V, Damodaran, B Kannan, K Poulose Jacob. *An Energy Efficient Tree based Adaptive Routing Protocol for Wireless Sensor Networks*, **International Conference on Information Processing**, UVCE, Bangalore, Karnataka,, India, Aug 10-12 (2007)

8. **G Santhosh Kumar**, Lino A V, Damodaran, Jose Mathew, K Poulose Jacob. *Evaluation of the Power Consumption of Routing Protocols for Wireless Sensor Networks*, **Proceedings of the International Symposium on Ad-Hoc and Ubiquitous Computing**, NITK, Surathkal, India, Dec 20-23 (2006) http://dx.doi.org/10.1109/ISAHUC.2006.4290675

Glossary of Symbols and Abbreviations

Symbols

ε_{elec}	Energy dissipated by transmitter amplifier
λ	Poisson process intensity
CH_ADV	Cluster Head Advertisment
CH_{prob}	Probability of becoming CH
$d_{ij}(t)$	Distance from node i to j at time t
D_i	Length of the segment in Voronoi cell
$E[C]$	Expected energy consumption
E_{elec}	Energy dissipated to run the transmitter
$E_{Tx}(k)$	Energy spent to receive k bit packet
$E_{Tx}(k, d)$	Energy spent to transmit k bit packet to a distance d
$JOIN\_REQ$	Join Request
L_v	Total length of all segments in Voronoi cell
$M_i(t)$	Mobility Factor
MY_CH	CH of a node
N_{CH}	Cluster Head of node N
N'_{CH}	New Cluster Head of node N
PP_i	Poisson process of intensity λ_i
REJ_JOIN	Join request rejected
R_{ij}	Remoteness
R_x	Reception
S_{nbr}	Set of neighbor nodes
S_u	Set of uncovered nodes
S_{WD}	Set of withdrawn nodes
$T(n)$	Threshold value chosen by a node
T_x	Transmission
V_{max}	Maximum Velocity

Abbreviations

ADR	Angle Deviation Ratio
ASP	Active Server Pages
BS	Base Station
CBR	Continuous Bit Rate
CH	Cluster Head
CSMA	Carrier Sense Multiple Access
CSMA/CA	Carrier Sense Multiple Access/Collision Avoidance
EJB	Enterprise Java Beans
HTTP	Hypertext Transfer Protocol
J2EE	Java 2 Enterprise Edition
MAC	Media Access Control
MWSN	Mobile Wireless Sensor Network
RMI	Remote Method Invocation
RSSI	Received Signal Strength Indication
SD	Standard Deviation
SDR	Speed Deviation Ratio
SOA	Service Oriented Architecture
SOAP	Simple Object Access Protocol
SQL	Structured Query Language
TDMA	Time Division Multiple Access
UDDI	Universal Description Discovery and Integration
UML	Unified Modeling Language
URL	Uniform Resource Locator
WSDL	Web Services Description Language
WSN	Wireless Sensor Network
XML	Extensible Markup Language

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Chapter 1

Introduction

Contents

1.1 Wireless Sensor Networks

Information revolution by World Wide Web has changed the way in which people learn, work and play. But the information is largely confined to the on-line world. Every second, information is created through naturally occurring events in the physical world but these events go largely unnoticed and the information is lost. Sensing the physical world by embedding large collection of self organizing micro computers with appropriate sensors attached, forms the next revolutionary jump in information gathering and processing. These sensor nodes can then together form a *Wireless Sensor Network* (WSN) . A recent survey [Yick 2008] provides valuable insight on this exciting area. A WSN can monitor (sense) a region or phenomenon of interest and provide useful information about it by combining measurements (computing) taken by individual sensor nodes and then routed (communication) over the wireless interface to a base station. A base station provides a connection to the wired world where the collected data is processed, analysed and presented to useful applications. Thus by embedding processing and communication within the physical world, WSN can be used as a tool to bridge real and virtual environments. The process of harmonizing these two dimensions can be achieved as illustrated in Fig. 1.1. It shows two sensor fields

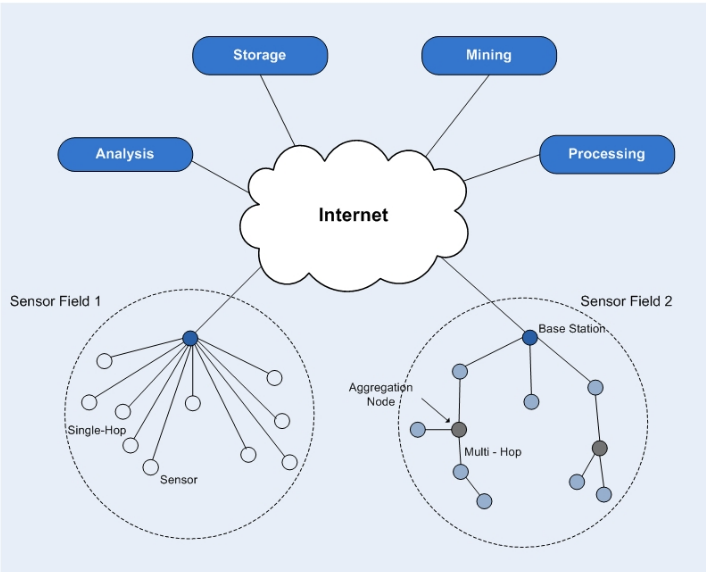

Figure 1.1: Wireless Sensor Network

monitoring two different geographic regions and connected to the Internet using their base stations. The main task of a sensor node in a sensor field is to detect events, perform local data processing and then transmit the data. In *Sensor field 1*, the sensors communicate directly with the base station using a single hop. A multi-hop communication happens in *Sensor field 2*, where sensors collaborate to propagate aggregated sensor data towards the base station. Apart from sensing, a sensor node is responsible for receiving the data sent by its neighbours and forwarding these data to one of its neighbours according to the routing decisions.

Typically, a sensor node is a tiny device that includes four basic components: a sensing subsystem for data acquisition from the physical surrounding environment, a processing subsystem for local data processing and storage, a wireless communication subsystem for data transmission and a power supply subsystem consisting of a battery with a limited energy budget. Moreover, additional components can also be integrated into the sensor node depending on the application. These components include a power generator, a mobilizer and a location finding system. The general hardware architecture of a sensor node [Akyildiz 2010] is depicted in Fig. 1.2 and the components are explained as follows;

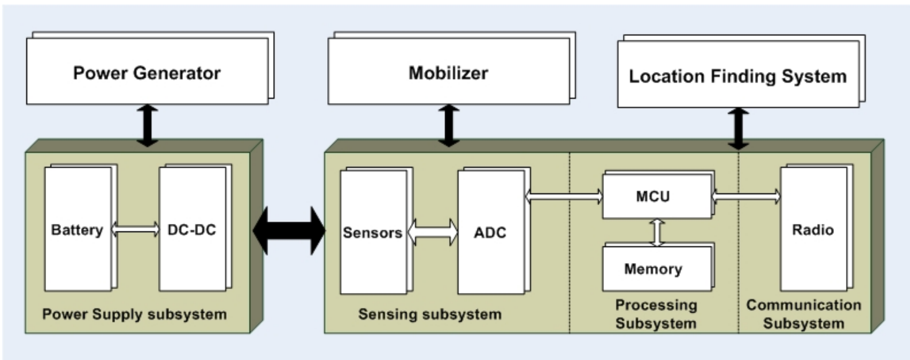

Figure 1.2: Hardware Architecture of a Sensor Node

- *Sensing Subsystem*: It includes several sensing units, which provide information gathering capabilities from the physical world. Each sensor unit is responsible for gathering information of certain type, such as temperature, humidity, or light and is usually composed of two sub units: a sensor and an analog-to-digital converter (ADC). The analog signals produced by the sensor are converted to digital signals by the ADC and fed into the processing unit. MTS310CB, MTS300CB and MDA100CB (http://www.memsic.com) are sensor boards capable of sensing light, temperature, sound, vibration and magnetic anomaly. These boards are used with IRIS, MICAz and MICA2 motes.

- *Processing Unit:* The processing unit is the main controller of the wireless sensor node, through which every other component is managed. The processing unit may consist of an on-board memory or may be associated with a small storage unit integrated into the embedded board. The processing unit manages the procedures that enable the sensor node to perform sensing operations, run associated algorithms, and collaborate with other nodes through wireless communication. IRIS and Mica mote family of nodes are equipped with 8-bit Atmel AVR micro-controllers with a speed of 4-16MHz and 128-256 kB of programmable flash.

- *Communication Unit*: Communication between any two nodes is performed by radio (transceiver) units. A communication unit implements the necessary procedures to convert bits to be transmitted into radio signal (RF) and recovers them at the other end. The MICA2 node includes a 433/868/916 MHz transceiver at 40 kbps. MICAz and IRIS nodes are equipped with IEEE 802.15.4 compliant radio and operate at 2.4 GHz with 250 kbps data rate.

- *Power Unit:* One of the most important components of a wireless sensor node is the power unit. Usually battery power is used, but other energy sources are also possible. Each component in the wireless sensor node is powered through the power unit and the limited capacity of this unit requires energy-efficient operation of the tasks performed by each component.

- *Location finding system*: Most of the sensor network applications, sensing tasks, and routing techniques need knowledge of the physical location of a node. This system may consist of a GPS (Global Positioning System) module or a software module that implements localization algorithms.

- *Mobilizer:* A mobilizer may sometimes be needed to move sensor nodes when it is necessary to carry out the assigned tasks. Mobility support requires extensive energy resources and should be provided efficiently. The mobilizer controls the movement of the sensor node.

- *Power Generator*: While battery power is mostly used in sensor nodes, an additional power generator can be used for applications where longer network lifetime is essential.

The main concern for the operation of WSNs is the energy consumption. For most applications, it could be impossible or inconvenient to recharge the battery, because nodes may be deployed in a hostile or impractical environment. On the other hand, the sensor network should have a lifetime long enough to fulfil the application requirements. In many cases a lifetime of the order of several months or even years may be required. Among the components described above, the radio unit is the most important part of a sensor node because it consumes much energy and provides connectivity to the rest of the network. Table 1.1 shows typical characteristics of commercially available sensor nodes.

Table 1.1: Characteristics of Sensor Nodes

	Mica2 (AVR)	**MicaZ (AVR)**	**Telos (T1MSP)**
wakeup	0.2 ms	0.2 ms	0.006 ms
sleep	30 μ W	30 μ W	2 μ W
active	33 mW	33 mW	3 mW
radio	21 mW	45 mW	45 mW
data rate	19 kbps	250 kbps	250 kbps
voltage	2.5 V	2.5 V	1.8 V
lifetime	453 days	328 days	945 days

The lifetime calculation shown in the table is based on sensors networked with a pair of AA batteries and reporting data once in every 3 minutes (<1% of duty cycle). It is clear that the battery plays a vital role in determining lifetime of a sensor node. Moreover, previous studies [Raghunathan 2002] and recent studies [Fan 2010] have experimentally measured the dynamic power consumption of sensor nodes and reported that the data transmission is very expensive in terms of energy consumption. The cost of energy in transmitting a single bit of information is approximately the same as that needed for processing a thousand operations in a typical sensor node [Pottie 2000]. In addition to energy constrains, a sensor node is also constrained in terms of processing power and memory.

From the above discussion, the first and often the most important design challenge for a WSN is energy-efficiency. This requirement permeates every aspect of sensor node and network protocol design. In this thesis, prime importance is given to routing schemes designed to achieve energy-efficiency.

1.2 Mobile Wireless Sensor Networks

Compared to static deployment of sensors, there has been a growing interest to study and build systems of self-organizing networks of mobile wireless nodes that do not depend on any infrastructure. In mobile wireless sensor networks (MWSN), nodes have locomotive capability. They can self-propel via springs, wheels, or they can be attached to transporters . Mobile sensors are deployed to achieve network load balancing, prolonging network lifetime, and improving network coverage. Mobile sensors are very effective in random deployment of sensors in many potential working environments, such as disaster relief operations, hostile areas, object tracking, remote harsh fields, and contaminated urban regions, where manual deployment of sensor may not be possible.

The mobility approaches for enhancing the WSN lifetime can be classified into four functional categories of mobile entities: mobile base stations (BSs), mobile sensors, mobile relaying nodes, and mobile cluster heads (CHs). The underlying functionalities of these are explained [Sudip Misra 2009] as:

Mobile BSs: The basic role of the BS is to collect the data generated from various sensors. Additionally the mobile BS mounted on the mobile unit can effectively enhance the lifetime by periodically or continuously changing its locations according to a predefined strategy. The increase of lifetime is due to two reasons. At first, there are no fixed set of sensors close to the BS when the BS is moving. This helps to disperse the bottleneck sensors around the network which again evenly dissipates energy. Second, the number of transmission hop from the sensor to the BS could be reduced with an efficient data transmission scheduling.

Mobile Sensors: Mobile Sensors can be distributed in the network domain with minimum human intervention like other stationary sensors. In static WSN, the coverage and connectivity are fixed once the deployment stage is performed. On the other hand, the mobile sensor could be used to form an ideal topology which improves the coverage and connectivity, or releases the relaying load for some bottleneck nodes.

Mobile relaying node: A mobile relaying node is a special mobile entity designed for releasing the relaying load of some sensors in the network. These nodes roam around to collect data from nearby sensors and deliver them to the BS.

Mobile cluster heads: The mobile CH-based approach takes advantage of a hierarchical network architecture to increase the WSN lifetime. A mobile CH can be one of the mobile sensors through an election process or a special node placed manually. They form clusters in the network and forward the information collected within their own cluster to the BS. Unlike stationary CHs, mobile CHs can increase the energy-efficiency and intelligently form the cluster topology adaptively according to the environment or changes in the network mission.

These mobile units can be introduced naturally or placed artificially. The mobility pattern of each mobile entity is typically determined based on specific application and the network size. The mobile units could be of different types such as *controllable mobile units* in which mobile units follow some predefined trajectories. The *unpredictable mobile units* in which mobile units move in a random fashion such that the next movement cannot be predicted. The *uncontrollable but predictable mobile units* such as bus or train that move according to a predefined schedule.

Mobility in WSN elongates network life time since it can spread out the hot spot over time by continuously relocating the mobile BS or mobile relay nodes. It extends coverage by moving mobile nodes to uncovered region while spreading out the network as much as it can while connectivity is maintained. Also, mobile relay units are beneficial in reconnecting broken links in the network in the case of network partition. In short, the mobility of sensors and base station in the MWSN is a valuable capability which gives an extra dimension in designing effective algorithms to improve the WSN performance.

1.3 Applications

Wireless sensor networks offer the opportunity to apply computer science concepts to obtaining measurements in challenging environmental field settings. It has unlimited potential for numerous application areas including environmental, heath-care, military, transportation, entertainment, home automation, traffic control crisis management, homeland defence, and smart spaces. The following sections describe some of the realizations of static and mobile sensor networks.

1.3.1 Static Sensor Network Applications

One of the earliest deployments of a large sensor network was carried out in the summer of 2002 on Great Duck Island [Polastre 2004] to enable non-intrusive and non-disruptive monitoring of sensitive wildlife and habitats. The Island is home to Leachs Storm Petrels that nest in separate patches within three different habitat types. A sensor network of 32 nodes was deployed for monitoring the micro-climate in and around the nesting burrows and the data made available to the researchers over the Internet.

Sensor networks have been applied to structural health monitoring of mechanical systems like studying vibrations on the Golden Gate Bridge [Kim 2007], Wisden Sensor Network [Chintalapudi 2006, Xu 2004] and BriMon [Chebrolu 2008].

Wireless sensor networks for health care have emerged in the recent years. SMART [Curtis 2008] is an integrated wireless system for monitoring unattended patients. A sophisticated wireless sensor node was employed for monitoring patients with Parkinsons Disease [Patel 2009]. An in-depth clinical trial was carried out to assess the feasibility of a reliable patient monitoring system using WSNs [Chipara 2009]. MediSN [Ko 2010] is a sensor network multi-hop system for monitoring patients' vital signs in hospitals and disaster events.

Wireless sensor networks have motivated a large number of researchers in the field of precision agriculture. WSN can play an important part in the handling and management of water resources for irrigation, in understanding the changes in the crops to assess the optimum point for harvesting, in estimating fertilizer requirements and to predict crop performance more accurately. The capacity of WSN devices to collect measured values in broad ranges of soil and environmental conditions has been demonstrated [Riquelme 2009]. The developed system helped to successfully monitor a crop of ecological cabbage for the entire growing season with the required precision . The growing conditions of vegetables in a green house were examined by monitoring temperature in the green house, soil temperature, dew point, humidity and light intensity [Yu 2009]. The development of an affordable, real-time, mobile system for fruit growers to monitor air temperature and frost protection equipment (wind machines) based on sensor network is also studied [Pierce 2008].

Real-time tilt monitoring of landslide prone slopes by sensor networks will provide immediate notification of landslide activity, potentially saving lives and property. A sensor network using a collection of instruments is proposed to detect ground movements and collectively estimate the displacements of sensor nodes embedded in a hill under observation [Terzis 2006]. Real-time monitoring of landslide using sensor networks is also discussed in [Lee 2009]. AMRITA University of India has deployed India's first landslide detection system using wireless sensor network at Munnar, Idukki, Kerala, India. [Ramesh 2009, Kunnath 2010].

There are other successful systems developed for various applications like automatic people counting [Byung-rak Son 2007], ZebraNet [Zhang 2004] for tracking zebra movements, volcano monitoring [Werner-Allen 2006] and understanding micro-climates in redwood canopies [Tolle 2005].

1.3.2 Mobile Sensor Network Applications

TrueMobile [Johnson 2006] is the first attempt to build a mobile wireless and sensor test-bed in which robots carry motes and single board computers through a fixed field of sensor equipped motes. The users can interactively position the robots, control all the computers and network interfaces and log data. Robomote [Dantu 2005] was designed to be a tabletop platform for experiments to evaluate algorithms designed for mobile sensor networks.

CarTel project [Bychkovsky 2006] has investigated a mobile distributed sensor system where sensors are located on the auto-mobiles. In this system, a mobile sensor is designed to cover a larger area than a static sensor. The mobile sensor can also act as a data Mule, which is capable of collecting a volume of data from static sensors in a sequence, and later delivers them to the base station.

iMouse [Tseng 2007] is an integrated mobile sensor network system for surveillance where mobile sensors move to event locations, exchange messages with other sensors and take snapshots of event scenes, and transmit images to the server. Pothole Patrol [Eriksson 2008] is a mobile sensor network to detect and report the surface conditions of the roads. The system uses inherent mobility of the participating vehicles, opportunistically gathering data from vibrations and GPS sensors, and processing the data to asses the road surface conditions.

Despite the significant efforts made, successful deployments and real world applications of sensor networks are still scarce, labour intensive and often cumbersome to achieve.

1.4 Motivation

The vast number of solutions that have driven the research community over the years made WSN phenomenon a reality. However, their proliferation has so far been limited to the research community with just a minimum number of commercial applications. The major challenge for the proliferation of WSNs is energy. Extremely energy-efficient solutions are required for each aspect of WSN design to deliver the potential advantages of the WSN phenomenon. Therefore, in both existing and future solutions for WSNs, energy-efficiency is the major challenge. Routing protocols for sensor networks should try to minimize energy consumption in order to maximize the network life time. Among the many routing protocols that have been developed for WSNs, the cluster-based protocols claims more energy-efficiency compared to others [Akkaya 2005]. These class of protocols are most suitable for applications like habitat monitoring which require continuous stream of sensed data. The most interesting research issue regarding cluster based protocols is how to form the clusters so that the energy consumption is optimized.

Clustering is one of the basic approaches for designing energy-efficient, robust and highly scalable sensor networks. Clustered organization dramatically reduces the communication overhead, thereby minimizing energy consumption and interference among the sensor nodes. Moreover, by aggregating the sensor's data at a designated node called cluster head (CH), the total amount of data to the base station can be reduced, saving energy and bandwidth resources. Since most of the clustering protocols are based on local properties, clusters generated by these protocols are often not optimal. In this backdrop, the question *how to create load balanced energy-efficient cluster* assumes greater significance. Each clustering algorithm is composed of two phases namely, the setup phase and steady state phase. The major issue in these algorithms is the CH selection. So, it is important to find out *how to select the best candidates for taking up the cluster head roles*? Many approaches based on different criteria are suggested by researchers [Abbasi 2007, Boyinbode 2010]. Many clustering algorithms require re-clustering after a round of the protocol operation, causing extra energy consumption [Heinzelman 2000, Younis 2004b]. It is worth to *investigate a way to reduce this extra energy consumption.*

In static networks, the mobility of sensors, users and the monitored phenomenon is totally ignored. It is interesting to note that several applications of sensor networks are inherently mobile [Munir 2007]. So, the next evolutionary step for sensor networks is to handle mobility in all its forms. One motivating example could be a network of environmental monitoring sensors, mounted on vehicles used to monitor current pollution levels in a city. In this example, the sensors are moving, the sensed phenomenon is moving and the users of the network move as well. Many protocols for WSNs proposed in the literature assume that nodes are static. The *effect of mobility on the performance of these protocols is of prime importance* in designing of mobile wireless sensor networks (MWSNs). Mobility of nodes can lead to disconnection of cluster members from their CHs causing data loss. In a given mobility scenario, one can ask for *an appropriate mechanism to select the cluster head so that the data packets reach the base station successfully.*

The vision of sensor web is to have worldwide integrated sensor network that may provide the functionalities similar to those available through the Internet. Various types of web-resident sensors, instruments, image devices, and repositories of sensor data should be made discoverable, accessible, and controllable via the World Wide Web. However, the effort needed to develop such applications is enormous due to the fundamental characteristics of sensor networks. Service

Oriented Architecture (SOA) has been considered as a felicitous candidate for developing open, efficient, inter-operable and scalable sensor network applications [Prinsloo 2006]. The node sensing capability is presented as an in-network service and presented as a modular discoverable service. Also, the application developers compose services into applications and into other services. It is desired to use the framework based on SOA to develop an application which deliver the sensor data to the end user in a flexible way.

1.5 Objectives

The main objective of the work reported in this thesis is to design and develop energy-efficient routing schemes for static and MWSNs. A routing scheme is said to be energy-efficient if it ensures both low average energy consumption over time and smaller standard deviation of energy consumption of sensor nodes. Such a scheme should aim for one or more aspect of the following: Minimizing the total energy spent in the network, minimizing the number of data transmissions, maximizing the number of alive nodes over time or balancing the energy dissipation among the sensor nodes in the network. It is very difficult to achieve all these goals at the same time. The WSN design often employes some approaches as energy-aware techniques, data aggregation, clustering and multi-hop communication to extend the network life time. Moreover, when mobility is added as an extra dimension to WSNs, it is also important that the scheme should ensure successful data transmission from node to base station.

To achieve this, the thesis has concentrated on the following areas to narrow down this broad objective.

- To compare the power consumption of basic routing approaches for sensor networks
- To propose an enhancement with respect to energy-efficiency and load balancing to the existing cluster-based protocol for static sensor networks.

- To investigate the impact of mobility on various routing schemes and to identify the performance metrics that affect routing.
- To propose an elegant CH election method and a routing scheme for mobile sensor networks.
- To design and develop a service oriented architecture based application for WSNs.

1.6 Outline of the thesis

The rest of the thesis is organised as follows:

Chapter 2 is a systematic survey on existing routing protocols for static and mobile wireless sensor networks. LEACH protocol and various schemes based on this single protocol in the literature are also given.

Chapter 3 discusses the power consumption of basic routing schemes. A tree based adaptive routing protocol is proposed by modifying basic LEACH protocol. An analytical model to discuss the energy consumption of the proposed protocol is also discussed.

Chapter 4 formulates a scheme for generating energy aware near optimal load balanced clusters by partitioning the network using neighbor node information.

Impact of different mobility models on routing characteristics of various routing protocols is covered in Chapter 5

When mobility is introduced in cluster based routing protocols it is important to ensure high success rate in data transfer between the cluster head and the collector nodes. Chapter 6 describes a scheme for achieving this.

Chapter 7 focuses on development of an application based on service oriented architecture to gather data collected by a sensor network through the Internet as a web service.

The last chapter recapitulates the thesis and mentions possible future research directions.

Chapter 2

Survey of Energy-Efficient Cluster based Routing Schemes

Contents

2.1 Introduction

One of the most important challenges of WSN design is to develop a scheme or protocol that allows the numerous sensor nodes that are randomly deployed behave in a collaborative and organized way. Each sensor node wants to maximize its own utility function. In addition, the entire network needs balance in resource assignments to perform in a way that is useful and efficient. Network routing protocol design becomes far more critical to WSNs performance than that in conventional communication networks. Many researchers have suggested routing solutions for WSNs. In this chapter a brief review of the work done in this area, especially routing solutions pertaining to energy-efficiency is presented. Cluster based routing solutions proposed in the literature that are directly related to this work are discussed in separate sections.

2.2 Routing in sensor networks

Routing in sensor networks is very challenging due to several characteristics that distinguish them from contemporary communication and wireless ad hoc networks. A study [Al-Karaki 2004] presents the following facts that make routing different from other networks. First of all, it is not possible to build a global addressing scheme for the deployment of sheer number of sensor nodes. Therefore, classical IP-based protocols cannot be applied to sensor networks. Second, contrary to typical communication networks almost all applications of sensor networks require the flow of sensed data from multiple regions (sources) to a particular sink. Third, generated data traffic has significant redundancy in it since multiple sensors may generate same data within the vicinity of a phenomenon. Such redundancy needs to be exploited by the routing protocols to improve energy and bandwidth utilization. Fourth, sensor nodes are tightly constrained in terms of transmission power, on-board energy, processing capacity and storage and thus require careful resource management.

The proposed routing protocols in the literature can be broken down into different groups based on various criteria like taxonomy of routing protocols based on network structure or organization, the route discovery process, and the protocol operation [Al-Karaki 2004]. Furthermore, these protocols are classified into multipath-based, query-based, negotiation-based, , coherent-based and

QoS-based depending on the protocol operation. They offer the design trade-offs between energy and communication overhead savings in every routing paradigm and also highlight the advantages and performance issues of each routing technique.

With respect to network organization, most routing protocols fit into one of three classes namely *Data-centric*, *Location-based* and *Hierarchical* protocols. Data centric protocols are query-based and depending on the naming of desired data, which helps in eliminating many redundant transmissions. Location-based protocols utilize position information to relay the data to the desired regions rather than the whole network. Hierarchical protocols aim at clustering the nodes so that cluster heads can do some aggregation and reduction in transmission in order to save energy. The present study describes these approaches in separate sections below. More stress is given to cluster based or hierarchical protocols. Comprehensive surveys are available on this area [Akkaya 2005].

2.3 Clustering in Sensor Networks

In a flat network, all nodes are typically assigned an equal role and functionality. The desired data are sent out to the network through multi-hop routes. To eliminate many redundant transmissions through the network, flat protocols focus on how to route data based on the application queries. Most flat protocols are data-centric and they ensure only the nodes that transmit the valuable data which match the query attributes. In many cases, flat protocols result in more complicated routing because of the large scale and dynamic network topology of WSNs. Sensor protocols for information via negotiation (SPIN) [Kulik 2002] and directed diffusion (DD) [Intanagonwiwat 2000] protocols are important flat protocols which motivated the design of many other protocols that follow similar concepts.

In hierarchical networks, nodes are separated to play different roles, such as

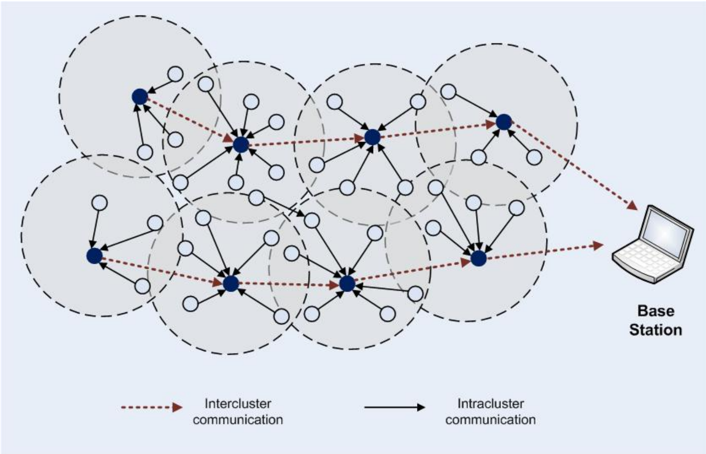

Figure 2.1: Routing process in a cluster based network

CHs and cluster members. The higher level nodes ie. cluster heads (CHs), manage the grouped lower level nodes (cluster members) and collect data from them. Each CH collects data from the cluster members within its cluster, aggregates the data, and then transmits the aggregated data to the sink. All of the hierarchical routing protocols aim at selecting the best CH and clustering the nodes into appropriate clusters in order to save energy. Since the CHs have responsibility for the collection, aggregation, and transmission of data over longer distances to the sink, they consume more energy compared to the other cluster members. The hierarchical clustering protocol may execute re-clustering and reselecting of CHs periodically in order to distribute the load uniformly among the whole network. Figure 2.1 depicts routing process in a typical cluster based network.

2.3.1 Clustering Objectives

The objectives of clustering algorithms vary depending on the requirements of the applications. The main objectives for the network clustering are [Abbasi 2007]:

- *Load balancing:* Forming equal-sized clusters becomes crucial for extending the network lifetime since it prevents the exhaustion of the energy of a subset of CHs at high rate and prematurely making them dysfunctional. Even distribution of sensors can also leverage data delay. When CHs perform data aggregation, it is imperative to have similar number of nodes in the clusters so that the combined data report becomes ready almost at the same time for further processing at the base-station or at the next tier in the network.

- *Fault-tolerance:* In some applications, sensor nodes may have to operate in harsh environments and thus nodes are usually exposed to increased risk of malfunction and physical damage. Tolerating the failure of CHs is usually necessary in such applications in order to avoid the loss of important sensor data. One way to recover from a CH failure is to re-cluster the network. Assigning backup CHs is another scheme pursued in the literature for recovery from a CH failure. Rotating the role of CHs among nodes in the cluster can also be a means for fault-tolerance in addition to their load balancing advantage.

- *Increased connectivity and reduced delay:* Unless CHs have very long-haul communication capabilities, e.g. a satellite link, inter-CH connectivity is an important requirement in many applications. This is particularly true when CHs are picked from the sensors population. The connectivity goal can be just limited to ensuring the availability of a path from every CH to the base-station or be more restrictive by imposing a bound on the length of the path.

- *Minimal cluster count:* This objective is particularly common when CHs are specialized resource-rich nodes. The network designer often likes to employ the minimum number of such nodes since they tend to be more expensive and vulnerable than sensors.

- *Maximal network longevity:* Since sensor nodes are energy-constrained, the network's lifetime is a major concern; especially for applications of WSNs in harsh environments. When CHs are richer in resources than sensors, it is imperative to minimize the energy for intra-cluster communication. On the other hand, when CHs are regular sensors, their lifetime can be extended by limiting their load and by rotating the role of cluster heads among the members. Adaptive clustering is also a viable choice for achieving network longevity.

2.3.2 Clustering Schemes

Many authors classify clustering schemes based on various criteria discussing the challenges involved in deploying clustering techniques in WSNs by identifying various parameters used to partition the network [Younis 2006]. Clustering involves grouping the nodes into clusters and electing a CH such that the members of cluster can communicate with their CH directly. Electing optimal number of CHs from a set of sensor nodes is same as the dominating set problem of graph theory. Since this is an NP-Complete problem, clustering algorithms discussed in literature are heuristic in nature. A simplest scheme for choosing a node as a CH is based on lowest identifier number among its neighbors. A node can become CH if it has higher node degree within a pre-specified transmission range. Another approach could be assigning weights to the nodes based on some properties, for example, remaining energy and node degree or some combination of parameters like mobility and average distance to neighbors. Whether clustering is done through a centralised approach or in a distributed way determines another criteria. Also, execution nature of clustering algorithm could be probabilistic or iterative. Hierarchical routing protocols is classified into two categories: random-selected-CH protocol and well-selected-CH protocol [Lung 2010]. The former randomly selects CHs and then rotates the CH task among all nodes, while the latter carefully selects appropriate CHs and then gathers nodes under the CHs based on the network status.

The clustering scheme must aim for prolonged lifetime of the network by consuming less energy for building and maintaining the clusters. The scheme should also concentrate on even energy dissipation in the network. When mobility is considered, apart from energy-efficiency the scheme should ensure successful packet delivery and cluster durability.

Following section discusses cluster based routing protocols that are mainly concentrating on energy-efficiency. Most of the protocols found in the literature try to incorporate one or many criteria to form clusters discussed above.

2.4 Cluster based Routing Protocols

In this section cluster based routing protocols proposed in the literature for static and mobile sensor networks are discussed.

2.4.1 Routing in static sensor networks

Low Energy Adaptive Cluster Hierarchy (LEACH) [Heinzelman 2000] is among the first clustering techniques for sensor networks. It incorporates randomized rotation of the high energy CH position among the sensors to avoid draining the battery of any one sensor in the network. The operation of LEACH is broken up into rounds. Each round contains two phases: set-up and steady-state phase. In the set-up phase, CHs are elected using a distributed algorithm. A node chooses a random number between 0 and 1. If the number is less than a threshold T (n), the node becomes a CH for the current round. The threshold is calculated as:

$$T(n) = \begin{cases} \frac{p}{1-p*(r\ mod(1/p)} & n \in G \\ \\ 0 & else \end{cases}$$

where p is the desired percentage of cluster heads, r is the current round and G is the set of nodes that have not been cluster heads in the past 1/p rounds.

LEACH assigns a fixed probability to every node so as to elect itself as a CH. The clustering process involves only one iteration, after which a node decides whether to become a CH or not. Nodes take turns in carrying the role of a CH.

PEGASIS [Lindsey 2002] is a chain based protocol. All the nodes in the network will be organized to form a chain with a leader node which is responsible for passing the final data to the BS. The node chain can be accomplished by using a greedy algorithm starting from some node, usually the farthest node from the BS. When a node dies, the chain is reconstructed in the same manner to bypass the dead node. For gathering data in each round, each node receives data from one neighbor, fuses with its own data, and transmits the data to the other neighbor on the chain. PEGASIS performs the data fusion at every node except the end nodes (leader node) in the chain. Finally, the leader transmits one message to the BS. Hierarchical PEGASIS (H-PEGASIS)is an extension to PEGASIS to reduce the delay for transmitting packets to the BS. In H-PEGASIS, the spatially separated nodes are allowed to transmit simultaneously. In this protocol the CDMA capable nodes are chained to form a tree like hierarchy. Each selected node in a particular level of the hierarchy transmits data to the node in its upper level. This method allows parallel data transmission and reduces the delay significantly. Simulation results show that H-PEGASIS performs better than PEGASIS by a factor of about 60.

TEEN [Manjeshwar 2001] is a hierarchical clustering based protocol developed for reactive networks in which nodes react immediately to sudden and drastic changes in the environment. Cluster formation and data transfer are done as in the LEACH protocol. At every cluster change the CH broadcast to its members two threshold values along with other attributes - Hard Threshold (HT) and Soft Threshold (ST). These values as well as the environment are sensed by the nodes continuously. When the node finds that the sensed attribute has reached HT, the node switches on its transmitter and sends the sensed data. The sensed value is stored in an internal variable SV in the node. In the current cluster period, the nodes will next transmit data only when the current value of the sensed attribute is greater than HT and the current value of the sensed attribute differs from SV by an amount equal to or greater than the ST. The use of HT and ST will reduce the number of transmissions in the network and hence it reduces the overall energy dissipation in the network. This scheme is suited for time critical data sensing applications.

HIT [Culpepper 2004] is based on a hybrid architecture that consists of one (HIT) or more clusters (HITm), each of which is based on multiple, multi-hop indirect transmissions. In order to minimize both energy consumption and network delay, parallel transmissions are used both among clusters and within a cluster. Performance evaluation has shown that HIT provides energy savings over LEACH, PEGASIS, and Direct Transmission for small areas and small numbers of nodes. HIT also greatly reduces the delay required to gather data from all sensors in a network by utilizing parallel, indirect transmissions.

HEED [Younis 2004a] is a distributed clustering protocol that considers a hybrid of energy and communication cost when selecting CHs. Only sensors that have a high residual energy can become CHs. In HEED each node is mapped to exactly one cluster and can directly communicate with its CH. The algorithm is divided into three phases:

1. *Initialization phase:* The algorithm first sets an initial percentage of CHs among all sensors. Each sensor then calculates its probability of becoming a CH based on the current energy and the maximum energy in the sensor and is not allowed to fall below a certain threshold.

2. *Repetition phase:* Every sensor goes through several iterations until it finds a CH that it can transmit to with the least transmission power. If it does not hear from any CH, the sensor elects itself to be a CH and informs its status change to neighbors. Finally, each sensor doubles its CH probability value and goes to the next iteration of this phase. This continues till the CH probability reaches 1.

3. *Finalization phase:* During this phase, each sensor makes a final decision on its status and it either picks the least cost CH or pronounces itself as the CH. Simulations have shown that HEED is better than LEACH in prolonging the network life time. This is because the final CHs are selected such that they are well-distributed across the network and communication cost is minimized.

BCDCP [Muruganathan 2005] is a centralized clustering based routing protocol which utilizes a high-energy BS to set up clusters and routing paths, perform randomized rotation of CHs, and carry out other energy intensive tasks. The key idea in BCDCP is the formation of balanced clusters. BCDCP operates in two phases: setup and data communication phases. The major activities in setup phase are CH selection, CH-to-CH routing path formation and schedule creation from each cluster. CHs are selected by BS from a list of nodes whose energy level is greater than the average value. BCDCP then forms desired number of clusters by using an iterative cluster splitting algorithm. Using Balanced Clustering technique, all the clusters formed are allocated with CHs selected from the list, such that the load is evenly distributed on all CHs. Once the clusters and the CHs have been identified, the BS chooses minimum energy path which is formed by connecting all the CHs using minimal spanning tree approach. To forward data to the BS, a CH is randomly selected. Finally the BS creates a TDMA schedule for all the clusters. In Data transfer phase, the CH gathers data from the cluster members fuses with its own data and forwards the data to BS through CH-to-CH routing path created in the setup phase. This protocol requires high energy BS to perform the energy intensive tasks as described above. Simulation results have shown that BCDCP outperforms LEACH and PEGASIS. It is also observed that performance gain of BCDCP enhances with the increase in area of the sensor field.

ECR [Tian 2007] uses the hybrid (cluster and chain) way to manage the networks. In ECR protocol once the topology is formed, the shape of cluster will not change, but the position of CH slips along the chain. Based on the Y-direction distance from the sensing area and BS, the area is divided into several sub areas with same width. The nodes in each sub area form a cluster and nodes in each cluster organize them into a chain by themselves according to the order of their X-coordinate. The operation of ECR is initiated by the BS by selecting a CH-leader randomly, leader of the CH chain. This is for the first round only but in coming rounds a node with maximum rest energy is selected as CH-leader. CH-Leader is the one which is responsible for transmitting data to the BS. The selected CH-Leader is also the CH of the cluster it belongs to. The other CHs are generated by a distributed algorithm based on their distance to the CH-Leader. A CH chain is formed by means of greedy algorithm with these CHs. During the steady state phase, CH gathers sensing data from non-CH nodes along the cluster-chain and processes them. The CH-leader collects data from CHs along the CH chain, fuses them and transmits the data to the BS directly. Simulation results show that ECR protocol outperforms LEACH and PEGASIS in terms of network life time. As the clusters are fixed or static, ECR saves the energy for cluster rebuilding in each round and hence saves the overall energy.

ERP [Ghiasabadi 2008] is a hybrid of clustering structure and chain based binary scheme. Nodes in the network are grouped into cluster chains with one node as CH. If there are N nodes then $\alpha\%$ of nodes are selected as CH. All nodes in a cluster use greedy algorithm to form a chain-based binary structure and this occurs at every level in the hierarchy. For gathering the data in each round, each node sends its data to its neighboring node which fuses the data and sends it to its neighbor in a given level of hierarchy. The nodes that receive data in each level rise to the next level. Finally at the top level, the only node remaining will be the CH. Once the CHs take all the data from all the nodes in its cluster, it aggregates the data and sends the fused data to its neighboring CH. This occurs at every level in the hierarchy and at the top level a single CH remains and it sends the fused data to the BS. Thus this protocol uses chain-based binary scheme not only within the cluster but between CHs also. This will reduce the energy and delay cost as well as the computation overhead at BS. Experiments show that the delay cost of this protocol is much lesser than LEACH. It is also observed that these results do not depend on the number of nodes in the network.

BCBE [Zhang 2008] is a clustering based routing protocol that was developed minimizing the disadvantages of LEACH that CHs may not be well distributed and the number of nodes in each cluster is distributed unequally. The prerequisite in this protocol is that the location information of two nodes and BS must be known and with this information every other node can compute its location. The protocol will arrange CHs in optimal positions for having balanced clusters. Simulations proved that a 100 node network has longest life time with 6 CHs. Each node after calculating their coordinates, calculates its distance from all the optimal positions. The node with shortest distance will be elected as CH and it will broadcast this information. All other non-CHs nodes can join with a CH by sending an ACK message. Then the CH will calculate a TDMA schedule and broadcast it to the members. When the remaining energy of the CH falls below a certain value, it can choose a suitable cluster member as its successor, based on the highest fitness value of the cluster member. BCBE has a more balanced distribution of CH and cluster members than LEACH. The simulation results show that the life time when using BCBE is much longer than that of LEACH.

SCHE [Muhamad 2008] was developed based on LEACH. The main objective of SCHE is to minimize the energy dissipation of each sensor node and reduce the energy dissipation for the whole network. The use of an appropriate CH election mechanism can reduce the energy consumption for each sensor nodes minimizing the mean energy consumption of the whole network. In SCHE this is attained by finding a stable or optimal probability of a node for becoming a CH and is given by

$$p = \sqrt{\frac{E_{amp} K_{data} L^2}{N(3E_{elec} K_{inter} + 2E_{amp} L^2 k_{data})}}$$

This will result in suboptimal operation and consumption of less power. Simulation results show that because of using the optimal probability p, SCHE reduces communication energy by as much as 95% compared to LEACH.

EMHR [Huang 2009b] is based on LEACH and employs multi-hop methodology for data transmission. CH selection for the first round is the same as in LEACH. In the next round CH is elected by comparing the energy value of all the nodes in the cluster and the largest energy node is selected as the CH. Then the elected node broadcasts the message of becoming the CH. In EMHR, the CH sends all the collected data of the cluster members to the BS by multi-hop. Each CH finds the optimized next-hop CH based on a weight function. By this way of a continuous selection next-hop CH, the data are passed along next-hop CH and the last CH sends all data to BS which saves the energy consumption of CH and hence reduces the overall energy consumption of the network. Simulations show that the energy strategy of electing CH decision in EMHR helps to achieve good performance in terms of network life time and balancing load among CHs energy consumption in wireless sensor networks.

CHIRON [Chen 2009] is energy efficient protocol that split the sensing field into a number of smaller areas, so that it can create multiple shorter chains to reduce the data transmission delay and redundant path, and therefore conserve the node energy and prolong the network lifetime. The operation of CHIRON consists of four phases:

- *Group construction phase:* In this phase the sensing field is divided into smaller areas using Beam Star [Mao 2007] technique. BS gradually sweeps the whole sensing area, by successively changing different transmission power levels as well as antenna directions and sends these control information to all nodes. From these control packets a node can easily determine which group they belonging to and also the distance to BS.

- *Chain formation phase:* In this phase all nodes in a group will be linked to form a chain and this process is same as in PEGASIS. A leader node for the chains formed is elected in Leader node election phase. Initially the node farthest away in the group is selected as leader and for the coming rounds the node with maximum residual energy is elected as leader. As the energy information is piggybacked with the fused data to the leader, the leader can determine which node will be the leader for the next round.

- *Data collection and transmission phase:* These two are similar to that in PEGASIS scheme. Each node's collected data is transmitted to the leader by passing through the nearest neighbor and the leader aggregates it. And then, starting from the farthest groups, the chain leaders collaboratively relay their aggregated sensing information to the BS by passing through nearest neighbor leader node, in a multi-hop, leader-by-leader transmission manner.

Simulation results have shown that CHIRON is better than PEGASIS and EPEGASIS schemes in terms of average data delay and redundant transmission path. The concept of using Beam Star topology helps the protocol to form multiple shorter chains which reduce the propagation delay as well as transmission paths and hence the network energy consumed is less.

CCRP [Bian 2008] is a balanced protocol based on LEACH that adopts a more balanced CH selection algorithm and an improved data transmission mechanism from the CH to the BS. The protocol is broken up into rounds and each round has setup phase and data transmission phase. CH election and cluster formation is done in setup phase. The CH selection is done as in LEACH. But while calculating the threshold value, remaining energy of the nodes and the number of neighbors of the node is considered and is calculated as

$$T(n) = \begin{cases} \frac{p}{1-p(rmod(1/p))}\left[\frac{E_c}{E_n} + \left(1 - \frac{E_c}{E_n}\right)\frac{num}{1/p-1}\right] & n \in G \\ 0 & else \end{cases}$$

where num is the number of neighbors, E_c is the current remaining energy of the node and E_m is the initial energy of the node. In the data transmission phase of CCRP a chain of CHs is constructed such that each CH will receive from and transmit to an adjacent CH. The chain is constructed by considering the distances between a selected CH and its nearest neighbor CH until all the CHs are included in the chain. After all CHs complete the process of data gathering from their cluster member nodes then the aggregated data are transmitted from one CH to another along the chain. Eventually the aggregated data are delivered to the BS by the CH that has the shortest distance to the BS. Experiment results show that CCRP performs better than LEACH in terms of the network life time as it distributes the energy consumption evenly among the sensor nodes in the network.

MEDC [Yuan 2008] is a chain-based data gathering protocol that puts forward the idea of multi layer chain, and uses the minimum total energy algorithm to construct the chain and maximum residual energy of nodes is the standard for selection of leaders. The first stage in this algorithm is to find the farthest node from BS as one end of the chain. Then each round selects a new node which is not in the chain such that the total average distance of the current chain with this new node increases to the minimum possible extent compared to the old chain. Using this criterion each new node is added either at the end of the old chain or inserted between two nodes that are already inserted. The hierarchical chain formation in this protocol is as follows: A linear chain among all the nodes is formed first and then divided into C groups, with each group having N/G successive nodes of the chain. There will be G groups of N/G nodes altogether. One node from each group will be active in the second layer and so there will be G nodes. In the second layer, these G nodes are divided into Gl groups of successive nodes. Within each group, we use the minimum total energy chain construction, to form local sub-chains. The leader of each local chain will be regarded as the active node in this group. The selection of leaders in each layer is based on the maximum residual energy of nodes in every round. But the leaders in the first round are just selected randomly. The experimental results show that MEDC works better than LEACH and PEGASIS, on prolonging the network lifetime as well as in reducing the network delay. Multi-hop-LEACH protocol [Xiangning 2007] is a cluster based protocol similar to LEACH. In order to transmit the data from one cluster head to base station it selects optimal path between the CH and the BS through other CHs. So the transmission is by using this intermediate cluster heads. Thus the multi-hop communication is achieved. Then, according to the selected optimal path, these CHs transmit data to the corresponding CH which is nearest to BS. Finally, this CH sends data to BS. M-LEACH protocol is almost similar as LEACH protocol with the only difference in making communication mode multi-hop instead of single hop between CHs and BS.

MR-LEACH protocol [Farooq 2010] works as same as the LEACH but this partitions the network into different layers of clusters. MR-LEACH routing protocol works in three phases:

- Cluster Formation at lowest level
- Cluster Discovery at different levels by Base Station
- Scheduling

In the cluster formation phase the cluster head selection is based on the residual energy of the nodes and the probability of becoming cluster head. The selected cluster heads thus form the clusters. The cluster discovery can be obtained by using the broadcast capability base station. The BS will broadcast its Identifier (ID) over the common control channel. All cluster heads which hear this broadcast will record the BS ID. Cluster heads which are near to the BS form layer one since they are at single hop distance from the BS. Layer one cluster heads are one hop away from layer two cluster heads, so that the base station finds out all the cluster heads in each layer. After the formation of cluster heads at different levels, member nodes scheduling needs to be done by using the Time Division Multiple Access (TDMA) scheme in sensor networks because it saves lot of energy compared to contemporary medium access techniques for wireless networks. Performance evaluation section has shown that MR-LEACH performs well compared to similar approaches given that network is divided into optimal number of layers. It is shown that MR-LEACH achieves significant improvement in the LEACH protocol and provides energy efficient routing for WSN.

MiCRA [Khedo 2009] is a hierarchical cluster-based routing scheme, that considers the following factors. First parameter is residual energy of nodes and the second one is the communication cost. MiCRA takes two levels of cluster heads(CHs) election. In the first level election use the same CH_{prob} equation as in HEED. In the second level election the CH_{prob} is calculated based on the following equation.

$$CH_{prob} = \left(\frac{E_{residual}}{E_{max}} \times \left(1 - \frac{ClusterSize}{NumNodes}\right)\right)$$

So the MiCRA contains the unequal topology of networks in which the cluster heads nearer to the base station have less number of cluster nodes than the cluster heads that are far away from the base station. Thus the overall consumption of energy and network lifetime will be optimized. It also reduces the clustering process to minimum time resulting the energy saving being more than in HEED.

EEHC [Bandyopadhyay 2003] is a distributed, randomized clustering algorithm for WSNs. This technique is divided into two phases; single-level clustering and multi-level clustering. In the single-level clustering, each sensor node announces itself as a CH with probability p to the neighboring nodes within its communication range. These CHs are named as the volunteer CHs. All nodes that are within k hops range of a CH receive this announcement either by direct communication or by forwarding. Forced CHs are nodes that are neither CH nor belong to a cluster. If the announcement does not reach a node within a pre-set time interval t that is calculated based on the duration for a packet to reach a node that is k hops away, the node will become a forced CH assuming that it is not within k hops of all volunteer CHs. The second phase, called multi-level clustering builds h levels of cluster hierarchy. The algorithm ensures h-hop connectivity between CHs and the base station. The CHs closest to the base station have disadvantage because they act as relays for other CHs.

Energy-efficient unequal clustering (EEUC) [Li 2005] is a distance based scheme, where the balance between the clusters are achieved. The size of the cluster near to the base station has lower cluster size compared to clusters that are far from the base station. In this scheme every node has the knowledge about the location and distance to the base station. In the data transmission phase the cluster head passes the data to the relaying node by using the following criteria;

$$s_i.R_{CH} = \{s_j | d(s_i, s_j) \leq ks_i.R_{comp}, d(s_j, BS) < (s_i, BS)\}$$

Experiment result shows that the EEUC clearly improves network life time over LEACH and HEED.

EECS [Ye 2007] protocol for wireless sensor networks better suits the periodical data gathering applications. This protocol is similar to the LEACH protocol where the network is partitioned into a set of clusters with one cluster head in each cluster. This protocol contains two phases: cluster head selection and cluster formation phase. In the cluster head selection phase well distributed cluster heads are elected based on the residual energy. After the clusters are selected, PLAIN nodes in EECS chooses the cluster head by considering not only the saving in its own energy but also balancing the workload of cluster heads, i.e. two distance factors: d(P_j ,CH_i) and d(CH_i,BS).Based on the following weighted function the PLAIN nodes will select their respective cluster heads $cost(j, i) = w \times f(d(P_j, CH_i)) + (1 - w) \times g(d(CH_i, BS))$, where f and g are two normalized functions.

$$f(P_j, CH_i) = \frac{d(P_j, CH_i)}{d_{f-max}};\ g(CH_i) = \frac{d(CH_i, BS) - d_{g-min}}{d_{g-max} - d_{g-min}}$$

where $d_{f-max} = exp(max\{d(P_j, CH_i)\})$, $d_{g-max} = max\{d(CH_i, BS)\}$ and $d_{g-min} = min\{d(CH_i, BS)\}$. EECS produces a uniform distribution of cluster heads across the network through localized communication with little overhead.

Simulation results show that EECS is effective in the consumption of energy and it prolongs the network lifetime as much as 135% of LEACH. The advantages of EECS include: 1) fully distributed. 2) low control overhead. 3) load balanced clustering mechanism. But the Communication between cluster head and BS is direct (single-hop).

PEACH [Yi 2007] supports the adaptive multilevel clustering in which clustering hierarchy is adaptively changed by circumstances. It can be used for the location aware and unaware wireless sensor networks. All existing clustering protocols can only support a fixed level of hierarchical clustering. Location-unaware PEACH protocol operates in a fully distributed manner. All sensor nodes are required to transmit and receive multiple packets to select cluster heads and join clusters. The packets are composed of advertisements and announcements from the cluster head nodes, and joined from the non-head nodes, and the scheduling information from the head nodes. However, Location Unaware-PEACH does not require additional transmission overhead except for overhearing a packet between other nodes The simulation results demonstrated that PEACH significantly improves the lifetime and the energy consumption of the wireless sensor networks compared with existing clustering protocols.

In CBRP [Zarei 2010] protocol the network is clustered by using some parameters and then constructing a spanning tree for sending aggregated data to the base station. The operation of CBRP is divided into two phases. Cluster head selection phase and routing tree generation phase. In the cluster head selection phase the CH election is based on the Cluster Head Selection Value(CHSV), the largest CHSV value node will become the cluster head. In routing tree generation phase each cluster head will select their parent sensor node based on the Parent Selection Value(PSV). Next, the routing tree is constructed and the transmission takes place. The CBRP has the following advantages:

- Alternating the role of cluster heads balancing the energy consumption among cluster members.

- Constructing spanning tree on cluster heads reducing energy consumption in it.
- CBRP considers the distance and residual energy of nodes and elects optimum cluster heads that can save more energy in nodes.

Experimental results show that CBRP balances the energy consumption among cluster heads and as a result more energy is saved in the network.

TREEPSI [Satapathy 2006] is a tree based multi-hop routing protocol to construct a tree-like hierarchical path of the nodes. In this approach the nodes will fuse the received data with their own data and forward the resultant data to their parent. This process is repeated till data are received by the root node. The data are collected at the root and finally root takes responsibility to transmit the data to the BS. After the death of node, a new tree like path is constructed. So the overhead per communication round is less as compared to the energy spent in the data collection phase. The simulation results shows that TREEPSI outperforms all the existing protocols in terms of energy efficiency. The proposed method provides up to 30% longer life to the sensor field as compared to PEGASIS for various network topologies.

TCDGP [Huang 2009a] is the combination of the cluster-based and tree-based protocol. The operation of the TCDGP contains three phases. 1. Cluster establishment 2. Construction of cluster-based tree 3. Data aggregation. In the cluster establishment phase the cluster head selection is based on the remnant power of each node. The threshold power is E_{th}(k,d). If remnant power is less than the threshold value, the node will not be a cluster head. After selecting the cluster heads, sink could compute all the distances between cluster head and sensor nodes according to the coordinates' information. In the cluster based tree construction, the sink will collect the information that the cluster head had labelled in each cluster and will build a path in minimum spanning tree (MST) to compute the tree path. In the data aggregation phase every node transmits the gathered data to the upper level nodes. The threshold mechanism prolongs the life of the root node and gives each node a chance to become the root node.

In the TBC [Kim 2010] protocol the nodes in a cluster form a tree with the root as the cluster-head, while the height of the tree is decided based on the distance of the member nodes to the cluster head. This protocol has mainly four stages.

- Cluster Formation
- Distance-Based Level Decision
- Configuration of Tree
- Data Collection and Transmission

Unlike LEACH, the proposed scheme constructs a tree inside the cluster. For this the Join-REQ message is stored in the cluster-head which contains the distance information between the node and cluster head. In the Distance-Based Level Decision, after the cluster formation each cluster constructs a tree with the member nodes where the cluster-head becomes the root. The distance of a node to the root serves as the basis for determining the level in the cluster. Then the average data transmission distance between two adjacent levels of the tree, d_a, can be calculated using $d_a = \frac{d_{max}}{\alpha}$. In the tree configuration stage the cluster-head decides the parent node of each member node to which it sends the data. To make the decision, the set of candidate parent nodes of N_i, PS_i, is defined using $PS_i = \{N_j \ for \ which \ L(j) = L(i) - 1\}$. In the Data Collection and Transmission stage each node sends the collected data to the parent node during the pre-allocated time slot appointed by the cluster-head. The collision among the nodes in the cluster can be avoided by assigning non-overlapping time slots. Simulation results show that the proposed scheme successfully balances the energy consumption among the nodes and thus significantly extends the network lifetime compared to the existing schemes such as LEACH, PEGASIS, and TREEPSI.

WST [Zhang 2010] is a LEACH based algorithm in which the selection of cluster heads is not only completely random, but is also taking into account the remaining energy, the distribution density of nodes and the distance from cluster heads to the base station. The cluster head selection is based on the threshold value T(n) and is calculated as follows. If a node n does not belong to G, where G is a collection of non-CHs in this round, then T (n) = 0; otherwise.

$$T(n) = \frac{p}{1 - p * (r\ mod(1/p))} * \left\{ w_1 * \frac{S(n).E}{E_0} + w_2 * \frac{S(n).Nb}{p * N} + \frac{1}{S(n).ToBS} \right\}$$

$S(n).E$ is the remaining energy of node n; E_0 is the initial energy; N is the total number of nodes; $S(n).Nb$ is the neighbor numbers of node n within a radius R; $S(n).ToBs$ is the distance between node n and the BS; and w1,w2,w3 are coefficients respectively. The selection process of WST-LEACH is similar to LEACH. In the construction of weighted spanning tree, it establishes a Weighted Spanning Tree through all the cluster heads. The calculation of the weight value depends on the factors such as remaining energy of the cluster head, distribution of surrounding nodes and the distance to the other cluster heads. The data is sent to the base station along the constructed WST. The weighted formula is constructed as follows;

$$W(i,j) = \frac{C(i).E}{E_0} * \frac{N}{C(i).Mb} * \frac{1}{d(i,j)^{\beta}}$$

W(i,j) depends on the cluster head i's remaining energy, the number of neighbor nodes and the distance to the parent cluster head. Simulation results show that WST-LEACH reduces the energy consumption with higher efficiency and extended the network lifetime.

2.4.2 Routing in mobile sensor networks

Supporting mobility in sensor nodes becomes increasingly useful in various applications. But, the introduction of mobility in sensor networks face important challenges as follows. Firstly, both space and time get renewed emphasis as defining parameters in the routing scheme. Secondly, the timely dissemination and processing of collected information become much more complex than resource optimisation. Thirdly, maintaining connectivity and maximizing the network life time become difficult. Basic approaches exploiting mobility for data collection were attempted [Ekici 2006] providing a comparison of mobility based communication proposals. Recent proposals for routing in cluster based mobile sensor networks are summarized below.

A mobility-aware routing protocol [Arboleda C. 2006] uses zone-base information and a cluster-like communication between nodes. The protocol operation has route creation stage where, a route from source node to base station is discovered and a route preservation stage in which defective routes are repaired.

LEACH-Mobile [Kim 2006a] extends LEACH protocol discussed in the previous section to support communication in a mobile WSN by the incorporation of mobile cluster members. The scheme is to be discussed in detail in Chapter .

LIMOC [Banerjee 2007] takes advantage of a mobile BS and hierarchical topology of clustering to maximize the lifetime of a WSN. It increases the lifetime of the network as well as makes the CHs move intelligently allowing collaboration among the CHs. Once the cluster formation step is completed, only the CHs move in the direction of the event, keeping the other members of the cluster static. Therefore, the 1-hop neighbors of each CH which are responsible for sending data directly to the CH keep changing accordingly. Thus, the energy of each cluster member is dissipated uniformly thereby avoiding a fixed set of sensors to continuously transmit data to the CHs and run out of energy eventually. The scheme proposes two strategies for CH movement. In the first strategy, the CH moves towards the point where the maximum residual energy exists in the network. And in the second strategy the CH moves towards the event in the network. The simulation results show that both schemes maximize the network life time.

Cluster based Energy-efficient Scheme (CES) [Lehsaini 2008] is a scheme for electing a cluster head to evenly distribute energy consumption in the network. In CES, each sensor calculates its weight based on k-density, residual energy and mobility and then broadcasts it to its 2-hop neighborhood. The sensor node with the greatest weight in its 2-hop neighborhood will become the cluster-head and its neighboring sensors will then join it. A comparison of CES with LEACH and LEACH-C revealed that the protocol provides good results in terms of the amount of data packets received at the base station.

Mobility and traffic adapted cluster based routing for mobile nodes (CBR-Mobile) [Awwad 2009] supports mobility of sensor nodes in an energy-efficient manner, while maintaining maximum delivery ratio and minimum average delay. The mobility and traffic adapted scheduling based MAC design enables the cluster heads to reuse the free or unused timeslots to support the mobility of sensor nodes. Each cluster head maintains two simple database tables for mobility and traffic to achieve this adaptation. The designed CBR-Mobile protocol enables mobile sensor nodes disconnected with their cluster heads to rejoin the network through other cluster heads within a short time. The proposed protocol achieves around 43% improvement on packet delivery ratio while simultaneously offering lower delay and energy consumption compared to LEACH-Mobile protocol.

2.5 Results and discussions

Routing in sensor networks has attracted a lot of attention in the recent years and introduced unique challenges compared to traditional data routing in wired networks. In this Chapter recent research results on data routing in hierarchical sensor networks were summarized. Fig. 2.2 shows a taxonomy of the routing protocols. These protocols mainly fits into four categories; *Cluster based protocols*, *Chain based protocols*, *Tree based protocols* and *Hybrid protocols*. Cluster based protocols are further divided into single cluster based and multi cluster based. Single hop and multi hop communication is possible in multi clustered protocols. Many protocols fall into multi hop category. In these protocols the communication takes place from CH to BS in a multi-hop way. In chain based protocols most protocols fit into hierarchical chain based. Only few protocols are suggested as tree based. There are some protocols which fit more than one category and were classified as hybrid protocols. Table 2.1 summarises the hierarchical protocols surveyed according to different metrics. The metrics considered are cluster formation, cluster head selection, power consumption and protocol operation. The CH plays the specialized role of performing data aggregation and sending it to the BS on behalf the nodes within its cluster. To select CHs residual energy of the node and distance to CH to BS are taken as key parameters. Most of the protocols use single hop or mulihop communication for intra cluster and inter cluster communication. The above discussed metrics have direct effect on the power consumption of the protocol. Thus, how to form the cluster is a more interesting and essential research issue concerning such protocols so that the energy consumption and various communication metrics such as delay are optimized. It is interesting to note that majority of the protocols consider homogeneous sensor nodes for the protocol design. This is due to fact that most applications uses homogeneous sensor nodes. Nodes with different computation and communication capabilities may be required for future sensor network applications.

2.6 Conclusions

In this chapter recent research papers which are relevant to the present work are discussed. The topics related to energy-efficient routing schemes in static and mobile sensor networks are also included. Most protocols were designed to reduce the energy consumption and to prolong the network lifetime. LEACH is one of the most popular cluster-based protocols which has been widely proposed. Many of the protocols discussed above are based on this single scheme. A taxonomy and a comparison based on various criteria of the surveyed protocols are presented. In mobile sensor networks in addition to energy-efficiency the protocol should support maximum rate of data delivery from nodes to cluster head and to the base station with minimum end-to-end delay.

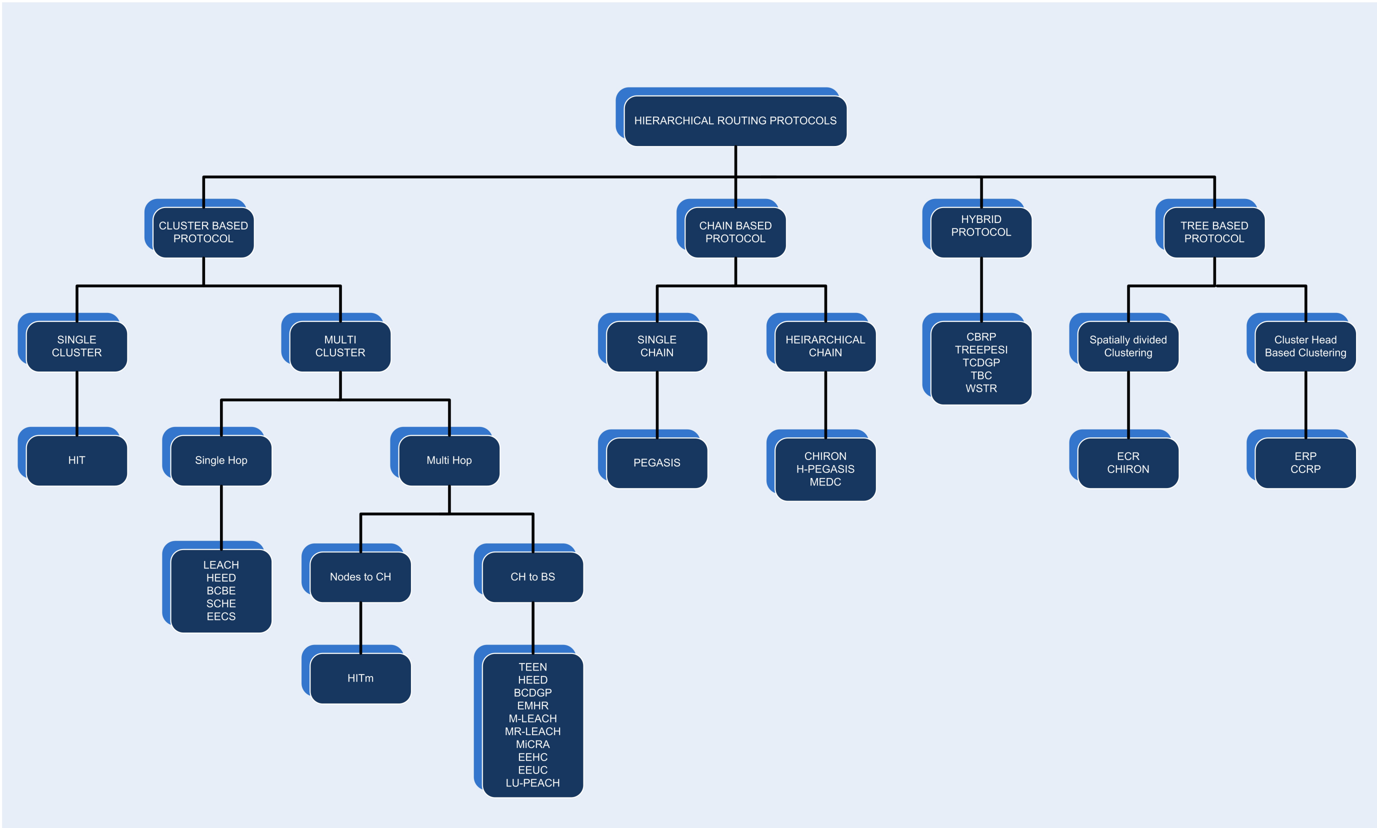

Figure 2.2: Taxonomy of hierarchical routing protocols

Table 2.1: Comparison of hierarchical routing protocols

SCHEME	Cluster Head Selection		Cluster Formation		Delay	Power Consumption	Aggregation	C/ D [a]	Het/ Hom [b]
	Dist. CH to BS	Residual Energy	Nodes to CH	CH to BS					
LEACH	NO	NO	DIRECT	DIRECT	LOW	AVERAGE	YES	D	Hom
M-LEACH	NO	YES	DIRECT	MULTI-HOP	HIGH	AVERAGE	YES	D	Hom
MR-LEACH	NO	YES	DIRECT	MULTI-HOP	HIGH	AVERAGE	YES	C	Hom
PEGASIS	-	-	-	-	-	HIGH	NO	D	Hom
MICRA	NO	YES	DIRECT	MULTI-HOP	HIGH	LOW	YES	D	Hom
EEHC	NO	YES	DIRECT	MULTI-HOP	LOW	AVERAGE	YES	D	Het
EEUC	YES	YES	DIRECT	MULTI-HOP	LOW	LOW	YES	D	Hom
EECS	YES	YES	DIRECT	DIRECT	LOW	AVERAGE	YES	D	Hom
LU-PEACH	NO	YES	DIRECT	MULTI-HOP	MEDIUM	HIGH	YES	D	Hom
CBRP	NO	YES	DIRECT	MULTI-HOP	MEDIUM	AVERAGE	YES	D	Hom
TREEPSI	-	-	DIRECT	MULTI-HOP	-	LOW	YES	D	Hom
TCDGP	YES	-	MULTI-HOP	MULTI-HOP	-	AVERAGE	YES	D	Hom
TBC	YES	NO	MULTI-HOP	MULTI-HOP	LOW	HIGH	YES	D	Hom
WSTR	YES	YES	DIRECT	MULTI-HOP	HIGH	LOW	YES	D	Hom
TEEN & APTEEN	NO	NO	-	-	MEDIUM	HIGH	YES	D	Hom
MECN & SMECN	-	-	-	-	-	AVERAGE	NO	D	Hom
H-PEGASIS	-	-	-	-	-	HIGH	NO	D	Hom
ERP	NO	NO	DIRECT	MULTI-HOP	LOW	AVERAGE	YES	D	Hom
CCRP	YES	YES	DIRECT	MULTI-HOP	MEDIUM	AVERAGE	YES	D	Hom
ECR	NO	NO	DIRECT	MULTI-HOP	HIGH	AVERAGE	YES	C	Hom
EMHR	YES	YES	DIRECT	MULTI-HOP	HIGH	LOW	YES	D	Hom
HIT, HITm	NO	NO	MULTI-HOP	DIRECT	LOW	LOW	YES	D	Hom
BCDCP	NO	YES	DIRECT	MULTI-HOP	MEDIUM	HIGH	YES	C	Hom
BCBE	YES	YES	DIRECT	DIRECT	HIGH	LOW	YES	C	Hom
SCHE	YES	NO	DIRECT	DIRECT	-	AVERAGE	YES	D	Hom
CHIRON	NO	YES	MULTI-HOP	MULTI-HOP	-	AVERAGE	YES	D	Hom
MEDC	NO	YES	MULTI-HOP	MULTI-HOP	-	HIGH	YES	D	Hom

[a] Centralised / Distributed
[b] Heterogeneous / Homogeneous

Chapter 3

Tree based energy aware routing protocol

Contents

3.1 Introduction

Traditional routing protocols focus on choosing the optimal path to destination. But unlike the traditional routing protocols that minimize delay, many of the routing protocols for WSNs try to optimally utilize the minimal resources with the network nodes. They especially try to minimize the energy required for communication, as nodes in a sensor network are energy-constrained. The present chapter is divided into two parts. In the first part, a comparative study and implementation of four basic routing protocols namely Flooding, Gossiping, Gradient Based Routing and LEACH, a cluster based routing scheme are presented. The power consumption of individual nodes and hence the power consumption of the entire network under the chosen protocols is of interest here. In the second part, a tree based protocol is proposed by understanding the problems associated with the basic LEACH protocol. An analysis and a comparison of the proposed protocol with LEACH is also presented.

3.2 Power consumption of routing schemes

A brief description of the routing schemes considered for the study is given below:
Flooding and Gossiping: Flooding is a classical and straight forward mechanism to disseminate data in WSNs, which takes the broadcasting nature of the wireless medium. To deliver a particular packet from the source to the destination node with flooding, the source node broadcasts the data to all the neighbors. Upon receiving the packet, each neighbor will broadcast a copy of the packet to its neighbors. This process continues until the packet arrives at the destination or the packet is dropped. Flooding is easy to implement and it requires no costly topology maintenance or route discovery. It has a major drawback of increasing the network load with redundant traffic. A node may blindly broadcast whatever it receives, regardless of whether or not the neighbor has already received a copy from another source. This leads to implosion problem [Heinzelman 1999] resulting in multiple copies of the same data packet floating around the network. Sensor nodes often cover overlapping geographic areas and gather overlapping pieces of event data. The sensed data received by the neighbors of the nodes would contain some part of the data that is redundant, which is known as overlap [Heinzelman 1999]. To avoid the problem of flooding redundancy, gossiping [Hedetniemi 1988] takes a step further by just selecting one random node to

forward the packet rather than broadcasting.

Gradient Based Routing (GBR): In this scheme [Schurgers 2001], a gradient is determined on the basis of the number of hops to the sink. GBR uses interests to capture a sink's desire to receive certain type of information and during flooding of these interests, gradients are established on each node. Each interest announcement message records the number of hops it has travelled since leaving the sink. This allows nodes in the network to determine their distance to the sink (which is called as height) and the difference between a node's height and the height of its neighbor is considered to be the gradient on the link between these two nodes. A data packet is then forwarded on the link with the largest gradient.

LEACH: Basic working of the LEACH protocol was described in Chapter 2. With LEACH, cluster heads are responsible for all communication between their cluster members and a base station and the aggregation of data coming from its cluster members in order to eliminate redundancies.

3.2.1 Implementation and Simulation

TinyOS [Hill 2000] has become a popular environment for experimenting with sensor network applications, due to its modular nature and support for several common sensor node platforms. It supports a simulation environment called TOSSIM [Levis 2003]. In TOSSIM, the TinyOS application is compiled directly into an event driven simulator that runs on the simulation host. This design exploits the component-oriented nature of TinyOS by effectively providing drop-in replacements for the TinyOS components that access hardware; TOSSIM provides simulated hardware components such as a simple radio stack, sensors, and other peripherals. This design allows the same code that is run on real hardware to be tested in simulation at scale. PowerTOSSIM [Shnayder 2004] makes use of the TinyOS and TOSSIM component model to instrument hardware state transitions for the purpose of tracking power consumption.

TinyOS provides a multi-hop architecture to specify multi-hop routing applications. The architecture contain two major components viz. a packet movement logic MultiHopEngineM for multi-hop routing and MultiHopLEPSM module for path selection. The components MHFloodingPSM (flooding), MHGossipingPSM (gossiping), MHGbrPSM (GBR) and MHLeachPSM (LEACH) were implemented by modifying the base components using the language nesC [Gay 2003]. These components maintain routing state and are responsible for selecting a route for a packet. A loss topology is defined to allow a node to communicate with all nodes within a 5×5 square around itself. All the protocols were simulated for a period of 500 seconds. The power consumption of the routing protocols is calculated using PowerTOSSIM . It computes the energy totals for various hardware components of each node. Power consumed by the CPU and radio mainly contributes to the total energy spent by each nodes in the network. The simulation also tracked the number of messages sent, received and forwarded through each node.

3.2.2 Results and discussions

Using PowerTOSSIM, power usage per node (median and standard deviation) and power usage per message sent for each of the protocols were tabulated. The power usage per message sent is calculated as:

Power usage per message = Total power consumed by all nodes / Total number of message sent from all nodes.

The median of the power usage per node for the four protocols are shown in Fig. 3.1. The median of the power usage indicates the average power consumption of the protocol across the network. Fig. 3.2 shows the standard deviation per node. The standard deviation of the power usage per node gives an estimate of evenness of power consumption across the network. The average power usage for each message sent for the protocols is shown in Fig. 3.3. The average hop count gives an estimate of the latency measure for the protocol. It is calculated as:

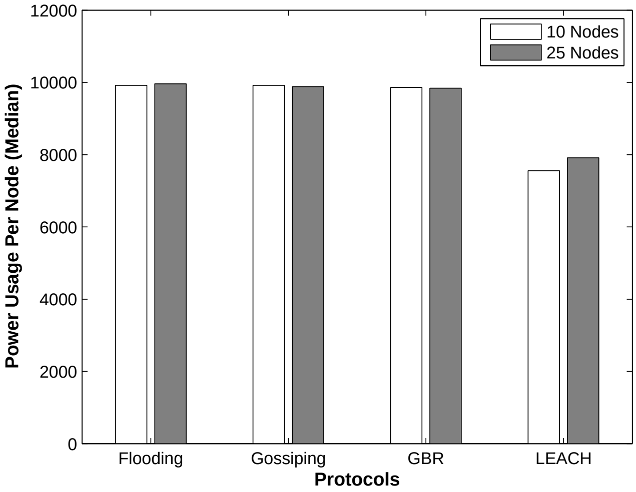

Figure 3.1: Power usage per node (Median)

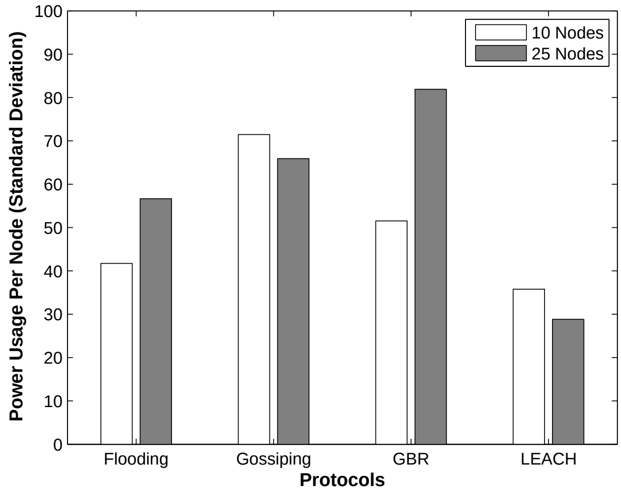

Figure 3.2: Power usage per node (Standard Deviation)

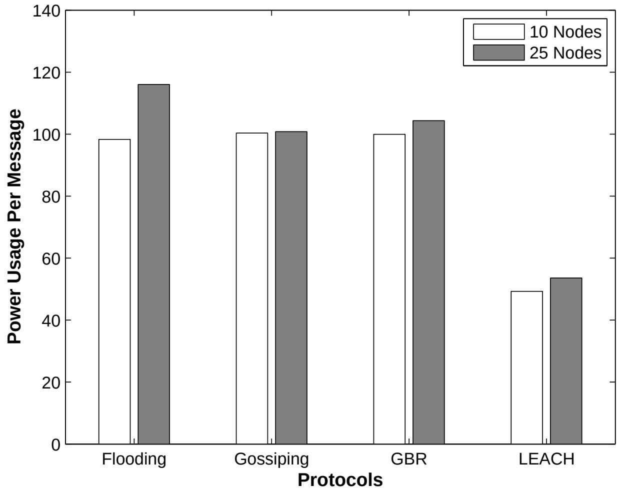

Figure 3.3: Power usage per message sent

Average hop count = Total hop count of the messages delivered to the UART address of the base station / Total number of messages. Fig. 3.4 shows the average hop count of the messages forwarded to the base station.

Cluster based protocols were found to be energy efficient when compared with the other schemes. In LEACH protocol, it is assumed that each node can transmit directly to the CH and the sink, which may not be applicable for networks deployed in large regions. Moreover, the idea of dynamic clustering incurs extra overhead for the cluster head formation and maintenance. A close observation of LEACH protocol revealed the following issues:

1. LEACH assumes that all nodes are able to reach the base station, which affects the scalability of the protocol.

2. The overhead involved in the protocol due to changes in CH and calculations therein leads to energy inefficiency. This problem can be addressed by reducing the number of rounds in the cluster rebuilding phase.

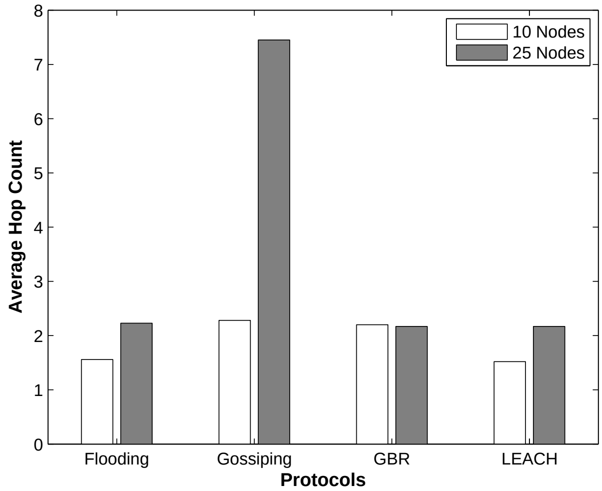

Figure 3.4: Average hop count of the messages forwarded to the BS

3. LEACH takes a stochastic approach to elect the CHs. There is a possibility to elect even low energy nodes as CHs. Moreover, the clusters formed are not balanced and hence not energy-efficient.

The first two issues can be addressed by introducing multi-level clusters and support for multi-hop routing. Next section proposes a protocol to overcome first two problems mentioned above related to LEACH. The third problem will be addressed in Chapter 4.

3.3 Tree based Adaptive Routing Protocol (TAR)

Tree based adaptive routing (TAR) technique is an extension of LEACH protocol, which is a self-organized cluster based approach for continuous monitoring. The basic LEACH protocol has been extended for energy-efficiency by many authors [Bandyopadhyay 2003, Hussain 2006]. However these protocols does not consider the energy loss associated with rebuilding phase in which all the nodes in the cluster participate in forming new clusters upon the request from the base node.

The main objective of TAR protocol is to generate energy efficient clusters for randomly deployed sensor nodes. Clusters are formed as an m-ary tree. The base station forms the root of the tree. The child nodes of the root are the cluster heads of the next level of nodes. This continues in a recursive manner until the leaves are reached which are ordinary member nodes. Each cluster is managed by its cluster head. The cluster heads of a particular level of the tree act as a member node of its parent cluster head. Cluster heads at various levels receive messages from cluster members and transmit the aggregated message to the immediate cluster head of the previous level (parent). A depiction of the structure formed is as shown in Fig. 3.5.

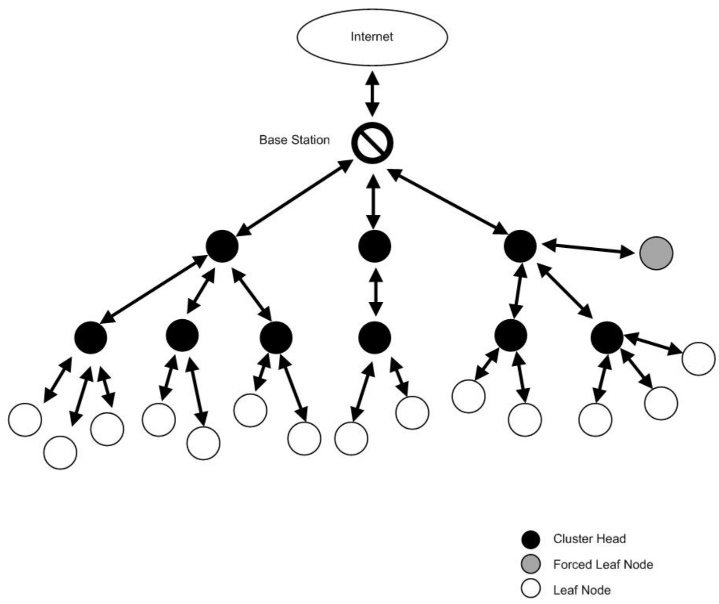

Figure 3.5: Structure of TAR

This process continues until the messages reach the base station. As all the transmissions are multi-hop, the messages are transmitted as short range broadcastmessages.

3.3.1 TAR Protocol details

Working of the protocol consists of an *election phase*, a *data transfer phase* and a *rebuilding phase*

- **Election phase:** In the election phase, the sensor nodes self organize into a new set of clusters where each set of cluster contains a cluster head. The base station issues a build request. In response to that, m nodes identify themselves as cluster heads of the first level. Each selected cluster head broadcasts a short-range advertisement. Each sensor node chooses its cluster head on the basis of the signal strength of the received advertisement. The sensor node will transmit short-range acknowledgement to inform their cluster head about their decision along with their node details. All the clusters heads which have more than m nodes assigned to it form m sub clusters. This process repeats recursively until all the cluster heads have less than or equal to m nodes. If any cluster head has no member nodes assigned to it, then it will be forced to function as an ordinary sensing node.

- **Data transfer phase:** In the data transfer phase, the leaf nodes transmit data to their respective cluster head and the cluster head transmits the aggregated data to the cluster heads at the previous level and so on. Here all data transmission are through levels so that the aggregated messages from one level are transmitted to the higher level in the hierarchy. This results in very little chance for data loss and data replication.

- **Rebuilding phase**. In the rebuilding phase, if the energy level of a cluster head falls below a threshold value, it sends a trigger message to its parent cluster head. That cluster head issues a rebuild request. Only the sub trees coming under that parent cluster head will be rebuilt without altering the remaining part of the network. This subsequently reduces the energy required for rebuilding.

The energy used in the network for the information gathered by the sensors to reach the processing center will depend on the value of m in our algorithm. Since the objective of the work is to organize the sensors in clusters to minimize this energy consumption, it is required to find out the value of m in the algorithm that would ensure minimization of energy consumption.

3.3.2 Analysis of the TAR algorithm

Total energy required by a hierarchical cluster system of wireless sensor nodes is calculated in [Bandyopadhyay 2003]. The method is adopted here to calculate the total energy required for the proposed tree based system. Following assumptions were made:

1. The sensors in the wireless sensor network are distributed as per a homogeneous spatial Poisson process of intensity λ in 2-dimensional space.

2. All sensors transmit at the same power level and they have the same radio range r.

3. Each sensor uses 1 unit of energy to transmit 1 unit of data.

4. The communication environment is contention free and error-free.

According to homogeneous spatial Poisson process, the number of sensors in a square area of side $2a$ is a Poisson random variable, N with mean λA , where A=$4a^2$. Let us assume that for a particular realization of the process there are n sensors in this area. Also assume that the processing center is at the center of the square. There will be m cluster heads at the first level. Let D_i

be a random variable that denotes the length of the segment from a sensor located at (x_i, y_i), i=1,2,..m to the processing center in the first level. Then from [Bandyopadhyay 2003],

$$E[D_i|N = n] = \int_A \sqrt{x^2 + y^2}\left(\frac{1}{4a^2}\right) dA = 0.765a \tag{3.1}$$

Since there are m CHs and the location of any CH is independent of the locations of other CHs, the total length of the segments from all these CHs to the processing center is $0.765ma$. The cluster heads and the non-cluster heads are distributed as per independent homogeneous spatial Poisson processes PP_1 and PP_0 of intensity $\lambda_1 = \lambda m/$n and $\lambda_0 =$ (1 - $m/$n)λ respectively.

The square area can be partitioned into a number of Voronoi cells, each of which corresponds to a PP_1 processing point, called its nucleus, which will form the first level cluster heads. If a Voronoi cell contains more than m PP_0 sensor nodes, the Voronoi cell is further divided into m number of Voronoi cells. i.e. m number of PP_0 nodes become PP_1 cluster heads of each interior Voronoi cell. This is repeated until each interior Voronoi cell contains less than or equal to m number of PP_0 sensor nodes.

With respect to each interior Voronoi cell, the data transmission is of single hop, where each PP_0 node broadcasts its sensed data to the corresponding PP_1 node as per its TDMA schedule. At this time, other nodes turn off their radios. PP_1 nodes aggregate the data and send it to the outer level Voronoi cells' PP_1 node and this process continues. Let L_v be the total length of all segments connecting the PP_0 process points to the nucleus in a Voronoi cell, then according to the result in [Foss 1996]

$$E[L_v|N = n] = E[L_v] = \frac{\lambda_0}{2{\lambda_1}^{3/2}} \tag{3.2}$$

The energy required to transmit one unit of data from all sensor nodes to respective cluster heads is given by

$$E[C_1] = \frac{E[L_v]}{r} \tag{3.3}$$

where C_1 is defined as the total energy used by the sensors in a Voronoi cell to communicate one unit of data to the cluster head.

The total energy required to transmit one unit of data by all the sensor nodes to respective cluster heads in the same level is given by

$$E[C_2] = m * E[C_1] \tag{3.4}$$

The total energy required to transmit one unit of data by all the sensor nodes to respective cluster heads in the i^{th} level is given by

$$E[C_2] = m^{i-1} * E[C_1] \tag{3.5}$$

The energy required to transmit one unit of data up to the cluster heads at level one is given by

$$E[C_3] = m^{i-1} * E[C_1] + m^{i-2} * E[C_1] + \cdots + m^2 * E[C_1] = \sum_{k=2}^{i-1} m^k * E[C_1] \tag{3.6}$$

The energy required to transmit one unit of data from the cluster heads at level one to the processing center is given by

$$E[C_4] = \frac{0.765ma}{r} \tag{3.7}$$

The total energy required by the system is given by

$$E[C] = E[C_3] + E[C_4] = \sum_{k=2}^{i-1} m^k * E[C_1] + \frac{0.765ma}{r} \tag{3.8}$$

where C is the sum of the total energy spent in the system.

3.3.3 Comparison of TAR with LEACH

In LEACH and other clustering protocols, the data transmission is through multiple hops, but in TAR protocol every data transmission is single hop. This invariably reduces the energy consumption per message and also the chance for data loss and data replication. Considering the rebuilding phase, in case of former protocols the entire network is rebuilt when the power of any cluster head goes down. But in case of TAR, only the sub trees related to that cluster head would be rebuilt without altering the remaining part of the network. This reduces the time and energy required for rebuilding. TOSSIM is used to evaluate the implemented protocols. A loss topology is defined which allows a node to communicate with all nodes within a 5×5 square around itself. Both the protocols were simulated for a period of 300 seconds. The power consumption of the routing protocols is calculated using the PowerTOSSIM. The simulation also tracks the number of messages sent, received and forwarded through each node.

3.4 Results and discussions

Power usage per node and power usage per message for the TAR protocol were found. The data were used to compute median and standard deviation (SD) and plotted graphically. The median of the power usage will give the average power consumption of the protocol across the network nodes. The standard deviation of the power usage per node will give an estimate of evenness of power consumption across the network nodes. Also the power usage per message is calculated to get the average power usage for each message sent across the network. The performance of the TAR protocol was compared with that of LEACH protocol for different number of nodes as shown in Figs. 3.6, 3.7 and 3.8. It can be observed that the energy consumption of TAR protocol is more evenly spread and the power usage per message sent is considerably less as the number of nodes increases. The energy saving during rebuilding plays a crucial role in

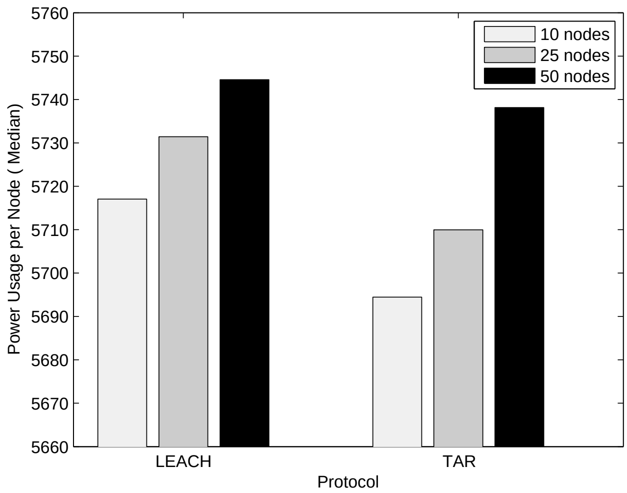

Figure 3.6: Power usage per node (Median)

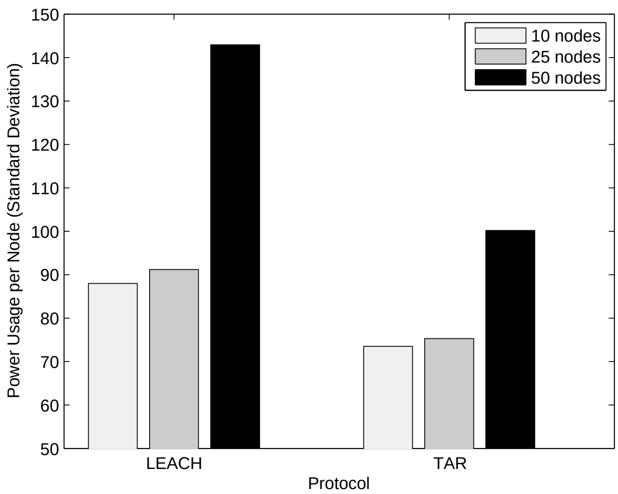

Figure 3.7: Power usage per node (Standard Deviation)

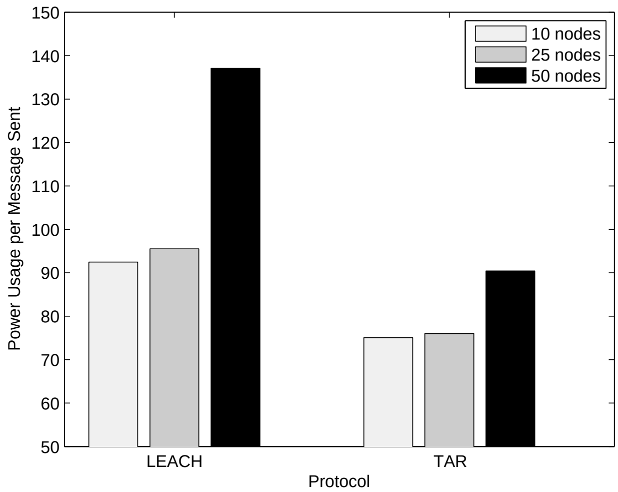

Figure 3.8: Power usage per message sent

energy consumption. This is because as the network becomes larger, in LEACH protocol a rebuilding results in entire restructuring of the network, where in TAR protocol only a small portion of the network (sub tree) is rebuilt. The protocol was simulated for various m values. It is found that higher and very low value of m will produce undesired effects and a medium m value (around 25%) is best suited.

3.5 Conclusions

The power consumption of four basic protocols were studied. The simulated value of energy consumption for each node as well as the total number of transmitted messages were studied for the protocols Flooding, Gossiping, GBR and LEACH. The median and standard deviation of energy consumption has shown that cluster based scheme is more energy-efficient than other schemes. The result was obtained by implementing these protocols in TinyOS and using power profiling tool PowerTOSSIM simulator. The implemented protocols can be directly used with real mica mote sensor nodes.

A new tree based multi-level routing scheme was suggested to overcome some problems with LEACH protocol. An analysis of energy consumption of the proposed protocol is presented. The scheme is compared with the LEACH protocol and it was found to provide better energy-efficiency. The tree structure of the proposed scheme uses multi-level data routing to minimize the energy consumption. The partial rebuilding of clusters in TAR also helps to minimize the energy overhead of LEACH. The simulation results show the TAR protocol enhances the total lifetime of the network. The tree structure of the TAR protocol also allows an efficient way to query the sensor network from the base station.

The next chapter addresses the issue of non-uniform clusters generated in the LEACH protocol.

CHAPTER 4

Energy Aware Cluster based Multi-hop Routing Protocol for Sensor Networks

Contents

4.1 Introduction

Clustering is one of the basic approaches for designing energy-efficient, robust and highly scalable sensor networks. Clustered organization dramatically reduces the communication overhead, thereby minimizing energy consumption and interference among the sensor nodes. Moreover, by aggregating the sensor's data at a designated node called cluster head (CH), the total amount of data to the base station can be reduced, saving energy and bandwidth resources. Since most of the clustering protocols are based on local properties, clusters generated by these protocols are often not optimal. In this backdrop, the question how to create a load balanced energy-efficient cluster assumes greater significance. Each clustering algorithm is composed of two phases namely, the set-up phase and steady state phase. The major issue in these algorithms is the CH selection. So, it is important to investigate how to select the best candidates for taking up the cluster head roles.

Clustering in a distributed environment is an interesting problem to work with. The quality of the clusters formed are determined by the clustering objectives, which was mentioned in section 2.3.1 of Chapter 2. A good clustering scheme should partition the network into clusters such that each node has at least one cluster head as its neighbor, thus a maximal independent set of CHs formed to have load balanced clusters. In addition, multi-hop communication is necessary for monitoring a large region since the communication range of sensor nodes are generally limited in order to conserve energy. So a combination of clustering and multi-hop communication is desirable for data collection on a large scale sensor network. In this chapter, a scheme for forming energy-efficient load-balanced clusters with an appropriate mechanism to elect cluster head is discussed. The proposed scheme is compared with the LEACH protocol.

4.1.1 Related Work

Many cluster based data gathering protocols have been proposed for sensor networks in literature and a comprehensive survey was presented in Chapter 2. LEACH is the base of most cluster based protocols and it uses a stochastic model for cluster head selection. In HCR [Kandula 2004], each cluster is managed by a set of associates and the clusters are retained for a longer period of time. Within each cluster the role of cluster head is rotated among the associate members using a round robin technique. HEED [Younis 2004b] uses a hybrid approach based on residual energy and communication cost to select cluster heads. In LEACH, HEED and HCR, each node probabilistically decides on its role and hence cannot guarantee optimal distribution of cluster heads. WCA [Chatterjee 2002] and DCA [Basagni 1999] are weight based clustering algorithms where node with highest weight is elected as cluster head. Weight is computed based on node's local properties such as node degree and residual energy. But defining a good weighing function is difficult.

When electing cluster heads, most distributed clustering techniques are based on local properties. Most of the distributed algorithms for cluster formation are often unsatisfactory due to the lack of information from neighbors. Clustering can be improved by incorporating information from neighbor nodes. ELCH [Lotf 2008a] and VCA [Qin 2005] achieve this by using a voting technique to elect the cluster heads, where the decision of a node to become a cluster head is determined by its neighbors. VCA uses a fitness function based on energy and node degree for load balancing in clusters. But vote calculation in VCA depends only on the residual energy of nodes and does not take into account the distances between the nodes. The voting technique in ELCH uses both the residual energy and distance. But optimal cluster formation in ELCH takes place only in the first round and clusters lack load balancing.

4.2 Proposed Scheme

Vote calculation in Energy Aware Cluster based Multi-hop Routing Protocol (EACM) is based on residual energy and distance between nodes as in the case of ELCH. The protocol achieves load balancing by rejecting join request from nodes if the size of a cluster goes beyond a maximum cluster size. Also nodes select the cluster head that has the minimum number of neighbors. EACM is proposed for both static and dynamic clustering schemes. The operation of EACM is broken up into fixed duration rounds, where each round consists of two phases: set-up phase and steady-state phase. During the set-up phase, nodes are organized into clusters and in the steady-state phase actual data transfer takes place. To minimize overhead, steady-state phase is long compared to set-up phase. In static-EACM, cluster formation takes place only in the first round and at the end of each TDMA frame the role of cluster head is rotated among the cluster members for even energy dissipation. In dynamic-EACM nodes are organized into clusters at the beginning of each round. The following sub sections discuss the two phases in detail.

4.2.1 Set-up phase

During the Set-up phase sensor nodes are organized into clusters. For cluster head selection a voting technique is used which ensures that the adaptability of a node to become a cluster head is reflected from all its neighbors. The cluster size is limited by a set maximum ($MAX\_CLUSTER\_SIZE$). For cluster formation, each node broadcasts residual energy level and computes the distance to its neighbors based on the strength of the received signal. Nodes compute and cast vote to neighbors based on residual energy and distance. The vote a node i casts to its neighbor j based on energy and distance is given in equation 4.1 [Lotf 2008b].

$$V(i,j) = \begin{cases} \dfrac{\left[\dfrac{e_j}{dij}\right]}{\sum\limits_{d_{ik} \leq R} \dfrac{e_k}{d_{ik}}} & d_{ij} \leq R \\ \\ 0 & d_{ij} > R \end{cases} \tag{4.1}$$

Nodes collect vote from neighbors and broadcast the total vote received. If a node finds that it has the highest vote among its neighbors, it declares itself as the cluster head by sending the cluster head advertisement (CH_ADV). Non cluster head nodes send join request ($JOIN\_REQ$) to the neighbor cluster head that has the minimum node degree.

Selecting the cluster head with minimum node degree helps to balance the size of the clusters formed. If the number of JOIN_REQ a cluster head has received is more than MAX_CLUSTER_SIZE, it sends REJ_JOIN message which contains the node IDs of rejected nodes. This rejection is based on the following criteria:

1. The nodes that have heard the maximum number of CH_ADV will be rejected.

2. In case of a tie, the nodes that are far away from the cluster head will be rejected.

The cluster heads whose cluster size equals the MAX_CLUSTER_SIZE and nodes which are cluster members withdraw from the clustering process by sending the WITHDRAW message and go to the sleep mode. The cluster heads whose cluster size is less than the maximum cluster size remain active to receive more JOIN_REQ in the next round. The active non cluster head nodes repeat the clustering procedure until all nodes are covered. After cluster formation, all nodes switch to the active mode. Cluster head nodes prepare and transmit TDMA schedule to cluster members. A detailed description of the process is given in Algorithm 1.

4.2.2 Steady-state phase of static-EACM

In static-EACM, clusters are formed during the set-up phase of the first round. These clusters remain same throughout the network lifetime but the role of the cluster head rotates among the members of the cluster. Nodes send their data to the cluster head at most once per frame during their allocated TDMA slot. The duration of each slot in which a node transmits data is constant, so the

Algorithm 1 Cluster Generation

Initialize Broadcast Neighbour_Msg (NodeID, Res_Energy)

S_{nbr} = {n |n is within my transmission range R}

$S_u = S_{uncovered} = S_{nbr}$, $S_{CH} = \emptyset$, $S_{WD} = \emptyset$, IS_CH=false, cluster_size=0, IS_CLUSTER_MEMBER=false, MY_CH=$\emptyset$, degree(node)= $|S_u|$

node i estimates distance d_{ij} to j $\in S_u$

Clustering

repeat
Node i computes and casts vote v(i, j) to neighbor j S_u using equation (1) and collects the votes
total vote(NodeID) = $\sum_{j \in S_u} v(j, NodeID)$
Broadcast total vote and then collect total vote from neighbors
if (total vode(NodeID) $\geq$ max {total vote(n) | n $\in S_u$}) **then**
IS_CH= true, MY_CH=NodeID, send CH_ADV
collect incoming CH_ADVs
$S_{CH} = S_{CH} \cup$ {n | CH_ADV heard from n}
if (IS_CH && $S_{CH} \neq \emptyset$) **then**
MY_CH = {n | n S_{CH} && degree (n) is minimum}
IS_CLUSTER_MEMBER=true, send JOIN_REQ to CH
if (IS_CH) **then**
collect JOIN_REQ
cluster_size = $\sum$ JOIN_REQ
if (IS_CH && cluster_size > MAX_CLUSTER_SIZE) **then**
send REJ_JOIN to (*cluster_size* - MAX_CLUSTER_SIZE) nodes based on JOIN_REQ rejection criteria
collect REJ_JOIN
if (node $\in$ REJ_JOIN) **then**
MY_CH =$\emptyset$, IS_CLUSTER_MEMBER=false
if (IS_CH && *cluster_size* == MAX_CLUSTER_SIZE \|\| IS_CLUSTER_MEMBER) **then**
send WITHDRAW message, go to sleep mode
collect WITHDRAW message $S_{WD} = S_{WD} \cap$ { n | WITHDRAW heard from n}
S_u = { n | n S_{nbr} and n S_{CH} and n S_{WD}}
until (MY_CH $\neq \emptyset$)

time to send a frame depends on the number of nodes in the cluster. Nodes wake up only during their allocated slot and transmit data and residual energy level to the cluster head. Fig. 4.1 shows the network operation of EACM with static and dynamic clusters. Cluster heads aggregate the data collected from

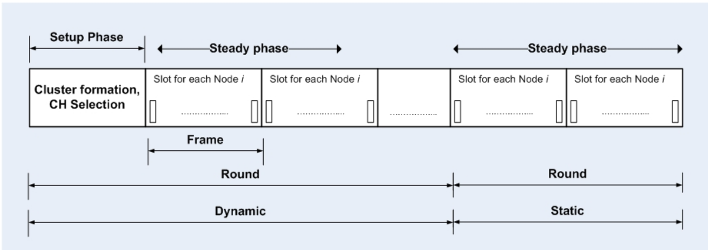

Figure 4.1: Network operation of static and dynamic EACM

their member nodes and transmit the compact data to the base station. Cluster heads communicate with other cluster heads to form multi-hop paths by sending beacons at inter cluster communication range. This helps to avoid redundant transmissions to the base station during multi-hop communication. The next

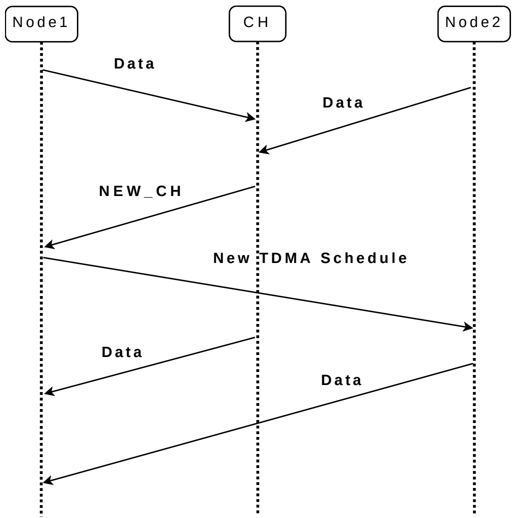

Figure 4.2: Mobile node chooses new CH in EACM

hop cluster head that has the highest residual energy is selected to forward the data packet to the base station. At the end of each TDMA frame cluster head nodes select the node that has the highest energy among its members as the new cluster head for the next round by sending the NEW_CH message. The sequence of messages transmitted during steady-state phase of static EACM is shown in Fig. 4.2.

4.2.3 Steady-state phase of dynamic-EACM

The problem with static-EACM is that the nodes that belong to the small sized clusters deplete their battery power rapidly since they have to perform the energy consuming task of cluster head more frequently. In order to avoid this, clustering is made dynamic where nodes organize into clusters during the set-up phase of each round using the same clustering algorithm described in section 4.2.2. To minimize the clustering overhead steady-state operation is divided into fixed number of TDMA frames. Nodes sense and transmit their data to the cluster head on the allocated TDMA slot. The cluster head receives data from all its members, aggregates it and transmits it to the base station by using multi-hop communication. Choosing the cluster head with more residual energy as relay node, helps to balance energy consumption. Cluster head nodes retain their role until the next round.

4.3 Simulation and performance evaluation

4.3.1 Radio Model

In this work, the first order radio model [Heinzelman 2000] is used. Fig. 4.3 depicts the model. The radio dissipates E_{elec} = 50nJ/bit to run the transmitter and receiver circuitry and ε = 100pJ/bit/m^2 for the transmitter amplifier. In order to transmit a k bit packet over a distance d, the energy spent on the radio is given by Equation 4.2

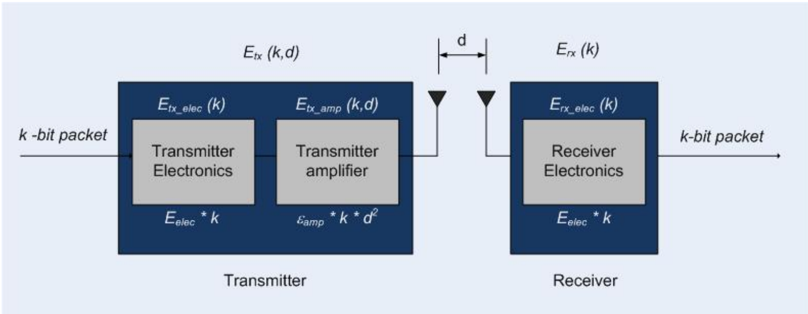

Figure 4.3: Radio Model

$$
\begin{aligned}
E_{Tx}(k,d) &= E_{Tx-elec}(k) + E_{Tx-amp}(k,d) \\
E_{Tx}(k,d) &= E_{elec} * k + \varepsilon * k * d^2
\end{aligned}
\tag{4.2}
$$

and to receive a packet of length k bits the radio expends:

$$
\begin{aligned}
E_{Rx}(k) &= E_{Rx-elec}(k) \\
E_{Rx}(k) &= E_{elec} * k
\end{aligned}
\tag{4.3}
$$

4.3.2 Network Model

To evaluate the performance of LEACH and EACM the following network model is used. The network consists of 100 nodes deployed randomly to continuously monitor a 500 × 500 m^2 area. Base station is located outside the sensor field. All nodes are position unaware and homogeneous. The nodes are capable of operating in active mode and low power sleep mode and they can use power control to change the transmission range for intra cluster and inter cluster communication. Initial energy of each node is assumed as 10J and data size as 250 bytes.

4.3.3 Performance Evaluation

The performance of LEACH protocol for different percentage of CHs (p) is evaluated. From the results shown in Fig. 4.4, it is observed that there exists an

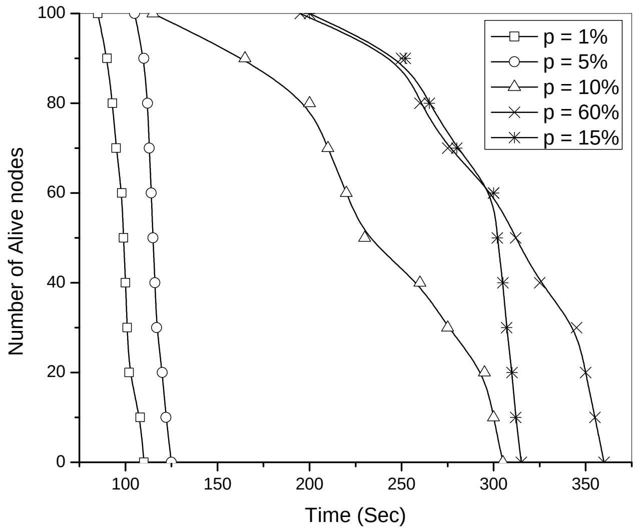

Figure 4.4: Performance of LEACH for various %of CHs

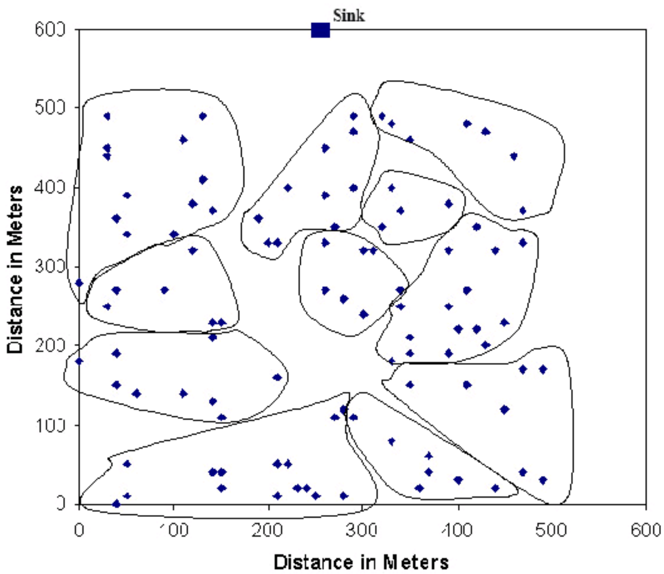

Figure 4.5: Non uniform clusters formed in LEACH

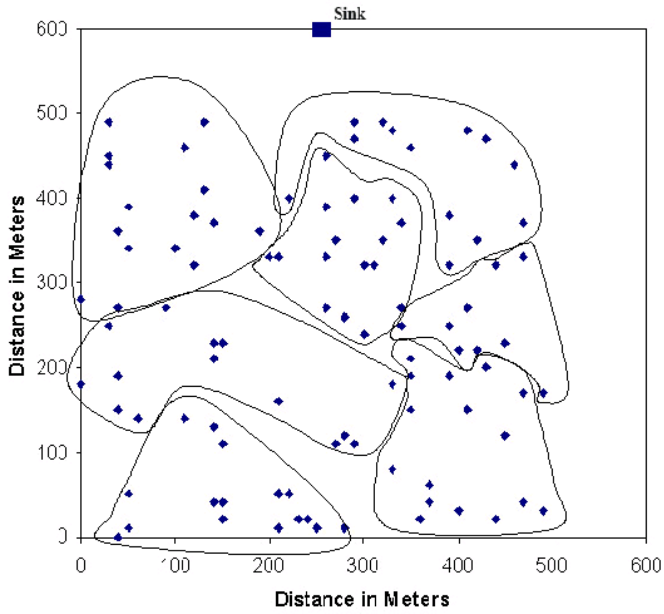

Figure 4.6: Uniform clusters formed in EACM

optimal range for the value of p [Heinzelman 2000]. If the value of p goes below this range, the number of clusters formed will be low and some nodes in the network have to transmit their data very far to reach the CH, causing more energy wastage. If it goes above the optimal range the number of clusters formed will be high, which in turn increases the number of direct communications to the base station. The clusters generated in a specific round of LEACH and EACM is shown in Fig. 4.5 and Fig. 4.6. It can be argued that more load balanced clusters are generated for EACM when compared with LEACH. The voting scheme and the restriction on number of nodes that joins with a particular CH has resulted in uniform clustering.

The performance of static and dynamic EACM is compared with that of LEACH. Fig. 4.7 shows the number of alive nodes in the network over time with direct communication between cluster heads and base station. It can be observed that first node death occurs earlier in LEACH compared to static-EACM. This

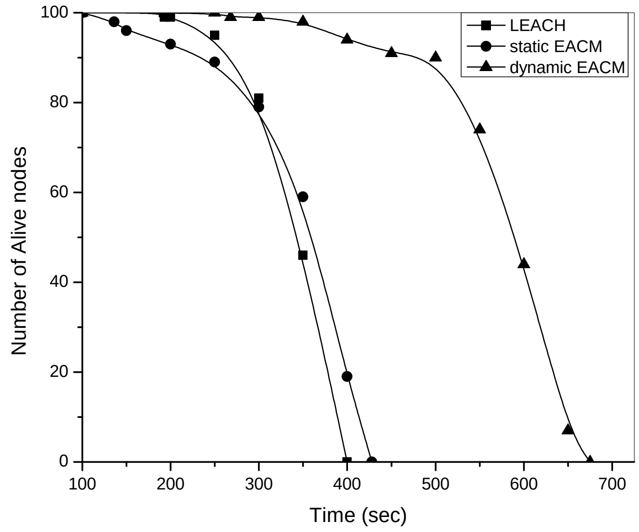

Figure 4.7: Network lifetime: direct communication

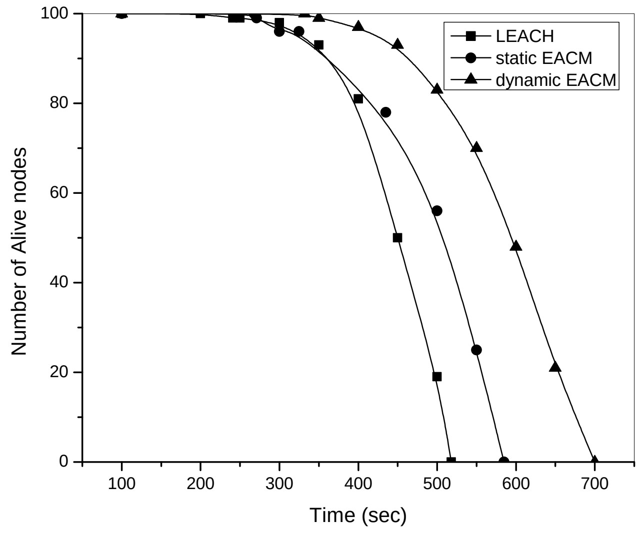

Figure 4.8: Network lifetime: multi-hop communication

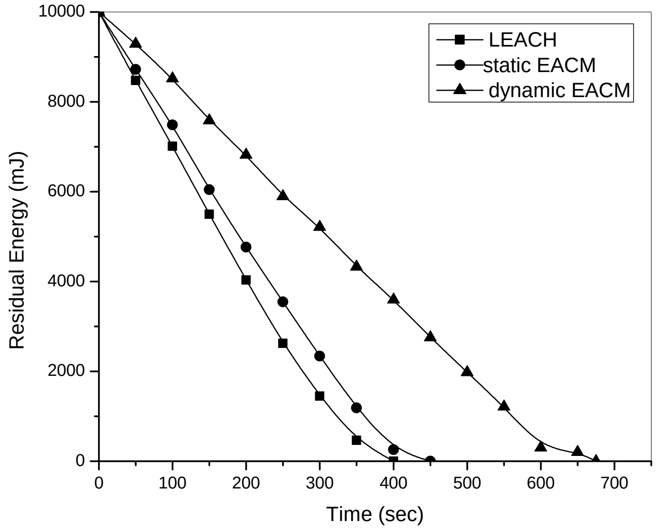

Figure 4.9: Energy dissipation: direct communication

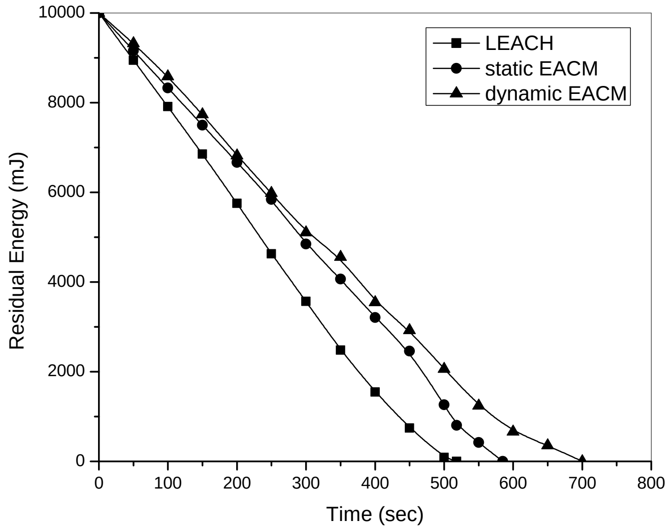

Figure 4.10: Energy dissipation: multi-hop communication

is because nodes that belong to small sized clusters dies first since these nodes have to perform the high energy consuming task of cluster head more frequently.

EACM's static clustering performs better than LEACH on the average lifetime of sensor nodes. Dynamic-EACM outperforms LEACH and its static clustering version on both first node death time and average sensor lifetime. Fig. 4.8 plots network lifetime over time with multi-hop communication between cluster heads for transmitting messages to the base station.

Fig. 4.9 and Fig. 4.10 shows the average residual energy of sensor nodes over time for direct and multi-hop communication. It can be seen that energy consumption in EACM is lower than in LEACH.

4.4 Conclusions

EACM takes advantage of hierarchical topology of clustering to maximize the lifetime of wireless sensor networks. It uses a voting based clustering algorithm to distribute the cluster heads uniformly throughout the network. In static-EACM the role of cluster head is rotated among the cluster members to balance the energy consumption within clusters. In dynamic-EACM nodes are re-clustered and new cluster heads are elected after each round for even energy dissipation. Also the cluster head nodes organize themselves to perform multi-hop communication to the base station which significantly reduces the energy consumption. Most of the clustering algorithms presented in the literature uses local properties like nodes remaining energy to elect cluster head. This study reveals that the neighbor node information plays an important role in deciding a node to become cluster head or not.

Chapter 5

Impact of Mobility on Routing Protocols

Contents

5.1 Introduction

Research on mobile Wireless Sensor Networks (MWSNs) is quite interesting and recent. Mobility in these networks has been exploited for improving sensing and communication coverage. The sensors move into positions that minimize the energy cost of reporting streams of data to the sink [Goldenberg 2004]. The coverage hole problem is addressed by moving sensors from areas that are densely deployed to areas with coverage holes [Wang 2006]. The distributed algorithms for the mobility of sensor nodes have been investigated [Rao 2004] where mobility algorithms are proposed to move the nodes to positions that reduce transmission power needed to send the data to the sink.

The dynamic nature of mobile wireless sensor networks introduces unique challenges in aspects like data management, accuracy and precision, coverage, routing protocols, security and software support. Many of the problems mentioned above which are related to static deployment of the sensors are well addressed by the researchers. One of the most important constraints on sensor nodes is routing data when the nodes are mobile. The conventional routing protocols for static sensor networks may not be suited or are to be optimized once mobility is introduced. To study the performance of routing protocols under such conditions, the mobility patterns of the entire network is to be considered. This chapter examines the performance issues especially on routing associated with mobility in WSN.

The impact of node mobility on routing protocols across different sets of mobility patterns is investigated. The well-known MANET protocols; Dynamic Source Routing (DSR), Destination-Sequenced Distance-Vector(DSDV) and Ad Hoc On-Demand Distance Vector Routing (AODV) have been taken into consideration for the study. The routing protocols behavior under the models like Random Way Point (RWP), Freeway (FW), Manhattan Mobility Model (MH) and Reference Point Group Mobility (RPGM) are of interest. The metrics end-to-end delay, throughput and normalized routing load were chosen to investigate the routing behavior. The chosen protocols for the study and the mobility models are briefly described below.

5.2 Routing Protocols

The ad-hoc routing protocols are mainly divided into two categories:

- Table-driven routing protocols: In table driven routing protocols, each node maintains the route table containing consistent and up-to-date routing information about all nodes in the network.

- On-Demand routing protocols: Whenever a source node wants to send data to a destination node, it first finds out the path to the destination using route discovery mechanism. It is suitable for networks where frequency of communication is minimum since the routing overhead is less.

A number of routing protocols like DSDV, DSR, AODV and Temporally-Ordered Routing Algorithm (TORA) are normally used in ad hoc networks.

5.2.1 Destination-Sequenced Distance-Vector Routing (DSDV)

The DSDV routing algorithm [Perkins 1994] is built on top of Bellman-Ford routing algorithm. In this routing protocol, each mobile node in the network keeps a routing table. Each of the routing table contains the list of all available destinations and the number of hops to reach. Each table entry is tagged with a sequence number which is originated by the destination node. Periodic transmissions of updates of the routing tables help maintaining the topology information of the network. If there is any new significant change for the routing information, the updates are transmitted immediately. So the routing information updates might either be periodic or event driven. DSDV protocol requires each mobile node in the network to advertise its own routing table to its current neighbors. The routing updates could be sent in two ways: one is called a full dump and the other is incremental. In case of full dump the entire routing table is sent to the neighbors where as in the case of incremental update, only the entries that require changes are sent. Full dump is transmitted relatively infrequently when no movement of nodes occurs. The incremental update could be more appropriate when the network is relatively stable so that extra traffic could be avoided. But when the movements of node becomes frequent full dumps could be used.

5.2.2 Dynamic Source Routing (DSR)

In this protocol [Johnson 1996], the mobile nodes are required to maintain route caches or the known routes to dynamically discover route from the source to the destination. The route cache is updated when any new route is known for a particular entry in the route cache. Routing in DSR is done using two phases: route discovery and route maintenance. When a source node wants to send a packet to a destination, it first consults its route cache to determine whether it already knows about any route to the destination or not. If there is already an entry for that destination, the source uses that to send the packet. If not, it initiates a route request broadcast. This request includes the destination address, the source address and a unique identification number. Each intermediate node checks whether it knows about the destination or not. If the intermediate node does not know about the destination, it again forwards the packet and eventually this reaches the destination. A node processes the route request packet only if it has not previously processed the packet and its address is not present in the route record of the packet. A route reply is generated by the destination or by any of the intermediate nodes when it knows about how to reach the destination.

5.2.3 Ad-hoc On-Demand Distance Vector (AODV) Routing

AODV [Perkins 1999] is basically an improvement of DSDV. But, AODV is a reactive routing protocol and not proactive. It minimizes the number of broadcast by creating routes based on demand, which is not the case for DSDV. When any source node wants to send a packet to a destination, it broadcasts a route request (RREQ) packet. The neighboring nodes in turn broadcast the packet to their neighbors and the process continues until the packet reaches the destination.

During the process of forwarding the route request , intermediate nodes record the address of the neighbor from which the first copy of the broadcast is received. This record is stored in their route tables, which helps for establishing a reverse path. If additional copies of the same RREQ are later received, these packets are discarded. The reply is sent using the reverse path.

5.3 Mobility Models

There is much attention currently focused on the development and evaluation of wireless routing protocols for wireless sensor networks. Most of this evaluation have been performed with the aid of various network simulators (such as ns-2 and others) and synthetic models for mobility and data patterns. These models have a great effect upon the results of the simulation and thus the evaluation of protocols. Some of the models being considered in the present work are listed below [Camp 2002].

5.3.1 Random Waypoint (RW) Model

The Random Waypoint model is the most common mobility model used by the research community. This model is an extension of random walk. In this a node starts its journey from a point, chooses a velocity between [0, V_Max] towards an intermediate destination in a random manner. It stays at the intermediate location for a specified period called pause period and at the end of pause period the node propagates to a new random destination with a new chosen velocity. This mobility model is incorporated in the network simulator ns-2.

5.3.2 Reference Point Group Mobility (RPGM) Model

In the RPGM model, a node is selected as a leader in a random fashion and other nodes forms a group around it. The group center moves on a predefined trajectory. By choosing the trajectory of the groups, several realistic scenarios can be obtained. If the groups are maintained as disjoint they can simulate the movements of a deployed military group that performs similar actions in different parts of the battlefield. In this model, each node deviates its speed and direction from that of the leader as follows:

- Velocity member (t) = Velocity leader (t) + random () * SDR * Max_speed
- Angle member (t) = Angle leader (t) + random () * ADR * Max_angle

Where 0 <= SDR, ADR <= 1. SDR is the Speed Deviation Ratio and ADR is the Angle Deviation Ratio. SDR and ADR are used to control the deviation of the velocity (magnitude and direction) of group members from that of the leader. Since the group leader mainly decides the mobility of group members, group mobility pattern is expected to have high spatial dependence for small values of SDR and ADR.

5.3.3 Freeway Mobility (FW) Model

The FW model emulates the motion behavior of mobile nodes on a freeway. It can be very well used in exchanging traffic status or tracking a vehicle on a freeway. In this model maps are being used. There are several freeways on the map and each freeway has lanes in both directions. The following are the differences between Random Waypoint and Freeway:

- Each mobile node is restricted to its lane on the freeway.
- The velocity of mobile node is temporally dependent on its previous velocity. Formally, vecVelocityi(t+1) = vecVelocityi(t) + random() * vecai(t)
- If two mobile nodes on the same freeway lane are within the Safety Distance (SD), the velocity of the following node cannot exceed the velocity of preceding node. Formally, for all i, for all j,for all t if Di,j(t) < Safety_Distance, then vecVelovityi(t) < vecVelocityj(t), if j is ahead of i in its lane.

Due to the above relationships, the Freeway Mobility pattern is expected to have spatial dependence and high temporal dependence. It also imposes strict geographic restrictions on the node movement by not allowing a node to change its lane.

5.3.4 Manhattan Mobility (MH) Model

Manhattan Mobility model is useful in modelling movements in an urban area where a pervasive computing service between portable devices is provided. In this model maps composed of a number of horizontal and vertical grids are used to model the streets. The mobile node is allowed to move along the grid of horizontal and vertical streets on the map. At an intersection of a horizontal and a vertical street, the mobile node can turn left, right or go straight with certain probability. Except the above difference, the inter-node and intra-node relationships involved in the Manhattan model are very similar to the Freeway model. Thus, the Manhattan mobility model is also expected to have high spatial and temporal dependence. It too imposes geographic restrictions on node mobility. However, it differs from the Freeway model in giving a node some freedom to change its direction.

The general metrics that differentiates one mobility model from other are:

1. Velocity of specified node at a particular instant of time t.
2. Speed of specified node at a particular time t.
3. Angle made by Velocity vector at time t with the X-axis
4. Acceleration vector of node at time t.
5. X, Y, Z co-ordinate of node at time t.
6. Node to node distance at time t.
7. Transmission range of a mobile node.

8. Number of mobile nodes.

9. Degree of Spatial Dependence: It is the extent to which the velocities of two neighboring nodes are similar.

10. Degree of Temporal Dependence: It is the extent of similarity of the velocities of a node at two time slots that are not too far apart. It is a function of the acceleration of the mobile node and the geographic restrictions.

5.4 Simulation Model

In this work ns-2 (http://www.isi.edu/nsnam/ns/) simulation tool is used for evaluation of the protocols under various mobility models. ns-2 supports simulating multi-hop wireless networks in compliance with physical, data link, and medium access control (MAC) layer. IEEE 802.11 for wireless LANs is used as the MAC layer protocol. An un-slotted carrier sense multiple access (CSMA) technique with collision avoidance (CSMA/CA) is used to transmit the data packets. The radio model uses characteristics similar to a commercial radio interface with a bit rate of 2 Mb/s and a nominal radio range of 150 m. The protocols maintain a send buffer of 50 packets. It contains all data packets waiting for a route. When a packet waits more than 60 seconds in the buffer it will be dropped to avoid indefinite buffering. All packets (both data and routing) sent by the routing layer are queued at the interface until the MAC layer transmits them. The interface queue has a maximum size of 50 packets (512 bytes per packet) and is maintained as a priority queue with two priorities each served in FIFO order. Routing packets get higher priority than data packets. To generate packets a Continuous bit rate (CBR) traffic source is used. The source-destination pairs are spread randomly over the network. The number of source-destination pairs and the packet-sending rate in each pair is varied to change the offered load in the network. The mobility models are simulated using the tool IMPORTANT [Bai 2003] which generates the scenarios that can be directly called from ns-2 script. The simulation configuration uses a 1000 m $\times$ 1000 m field with a maximum of 40 nodes. Each packet starts its journey from a random location to a base station with a chosen scenario. Once the destination is reached, another random source is targeted. Simulations are run for 850 simulated seconds. Identical traffic scenarios are used across protocols to gather fair results. Most of the analysis are done using Trace graph; a network trace file analyzer used for network simulator ns-2 for processing of traces.

5.5 Experiment

The main focus is given to see whether mobility affects protocol performance or not. The performances of DSR, AODV and DSDV across different set of mobility models are simulated and tested. The main metrics used for studying performance of the protocols are End-to-End delay, throughput and normalized routing load. The normalized routing load is the ratio of number of routing packets sent to that of the number of data packets received at the destination. This ratio evaluates the efficiency of routing in terms of extra load introduced to the network by mobility. The end-to-end delay variations against throughput for various mobility models are studied first. Fig. 5.1 shows the variations for routing protocols using mobility model Freeway. In DSDV, the delay increases almost linearly with the throughput except for very low and very high throughput. The traces are obtained by fixing the number of nodes to 10 and speed at 10 m/s. In AODV and DSR when throughput is low the delay increases steeply. But for medium range of throughput it linearly decreases. The relative ranking of AODV and DSR seems to be comparable in Freeway model. In RPGM mobility model the delay variation shown for various routing protocols is given in Fig. 5.2. In the RPGM mobility model, the delay remains almost the same for entire throughput except for low throughput for the DSR protocol. The DSR shows a steady performance irrespective of the variations. The DSR outperforms the

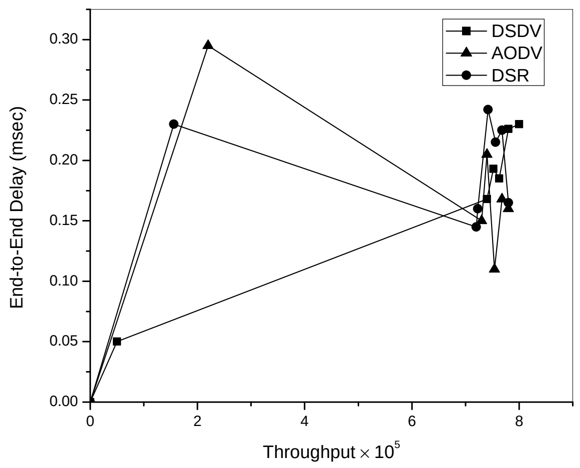

Figure 5.1: End-to-End delay variations Vs Throughput: Freeway

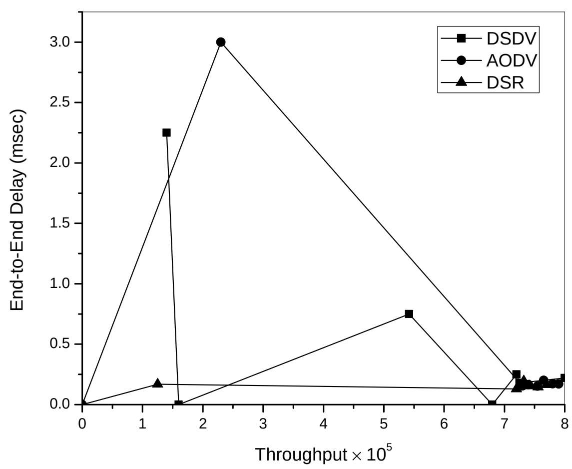

Figure 5.2: End-to-End delay variations Vs Throughput: RPGM

AODV and DSDV protocols.

In AODV for middle range of throughput the performance is comparable as in Freeway model. In DSR the delay dip rate is negligibly small compared to AODV. In Manhattan mobility model the delay variation for various routing

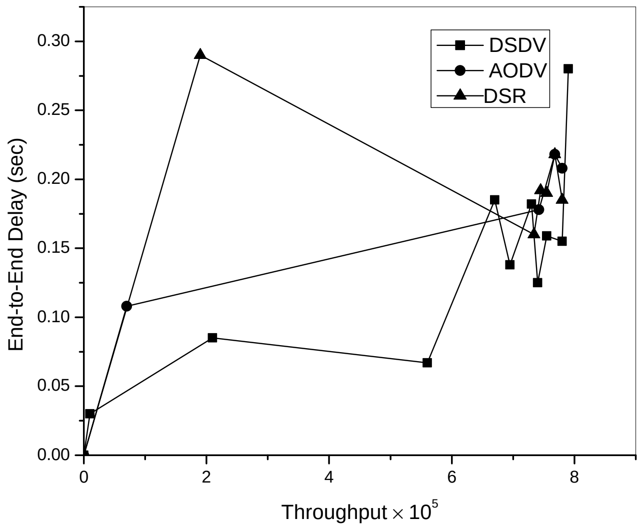

Figure 5.3: End-to-End delay variations Vs Throughput: Manhattan

protocols is shown in Fig. 5.3. In this mobility model, AODV and DSDV perform better compared to DSR. In all the three mobility models the AODV and DSR routing are comparable, whereas DSDV protocol is very much dependent on the mobility pattern. Since DSDV belongs to proactive table driven category, mobility variations can easily affect routing performances. The variation of end-to-end delay against number of nodes for Freeway mobility model is shown in Fig. 5.4.

It is observed that as the number of nodes increases the AODV and DSDV perform worst compared to DSR. In DSDV an increase in overhead of routing messages is observed when the number of nodes is increased. The DSR may not cause any drastic end-to-end delay variations since it is an on-demand protocol.

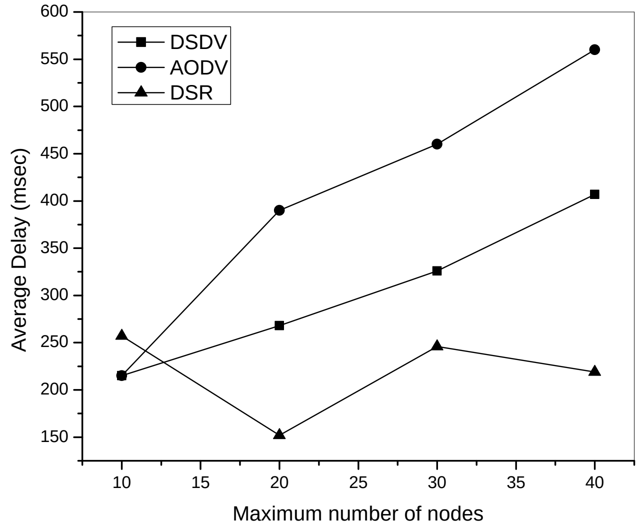

Figure 5.4: Delay variations Vs Number of nodes: Freeway

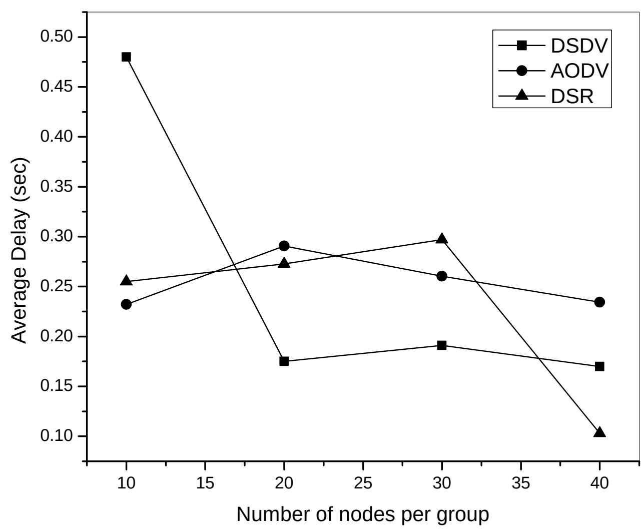

Figure 5.5: Delay variations Vs Number of nodes: RPGM

The speed maintained for all the traces is 10 m/s. The RPGM routing protocol makes use of the relative properties of group action. The delay is almost comparable for medium range of nodes per group, whereas the routing suffers for lower range in DSDV. As observed from Fig. 5.5, DSDV makes use of multi-hoping

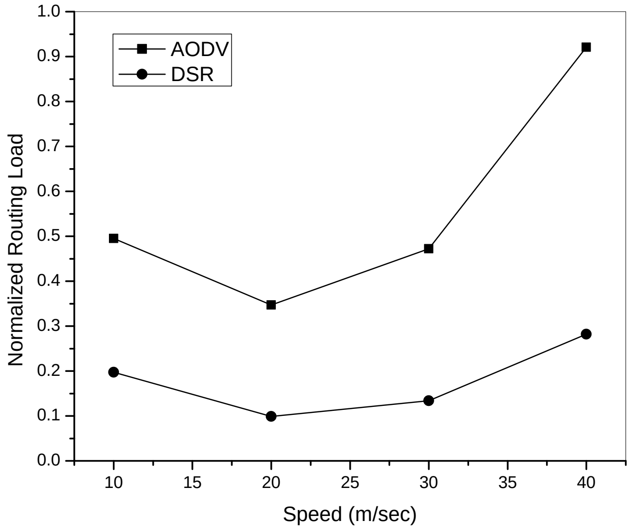

Figure 5.6: Normalized routing load Vs Speed variations: Freeway

concept well. As the group crowd reduces the node degree affects the routing. To plot the above figure speed deviation (0.1), angle deviation (0.2) and number of groups (one) are kept constant.

Normalized routing load against the speed variation is shown in Fig. 5.6. The routing overhead is less in DSR compared to AODV. Since the DSDV offers relatively very high routing loads (30 times more than that of AODV), it is not taken into consideration for the study. The very high overhead observed in DSDV is due to flooding of routing packets across the nodes periodically. But in all the other cases the routing load overhead increases with mobility.

As shown in Fig. 5.7, routing load shoots up in DSDV as the number of nodes increases. When the number of nodes increases AODV outperforms DSR. Even

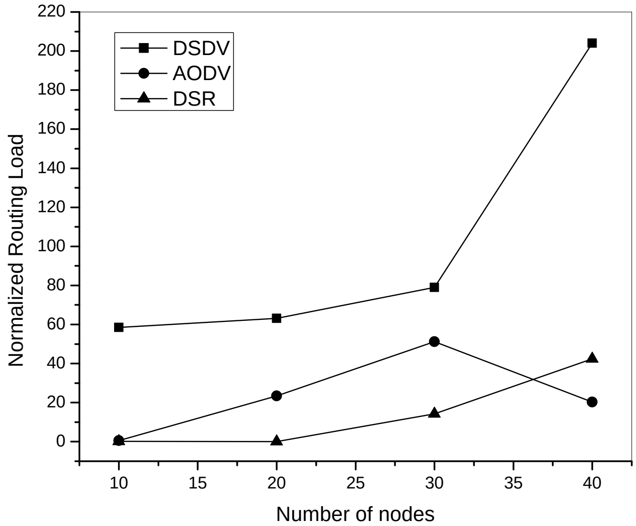

Figure 5.7: Normalized routing load Vs Number of mobile nodes: Freeway

though all of the protocols make use of multi-hoping, DSDV does not perform like DSR due to the extra overhead incurred in message exchanges overriding the benefits of multi-hoping.

In all other cases, DSR demonstrates significantly lower routing load than AODV and DSDV when the number of nodes are increased.

The studies on routing protocol for various mobility models are concluded thus:

- End-to-End Delay Comparison: DSDV and DSR offer similar fractions for Freeway and Manhattan mobility models, whereas in RPGM, DSR offers a flat performance irrespective of throughput variations.

- Average delay with respect to number of nodes: In Freeway, DSR outperforms AODV and DSDV. But all the three routing protocols show that delay increases with increase in node size. In RPGM, AODV and DSDV out perform DSR when number of nodes increases.

- Normalized Routing Load: DSDV offers very high routing overhead compared to AODV and DSR.
- Routing Load: AODV outperforms DSR and DSDV when the number of nodes increases.

5.6 Conclusions

In this chapter the impact of mobility pattern on routing performance of mobile sensor network is studied using a simulated environment. It is observed that the mobility pattern of nodes has great influence on the performance of routing protocols. The conclusion is consistent with the similar studies done in this area. The study has compared different routing protocols and it was found that performance rankings of the protocol metrics vary with mobility patterns. It can be inferred that the choice of a routing protocol heavily depends on the underlying mobility pattern of the application under consideration.

Chapter 6

LEACH-Mobile Enhanced

Contents

6.1 Introduction

This chapter describes the design and analysis of a scheme for data routing that is suitable in mobile centric wireless sensor network applications. Designing energy-efficient routing protocols for such applications is challenging due to the frequent changes in the network topology. Cluster based protocols are more useful in the context of energy-efficiency but most of the protocols suggested in the literature do not support node mobility. When mobility is introduced in cluster based routing schemes it is important to ensure a constant connectivity between the nodes; especially between a data collector node and a cluster head (CH). This results in minimum loss of data when nodes are sending data to CH. Also, the scheme should consider re-joining of the nodes when a node leaves from one cluster to another. Cluster head election algorithm plays an important role to keep the clusters durable. The LEACH-ME protocol assumes basic clustering operations defined in LEACH protocol except all nodes are mobile. The basic idea of the proposed protocol is to make sure as much as possible that the cluster heads are from the group of mobile nodes having minimum node mobility or they are in a group motion with the other cluster members. By doing the modified election process for cluster heads or modified rotation of duty of cluster heads, the protocol makes sure that the clusters are disturbed minimally in the event of movement of cluster heads.

6.1.1 Related Work

This section briefly outlines the related work in mobile sensor network (MSN) and LEACH protocol improvements. Researchers have only recently started to study the sensor movement and unique attributes of mobile sensor networks, since the sensor networks were originally assumed to consist of only static nodes. It has been suggested that the mobility of sensor nodes improves the sensing coverage [Liu 2005]. Robotic Fleas project in Berkeley [Bergbreiter 2007], Robomote [Dantu 2005] and Parasitic Mobility [Laibowitz 2005] were attempts to enable mobility in sensor networks. It is shown that data mule approach can be used to efficiently collect the data by minimizing the data delivery latency with minimum energy consumption in a controlled mobile sensor network[Anastasi 2007]. A number of approaches exploiting mobility for data collection in sensor networks are discussed [Ekici 2006]. Adaptive Sampling and Prediction (ASAP) (http://engineering.princeton. edu/gallery/asap/index.htm) is a real world application of MSN where a fleet of undersea mobile sensor nodes coordinate and collect measurements of ocean parameters without human intervention. A sensor network based adaptive navigation system has been developed [Chen 2008] where sensors equipped on vehicles collect real-time traffic information and exchange among the neighbour vehicles. A mobility management service layer is proposed in SensorNet Protocol [Ali 2006]. It is a cross layer approach where mobility information is stored in a database visible across all layers. A new concept called network dynamics is introduced to solve mobility management issues [Ma 2008]. This work is an early attempt to formulate laws that govern mobility motivated by classical dynamics that study the movement of objects. In short, mobility of sensor nodes is of great importance and there is an uprising research trend towards the leverage node mobility to enhance network performance in terms of energy-efficiency, coverage, lifetime, localization and fault tolerance.

6.1.2 LEACH Protocol Enhancements

Low Energy Adaptive Clustering Hierarchy (LEACH) [Heinzelman 2002], is one of the most popular hierarchical routing protocols for wireless sensor networks. The idea is to form clusters of the sensor nodes based on received signal strength indicator (RSSI) and use local cluster heads as routers to the sink. LEACH has motivated the design of several other protocols which try to improve upon the cluster-head selection process [Yang 2007]. LEACH protocol does not consider the mobility of sensor nodes. In mobility centric environments an agent based data collection scheme is put forward where a mobile agent effectively processes the data and saves the total energy spent by the network [Hee-Jin 2008, Arboleda C. 2006]. LIMOC [Banerjee 2007] is a scheme to enhance the life time of network in which energy rich moving cluster heads collaborate intelligently each other to route the data to the base station. The enhancement to LEACH to support mobility is introduced as LEACH-Mobile, in short LEACH-M [Kim 2006b]. The basic idea in LEACH-M is to confirm whether a mobile sensor node is able to communicate with a specific cluster head.

6.2 LEACH Mobile Enhanced Protocol

The study adopts the proposals in the LEACH-M protocol and extends it by proposing the concept of remoteness for cluster head election. This section explains the cluster head election and maintenance of both LEACH-M and LEACH-ME protocols.

6.2.1 LEACH Routing Phases

The LEACH operations are mainly in two major phases - Set-up phase and Steady-state phase. Set-up phase is the initial one and this is the phase where all cluster formation takes place. This phase is relatively short compared to the steady-state phase. In this phase, one of the basic ideas in LEACH-ME is to confirm the election of specific cluster heads which either have no node movement or minimum relative node movement. In the steady-state phase, the cluster head and non-cluster head nodes receive a particular message at a given time slot according to TDMA time schedule of sensor cluster, and then reorganize the cluster with minimum energy consumption. The steady state phase does the actual data transfer between the sensing node and the sink.

6.2.2 Cluster Head Election and Maintenance in LEACH-M

LEACH-M uses the same set-up procedure used in the basic LEACH protocol. In LEACH, the nodes organize themselves into local clusters, with one node acting as the local base station or cluster-head. If the cluster heads are chosen *a priori* and remain fixed throughout the system lifetime, as in conventional clustering algorithms, it is easy to see that the sensors chosen to be cluster-heads would die quickly due to overloading. This will end the useful lifetime of all nodes belonging to the clusters. Thus LEACH includes randomized rotation of the high-energy cluster-head position such that it rotates among the various sensors in order not to drain the battery of a single sensor. In addition, LEACH performs local data fusion to *compress* the amount of data being sent from the clusters to the base station, further reducing energy dissipation and enhancing system lifetime. Sensors elect themselves to be local cluster-heads at any given time with a certain probability. These cluster head nodes broadcast their status to other sensors in the network. Each sensor node determines to which cluster it wants to belong by choosing the cluster-head to which minimum communication energy is required. Once all the nodes are organized into clusters, each cluster-head creates a schedule for the nodes in its cluster. This allows the radio components of each non-cluster-head node to be turned off at all times except during its transmit time, thus minimizing the energy dissipated in the individual sensors.

LEACH-M ensures the communication of a node with a CH even if node is in motion by transmitting *data request* packet from CH to the sensor node in its allocated time slot using TDMA scheme. For this purpose, a member node N of a cluster with cluster head N_{CH} waits two timeslots of two consecutive frames to decide whether N has moved [Kim 2006b]. When the node N does not receive any *data request* at the beginning of a timeslot from N_{CH} it goes to sleep mode and waits for the *data request* from N_{CH} until the next frame. If N does not receive any *data request* in the next frame as well, it requests for a *join-ack* message to join in a new cluster. Then N joins to a new CH N'_{CH} which is in the range of N and from which it receives the advertisment message for the first time by sending a registration message. The N'_{CH} then sends N a TDMA schedule, which contains timeslots that are assigned to all members including N. Similarly when N_{CH} does not receive data from N in two consecutive rounds, N_{CH} discards from its membership and removes N from its TDMA slot considering that N has moved. However, LEACH-M handles node mobility by assuming that the CHs are stationary. Hence, LEACH-M is not considered efficient in terms of energy consumption and data delivery rate because a large number of packets are lost while the node keeps moving before selecting a new CH for the next round.

The above issue is addressed by choosing a CH with minimal mobility factor. Mobility factor is calculated by introducing an extra time slot during TDMA scheduling and a node with minimum mobility factor is selected as a CH. The concept and operation of the protocol is explained in the subsequent sections.

6.2.3 Cluster Head Election and Maintenance in LEACH-ME

In LEACH the election and cluster head rotation makes sure that the cluster heads do not die due to prolonged extra work. This is done by the random rotation of the cluster head duty across the nodes in the cluster by considering the energy level of the nodes. In view of mobility centric environment, the election of a CH or the rotation of the CH on purely the energy level without considering the node mobility can cause serious problem. A node with sufficiently rich energy level, taking over the duty of cluster head possessing high mobility, may move out of the cluster, causing the cluster to become headless. The situation causes the cluster to go for a new cluster head. But again the mobility of the nodes is not considered causing the same process to repeat. To cope with the situation of cluster head going out of reach due to mobility, the head rotation process needs to consider the nodes mobility. The nodes need to maintain certain additional information to make room for handling mobility. Following are some of the information the node should maintain [Arboleda C. 2006]:

- Role: to indicate if the sensor is acting as a Cluster head CH (value=1) or as a participating node (value=0) in the zone

- Mobility Factor: calculated based on the number of times a node changes from one cluster to another or on the basis of remoteness.

- Members List: if the node is a cluster head, a list which contains references to the nodes associated with its Cluster.

- TDMA Schedule: Time slot information, when data need to be collected from the sensor nodes by the cluster head.

The node needs to maintain all these four information, in which the mobility factor is the one with prime importance for the election of cluster head. There are different approaches to calculate mobility factor. One approach is to calculate the transitions the node makes across the cluster and the other one is through the concept of remoteness [Kwak 2003]. The proposed scheme primarily focuses on the latter method for the cluster head election.

1. *Mobility factor based on transition count:* The node associated to a cluster in motion may break its association to the cluster head and create a new association with a new cluster head in its new territory. The mobility factor is calculated based on the number of times the node moves from one cluster to another.

2. *Mobility factor through the concept of remoteness:* Mobility measure should have a linear relationship with link change rate. If all the nodes in the cluster are in group motion like in RPGM, even though the nodes are in motion, the average link change is minimal, maintaining high spatial dependency. The node movement in such scenarios does not make any breakage of association with the cluster head. So remoteness can be treated as a measure of mobility factor.

Let $n_i(t), i = 0, 1, 2, \ldots N-1$, where N is the number of nodes, represents the location vector of node i at time t and $d_{ij}(t) = |n_j(t) - n_i(t)|$, represents the distance from node i to j at time t. Then the remoteness from node i to j at time t is $R_{ij}(t) = F(d_{ij}(t))$ where F is the function of remoteness. For a simple choice of F as identity function, the remoteness is just the distance between the nodes. As a node moves relative to the other nodes, remoteness remains proportionate to its previous values. But as the node moves in a manner, in which its speed and angular deviation from the current state are not predictable, remoteness changes in time. Thus the definition of relative mobility measure in terms of remoteness of a node as a function of time with respect to its immediate neighbors is

$$M_i(t) = \frac{1}{N-1} \sum_{j=0}^{N-1} \left| d'_{ij}(t) \right| \tag{6.1}$$

In order to calculate $d_{ij}(t)$, from i^{th} node to all its j^{th} neighboring nodes, the broadcast medium may be used. In LEACH protocol all nodes in a cluster are time synchronized with the cluster head. The TDMA schedule issued by the cluster head is complied by the nodes. Each node uses its time slot given by the schedule to communicate to the cluster head. To reduce energy consumption during the other time slots not intended for a node, the node goes to sleep mode. Therefore even though a node is in the radio range of its neighboring nodes, it can not hear the information sent by its immediate neighbors. In order for nodes to hear simultaneously, the cluster head gives an extra time slot as shown in Fig. 6.1 During the period of extra time slot, called ACTIVE slot ,

Figure 6.1: TDMA time slots in LEACH-ME protocol

all nodes need to send their broadcast IDs. As all nodes are time synchronized with cluster head and use radio propagation, the node i can make use of the ID broadcast of all the nodes it hears and calculate $d_{ij}(t)$. Let the beacon sent by a neighboring node was at the start of ACTIVE time slot t_1 and was received at time t_2. The distance $d_{ij}(t)$ = Radio velocity $\times |t2 - t1|$. Upon receiving the information from all the nodes, it is possible to calculate the mobility factor for N neighbors through equation 6.1. The node with least mobility factor is considered for the next cluster head, provided the energy level of that node is not below the threshold. Also the transition count for the node is checked to be minimal among all its neighbors. The state diagram for the remoteness calculation and the new cluster head election is shown in Fig. 6.2 The method is explained in steps as

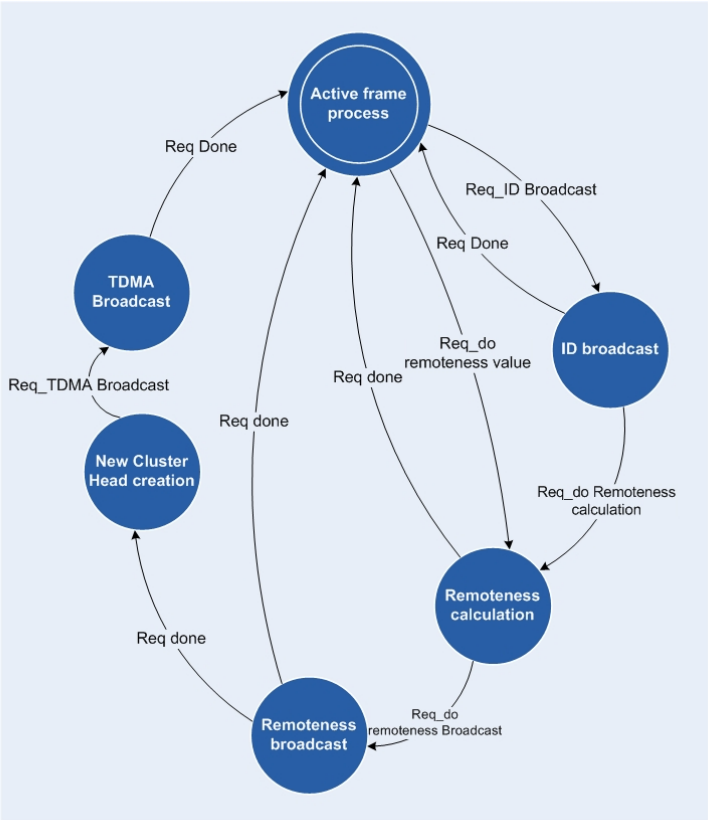

Figure 6.2: State diagram: remoteness calculation and new CH election

given below. A normal node is denoted as { a } and the cluster head as c. The following steps illustrate cluster head election process.

1. Cluster head c sends ACTIVE message to all its cluster members to wake up simultaneously
   ACTIVE: $c \rightarrow \{a\}$: wake up

2. Upon receiving the ACTIVE message, all cluster members broadcast their IDs with time-stamp. All cluster member nodes set time-out to receive broadcast of their entire neighboring node IDs. The ID_broadcast helps individual node to know its neighbors.
   ID_broadcast: {a} → NEIGHBORS: know_neighbors

3. Once the broadcast ID timer expires, each node calculates the remoteness based on the IDs received and the time of reception. The calculated remoteness information is broadcast by each node. The process helps to know the remoteness of neighbors of each other.
   remoteness: {a} → NEIGHBORS: know_remoteness

4. Once all the remoteness values of neighbors are received nodes can go for cluster head election, where the node with minimal mobility factor is elected as cluster head, provided its energy level is not below the threshold.

Initial creation of clusters is based on certain random selection. The number of cluster heads is based on a suggested percentage of cluster heads for the network. LEACH protocol uses 5% of the total number of nodes. In view of mobility, the figure can go high depending on the spatial dependency factor and the speed with which the node moves. A probable figure is of the order of 5 -15 % of the total number of nodes. It may be noted that the cluster head election need not be done at every TDMA time slot. ACTIVE time slot can be introduced periodically after a certain number of regular TDMA periods. The periodicity can be decided based on the mobility of the nodes.

6.2.3.1 ACTIVE slot deciding phase

Calling ACTIVE slot in regular basis without considering the nature of the mobility of the nodes can cause extra loss of energy to the nodes and hence cause threat to the life of nodes. So the selection of periodicity of ACTIVE slot in TDMA schedule should be flexible based on the nature of mobility of the nodes.

It is desirable to have a measure to decide the periodicity of the ACTIVE slot. The approach followed is the transition count as measure to periodicity decision. For a specific cluster the average transition count of members decides the slot frequency. The node which migrates from one cluster to another cluster during the steady state phase needs to have a count of such transitions it has made. The concept is stated earlier as mobility factor based on transition count. In order to have the average transition count of the cluster there should be certain information with the cluster head regarding the individual transition count of the node members. But there is no additional time slot available to communicate the transition count of the nodes to the cluster head. To resolve this, each node that gets a data request from the cluster head needs to send back data along with information on transition count to the cluster head. Cluster head needs to process the transition count information separately. The decision of including ACTIVE slot in the next TDMA cycle is taken based on the average transition count calculated for the last few cycles. Transition count beyond the threshold decides the ACTIVE slot induction. The method explained is put in steps as given below.

1. Cluster head sends data request to the respective nodes in their TDMA time slot. If the TDMA cycle does not contain ACTIVE slot, then the data request is sent with the active flag as zero.
   REQ_Data/active = 0: $c \rightarrow \{\text{a}\}$: get data

2. Upon receiving the data request from the cluster head, the cluster member sends its data along with transition count for the last few cycles to the cluster head.
   DATA: $\{\text{a}\} \rightarrow c$: send data and transition count

3. Once all the data from cluster members are available, the cluster head calculates the average transition count for the last few cycles and decides whether it is above the threshold decided earlier. If the value is above the

threshold, then all the cluster members are intimated about the inclusion of ACTIVE slot in the next TDMA cycle by setting active flag in the REQ_Data

REQ_Data/active = 1: $c \rightarrow \{a\}$: get data and reschedule

4. Upon receiving the data request with active flag set, the cluster members need to reschedule the TDMA time slot accordingly to include the ACTIVE frame.

6.2.3.2 Steady State phase in LEACH-ME

In the set-up phase of LEACH, the clusters are organized and cluster heads are elected. Configuration formed in the set-up phase is used to transfer monitored data to the base station during the steady state phase. Because of that, it can not accommodate the alteration of cluster by mobile sensor nodes during the steady-state phase. It is possible to resolve this problem by a simple and traditional method that adds membership declaration of mobile nodes to typical LEACH protocol. In LEACH-M scheme, the member nodes nodes, instead of sending the data to the cluster head in their allotted time slot in the TDMA schedule, wait for a request (REQ_Data) from the cluster head to send data. In the vicinity of mobility it may happen that the REQ_Data sent to a particular node by the cluster head is not received by the node, since it has moved to a new location which is not in the radio range of its current cluster head. After sending the REQ_Data, if no response is obtained from the node before the time slot allotted for that node, the node will be marked as mobile-suspect. If the same thing repeats for the next time slot allotted for the same node, then the suspect node is declared as mobile and the time slot for that node is deleted from the TDMA schedule. On the other hand, if the node does not receive any REQ_Data from the cluster head when it is awake, it marks itself as suspect of non-member of cluster. During the next frame slot allotted to this node, if the same thing repeats, then it takes the decision that it is not a member of the cluster. Once a node becomes a non-member in any of the cluster, it looks for a cluster to join by sending a broadcast JOIN_REQ. The cluster head hearing the JOIN_REQ allots a time slot in its TDMA schedule and broadcasts it to all the member nodes including the new member. Upon receiving the new TDMA schedule the mobile node now becomes part of the cluster and uses the new cluster schedule. The sequences of messages are shown in Fig. 6.3. The

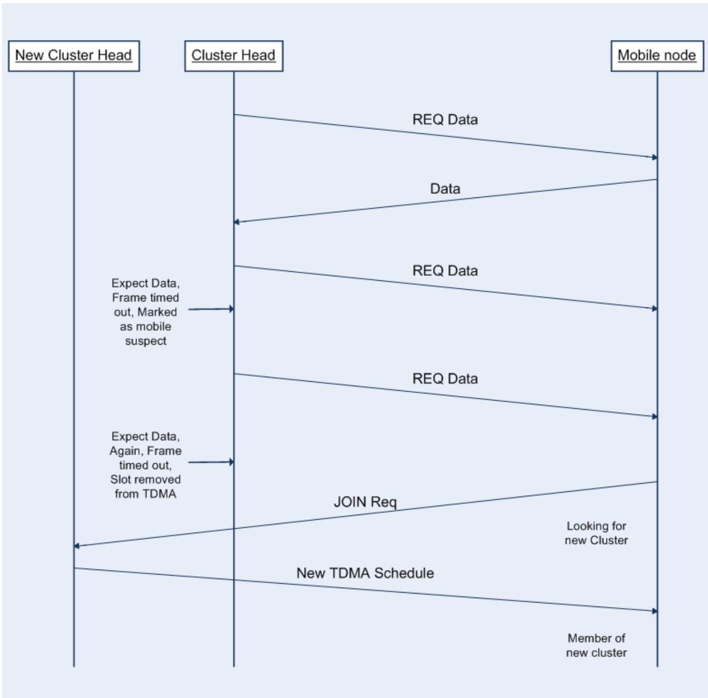

Figure 6.3: Message sequences for cluster join of a mobile node

first order radio model used in LEACH and LEACH-M is used for LEACH-ME, where radio dissipates $E_{elec} = 50$ nJ/bit to drive the transmitter and the transmit-amplifier dissipates $\varepsilon_{elec} = 100$ pJ/bit/m^2. It is assumed that radio can be turned on or off as and when required, to save energy. Also the radio spends the minimum energy required to reach the destination. The transmission

cost of LEACH-M is different from LEACH-ME because of the additional effort to calculate the remoteness at the ACTIVE slot. Assuming k-bit message is sent on normal slot and k_{active} is sent during ACTIVE slot, transmission and receiving cost for a distance of d for k-bit can be calculated as follows:
Transmitting cost for LEACH-M:

$$E_{Tx}(k,d) = E_{Tx-elec}(k) + E_{Tx-amp}(k,d) \tag{6.2}$$

$$= E_{elec} * k + \varepsilon_{elec} * k * d^2 \tag{6.3}$$

For N nodes in the cluster, the total transmission cost per TDMA cycle is:

$$E_{Tx-cluster}(k,d) = (N-1) * E_{elec} * k + \varepsilon_{elec} * k * \sum_{i=1}^{N} d_i^2 \tag{6.4}$$

Transmitting cost of LEACH-ME per TDMA cycle is transmitting cost of LEACH-M per TDMA cycle added with cost corresponding to the active slot.

$$E_{Tx-cluster}(k,d) = (N-1) * E_{elec} * k + \varepsilon_{elec} * k * \sum_{i=1}^{N} d_i^2 + 2(N-1) * E_{elec} * k_{active} + 2 * \varepsilon_{elec} * k_{active} * \sum_{i=1}^{N} d_i^2 \tag{6.5}$$

In active slots the k_{active} bits need to be sent twice, one for ID transmission and the other for remoteness transmission. The extra energy is dissipated in the ACTIVE slots to achieve awareness of the remoteness to elect the cluster head. The number of bits in active frame is assumed to be less than that of the data frame bits. The reception cost will be same in LEACH-M and LEACH-ME and is given by

$$E_{Rx}(k) = E_{Rx-elec}(k) = E_{elec} * k \tag{6.6}$$

The radio channel is assumed to be symmetric for given signal to noise ratio.

6.3 Experimental Design

6.3.1 Simulation Setup

A simulation model is implemented with a network of size 100 $\times$ 100 with 100 nodes. The base station is placed at a position of (50,50). Table 6.1 shows the network parameter and their respective values used in the simulation. The simulation is carried out in ns-2 with IMPORTANT framework for supporting mobility.

Table 6.1: Simulation parameters and their values

Parameter	**Value**
Network Size	100 $\times$ 100
Number of nodes	100
Number of clusters	5 -15 % of total nodes
Base station position	(50,50)
Data REQ Packet size	16 bytes
Data Packet size	512 bytes
ACTIVE Wakeup REQ	16 bytes
ACTIVE Wakeup Response	64 bytes
ACTIVE slot Remoteness Tx Packet size	64 bytes
Energy consumption for Tx	Packet Size * 4.602 μJ/bit
Energy consumption for Rx	Packet Size * 2.34 μJ/bit
Initial node energy	10J

6.3.2 Simulation Results and discussions

The energy cost for transmission (Tx) and reception (Rx) is derived from actual Mica 2 mote hardware [Shnayder 2004]. Mica 2 mote is powered by two regular AA batteries with 3V and each battery is capable of delivering the equivalent of

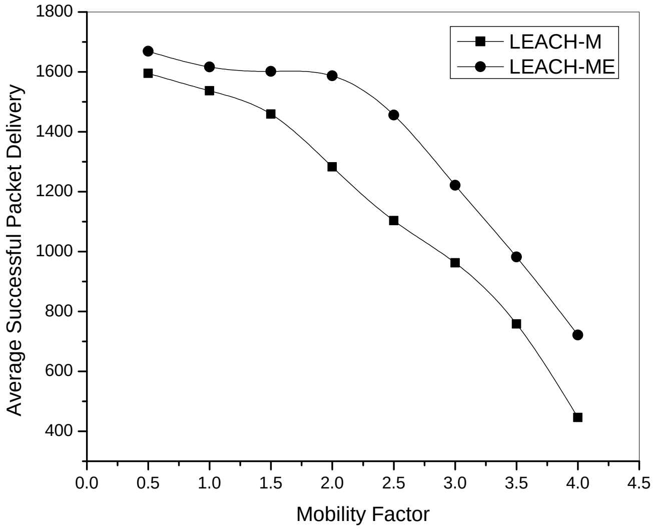

Figure 6.4: Average successful packet delivery

1.2 Amperes (1200 mA) for one hour. The radio uses 4.602 μJ/bit for Tx and 2.34 μJ/bit for Rx presuming it is transmitting with a power of +10dB. This model is better than the first order radio model since it reflects the actual parameters for energy consumption. The simulation is carried out for different rounds of the protocol. It is desired to obtain values corresponding to the total energy spent by the network and the remaining energy of the network. The successful packet delivery from node to CH and average successful transmissions for different mobility factor are also noted. The performance of LEACH-ME is compared with that of LEACH-M protocol by fixing the number of nodes constant and changing number of rounds at different runs of the simulation. Fig. 6.4 shows the average successful packet delivery for different mobility factors. LEACH-ME shows a better figure than LEACH-M because of the remoteness calculation with in a cluster to select a node as a CH. In LEACH-ME a node tends to select a CH which is relatively less mobile maintaining a spatial and temporal relationship with its CH. Fig. 6.5 shows that the end-to-end delay of LEACH-ME is lower

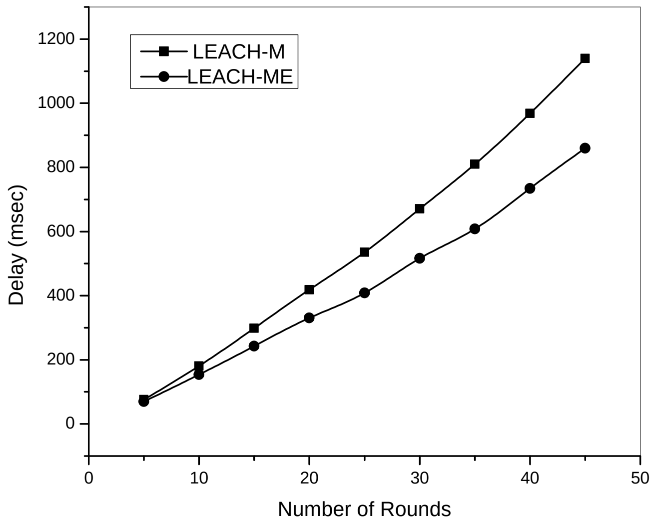

Figure 6.5: End-to-End delay

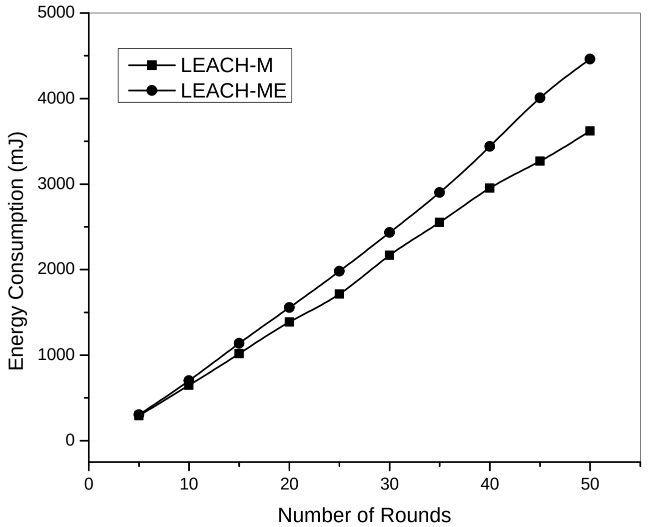

Figure 6.6: Energy consumption of the network

than LEACH-M for different rounds. This is due to the high spacial and temporal dependence between the CHs and node members within respective clusters.

Fig. 6.6 and Fig. 6.7 show the energy consumed by the network for the different rounds of the protocol. LEACH-ME protocol consumes slightly more energy than LEACH-M when the number of rounds is increased. This behavior is due to the extra computation and communication involved in the remoteness calculations.

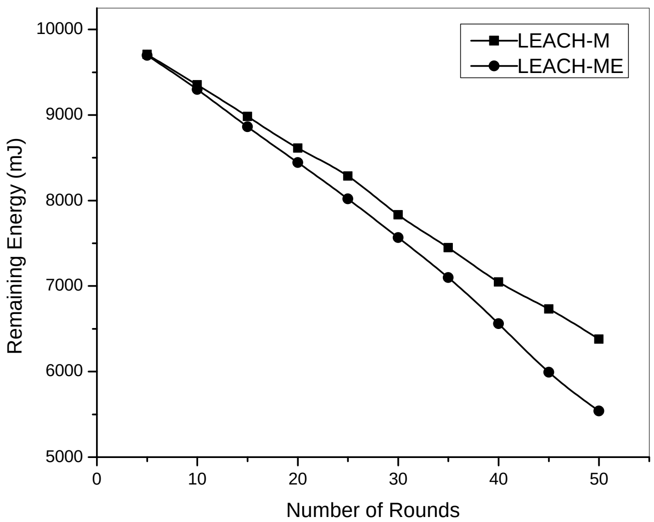

Figure 6.7: Remaining energy of the network

6.4 Conclusions

A cluster based routing protocol for mobile sensor networks is proposed giving more importance to ensure successful delivery of sensed data from source to base station. The challenge was to handle cluster durability when nodes are dynamically changing. By introducing the concept of remoteness for cluster head election, it is ensured that an appropriate node with relatively less mobility will be elected as CH. The proposed protocol is simulated with a realistic energy consumption model based on Mica 2 mote sensor node and the results are presented. The protocol is compared with LEACH-M protocol and LEACH-ME has been found to be better in average successful communications with minimum end-to-end delay but compromising some energy.

Chapter 7

Service Oriented Architecture for Retrieving Data from Wireless Sensor Networks

Contents

7.1 Introduction

Wireless Sensor Networks have paved the way for smart environments and is expected to grow exponentially and gain a stronghold across industry verticals such as building automation, transportation and industrial applications. The benefits of wireless sensor networks in diverse sectors are enormous and will serve the purpose of demonstrating their capabilities. WSNs basically consists of large number of sensor nodes that are interconnected by a wireless network and play the role of a highly parallel, accurate and reliable data acquisition system.

Apart from the data sensing process WSNs have network issues related to mobility, tracking and data aggregation to be resolved so that data measured from the required location are sensed and communicated to the base station effectively. All these issues are complex and sensors are loaded with programs to handle them. This further restricted the utility of WSNs due to complex and closely coupled applications as they were neither flexible nor interoperable. To enhance the utility of such sensing, the application specific requirements have to be separated from the data dissemination functions.

This chapter addresses this by separating the data sensing and data communicating functions in such a manner that the sensed data can be used by any user irrespective of what platform they are working on. This work follows the Service Oriented Architecture (SOA) approach to attain the desired feature of separation of concerns.

7.2 Related Work

Several research activities have been carried out in addressing common quality factors and exclusive factors of WSNs applications by providing some architectural models. But, most of the research activities focus on exclusive factors such as power efficiency and traffic reduction. In most reported works, satisfaction of common factors is usually derived from satisfaction of exclusive factors. In the context of distributed systems, solutions such as Java RMI (Remote Method Invocation), EJB (Enterprise Java Beans) and CORBA (Common Object Request Broker Architecture) are reported [Team 2000, Group 1994]. Although CORBA and EJB provide a confident infrastructure for satisfying quality factors of applications, using CORBA, XML, SQL and JAVA is not an efficient choice for sensor networks because they are normally heavily weighted in terms of memory and computation.

Studies were conducted on the application of SOA to sensor networks which is similar to the present work [Golatowski 2003]. The main objective of the current work is the connection of consumers and service providers in a loosely-coupled way in order to improve flexibility and extensibility. It uses a simple and clear interface to bind all participating software components and provides service reuse.

In event-based area, most of the initial related research have concentrated on leveraging event-driven mechanism in a fixed network. But the emergence of mobile systems in recent years, with properties such as client mobility, wireless communications and resource limitations, has opened up new research topics on how to efficiently adapt the publish/subscribe model for mobile environments. The combination of unique characteristics in publish/subscribe model makes it advantageous in a mobile or wireless environment. Some research has been carried out in this area that focus on different aspects of mobile computing. Due to the commonalities between mobile environments and sensor networks, the results of these works provide useful hints in finding appropriate models and methods for WSN applications.

More recent works [Delicato 2003] have presented flexible architecture for WSNs wherein the communication and data collection issues have been separated to give rise to expressive services based architecture for data sensing. They have used the web service technologies to achieve the flexibility. Studies [Delicato 2003, Mohamed 2005, Tsenov 2007] have motivated and provided the direction to the work that has gone into this thesis. When most of the work mentioned above aims at designing a middleware for WSNs, this work proposes a service based framework where the capability of WSN is expressed as service that is published and can be subscribed by clients. The main emphasis here is on interoperability which makes the architecture universal.

7.3 Service oriented architecture and web services

Service Oriented Architecture (SOA) builds upon decades of distributed computing technologies and advocates the delivery of software applications in the form of an open interface based on strict contracts, leading to loosely coupled systems which are implementation independent.

A service-oriented architecture is an information technology approach or strategy in which applications make use of (perhaps more accurately, rely on) services available in a network such as the World Wide Web. A service-oriented architecture implementation involves development of applications that use services, making applications available as services so that other applications can use those services, or both.

A service provides a specific function, typically a business function, such as analyzing an individual's credit history or processing a purchase order. A service can provide a single discrete function, such as converting one type of currency into another, or it can perform a set of related business functions, such as handling the various operations in an airline reservations system. Services that perform a related set of business functions, as opposed to a single function, are said to be *coarse grained*. Multiple services can be used together in a coordinated way. The aggregated, or composite, service can be used to satisfy a more complex business requirement. In fact, one way of looking at an SOA is as an approach to connecting applications (exposed as services) so that they can communicate with (and take advantage of) each other. In other words, service oriented architecture is a way of sharing functions (typically business functions) in a widespread and flexible way.

A web service is a service that communicates with clients through a set of standard protocols and technologies. These web services standards are implemented in platforms and products from all the major software vendors, making it possible for clients and services to communicate in a consistent way across a wide spectrum of platforms and operating environments. This universality has made web services the most prevalent approach to implementing SOA.

Optionally, SOA can also include a service that provides a directory or registry of services. The registry contains information about the service such as its interface. A client can discover services by examining the registry. A registry can also be coupled with a repository component that stores additional information about each service. This additional *metadata* can include business process information such as policy statements.

Web Services are based on XML and provide a means to develop distributed systems that follow SOA. Services are described in an XML based dialect (WSDL). In a similar fashion, the request and reply messages exchanged in such systems are formatted according to the Simple Object Access Protocol (SOAP). SOAP messages can be encoded and transmitted by using Web protocols such as the Hypertext Transfer Protocol (HTTP). Various industrial technologies and application platforms such as .NET from Microsoft, J2EE from Sun Microsystems, and WebSphere from IBM are targeted at supporting the development of applications based on Web Services.

Web Services are the software components that are well defined, self-contained, and does not depend on the context or state of other services. Web services essentially use XML to create a robust connection. The web services architecture has three roles: a provider, a requester, and a broker. The provider creates the web service and makes it available to clients who want to use it. A requester is a client application that consumes the web service. The broker, such as a service registry, provides a way for the provider and the requester of a web service to interact. The provider, requester, and broker interact with each other through the operations of publish, find, and bind. A provider informs the broker about the existence of the web service by using the broker's publish interface to make the service accessible to clients. The information published describes the service and specifies where the service is located. The requester consults the broker to locate a published web service. With the information it gained from the broker about the web service, the requester is able to bind, or invoke, the web service. Fig. 7.1 illustrates a basic service-oriented architecture.

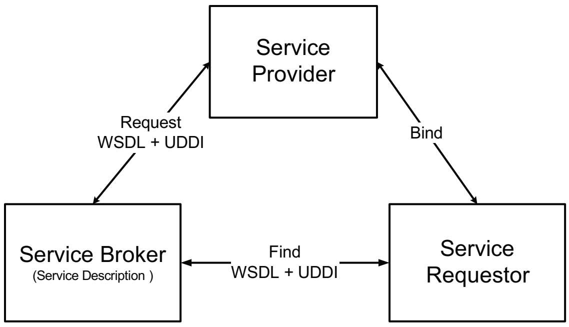

Figure 7.1: Service Oriented Architecture using Web services Technology

7.4 Web Services for data retrieval from WSN

7.4.1 Background

To achieve energy-efficiency a cluster-based mechanism is adopted for node communication and routing. In a cluster-based system, sensor nodes form clusters; a cluster head for each cluster is selected according to some negotiated rules. Sensor nodes only transmit their data to their immediate local cluster head and the cluster head conveys the data towards the sink node. Consequently, more powerful nodes in the topology play the role of cluster heads and other nodes are responsible for sensing data and forwarding them to cluster nodes. Each cluster node here is treated as the base station. It is on these cluster nodes that the web service for reading the sensor data is stored. The cluster nodes have the capability of identifying the locations of sensor nodes. The cluster head nodes are connected to the web server which acts as the service broker.

The web server contains discovery documents of the web service that can be transferred to clients requesting that particular service. All communication between the service and server or clients is in the XML format. Hence the clients can use their web browser to view the result.

7.4.2 Purpose

The architecture that is developed enables a person to obtain real time data from the WSN of an area by connecting to the World Wide Web. The facility is provided by web services located at the WSN cluster nodes. These services are published on a web server, which also hosts the web portal of the application GUI.

The users of the application can type in URL in the browser to access the application's GUI. The user has to provide information regarding the area from where he wants the real time data and the dissemination method - whether continuous/periodic or reactive. The application then sends these parameters with the web service description to the web server.

With the help of discovery documents the server passes on the request to the corresponding web service which processes the data from the sensor nodes and sends the data back to the web application.

7.5 System Architecture

The proposed architecture for data acquisition from sensor networks is based on Service Oriented Architecture and hence the architecture can best be described by their physical components and their interactions [Bianco 2007]. Since web service technology was chosen to implement the architecture the key quality attribute of interoperability will be attained with the help of the interoperability stacks that deal with service description, communication and discoverability. Fig. 7.2 describes the functionality of the system with a UML Use case diagram.

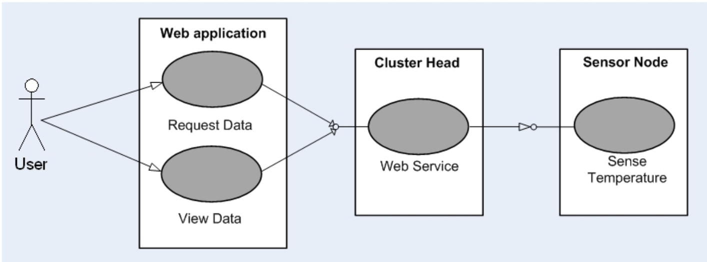

Figure 7.2: Use Case diagram of DataRetrieve

7.5.1 Physical Components

The application is designed to have a cluster based mechanism to collect, process and route the sensed data. The member nodes sense the temperature information and forwards it to the corresponding cluster heads. The cluster head processes the data and routes it to the base station. The base station is connected to the client through the web server. The clients of the application use their web browser to view the data sensed from desired locations. To summarize, the system consists of:

1. Client / User (Service Requester) - requests for real time data. All requests and responses use HTTP protocols.

2. Web Server(Service Broker) - hosts the web application with which the client interacts and store information regarding the available web services. The server passes information between the application and the service.

3. Cluster Head / Gateway Node (Service Provider) - The web service is located on this node. The data from the sensors are processed by the web service and sent back to the client application.

4. Sensor Nodes - Senses data at regular intervals and stores data in data stores.

7.5.2 System Architecture with SOA interoperability stacks

Web services have their description as WSDL files which are to be retained at the web server for identification. The web server also maintains a database of cluster head web services along with discovery documents and their locations (CH Db). Since SOAP messages are used for communication there should be a

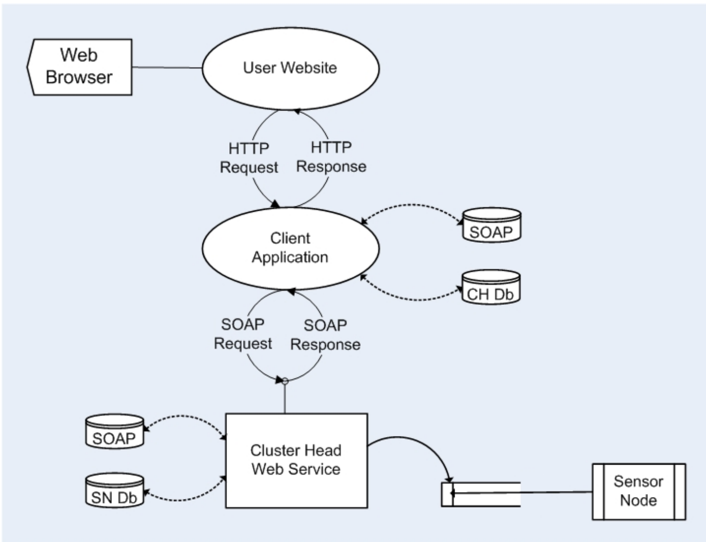

Figure 7.3: Top level run time view

SOAP module, to encrypt and decrypt SOAP messages, with the web server and also with the cluster heads. The cluster heads maintain a database of sensors in its cluster and their locations (SN Db), to locate the ideal sensor from where data has to be collected.

A top level run time view of the architecture is shown in Fig. 7.3. The sequence of operations involved in the interaction between the user and the architecture is described below:

1. The client interacts with a portal to locate a web service for its requirement.
2. The web server identifies the location of the required web service with the help of service description files -.wsdl files and discovery documents- .disco files.
3. The Web service is invoked by a web form application using an SOAP Request message to the web server
4. The Web server sends the SOAP message to the required Web Service (DataRetrieve) located on the gateway node of WSN.
5. The web service receives and unravels the SOAP request with the help of the SOAP library present in the .NET framework above which it operates.
6. The SOAP request passes on the required parameters for processing the data received from the gateway's sensor nodes
7. The DataRetrieve Web service collects and computes the sensor data and sends it back to the Web application packed in the SOAP response format.
8. The client application extracts the required reading from the message and passes it to the website as an HTTP response.

7.6 Experimental set up and Implementation

An experiment was set up for the implementation which consisted of Mica2 motes and a web server. The application for receiving real time data from sensors has been implemented and tested in .NET platform. The experimental set up is shown in Fig. 7.4 The MPR400CB is the processor board used by Mica 2 motes.

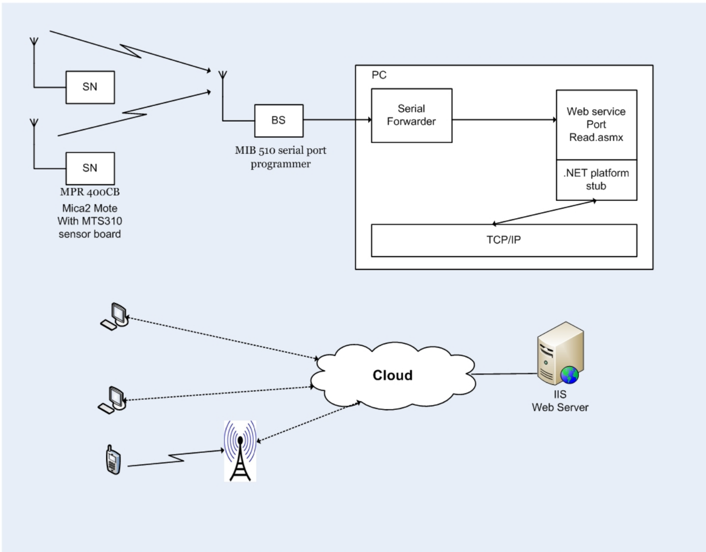

Figure 7.4: Experimental set up

It is based on Atmel ATmega 128L, a low power micro controller which runs TinyOS from its internal flash memory. The MTS310 sensor is used to sense the temperature. The sensed data is forwarded to the MIB510 serial port programmer which is acting as the base station interface. It is programmed to collect temperature data at regular time intervals. The raw temperature data sent by the nodes are then forwarded to the application by serial forwarder program. Then the raw data must be converted to actual temperature data before presenting it to the client program. The client and server side implementations are briefly described below.

1. Client side implementations - Clients can access the application using any standard web browser.

2. Server side implementations - Web application (SensorDataView.aspx) was implemented in ASP.NET. To facilitate the application, the following Microsoft products were installed.

   (a) Internet Information Server

   (b) .NET Framework

3. Web service Technology

   (a) XML Web service was coded in ASP.NET to retrieve Temperature Data from Mica2 sensors. (MicaMoteRead.asmx). One web method PortRead was defined.

   (b) Web service description (MicaMoteRead.wsdl) and discovery files (MicaMoteRead.disco) were auto generated by the .NET tool.

4. Sensor Node Programming

   (a) Two sensors (MPR 400CB Mica2) with MTS310 Sensor Data Acquisition Board were fused with programs in nesC to sense the Temperature. Fig. 7.5 shows the wiring diagram of the temperature sense program *SenseToService.nc*

   (b) One Mica2 node was mounted on a MIB 510 serial port programmer to form the base station and was connected to a PC via a serial port. The base station was programmed to receive the temperature data as RF signals at regular time intervals. The RF signals were converted to Integer format and sent to the serial buffer of the PC.

7.7 Results and discussions

The proposed SOA architecture for collecting data from sensor network is implemented successfully. The service is tested by obtaining the sensed temperature

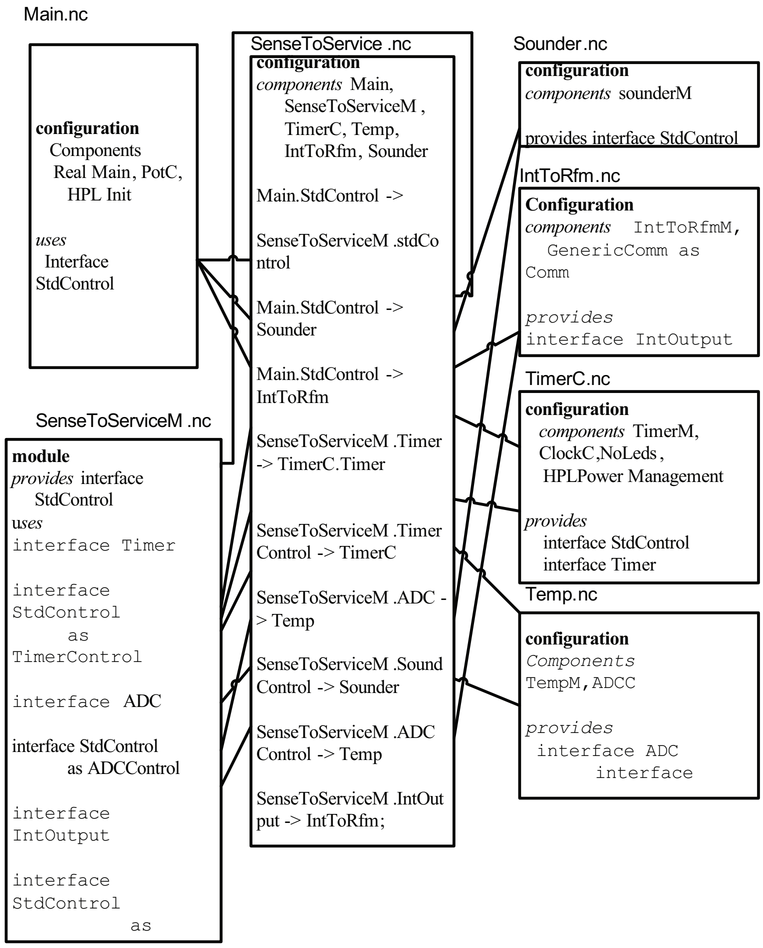

Figure 7.5: Wiring diagram of SenseToService

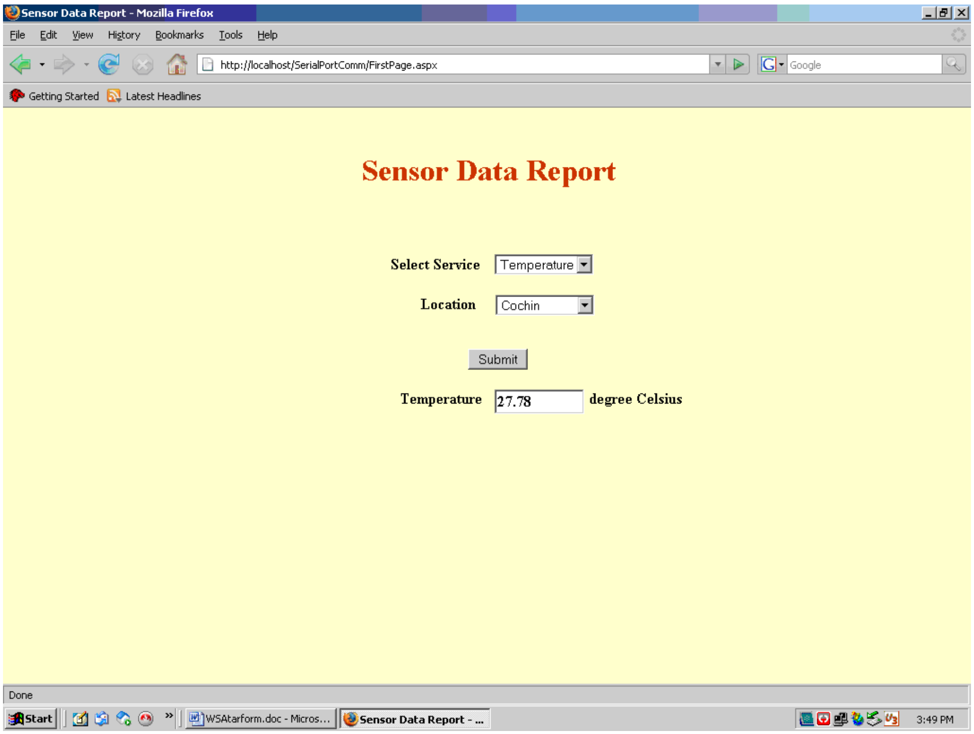

Figure 7.6: Result obtained in a web page

in a text box of a web form. It is also tested by invoking the service from a mobile phone application implemented using Open Wave Simulator. The results are shown in Fig. 7.6 and Fig. 7.7.

7.8 Conclusions

The need for separating the data sensing and communicating operations of the WSNs so as to enhance its utility to a number of users along with platform independence has been explained. A Service Oriented Architecture using Web Service technology was proposed which focused on interoperability. The framework pro-

Figure 7.7: Result obtained in a mobile phone

posed facilitates an organization, with certain on site data acquisition capability, to publish that capability as a service on the Internet. Any user who requires this kind of data can subscribe to the service without worrying about the underlying intricacies. The chapter also shows an experiment that was conducted as part of the study whereby Mica2 sensors were used to measure temperature from the environment and this was published as a web service that could be accessed by web applications.

CHAPTER 8

Summary and Future Directions

Contents

8.1 Summary

The theme of the thesis is centred around one important aspect of wireless sensor networks; the energy-efficiency. The limited energy source of the sensor nodes calls for design of energy-efficient routing protocols. The schemes for protocol design should try to minimize the number of communications among the nodes to save energy. Cluster based techniques were found energy-efficient. In this method clusters are formed and data from different nodes are collected under a cluster head belonging to each clusters and then forwarded it to the base station. The survey presented in the Chapter 2 has offered promising improvements over the conventional routing techniques based on clustering; however there is still much work to be done. Appropriate cluster head selection process and generation of desirable distribution of the clusters can reduce energy consumption of the network and prolong the network lifetime. In this work two such schemes were developed for static wireless sensor networks.

In the first scheme, the energy wastage due to cluster rebuilding incorporating all the nodes were addressed. A tree based scheme is presented to alleviate this problem by rebuilding only sub clusters of the network. An analytical model of energy consumption of proposed scheme is developed and the scheme is compared with existing cluster based scheme. The simulation study proved the energy savings observed.

The second scheme concentrated to build load-balanced energy efficient clusters to prolong the lifetime of the network. A voting based approach to utilise the neighbor node information in the cluster head selection process is proposed. The number of nodes joining a cluster is restricted to have equal sized optimum clusters. Multi-hop communication among the cluster heads is also introduced to reduce the energy consumption. The simulation study has shown that the scheme results in balanced clusters and the network achieves reduction in energy consumption.

Recent researches show that there has been an increased interest to the mobility in sensor networks. The impact of mobility on routing algorithms under various mobility patterns were considered next, to study the performance metrics. The main conclusion from the study was the routing scheme should pay attention on successful data delivery from node to base station in addition to the energy-efficiency. The cluster based protocols are extended from static scenario to mobile scenario by various authors. None of the proposals addresses cluster head election appropriately in view of mobility. An elegant scheme for electing cluster heads is presented to meet the challenge of handling cluster durability when all the nodes in the network are moving. The scheme has been simulated and compared with a similar approach.

The proliferation of sensor networks enables users with large set of sensor information to utilise them in various applications. The sensor network programming is inherently difficult due to various reasons. There must be an elegant way to collect the data gathered by sensor networks with out worrying about the underlying structure of the network. The final work presented addresses a way to collect data from a sensor network and present it to the users in a flexible way.

A service oriented architecture based application is built and data collection task is presented as a web service. This will enable composition of sensor data from different sensor networks to build interesting applications.

The main objective of the thesis was to design energy-efficient routing schemes for both static as well as mobile sensor networks. A progressive approach was followed to achieve this goal.

8.2 Future Directions

Routing protocols for future sensor networks need to address energy-efficient solutions that make localised decisions; they include protocols that effectively exploit redundancy for energy-efficiency and reliability, protocols for newly emerging topologies and integrated solutions to routing and in-network processing of sensor data. The proposals made in Chapter 3 and 4 can be extended by including more parameters to make decisions to form clusters based on local parameters and using neighbor node information. The information from the other layers such as MAC and physical layer can also be utilised in the cluster building and routing process.

Mobility based energy conservation schemes are relatively new in the field of wireless sensor networks and many aspects need to be studied with more attention. Energy-efficient schemes to elect cluster heads with respect to the characteristics of mobility pattern of the nodes are important. The scheme should also try to minimize the missing contacts with the mobile nodes to enhance data delivery rate. Developing a scheduling mechanism based on the past history and choosing appropriate communication parameters to achieve the above goals can be considered as a future work.

The work on mobile sensor network mainly calls for design of a framework to select appropriate protocols when nodes follow different mobility patterns. The application layer should select and adapt routing algorithms depending on the dynamism in the actual network.

A formal mathematical approach to model various aspects of static as well as mobile sensor networks is seldom seen in the literature. Analytical models to investigate the statistics of the energy consumption in sensor networks is an interesting area to pursue. Such models can provide probabilistic lifetime assurance in time critical sensor network applications. Developing a general framework to analyse the energy consumption of numerous protocols suggested in the literature incorporating various network topologies can be taken as a future direction. Modelling of mobile sensor networks as dynamic graphs to study node association and disassociation to a cluster head node or to a base station will provide a hint on selection of appropriate protocols for clustering and energy-efficient routing.

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