Energy Efficiency in Data Dissemination Protocols of Wireless Sensor Networks

A Thesis Presented

By

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ACCEPTANCE

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Accepted by the Faculty of Informatics, St. Mary's University, in partial fulfilment of the requirement for the degree of Master of Science in Computer Science

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DECLARATION

I, the undersigned, declare that this thesis work is my original work, has not been presented for a degree in this or any other universities, and all sources of materials used for the thesis work have been duly acknowledged.

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LIST OF ACRONYMS AND ABBREVIATIONS

ACA	Autonomous Component Architecture
ACK/NACK	Acknoledgment/No Acknowledgment
ALERT	Automated Local Evaluation in Real-Time
AODV	On-demand Distance Vector routing
API	Application Programming Interface
CBPER	Cluster Based Power Efficient Routing
CBR	Cell Based Routing protocol
CBR-WSN	Cell Based Routing Protocol
CDMA	Code Division Multiple Access
CODE	Coordinate-based Data Dissemination
CSIP	Collaborative Signal and Information Processing
CSMA/CA	Collision Sense Multiple Access/Collision Avoidance
DA	Data Announcement
DARPA	Defense Advanced Research Projects Agency
DCF	Distributed Coordination Function
DD	Direct Diffusion
DVS	Dynamic Voltage Scaling
GAF	Geographic Adaptive Fidelity
GPS	Global Positioning System
GPSR	Greedy Perimeter Stateless Routing
IEEE	Institute of Electrical and Electronic Engineers
LEACH	Low-Energy Adaptive Clustering Hierarchy
MAC	Medium Access Control
MCU	Microcontroller Unit
ns-2	Network Simulator 2
QoS	Quality of Service
Tcl	Tool Command Language
TDMA	Time Division Multiple Access
TTDD	Two Tier Data Dissemination
TTL	Time-To-Live
TUV WSSN	Vienna University of Technology Wireless Self-Sustaining Sensor Network
VLSI	Very Large Scale Integration
WANET	Wireless Adhoc Network
WLAN	Wireless Local Network
WSN	Wireless Sensor Network

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ABSTRACT

Networks of small, inexpensive, disposable, and smart sensors are emerging as a new technology with tremendous potential. Wireless sensor networks can be randomly deployed inside or close to a phenomenon to be monitored without the need for human intervention. Energy supplies of sensor nodes are not replenished or replaced and, therefore, nodes only participate in the network for as long as they have energy. This fact necessitates energy efficiency considerations in the design of every aspect of such nodes. Energy of the nodes is the primary metric that dominates wireless sensor networks due to its profound impact on network operational lifetime. Energy consumption in sensor nodes occurs mainly due to computational processing and, to a greater extent, communication. The most important objective of this research work is to understand and to make in-depth analysis of the problem of energy constraint in wireless sensor networks. Based on which it is proposed energy efficient data dissemination protocol, called Cell Based Routing Protocol (CBR-WSN). The algorithm finds three optimal paths to adjacent cells out of eight possible paths based on two criteria - transmission cost and available energy level. Each cell offers maximum energy sensor node to forward packets towards the sink. We approach the problem of energy conservation from the aspect of network protocols. The proposed protocol has been evaluated against Direct Diffusion (DD), and Low Energy Adaptive Clustering Hierarchy (LEACH) protocols. Based on simulation results the CBR-WSN has enhanced the energy efficiency by 8.16% when compared to LEACH protocol. In fact, it is still possible to improve the energy efficiency by handling idle time energy waste and computation energy. Comparing the lifetime of the proposed protocol against LEACH, with similar simulation parameters, the proposed protocol has improved the lifetime by a minimum of 2%. Moreover, only cluster heads are responsible for data dissemination, coordination and scheduling node activities inside a cell. Cluster heads hand over their role when the residual energy becomes less than one of the cell member’s energy.

Keywords: Wireless Sensor Networks, Energy Efficient Protocols, Protocol Design, Cell Based Routing, Clustering Algorithms

CHAPTER ONE

INTRODUCTION

1.1. Background

The introduction of wireless sensor communications emerged as early as the beginning of the 21st century [1]. They are expected to bring the interaction between human and environment to a new level by enabling remote monitoring of an environment. The technology, however, is still in its infancy and is undergoing rapid evolution with a tremendous amount of research effort in the networking community.

The purpose of a wireless sensor networks (WSN) is to aid in monitoring a physical phenomenon by gathering and delivering information to the interested party. Sensor nodes are deployed into a particular field and perform certain tasks of sensing or tracking and convey information to a base station. WSN can be applied virtually in any field where monitoring is necessary e.g., security surveillance, military applications, environmental applications, health applications, home applications, traffic monitoring and so on [2]. Given this wide range of applications, WSNs are poised to become an integral part of our lives.

Despite being a fascinating topic, there still exist some challenges to be addressed in WSN. Nodes in, for example, WSNs are severely constrained by energy. A sensor node battery can hardly accommodate adequate energy, which affects its computing power and lifespan of sensor node. One of the crucial questions is how to prolong the network lifetime to a long time in the face of these limitations.

One option to prolong the lifetime of the WSN is, by designing efficient routing protocols [1]. It has been established that most of the energy consumption in a WSN comes from data reception and transmission [2] [3]. A good routing protocol, therefore, can reduce the number and size of unnecessary transmissions that take place, thus helping to alleviate the energy limitations in WSNs.

There has been a lot of work in recent years to develop new paradigms and services for sensor networks, including several efforts on data dissemination taking into account the unique features of sensor networks. In a WSN there are different types of protocols used to carry out the communication process between the nodes, so that they can transfer the collected data towards the sink. These are Routing protocols and Medium Access Control (MAC) protocols are used. As stated previously, Routing algorithm is one important research topic in wireless sensor networks. After sensor nodes gather the data, such data needs to be transmitted from the source nodes to the sink node. Due to limited energy, source node usually cannot send the data to the sink directly. The data need to be relayed by intermediate sensor nodes. There may be many routes from the source to the sink. Routing is to find the optimal route. When designing a routing protocol, we need to take into account nodes and possible change of network's topology due to the failure of nodes for various reasons [4] [5].

A number of routing protocols have been proposed to mitigate the energy utilization during data disseminations: for instance Direct Diffusion (DD) [6] [7] [8], Two Tier Data Dissemination (TTDD), Coordinate based Data Dissemination (CODE) and Cluster Based Power Efficient Routing (CBPER) [9] [10]. TTDD uses grid to reduce energy consumption [5], exploits local flooding within a local cell of a grid which sources build proactively. Each source disseminates data along the nodes on the grid line to the sinks. It does not optimize the path from the source to the sinks.

When a source communicates with a sink, the restriction of grid structure may multiply the length of a straight-line path by 2 so it takes longer time to reach destination. This approach, therefore, incurs more energy and longer delays. Moreover, frequent renewal of the entire path to the sink may increase energy consumption and the connection loss ratio. Moreover, TTDD's performance depends mainly upon its cell size. If the cell size is large, the local flooding increases energy consumption and the path between the source and the sink gets longer. CBPER is a cluster based energy efficient protocol based on TTDD and it is energy efficient with respect to dynamic rotation of cluster head, data aggregation, and data announcement or request without flooding. Moreover, CBPER supports multiple sources efficiently as well as mobility of sinks. However, some of its disadvantages are as follows: location information is required to organize clusters and even though CBPER [10] claims that the sub-optimality is well worth to gain high rate of data aggregation, the length of data delivery path is usually $\sqrt{2}$ times more than the optimal path because data delivery through dissemination points which are located at the corner of the rectangle. Due to this there is no chance of data delivery along the diagonal part of the rectangle.

Similarly, CODE uses coordinates to move the data from the source to destination based on geographical adaptive fidelity protocol [9]. CODE provides an energy efficient data dissemination path to mobile sinks for coordination sensor networks. However, this protocol is not efficient for large sensor network.

This thesis examines the weakness of aforementioned protocols and proposes a solution in regards to energy utilization by finding optimal path from the source to destination. The proposed protocol is called "Cell based Routing in Wireless Sensor Network (CBR-WSN)" where cells select the path to destination (sink) based on neighbors cell identification (id) in the direction of destination by moving either one cell up and down or left and right while comparing with short distance to sink. Moreover, the selected nodes should have an energy level above a given threshold.

1.2. Statement of the problem

Energy supplies of sensor nodes are not replenished or replaced and therefore nodes only participate in the network as long as they have sufficient energy. This fact necessitates energy efficiency consideration in the design of every aspect of such nodes. Energy consumption in sensor nodes occurs mainly due to computational processing and, to a greater extent, communication. The routing protocol employed by sensor nodes can minimize the number of transmissions that nodes make, find optimal path considering energy utilization as well as the computational complexity of routing path selection. It is therefore of critical importance that the routing protocol be designed with energy efficiency in mind.

The purpose of this thesis is to find protocol that is energy efficient and support real-time traffic for environments like habitat monitoring or area surveillance. These sensing nodes collect the information and pass them on to the network towards the sink for further actions. For a better functioning and a longer lifetime for a sensing node within the network, we need to consider its energy consumption as a major factor of concern.

1.3. Research Questions

To effectively work on the aforementioned research problem the following three research questions are set:

RQ1: What previous works have been done to improve the life time of WSNs by improving the energy consumption of nodes?

RQ2: What is the impact of node density on the energy consumption and life time of the WSN?

RQ3: How do we improve the energy consumption rate of WSN nodes?

1.4. Objectives of the Study

1.4.1. General Objective

WSN energy consumption is among the most important constraints that dominates WSN lifetime. This thesis attempts to improve energy utilization of the data gathering process in WSNs.

1.4.2. Specific Objectives

Based on the stated general objective the following specific objectives are formulated:

- To understand and analyze existing key WSN routing protocols we have investigated the limitations of routing techniques towards energy efficiency and optimal paths selection.
- Study energy efficient and network lifetime metrics.
- To improve, test and evaluate the improvements made in the proposed protocol against existing ones.

1.5. Scope of the study

The scope of this thesis is the development of an energy efficient routing protocol for WSNs that can be easily implemented on existing WSN nodes. Even though there are numerous proposals for WSN routing protocols, there is still a great need for protocols that can extend network lifetime, can be implemented easily on nodes using current technology and can be used for networks of any size.

1.6. Significance of the Research

This research work is motivated to improve the life time of WSNs by enhancing the energy consumption of sensor nodes. This is essential since extending battery life will improve the life time of the overall WSN. Since, much of the nodes in existing WSNs use the built-in battery for data collection, data dissemination and data reception improving the energy utilization of these processes is highly demanded. Therefore, in this research an attempt has been made to improve the energy utilization of WSN nodes during data gathering phase. This is significant since much research shows that this phase consumes the highest battery energy in the lifetime of WSN nodes.

1.7. Methodology

A key component in the design of any routing protocol is a thorough knowledge and understanding of factors that influence the specific network for which the routing protocol is intended. Therefore, a thorough literature study is done to identify and investigate the factors that influence the design of WSN routing protocols. The proposed protocol takes into account the major factors during protocol design.

The simulation reveals specifically about the performance of the proposed protocol by comparing it with similar routing protocols in relation to energy utilization; network life and optimal path. The simulation is carried out using J-SIM sensor simulator software because J-sim software practically good for designing sensor network..

1.8. Thesis Organization

The rest of this thesis is organized as follows. Chapter 2 covers more background information on wireless networks mainly WSNs. It also covers the criteria for comparing wireless ad hoc sensor network protocols and important issues for saving of energy consumption and discusses very important related works to understand the objective of this thesis work. Chapter 3 describes the overall grid construction and the algorithms used for determining cluster head and selecting path towards the sinks. Chapter 4 explains fundamental concepts of J-Sim simulator, the simulation implementation, analysis and evaluation of the proposed protocol using J-Sim. Chapter concludes the work and put forth recommendations for future works.

CHAPTER TWO

REVIEW OF LITERATURE AND RELATED WORKS

2.1. Introduction

Interest in packet-based wireless networks began in the 1970s with the Defense Advanced Research Projects Agency (DARPA) packet radio networks. The popularity of wireless networks has increased dramatically since that time, particularly within the past ten years. These networks now allow users to roam through a metropolitan area without losing connectivity. Recent advances in various areas of technology will allow us to realize large deployments of sensors communicating without wires and capable of gathering high resolution information from an area of interest. However, in order to understand how this is all possible, we must begin with the basics. There are two types of wireless networks – infrastructure-based and infrastructure-less or ad hoc [7] [8] [9] [10] [11].

The first type of wireless network, known as an infrastructure-based network, has fixed and wired gateways known as base stations or access points. Devices in this type of network communicate only through the nearest base station. In cellular networks a hand-off occurs when a user moves out of range of one base station and within range of another. The second type of wireless network is the infrastructure-less network. These networks have no fixed infrastructure of any kind. Instead, all nodes in the network function as routers to cooperatively discover paths and move data to destinations in the network. This activity, known as "multi-hop" forwarding, allows users that are beyond direct wireless transmission range to communicate [12] [13].

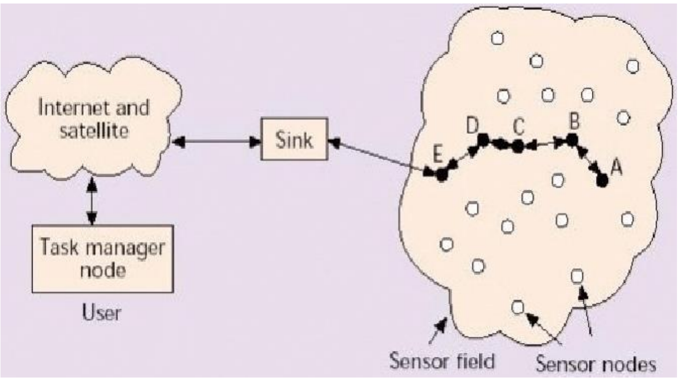


Figure 2.1: Communication architecture of a sensor network.

The communication architecture of the sensor network which is an infrastructure-less network is shown in Figure 2.1. The sensor nodes are usually scattered in a sensor field, an area in which the sensor nodes are deployed. The nodes in this network coordinate to produce high quality information about the physical environment. Each sensor node bases its decisions on its mission, the information it currently has, and its knowledge of its computing, communication and energy resources. Each of these scattered sensor nodes has the capability to collect data and route data back to the base stations. A base station may be a fixed node or a mobile node capable of connecting the sensor network to an existing communications infrastructure or to the Internet where a user can have access to the reported data [14] [15].

Data sensing and reporting in sensor networks is dependent on the application and time criticality of the data reporting. As a result, sensor networks can be categorized as time driven or event driven networks [16]. The former is suitable for applications that require periodic data monitoring. As such, sensor nodes will periodically switch on their sensors and transmitters, sense the environment, and transmit data of interest at constant periodic time intervals. Thus, they provide a snapshot of the relevant attributes at regular intervals. In the latter one, sensor nodes react immediately to sudden and drastic changes in the value of a sensed attribute due to the occurrence of a certain event. These are well suited for time critical applications [17].

A combination of these types of communication is also possible. Moreover, WSNs can involve single hop or multi-hop communication. In a single-hop WSN, a sensor node can directly communicate with any other sensor node or with the external base station. In multi-hop WSNs, however, communication between two sensor nodes may involve a sequence of hops through a chain of pair-wise adjacent sensor nodes. A single-hop communication may take place between the base station and the sensor nodes, while the communication among the sensor nodes is typically multi-hop. This thesis uses multi-hop communication so as to reduce communication cost [15] [16].

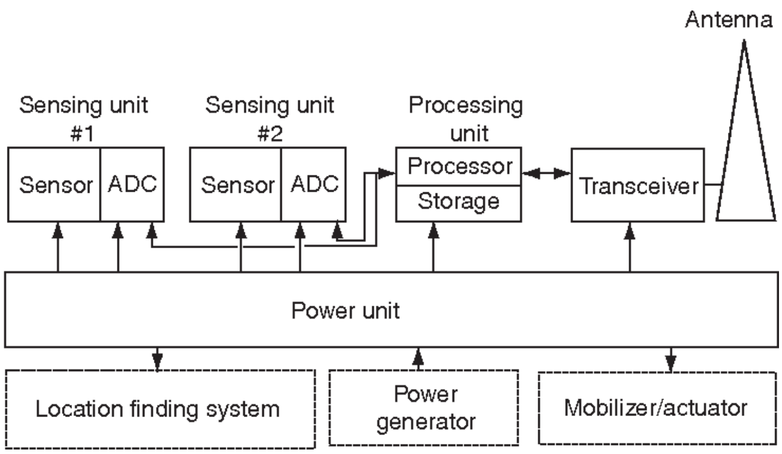


Figure 2.2: Typical sensor node.

Sensor networks require sensing systems that are long-lived and environmentally resilient. Unattended, self-powered low-duty-cycle systems are typical.

Power consumption is often an issue that needs to be taken into account as a design constraint. In most instances, communication circuitry and antennas are the primary elements that draw most of the energy [18]. Sensors are either passive or active devices. Passive sensors in element form include seismic, acoustic, strain, humidity, and temperature-measuring devices. Active sensors include radar and sonar; these tend to be high-energy systems. The trend is toward VLSI (very large scale integration), integrated optoelectronics, and nanotechnology; moreover, work is under way in earnest in the biochemical arena [19].

Ad hoc networks have served as an interesting area of study from an academic point of view, but have gained little attention from the industrial sector until recently [4]. Ad hoc networks present an ever-changing topology in which information poses a source must make its way toward a destination. The dynamic nature of these networks forms a difficult problem with no clear solution to satisfy all possible requirements. The complexity of this problem has captivated researchers since even before wireless communication networks emerged [11]. Some of the imagined applications for ad hoc networking include communication on a battlefield or other region struck by disaster, network gaming, content distribution and distributed conferencing and collaboration. Unfortunately, these applications have rather limited mass market appeal since much of our world is (or can be) equipped with base stations or access points to provide an infrastructure based network. Infrastructure based networks are generally much more efficient because bandwidth is a major constraint in ad hoc network. The available bandwidth in ad hoc network is inversely proportional to the number of nodes in the network when all are attempting to transmit because as the number of nodes increases, each node must use a greater proportion of the available bandwidth to forward traffic for other nodes [12].

Fortunately, there is a broad area of application for which an infrastructure based networking solution is not appropriate. Data acquisition from remote areas requires the use of disconnected sensors that function together to gather high resolution information and communicate the information to a point where it can be analysed and used. It is this area of application, known as sensor networks, that has grabbed the attention of a number of corporations for commercialization of sensor networking technologies [13].

A sensor network is essentially a wireless ad hoc network with some specific characteristics. The limited energy resources of the sensing devices make high-power, long-range transmissions impractical. Low-power transmissions coupled with multi-hop forwarding techniques must be used for moving information in a wireless sensor network. Given this situation, the study of routing in sensor networks begins with a look at routing in general wireless ad hoc networks.

A number of papers propose solutions to one or more of the limitations or problems. Our survey focuses on the suggested solutions in the following areas:

Energy Efficiency: This is a dominant consideration no matter what the problem is. This is because sensor nodes only have a small and finite source of energy. Many solutions, both hardware and software related, have been proposed to optimize energy usage.

Routing: Communication costs play a great role in deciding the routing technique to be used. Traditional routing schemes are no longer useful since energy considerations demand that only essential minimal routing be done.

Communication within a WSN can be initiated either by the source or by the destination. In source initiated protocols, nodes send data to the sink when they have data of interest. Source initiated protocols use time-driven or event-driven data reporting. This means that data is sent either at certain intervals or when nodes sense certain events. Destination originated protocols use query-driven reporting and nodes respond with data to queries that are sent by the sink or another node. Destination-initiated protocols, incur a large amount of overhead since requests are usually flooded through the network. This means that every request for data will result in flooding of the network.

2.2. Hierarchical Protocol

The proposed protocol uses a layer or Hierarchical protocol structure to carry out data dissemination. Each layer has a specific object.

Services Layer (API)
Dissemination Protocol
Routing Protocol
MAC Layer
Wireless Channel

Figure 2.3: Hierarchical Protocol

Figure 2.3 is a diagram illustrating a hierarchical protocol structure for data dissemination in a wireless sensor network. Protocol stack includes a wireless channel, a Medium Access Control (MAC) layer, a routing protocol layer, a dissemination protocol layer, and an Application Programming Interface (API) layer in the order of lowest to highest layers. The dissemination protocol is responsible for constructing grid. Energy saving techniques and protocols are being developed and implemented for each layer of the protocol stack for sensor networks. We approach the problem of energy conservation from the aspect of network protocols.

2.3. WSNs vs. Wireless Ad Hoc Networks

A wireless ad hoc network (WANET) is a temporary network that is set up between peer nodes to satisfy an immediate need [15]. Many protocols exist for wireless ad hoc networks, but are unsuitable for WSNs due to the unique requirements of WSNs. According to Akyildiz et al. [14], WSNs differ from other WANETs in seven areas, namely: network size, node density, node proneness to failure, frequency of topology changes, communication paradigm employed, resource limitations of nodes and node identification. Each of these areas is discussed in the following paragraphs.

The network size of a WSN can be anything from a few nodes up to many thousands of nodes. WANETs on other hand usually consist of less than a hundred nodes. A Bluetooth Pico net, which can consist of up to a maximum of eight nodes, is an example of a WANET. A wireless local network (WLAN) is another example of a WANET. WLAN is based on the IEEE 802.11b standard, which was developed by the Institute of Electrical and Electronic Engineers (IEEE). The size of a WLAN is limited to 32 nodes per access point [16].

IEEE 802.11 Standard is a multiple access technique based on CSMA/CA (Collision Sense Multiple Access/Collision Avoidance) [19]. While many improvements over the original 802.11 standard in terms of bandwidth, speed, modulation-schemes have been incorporated as part of wireless technologies as shown in Figure 2.4 [11], the basic protocol still remains the same. It lets the sender initially sense the carrier or medium to determine if it is idle for use by the sender. If the carrier is busy, the mobile defers transmission and enters the back-off state. The time period following this transmission is called the contention window and consists of a pre-determined number of transmission slots.

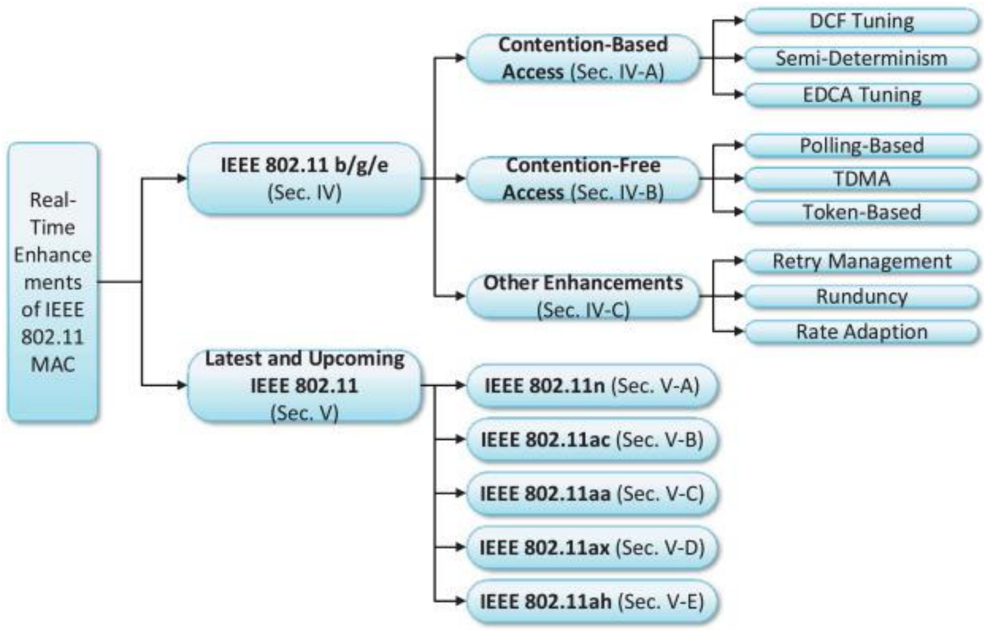


Figure 2.4: Various modifications suggested to the IEEE 802.11 standards [11]

Node density in a WSN is usually high, with a large number of nodes in a relatively small area, while other WANETs mostly consist of only a few nodes in close proximity of each other. This is due to the size of nodes. A WSN node can be cheap, while nodes of other WANETs are mostly notebook computers, palmtops or cellular telephones.

A WSN might be deployed in a remote or inaccessible area, such as a jungle or a disaster area. In such circumstances the node proneness to failure is high due to the possibility of nodes being damaged and failing. Some nodes might also drain their energy resources quicker than other nodes due to being on a routing path that is utilized more than other paths. Nodes in other WANETs have rechargeable energy supplies and are not subjected to adverse environmental conditions that could damage them to the extent of not being able to function any longer.

The frequency of topology changes in WSN is high, due to factors such as node failures, node additions, nodes moving and environmental interference. The network has to be able to adapt to these changes in node topology and number. Topology changes can happen as frequently as every few milliseconds. In other WANETs, nodes usually request to join the network and leave the network after a certain period of time, which is rarely less than a couple of minutes [23].

The communication paradigm employed in WSNs includes a large number of broadcasts that are sent through the network. These broadcasts are used for network set up and maintenance, discovery of neighbours and sending of data. Other WANETs usually use point to point communications, since the source knows how to reach the destination.

The resource limitations of nodes in WSNs include limited energy and bandwidth, compared to other WANETs. The energy resources of WSN nodes cannot be replenished, while other WANETs' nodes have rechargeable batteries. The limited data rate of up to a few kilobits per second in WSNs is small compared to data rates of between one and a few hundred megabits per second in other WANETs. The memory of WSN nodes is limited to a few kilobytes, while other WANETs' nodes can have gigabytes of memory. The processors employed in WSN nodes are limited. The TUV WSSN nodes, for example, use 4MHZ processors [20]. This is very limited, compared to the GHZ processors of notebook computers.

Node identification by means of globally unique identifiers are not always possible in WSNs, due to the possibly very large number of nodes in the network and the overhead caused by having a unique identifier for each node. In other WANETs, the nodes have unique identifiers such as internet protocol (IP) addresses.

The WSN is a new and unique class of WANET that differs considerably from other WANETs. The unique nature of WSNs implies that protocols designed for other WANETs cannot be implemented in WSNs and, therefore, new protocols have to be developed.

2.4. Applications of WSN

2.4.1. Military Applications

The initial wireless sensor network was used in the military applications. Since sensor nodes are low-cost, destruction of some nodes by hostile actions in the battlefields may not affect a military operation. The features of robustness, self-organizing and fault tolerance make sensor networks appropriate for military use. Distributed sensing has the advantages of being able to provide redundant and hence highly reliable information on threats as well as the ability to localize threats by both coherent and incoherent processing among the distributed sensor nodes. Examples of the military applications of sensor networks are monitoring army, equipment and ammunition and enemy surveillance [21].

Monitoring army, equipment and ammunition, equipment, vehicle and critical ammunition is attached with sensors. In the battlefield, the commanders can monitor the status of their armies, equipment, and ammunitions from reported data which are generated constantly by sensors and forwarded to the commanders.

2.4.2. Enemy Surveillance

The sensor network deploys heterogeneous collections of sensors capable of observing and reporting on various dynamic properties of critical terrains in a timely manner. Data reports from areas of the sensor network will be periodic and diverse, carrying a range of application specific data [22].

2.4.3. Forest Fire Detection

The sensor network densely deploys a lot of sensor nodes distributed in a wide forest area. These nodes are integrated with radio frequency system and may be supplied with power from solar cells which can be used for a long time. When the nodes detect the fire, they report the data to the central station. This application needs the real-time communication before the fire spreads and becomes uncontrollable [23].

2.4.4. Flood Detection

An example of the flood detection is the ALERT, which was developed by the National Weather Service in the 1970s. ALERT provides important real-time rainfall and water level information to evaluate the possibility of potential flooding. ALERT sensors are equipped with rainfall, water level and weather sensors. The detected data are reported via line-of-sight radio communication from sensor site to the central station [24].

2.5. Energy Consumption in WSNs

WSNs As a microelectronic device, the main task of a sensor node is to detect phenomena, carry out data processing timely and locally, and transmit or receive data. A typical sensor node is generally composed of four components [10]: a power supply unit; a sensing unit; a computing/processing unit; and a communicating unit. The sensing node is powered by a limited life battery, which is impossible to replace or recharge in most application scenarios. Except for the power unit, all other components will consume energy when fulfilling their tasks. Extensive study and analysis of energy consumption in WSNs are available [27].

2.5.1. Sensing Energy

The sensing unit in a sensor node includes an embedded sensor and/or actuator and the analogue-digital converter. It is responsible for capturing the physical characteristics of the sensed environment and converts its measurements to digital signals, which can be processed by a computing/processing unit [25].

Energy consumed for sensing includes: (1) physical signal sampling and conversion to electrical signal ;(2) signal conditioning; and (3) analog to digital conversion. It varies with the nature of hardware as well as applications. For example, interval sensing consumes less energy than continuous monitoring; therefore, in addition to designing low-power hardware, interval sensing can be used as a power-saving approach to reduce unnecessary sensing by turning the nodes off in the inactive duty cycles. However, there is an added overhead whenever transiting from an inactive state to the active state. This leads to undesirable latency as well as extra energy consumption. However, sensing energy represents only a small percentage of the total power consumption in a WSN. The majority of the consumed power is in computing and communication, as discussed next [26].

2.5.2. Computing Energy

The computing/processing unit is a microcontroller unit (MCU) or microprocessor with memory. It carries out data processing and provides intelligence to the sensor node. A real-time micro-operating system running in the computing unit controls and operates the sensing, computing, and communication units through micro device drivers and decides which parts to turn off and on [26]. Total computing energy consists of two parts: switching energy and leakage energy. The switching energy is determined by supply voltage and the total capacitance switched by executing software. The pattern of draining the energy from the battery affects the total computing energy expense. For example, a scheme of energy saving on computation is dynamic voltage scaling (DVS) [12], which can adaptively adjust operating voltage and frequency to meet the dynamically changing workload without degrading performance. The leakage energy refers to the energy consumption while no computation is carried out. Some researchers have reported that it can reach as much 50% of the total computing energy. Therefore, it is critical to minimize leakage energy [27] [28].

The concept of system partitioning can also be used to reduce computing energy in sensor nodes. Two practical approaches include removing the intensive computation to a remote processing center that is not energy constrained, or spreading some of the complex computation among more sensors instead of overloading several centralized processing elements. Energy expenditure for computing is much less compared to that for data communication. Experiments show that the ratio of communicating 1 bit over the wireless medium to that of processing the same bit could be in the range of 1000 and 10,000 [25] [29]. Therefore, trading complex computation/data processing for reducing communication amount is effective in minimizing energy consumption in a multi hop sensor network.

2.5.3. Communicating Energy

The communicating unit in a sensing node mainly consists of a short-range RF circuit that performs data transmission and reception. The communicating energy is the major contributor to the total energy expenditure and is determined by the total amount of communication and the transmission distance. As reported in Pottie and Kaiser, processing data locally to reduce the traffic amount may achieve significant energy savings [29] [30]. Moreover, signal propagation follows as exponential law to the transmitting distance (usually with exponent 2 to 4 depending on the transmission environment). It is not hard to show that the power consumption due to signal transmission can be saved in orders of magnitude by using multi hop routing with a short distance of each hop instead of single-hop routing with a long-distance range for the same destination.

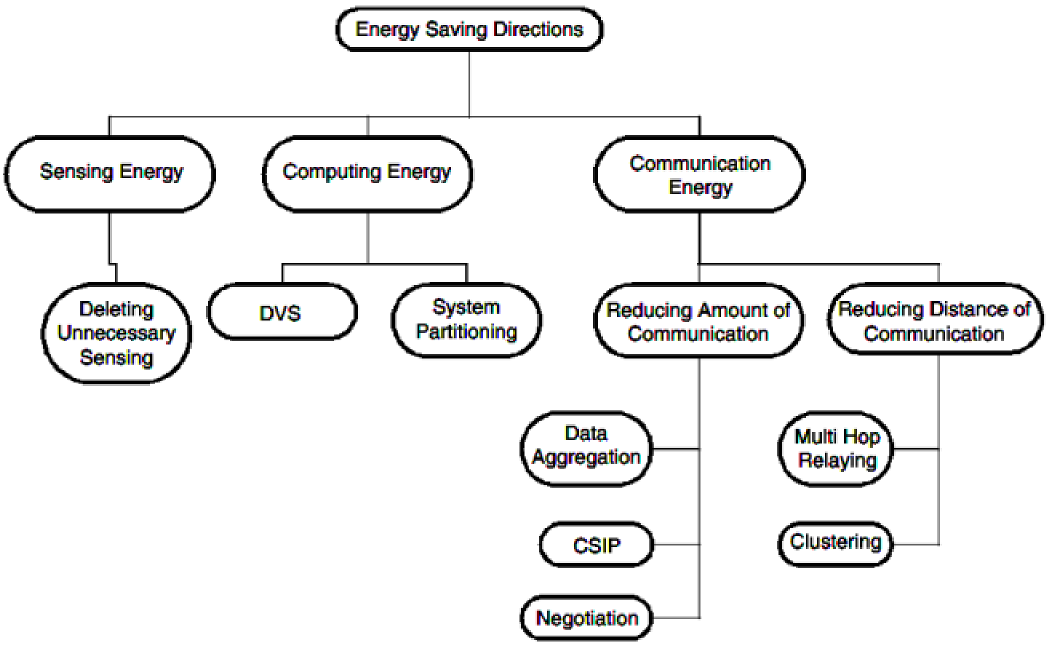


Figure 2.5: Energy-conserving directions in WSNs [29].

Therefore, minimizing the amount of data communicated among sensors and reducing the long transmitting distance into a number of short ones are key elements to optimizing the communicating energy; numerous efforts have focused on these objectives. Several approaches have been devised in order to reduce data communication. For instance,

- Data aggregation has been applied to eliminate redundancy in neighbouring nodes.
- Collaborative signal and information processing (CSIP) has been used to fulfil local data processing [20].
- Negotiation-based protocols have been introduced to reduce unnecessary replicated data.

Similarly, in order to decrease signal transmission distance, multi hop communication and clustering based hierarchies have been proposed to forward data in the network [22] [30].

Figure 2.5 summarizes energy-conserving directions with respect to optimizing sensing, computing, and communication energy consumption. Such approaches exhibit a high degree of dependency on one another. For example, eliminating unnecessary sensing could reduce data communication; in turn, communication energy consumption is reduced. However, this requires more sophisticated control schemes, which are supported by higher complexity computation, and may result in higher energy use for computation. Therefore, trade-offs should be made and some specific direction may take greater importance based on the nature of the application scenario.

2.5.4. Routing Challenges and Design Issues in WSNs

One of the main design goals of WSNs is to carry out data communication while trying to prolong the lifetime of the network and prevent connectivity degradation by employing aggressive energy management techniques. The design of routing protocols in WSNs is influenced by many challenging factors. These factors must be overcome before efficient communication can be achieved in WSNs. In the following, we summarize some of the routing challenges and design issues that affect routing process in WSNs. Node deployment: Node deployment in WSNs is application dependent and affects the performance of the routing protocol. The deployment can be either deterministic or randomized. In deterministic deployment, the sensors are manually placed and data is routed through predetermined paths. However, in random node deployment, the sensor nodes are scattered randomly creating an infrastructure in an ad hoc manner. If the resultant distribution of nodes is not uniform, optimal clustering becomes necessary to allow connectivity and enable energy efficient network operation. Inter-sensor communication is normally within short transmission ranges due to energy and bandwidth limitations. Therefore, it is most likely that a route will consist of multiple wireless hops.

Energy consumption without losing accuracy: sensor nodes can use up their limited supply of energy performing computations and transmitting information in a wireless environment. As such, energy conserving forms of communication and computation are essential. Sensor node lifetime shows a strong dependence on the effectively utilizing of battery [1]. In a multi hop WSN, each node plays a dual role as data sender and data router. The malfunctioning of some sensor nodes due to power failure can cause significant topological changes and might require rerouting of packets and reorganization of the network.

Data Reporting Model: Data sensing and reporting in WSNs is dependent on the application and the time criticality of the data reporting. Data reporting can be categorized as either time-driven (continuous), event-driven, query-driven, and hybrid [13] [31]. The time-driven delivery model is suitable for applications that require periodic data monitoring. As such, sensor nodes will periodically switch on their sensors and transmitters, sense the environment and transmit the data of interest at constant periodic time intervals. In event-driven and query-driven models, sensor nodes react immediately to sudden and drastic changes in the value of a sensed attribute due to the occurrence of a certain event or a query is generated by the BS. As such, these are well suited for time critical applications. A combination of the previous models is also possible. The routing protocol is highly influenced by the data reporting model with regard to energy consumption and route stability.

Node/Link Heterogeneity: In many studies, all sensor nodes were assumed to be homogeneous, i.e., having equal capacity in terms of computation, communication, and power. However, depending on the application a sensor node can have different role or capability. The existence of heterogeneous set of sensors raises many technical issues related to data routing. For example, some applications might require a diverse mixture of sensors for monitoring temperature, pressure and humidity of the surrounding environment, detecting motion via acoustic signatures, and capturing the image or video tracking of moving objects. These special sensors can be either deployed independently or the different Functionalities can be included in the same sensor nodes. Even data reading and reporting can be generated from these sensors at different rates, subject to diverse quality of service constraints, and can follow multiple data reporting models. For example, hierarchical protocols designate a cluster head node different from the normal sensors. These cluster heads can be chosen from the deployed sensors or can be more powerful than other sensor nodes in terms of energy, bandwidth, and memory. Hence, the burden of transmission to the BS is handled by the set of cluster-heads [32] [33].

Fault Tolerance: Some sensor nodes may fail or be blocked due to lack of power, physical damage, or environmental interference. The failure of sensor nodes should not affect the overall task of the sensor network. If many nodes fail, MAC and routing protocols must accommodate formation of new links and routes to the data collection base stations. This may require actively adjusting transmit powers and signalling rates on the existing links to reduce energy consumption, or rerouting packets through regions of the network where more energy is available. Therefore, multiple levels of redundancy may be needed in a fault-tolerant sensor network. Scalability: The number of sensor nodes deployed in the sensing area may be in the order of hundreds or thousands, or more. Any routing scheme must be able to work with this huge number of sensor nodes. In addition, sensor network routing protocols should be scalable enough to respond to events in the environment. Until an event occurs, most of the sensors can remain in the sleep state, with data from the few remaining sensors providing a coarse quality.

Network Dynamics: Most of the network architectures assume that sensor nodes are stationary. However, mobility of both BS's and sensor nodes is sometimes necessary in many applications [1]. Routing messages from or to moving nodes is more challenging since route stability becomes an important issue, in addition to energy, bandwidth etc. Moreover, the sensed phenomenon can be either dynamic or static depending on the application, e.g., it is dynamic in a target detection/tracking application, while it is static in forest monitoring for fire prevention. Monitoring static events allows the network to work in a reactive mode, simply generating traffic when reporting. Dynamic events in most applications require periodic reporting and consequently generate significant traffic to be routed to the BS [34] [35].

Transmission Media: In a multi-hop sensor network, communicating nodes are linked by a wireless medium. The traditional problems associated with a wireless channel (e.g., fading, high error rate) may also affect the operation of the sensor network. In general, the required bandwidth of sensor data will be low, on the order of 1-100 kb/s. Related to the transmission media is the design of medium access control (MAC). One approach of MAC design for sensor networks is to use TDMA based protocols that conserve more energy compared to contention based protocols like CSMA (e.g., IEEE 802.11). Bluetooth technology [20] can also be used.

Connectivity: High node density in sensor networks precludes them from being completely isolated from each other. Therefore, sensor nodes are expected to be highly connected. This, however, may not prevent the network topology from being variable and the network size from being shrinking due to sensor node failures. In addition, connectivity depends on the, possibly random, distribution of nodes.

Coverage: In WSNs, each sensor node obtains a certain view of the environment. A given sensor's view of the environment is limited both in range and in accuracy; it can only cover a limited physical area of the environment. Hence, area coverage is also an important design parameter in WSNs.

Data Aggregation: Since sensor nodes may generate significant redundant data, similar packets from multiple nodes can be aggregated so that the number of transmissions is reduced. Data aggregation is the combination of data from different sources according to a certain aggregation function, e.g., duplicate suppression, minima, maxima and average. This technique has been used to achieve energy efficiency and data transfer optimization in a number of routing protocols. Signal processing methods can also be used for data aggregation. In this case, it is referred to as data fusion where a node is capable of producing a more accurate output signal by using some techniques such as beam forming to combine the incoming signals and reducing the noise in these signals.

2.6. Routing in Ad Hoc Networks

The dynamic topology of a wireless ad hoc network changes the way routing mechanisms operate. In a mobile ad hoc network used for Internet access or voice communications the topology changes as mobile users move within the area covered by the network, or choose to connect and disconnect from the network. This is in harsh contrast to wired networks where topology changes are unlikely, typically occurring only when a highly reliable and dedicated router malfunctions. Wired networks use table-driven routing protocols that attempt to maintain consistent path information at each router. That is, the routing strategy in wired networks is proactive. However this method has been largely dismissed as inefficient for ad hoc networks due to the amount of signalling overhead required maintaining updated routing tables in a dynamic network. An alternative strategy known as source-initiated on demand or reactive routing has been adopted for mobile ad hoc networks [6].

Reactive routing builds routes as they are needed rather than attempting to maintain routes indefinitely. Route discovery is initiated only when a route to a destination is required. An established route is maintained until no longer required or until a link in the path becomes unusable. In general, a source requiring a route to a destination will broadcast a route request message. Confirmation of the route is sent back to the source when a route has been found. During route maintenance the source is informed of any errors occurring along the route and route discovery may be re-initiated. Demand driven routing eliminates the wasteful overhead required by table-driven protocols for maintaining unneeded routes in a changing environment. On-demand routing is similar to a connection-oriented service where parameters on the desired route can be specified in a manner similar to methods used in the nature of the devices and applications used in ad hoc networks gives rise to specific needs such as Quality of Service (QoS) support and power-aware routing. The on-demand route discovery schemes used in ad hoc networks can easily accommodate the addition of parameters to the route request. These parameters can specify thresholds used to discover energy-efficient or lightly-loaded routes. Not only is reactive routing more appropriate for ad hoc networks with dynamic topologies, it can help make better use of limited resources in the network.

2.7. Routing in Sensor Networks

In general, routing in WSNs can be divided into flat-based routing, hierarchical-based routing, and location-based routing depending on the network structure. In flat-based routing, all nodes are typically assigned equal roles or functionality. In hierarchical-based routing, however, nodes will play different roles in the network. In location-based routing, sensor nodes' positions are exploited to route data in the network. A routing protocol is considered adaptive if certain system parameters can be controlled in order to adapt to the current network conditions and available energy levels. Furthermore, these protocols can be classified into multipath based, query-based, negotiation-based, QoS-based, or coherent-based routing techniques depending on the protocol operation. In addition to the above, routing protocols can be classified into three categories, namely, proactive, reactive, and hybrid protocols depending on how the source finds a route to the destination. In proactive protocols, all routes are computed before they are really needed, while in reactive protocols, routes are computed on demand. Hybrid protocols use a combination of these two ideas. When sensor nodes are static, it is preferable to have table driven routing protocols rather than using reactive protocols. A significant amount of energy is used in route discovery and setup of reactive protocols. Another class of routing protocols is called the cooperative routing protocols. In cooperative routing, nodes send data to a central node where data can be aggregated and may be subject to further processing, hence reducing route cost in terms of energy use. Many other protocols rely on timing and position information. Establishment of an end-to-end path in a sensor network is not unlike the strategies used in general ad hoc networks. However, those schemes are not well adapted to the specific characteristics of the devices, networks and traffic flows present in sensor networks. Sensing devices are assumed to be quite unreliable with potential faults resulting from the unreliability of the wireless medium, depletion of the power resource or an external force in a hostile area of operation. Routing protocols must be resilient to these types of failure. Sensor networks also have an order of magnitude more nodes than most mobile ad hoc networks. Routing strategies must be scalable to at least a few thousand nodes to be practical for use in a sensor network.

We stated our focus to be on fields of static sensors. We have described the ever-changing topology as the rationale for reactive routing techniques in ad hoc networks. The likelihood of temporary or complete node failure in sensor networks makes the topology dynamic even though the nodes themselves are stationary. Further, the energy required to maintain changing routes that may not be needed would not be efficient for a sensor network. Thus demand driven routing protocols are used in static sensor networks. An opportunity for efficiency gains in sensor networks is in-network data aggregation, also known as data fusion. The monitoring station may not require the fine granularity of data offered by the sensor field. In this case intermediate nodes may collect data from a few different sources and forward only the summarized data toward the monitoring station. Monitoring stations are also known as sinks. Data aggregation can provide significant bandwidth and energy savings. Sensing devices require location knowledge for data collection applications. The location information can also be leveraged by the network layer for use in routing decisions. By simply moving data geographically closer to the destination we can greatly reduce the amount of stored routing information. A problem with geographic routing is how to route around holes in the sensor field. What happens when a packet reaches a node that is not the destination, but is the closest of its neighbours to the destination? The problem with horseshoe shaped holes is depicted in Figure 2.6. In most cases, sensors that are identified purely by geographic location are easily replaceable without greatly impacting the rest of the network.

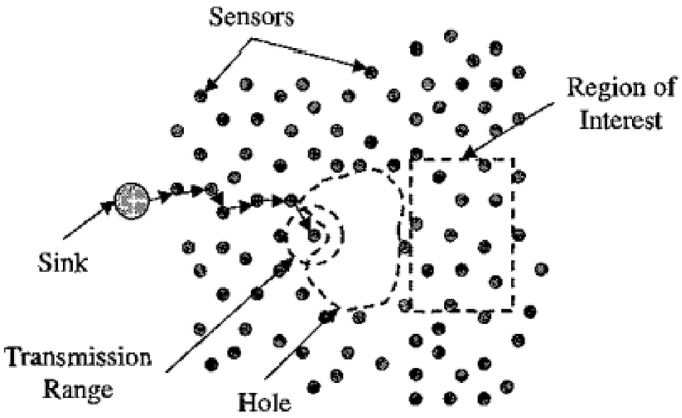


Figure 2.6: The problem with simple geographic routing when horseshoe shaped holes are encountered.

The small amount of power that is available must be stretched as thinly as possible to maximize sensor replacement cycles. Operating costs of the sensor field are reduced when sensor replacement occurs less often. As described in the previous section, reactive routing schemes can be used to find optimal routes for prolonging the useful lifetime of the network as a whole. The following four basic strategies are used for finding energy efficient paths [5].

Maximum Power Available: Sum the remaining battery power of nodes along the route. The route with the most total remaining battery power is chosen.

Minimum Hop Count: The route comprised of the smallest number of nodes is used. **Minimum Energy:** Select the route requiring the minimum energy to transmit the data packet Note that this strategy reduces to Minimum Hop Count in a homogeneous network of sensors with fixed transmission power.

Maximum Minimum Power Available Node: Compare the nodes with the minimum remaining battery power from each route. The number and mobility of sinks is another characteristic of the sensor field. A sole sink presents a single point of failure for the entire network. Using multiple, coordinated sinks provides redundancy against such a scenario. Assuming multi-hop forwarding, the sensors nearest to a sink will have the highest forwarding load since they are the link through which all communication for the sink must pass. When sinks are mobile this load is spread throughout the network.

Thus far, the requirements of a sensor network can be met by general approaches to routing in ad hoc networks. It is the unique traffic flows present in sensor networks that are really the distinguishing factor and present an opportunity for more efficient strategies.

When observation data becomes available, it must be routed back to the sink through sensors. Each task from a sink is directed toward a region of interest within the sensor field or the entire network (see Figure 2.7). In this scenario we have a one-to-many communication model with a sink collecting data from a group of sensors. Multicast protocols have been widely studied with respect to ad hoc networks; however the task request, data response Exchange is particular to sensor networks and opens the door to efficiency gains through specialization the protocols.

Figure 2.7: Tasks from sinks are assigned to sensors within the region of interest. Data captured by sensors is then relayed back to the sink.

2.8. Criteria for Comparing WSN Protocols

In the beginning comparing WSN protocols task sounds quite simple: “Define restrictions, problems, goals and possible usability scenarios of wireless sensor networks (WSN).” What is the primary goal of a wireless sensor network? The more sophisticated sensors get the more complex a scenario can be. It’s not any longer just gathering data and waiting for a command to send it to a sink. The mobile factor has come even to WSNs. Thinking of WSNs the, first question to be answered should be what defines a WSN, what kind of limits are there and what is the emphasis of the WSN. A classification proposed in [3] gives a good starting point. However it was designed to compare huge variety of protocols whereas in this thesis only protocols dealing with mobile agents are of interest. A more specialized classification has to be applied. The proposed criteria are chosen in order to compare the abilities of these protocols, trying to identify possible areas of improvement.

Definition: A Wireless Sensor Network is a distributed network of homogenous sensor nodes, which are able to collect data and transfer the information via radio signals. Data packets are delivered over large distances from source to sink using several hops as forwarders [33]. Each sensor node works in two operation modes: collecting data send and receive data. These modes are for example interrupts triggered or based within a simple operating system like TinyOS which is a common operating system in sensor devices. Wireless ad-hoc sensor networks have certain features and demands which should be supported by any wireless sensor network protocol. An overview is given starting with the collection given below. This collection finally is converted into a list of categories, which will be used to categorize and evaluate each protocol mentioned at the beginning of this chapter.

Network Topology: Is it a flat or hierarchical network topology? A flat network topology is a simple approach, where every node has the same features. It collects data and is used as a forwarder if necessary. Hierarchical networks use the advantages of clustering nodes, defining cell-masters and thus prevent lots of traffic. The avoidance of flooding the whole network is one thing, the usage of another routing protocol on top of the cell-masters another. Hierarchical network protocols are mostly two-layered, having a normal routing protocol underneath and another data delivery protocol on top. Data aggregation and other methods are used to reduce the number of transmissions, saving energy on each node. The lifetime of a sensor network is therefore increased. Energy Consumption: Does the protocol allow energy saving due to intelligent routing mechanisms. What are possible ways of saving energy (e.g. avoid flooding, unnecessary ACK/NACK packets)? Position Awareness: Is it necessary that nodes know their own position? What kind of a routing protocol is used on layer 3? Some protocols rely on the usage of geographic forwarding as layer 3 protocol. Are there alternatives and what are the problems with location unaware nodes? Robustness: The ability of the protocol to deal with defective areas. This includes the possibility to deal with normal link failures and the ability to increase/decrease transmits powers. Scalability: How easy is it to increase the number of nodes, sources or sinks? Is there an upper bound? A protocol should be able to manage lots of nodes and several sources and sinks. Clearly sinks and sources are a minor problem in flat topologies but can lead to resource problems in hierarchical networks. What distinguishes a ’good’ protocol from a ’bad’ one, which parameters of a protocol are important and which aspects (mentioned above) contribute to a fair evaluation? Each aspect has its individual influence within a wireless sensor network.

2.9. Related Works

This section describes current routing protocols for sensor networks. The survey contains a good overview of the state of the art in sensor network routing protocols. Given the requirements of a sensor network described in the previous sections we follow the description of each protocol with a critical analysis.

LEACH

LEACH is a clustering-based protocol that utilizes randomized rotation of cluster heads to evenly distribute the energy load among the sensors in the network. LEACH uses localized coordination to enable scalability and robustness for dynamic networks, and incorporates data aggregation into the routing protocol to reduce the amount of information that must be transmitted to the base station. The cluster heads are randomly chosen in order to randomize the distribution of the energy consumption and load among the sensors, and therefore taking the first step towards evenly distributing the energy consumption through the system's lifetime. Each cluster head acts as a gateway between the cluster members and the base station; the cluster head aggregates all the information received from its members and then sends one message directly to the base station. Note that the one message size that is sent to the base station is size independent from the number of messages the cluster head receives from its members [30].

The positive point in randomized cluster heads is the fact that the nodes will randomly deplete their power supply, and therefore they should randomly die throughout the network. Since the clustering implemented in LEACH is based on randomness, its cost is much less and realistically feasible when compared to the traditional clustering definition.

Although LEACH's clustering protocol seems promising, further evaluation is needed in analysing the set up and synchronization costs of maintaining the LEACH protocol. On the other hand, the randomized cluster heads will make it very difficult to achieve optimal results. It should also be obvious that since random numbers are utilized, the performance of the system will vary according to the random number generation and will not be as predictable as a system that is based on information that will lead it to make the best local decision possible. For LEACH to be a true clustering protocol as defined above, the cluster heads should be chosen according to certain metrics, such as location, power levels, etc. Figuring out the clusters topology requires global knowledge of every nodes position, which requires global synchronization. If the cluster heads would only have to be chosen once, the cost of obtaining the global information might be reasonable, however since the cluster heads would deplete their energy supply much faster than the rest of the nodes, each node can only be a cluster head temporarily, which implies that the clustering global synchronization would have to be done rather frequently.

The second drawback of LEACH is the assumption that 100% aggregation of data is a common characteristic of real world systems. There are applications where this assumption is reasonable; however most applications rely on the availability of more information to be finally received for evaluation and analysis. In LEACH, for each round, each cluster head receives a packet of 2000bits from x number of child nodes; it fuses all received packets together, 2000*x bits, and sends one packet of 2000 bits to the base station that is supposed to represent the data contained in x number of packets. It therefore assumes that a saving of a factor of x can be reasonably achieved. However, in practice, this technique would lead to large missing data and most likely unsuitable for most applications.

Disadvantage of LEACH is the fact that all of the nodes are required to be able to communicate directly with the sink. It is also required that the nodes be able to support different MAC protocols, since the cluster heads use two MAC protocols. The cluster head selection is also not efficient since nodes electing to be cluster heads might be concentrated in one part of the network. Moreover, the message overhead is large, as in most hierarchical protocols.

Two Tier Data Dissemination Protocol

A novel form of dynamic hierarchical routing has been proposed by Fan Ye et al. [5]. The Two-Tier Data Dissemination (TTDD) protocol creates a virtual grid structure on which data is delivered. The protocol assumes the availability of location knowledge and multiple, mobile sinks. Sinks may be mobile when they are contained in hand-held devices operated by a person walking through the sensor field. Sink mobility requires tracking their location to ensure an uninterrupted flow of data from the sources.

TTDD operation is initiated by the data source through advertisements. The source forms a virtual grid structure over the entire network and becomes the first crossing point of the grid (called a dissemination node). The advertisement is then sent to each adjacent dissemination node. Geographic routing is used to forward packets between dissemination nodes. Each neighbour in turn forwards the advertisement to its adjacent crossing points and so on until the grid covers the entire sensor field. Since the grid is based at the source, different sources will use different dissemination nodes [5]. Following the advertisement phase, data can be requested and sent using the grid structure. Data requests are flooded by sinks within an area the size of a cell. When a query reaches dissemination node for matching data, the query is sent toward the source using the reverse path of the advertisement. Finally, data is returned to the sink through the grid using the reverse path of the query. Routing information represents a soft-state and eventually expires. Therefore both data source advertisements and requests must be periodically retransmitted. Stored sink locations must expire because the sinks are mobile. As a sink moves, queries are retransmitted to find new dissemination nodes.

TTDD provides a number of positive solutions to difficult problems. Provided no partitions exist, data announcement messages will reach the entire network without full full-scale flooding. The use of distinct dissemination nodes by each source achieves load balancing and improves and scalability because each node will hold state for no more than a few sources at a time.

Unfortunately there are a number of significant drawbacks to the TTDD solution. First, the periodic signalling represents significant overhead in maintaining the grid structure. Second, failure of the single selected source could result in all data being lost from a small region of interest. Third, replication of routing information in sensors near to dissemination nodes is proposed as a way of dealing with node failure. The communication required for the replications only adds to the overhead. Fourth, TTDD does not provide a mechanism for requesting data from the sensor field. This limits the type of applications that can use TTDD to those involving triggered or event-driven data collection. Finally, the grid used by TTDD is static. If a single data source were to continuously transmit data to the sink, we find that TTDD does not follow an energy-efficiency strategy. Its adaptability to integration with an energy efficient scheme needs to be examined. It should also be noted that the dependence of TTDD on nodes at grid points only can lead to large energy imbalance. Also, the large communication overhead resulting from grid construction and maintenance can have a significant effect on energy consumption and network operation. The proposed protocol tackles energy utilization and grid construction approach.

Geographic Adaptive Fidelity (GAF)

GAF is a location based energy conservation protocol. In GAF redundant nodes are identified based on their geographic locations. The radio of a node is periodically switched off for balancing the load. Location information in GAF is provided by Global Positioning System (GPS) and GAF assumes that the location information is correct. GAF uses the concept of equivalent nodes. Equivalent nodes are intermediate nodes which are same in terms of their connectivity to other nodes with respect to communication. In GAF the network area is divided into small virtual grids such that all nodes in adjacent grids are in each other’s radio range. Thus in each virtual grid any one of the nodes can be used for routing. In GAF thus energy saving can be done by keeping the radio of one sensor node active per grid and switching off the radios of all the other sensor nodes. To further balance the energy dissipation in each grid the nodes in a grid are periodically rotated to be active, so that at any given time only one node is switched on per virtual grid [31].

Issues with GAF: GAF is dependent on global information. It fails in applications were geographic location information is not available and hence GAF can be used in very limited applications In GAF if a grid has only one node then is not possible to balance the energy usage for that virtual grid and the network may have pockets of low energy virtual grids which in turn may lead to network partitioning.

Directed Diffusion

Directed diffusion [9] is a popular routing protocol and is probably the best known WSN routing protocol. Many other routing protocols have been based on it. Directed diffusion is a destination initiated protocol that uses a flat network structure and reactive routing. The protocol uses data centric routing, where queries are directed at certain areas in the network and not the whole network. Directed diffusion consists of three stages, namely interest diffusion, gradient setup and data delivery. During interest propagation, the sink node floods an interest for named data through the network. Named data consists of attribute and value pairs. An attribute might be “temperature” and the value at one node might be “30”. A request for named data might be for all nodes that have the attribute “temperature” and values “>30” to respond with their data. The idea of using named data for requests is an efficient way to eliminate the possibility of receiving undesired or irrelevant data. The initial interest also specifies the initial rate at which the nodes have to interest to an interest cache. The interest cache contains an entry for each received interest the interest entry contains the ID of each neighbour from which the interest was received and the data rate towards that neighbour During the second stage of directed diffusion, nodes having attribute-value pairs matching the interest start sending data to all of the neighbours in the interest cache according to the specified data rate. Gradients are also set up for the interest. A gradient is simply the data rate at which to send data about a specific interest to a specific neighbour. Directed diffusion also incorporates data aggregation. Nodes receiving data directed at the sink add the data to a data cache. Nodes will check the data cache each time a data message is received to see if the data is new. If the data has already been seen the node will disregard the message. When data reaches the sink, it reinforces one or more paths by sending another interest. This interest is for the same named data but it is sent to a specific destination node along one path and specifies a higher data rate and longer time before transmission should be stopped. This path might be calculated by sending data only to the node from which the interest response was first received at each hop. During the last stage of the protocol, a node that has been reinforced sends data towards the sink at the data rate specified in the reinforcement message. The data is sent along the single path that was established. The three stages of directed diffusion one problem with directed diffusion is the overhead associated with the protocol. Interests are flooded, which consumes excessive amounts of energy. The initial replies from nodes are also flooded, adding to the energy waste. Another problem is the possibly large memory requirements for the nodes. Each node stores a table containing all the interests that it has received. Each interest entry also has one sub-entry for each node from which it received that interest. In a large sensor network of thousands of nodes there might be many interests and interest tables can grow exponentially.

Therefore, directed diffusion cannot be used for applications where data is needed from all of the nodes at frequent intervals [9].

All of the routing solutions proposed to date for sensor networks have shortcomings of one former another. In the chapters that follow we describe a new routing and addressing proposal for sensor networks called Cell Based Routing protocol (CBR WSN). The algorithm builds upon the grid construction concept used by Two-Tier Data Dissemination (TTDD) developed by Ye et al. in [5] and draws ideas from other work on sensor ad hoc networks. Our work aims to address the shortcomings of previous work particularly on energy efficiency. From previous works that are discussed above, all protocols have drawbacks in terms of energy utilizations particularly directed diffusion which has no concept of energy conservation strategy.

GAF tries to deploy energy conservation by on and off nodes at a time with in the grid what if a grid has one sensor node? The other drawback of GAF is a mechanism that uses to on and off the sensor nodes costs energy. The TTDD tries to address to lesser extent to minimizing the energy utilization by distributing the load to dissemination nodes. However, the problem with TTDD is that source node proactively creates grid without the interest of the sink in that case energy wasted and also every source create grids hence there will be energy issue for creating grid unnecessarily. Concerning to data delivery to the sink the route path is established by the side of square root of 2 instead of the shortest path therefore TTDD doesn’t use optimal path between the source and the destination.

CHAPTER THREE

THE PROPOSED ENERGY EFFICIENT ROUTING PROTOCOL

3.1. Introduction

CBR-WSN is proposed as a cell based routing energy efficient protocol based on the idea of two tier data dissemination (TTDD) protocol grid based data dissemination. The research is based on an idea first published by Fan Ye, et.al. [5]. However, our scheme is differentiated by a number of features; including the ability to gather data from specific regions of the sensor field; a more robust and energy efficient forwarding structure. The proposed protocol is designed to transmit packets in a multi-hop manner, wherein the consumption of power can be shared by all the nodes in the network, increases the network lifetime. In multi-hop transmission, selection of the intermediate node is done by not only considering the shortest path possible but also by taking into account the residual power of the potential intermediary nodes. This is important because selecting the same intermediate nodes often will result in depleting the intermediate nodes of their energy and causing the nodes to die which will, in turn, decrease the network lifetime. Therefore, the proposed protocol focuses on network longevity. The thesis is intended to provide cell based energy efficient routing based on each cell cluster head energy level. Each cell offers a high energy sensor node to forward packet toward the sink. The algorithm finds three optimal paths out of eight possible paths based on distance and cost towards the destination. The selected three paths are compared each other based on their transmission cost and available energy level. Our work aims to address the shortcomings of previous work of TTDD and LEACH in the following ways.

- Construct a more robust grid that provides multiple paths from data source to data sink.
- Use sink-initiated rather than source-initiated grid construction allowing for greater data fusion opportunities.
- Maximize the useful lifetime of the sensor field by preferring energy efficient paths.
- Better distribute the data forwarding workload.

3.2. Assumptions and Working of the Model

We consider that identical wireless sensor nodes are distributed randomly in a field. Each sensor node carries a radio trans-receiver whose transmitter has a fixed transmission range of R. There exist multiple paths between a pair of nodes. We further assume that each sensor node is stationary data can be sent from one to another in a multi-hope manner. There exist multiple paths between a pair of nodes. Further assume that each node contains an internal battery to support its sensing and communication activities. This battery can neither be replaced nor recharged. Furthermore, the transmitter power of the node is fixed for both data transmission and reception. When an event occurs, the surrounding nodes first exchange the information with cluster head. This section presents the basic design of proposed protocol, which works with the following network setting:

- A vast field is covered by a large number of homogeneous sensor nodes that communicate with each other through short range radios. Long range data delivery is accomplished by forwarding data across multiple hops.
- Each sensor node is assumed to be aware of its own geographic location. The network can use location services such as GPS to estimate the locations of the individual nodes.
- The sensor nodes are homogeneous and wireless channels are bidirectional. Each sensor node has constrained battery energy.
- After having been deployed, sensor nodes remain stationary at their initial locations.
- The power supply is restricted by sensor size.
- Processing power and memory capacity are limited by cost constraints.
- Radio transmission power, and thus communication range, is static.
- High failure rates are expected due to environmental conditions and depletion of power resources.
- Physical location in the sensor field is fixed and known.
- Sink nodes can be described by the following functionality: Energy resources are unlimited.

A. The Initiation Phase

The initialization phase takes place after all sensor nodes are deployed in the target field. This phase has two objectives.

- First, the localized flooding of HELLO message allows all nodes to be aware of the status of their immediate neighbours and calculate their grid id.
- Second, the flooding of HELLO messages from sink nodes gives opportunities for each node to calculate its shortest distance to the sinks, and provides the cell size of the grid and the base coordinate numbers are sent to set up grid construction.

Localized flooding of HELLO message starts with a simple neighbour discovery procedure and adds all found neighbour nodes to neighbour list only if in the same grid otherwise it ignores the message. The HELLO message has a predefined TTL (the cell size), a current timestamp and its own node ID. The timestamp can be used to drop messages if they are assumed to be too old.

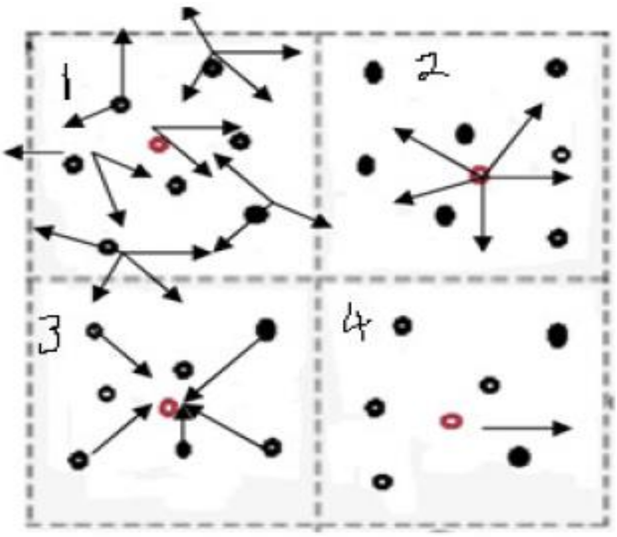


Figure 3.1: Initial Phase

B. Cluster Head Formation

During the initialization phase cluster heads are chosen based on the criteria: a sensor node closest to the centre of grid and the remaining energy level of sensor node. However, during initialization phase each sensor node begins with equal battery power, therefore sensor node having a shortest distance to the centre of grid will be elected as cluster head in each cell. In order to elect the cluster heads of each cell, if sensor nodes begin with equal battery power, all sensor nodes locally flood a representative head announcement packet (RH-packet) at a random period. The local flooding can be limited within the single cell by simply dropping the packet from neighbour cells. Each sensor node stores the location of its neighbour nodes and their header by sending the HA-packet. The selection criteria to be cluster head are the available energy level and proximity of the sensor nodes to the centre of the cell.

All sensor nodes simply send their data to the cluster head which aggregates it, and forward it to destination or sink. Because the cluster head consumes much more battery power than other sensor nodes, a role of the cluster head should be checked every time. The duration of the role of the cluster head depends on the remaining power of the battery or a threshold value. Before expiring the duration of the header, next header should be selected. Every sensor node except the header measures the remaining power of the battery and sensor nodes having the remaining power more than others locally flood the RH-packet. After cluster heads are elected they start to advertise their intention and the rest of the nodes decide which cluster to join, of course based on grid id. Once the clusters are formed, the cluster head creates a TDMA schedule and sends it to its cluster members. To reduce interference, each cluster communicates using different CDMA codes.

C. Cluster Maintenance

Cluster maintenance includes two parts: energy monitoring and cluster reconstruction. Energy monitoring is relatively straight forward. A cluster header will check its energy periodically. If the sensor's residual energy is below some threshold, it will invoke the cluster reconstruction process. In cluster reconstruction, when the residual energy of the cluster head (CH) is below some threshold, it will broadcast the SELECT_NEW_CH message to its cell members (neighbours). Any sensor, which is the member of cell (grid), receiving this message will check and reports its residual energy and location to the CH. If sensor node receives message outside of the cell then it will ignore the message then cluster head decide the sensor node with maximum residual energy as the new cluster head and pass control to the new cluster head. However, if two or more sensor nodes have the same residual energy then the node close to the centre of the grid will be chosen as cluster head.

D. Data Announcement and Role of Cluster Head

The sensor node which detects an interesting event becomes the source, generates a data announcement packet (DA-packet), and sends it to its cell cluster head. The DA-packet consists of the location information of the source, cell ID, sequence number and data generation time. When the interesting event happens, there may be several sensor nodes detecting it and send the DA-packets to the cluster head, the cluster head aggregates and compress the packets. Once the cluster head receives the DA-packet from the source, it takes the role; it has eight possible adjacent cluster heads to forward the data to sink. However, only three adjacent cluster heads are selected: horizontal, vertical and diagonal direction until finally the DA-packet reaches the sink. While propagating the DA-packet through cluster heads, each cluster header stores the packet forwarding information source's cell ID and data generation time written in the DA packet for requesting future data packets. With the grid structure the data announcement can be confined with one column of grid's cells instead of flooding whole network and only cluster headers in column cells need to keep the packet forwarding information. This can reduce the consumption of the battery power and storage capacity of sensor nodes

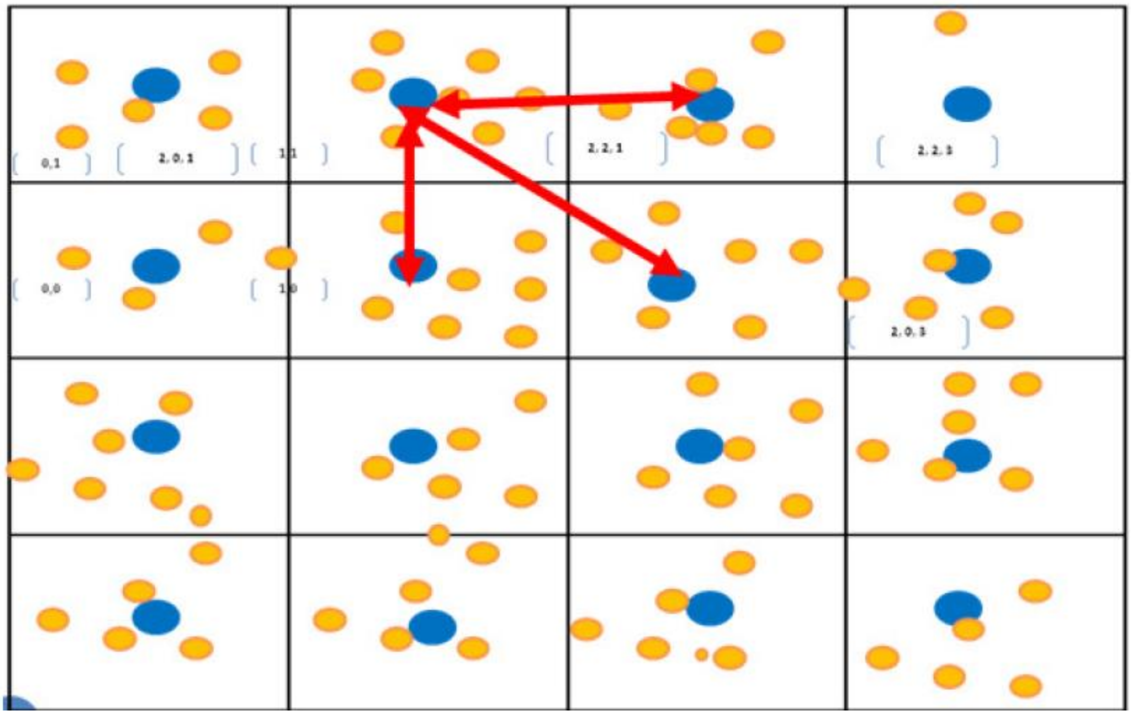


Figure 3.2: Sensor network path selection

Role of Cluster Head

- Participate in data dissemination and routing process
- Set up route
- Buffer (caching)
- Schedule nodes communication

E. Necessity of Location Awareness

Proposed protocol for sensor network requires location information for sensor nodes. In most cases location information is needed in order to calculate the distance between two particular nodes so that energy consumption can be estimated. Since, there is no addressing scheme for sensor networks like IP-addresses and they are spatially deployed in a region, location information can be utilized in routing data in an energy efficient way and grid construction. For instance, if the region to be sensed is known, using the location of sensors, the query can be diffused only to that particular region which will eliminate the number of transmission significantly. From a routing perspective, node locations are needed for one or more of the following purpose:

- Directing and processing location-based queries
- Supporting location-based routing and
- Using it to create grid construction and grid id

F. Energy Efficiency

Energy efficiency in a WSN concerns prolonging the lifetime of the network as a whole, by prolonging the lifetime of each individual node. The goal is to have the energy of all of the nodes in the network decrease at more or less the same rate. If some nodes deplete their energy sources sooner than other nodes, the network might become partitioned. Communication and computational processing are the two factors that consume the most of a WSN node’s energy. Therefore, to ensure that nodes survive for as long as possible, this thesis paper implements some design strategies:

- Usage of energy constraint routing mechanisms
- Avoidance flooding or localized flooding mechanisms within the cell.
- The grid construction is initiated by create grid every time when data to forward and therefore it reduces the number of messages that are transmitted by individual
- Cluster heads are selected based on the available residual energy level. Hence always maximum energy nodes are responsible
- Maximize the useful lifetime of the sensor field by preferring energy efficient paths and better distribute the data forwarding workload.

G. Radio Communication Model

In a WSN there are two types of energy costs; fixed cost in the electronics when transmitting or receiving a message, plus variable energy costs which are proportional to the distance of transmission. We assume a first-order radio model for a wireless sensor node and assuming d^n energy loss due to channel transmission where n is between 2 and 4.

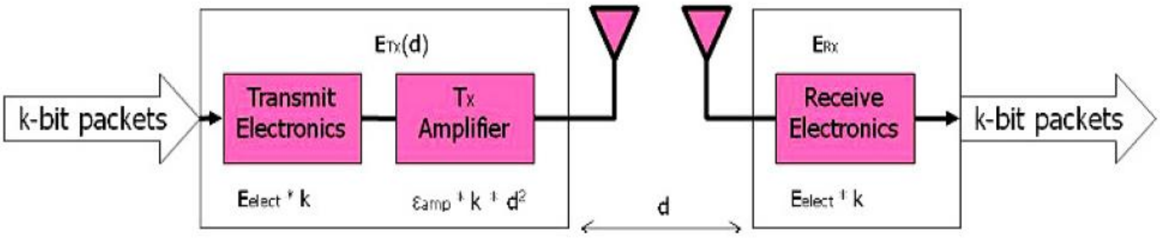


Figure 3.3: Communication model

The equations below show the energy spent when transmitting and receiving a signal – The energy dissipation E_{TX} of transmitting a K-bit message between two nodes separated by a distance d meters is given by

$$E_{TX(k,d)} = E_{elec} + (E_{fs} * d^2) + (C_1 * f(energy_j)) \qquad \textbf{(Eq. 3.1)}$$

Where E_{elec} denotes electronic energy and E_{fs} denotes transmit amplifier parameters.

Receiving - Energy cost incurred in the receiver of the destination sensor node E_{RX} is given by

$$E_{RX(d)} = E_{elec} * K \qquad \textbf{(Eq. 3.2)}$$

The most significant factor in the development of a wireless sensor network is typically communication power. Experimental evidence indicate that communication cost is at least two orders of magnitude higher than computation cost in terms of consumed power and the most energy consuming activity [26, 28]. It is necessary that the transmission distances of nodes are limited in order to conserve energy.

Residual Energy = C_1 * f (*energy* $_j$) this cost factor favours nodes with more energy. The more energy the node contains, the better it is for routing or the function for finding current residual energy of node j. The function 'f' is chosen to reflect the battery remaining lifetime**.** The value of C_1 is between 0 and 1.

H. Grid Construction

Grid is one of the most fundamental ways used to design scalable sensor networks. A grid algorithm arranges the network into subsets of nodes each with a cluster-head at approximately the centre of each grid. During the initialization phase the sink broadcasts its location, the size of the cell and the base or reference coordinate number. Thus the grid construction is initiated by the sink. After this information is provided, each sensor node calculates its grid id and cluster head election process. Grid construction is executed only once after the sensor nodes are deployed. We divide the sensor field into grids. Each grid has α x α square size.

For a sensor node at location (x, y), it can be aware of that it's the grid i, j where

$$i = \frac{(int)(X - X0)}{CELLSIZE} + 1, \quad j = \frac{(int)(Y - Y0)}{CELLSIZE} + 1 \qquad \textbf{Eq (3.3)}$$

The centre of the grid can be calculated as

$$X_C = \frac{2(CELLSIZE)_i - CELLSIZE}{2} \qquad \textbf{Eq (3.4)}$$

$$X_C = \frac{2(CELLSIZE)_j - CELLSIZE}{2} \qquad \textbf{Eq (3.5)}$$

For simplicity, we assume that the entire grid IDs are positive. To ensure that all the nodes in adjacent grids can communicate with each other directly, the grid size is set to less than equation 3.6.

$$CELLSIZE = \frac{\sqrt{2}}{2} * R \qquad \textbf{Eq (3.6)}$$

where R is the transmission range.

The aim of constructing grid is primarily to group sensor nodes into cell so as to elect a cluster node at each grid by comparing sensor nodes' residual energy capacity within cell. The cluster node is responsible to data dissemination.

I. Data Dissemination

When a sensor node wants to send a data packet, it forwards the data to cluster head. The cluster head aggregate the coming information and calculates the possible paths towards the sink. The possible adjacent grid options are grid ID (i + a, j + b), (i + a, j), (i, j + b), where grid ID (i, j) the source cluster head. Then, the cluster head finds the minimum cost among the available choices. If adjacent grid does not have a path then the cluster head assigns infinity value so that cost becomes high and hence the path will immediately be discarded.

1. Source node finds its cluster head and makes it as source agent within the cell.

2. Cluster head becomes source agent

3. Source agents choose each adjacent cells' cluster head

4. Find a & b which determine the direction as either 1 or -1

// this equation finds the direction of sink to help to select three possible candidates

$$a = \frac{(x - sinkX)}{|x - sinkY|} \qquad \textbf{Eq(3.7)}$$

Where x is not equal to sinkX.

$$b = \frac{(Y - sinkY)}{|Y - sinkY|} \qquad \textbf{Eq(3.8)}$$

Where Y is not equal to sinkY.

5. Finding closest three adjacent cells cluster head towards the sink.

a. search(i+a, j) horizontal cluster header

b. search(i, j+b) vertical cluster header

c. search(i+a, j+b) diagonal cluster header

6. Compare the three cluster heads cost

$\textbf{temp\_dest\_V} = E_{TX(k,dv)} = E_{elec} + (E_{fs} * dv^2) + (C_1 * f(energy_j))$

$\textbf{temp\_dest\_H} = E_{TX(k,dh)} = E_{elec} + (E_{fs} * dh^2) + (C_1 * f(energy_j))$

$\textbf{temp\_dest\_D} = E_{TX(k,d)} = E_{elec} + (E_{fs} * d^2) + (C_1 * f(energy_j))$

7. Set cluster head with minimum cost as source agent

```
If (temp_dist_H < temp_dist_V) {
        If (temp_dist_H < temp_dist_D)
                Flag=1; // horizontal
                Flag=3; // Vertical
}
Else if (temp_dist_V < temp_dist_D) {
        Flag=3; // vertical
        Flag=2; // diagonal
} */
```

8. Check sink whether source agent and sink are in the same grid

9. If yes

10. End

11. Else if go to 3

J. Sample Code of the Algorithm and Discussions

// result of a & b either 1 or -1

// this equation finds the direction of sink & helps to select three possible candidates

$$a = \frac{(x - sinkX)}{|x - sinkY|}$$

Where x is not equal to sinkX.

$$b = \frac{(Y - sinkY)}{|Y - sinkY|}$$

Where Y is not equal to sinkY.

R_Head_nbr(i+a, j) //find Horizontal cluster head

if(nbr_H != null)

temp_dist_H = EuclideanDist(nbr_x, nbr_y, nbr_z, sinkX, sinkY, sinkZ);

temp_dist_H = 1000000;

R_Head_nbr(i, j+b) //find Vertical cluster head

if(nbr_V != null)

temp_dist_V = EuclideanDist(nbr_x, nbr_y, nbr_z, sinkX, sinkY, sinkZ);

temp_dest_V = $E_{TX(k,dv)} = E_{elec} + (E_{fs} * dv^2) + (C_1 * f(energy_j))$

temp_dist_V=1000000;

R_Head_nbr(i+a,j+b) //find diagonal cluster head

if(nbr_D!=null)

temp_dist_D=EuclideanDist(nbr_x,nbr_y,nbr_z,sinkX,sinkY,sinkZ);

temp_dist_D=1000000;

//compare the three distances & pass control to the agent with less distance

compare_distance(temp_dist_H,temp_dist_V,temp_dist_D);

{

//int flag=0;

if(temp_dist_H < temp_dist_V){

if (temp_dist_H < temp_dist_D)

flag=1;

flag=3; }

else if (temp_dist_V < temp_dist_D)

flag=2;

*flag=3; } */*

```
//flag is used to identify either Horizontal, Vertical or Diagonal
if (flag = = 1){
        addRoute(this.nid, this.nbr_id, -1); }
if (flag = = 2){
        addRoute(this.nid, this.nbr_id, -1); }
if (flag = = 3){
        addRoute(this.nid, this.nbr_id, -1);}
```

Finding the right path in terms of having minimum cost path is all about this algorithm. Inside any one particular cell an event has occurred, the sensor nodes close to that event sense and forward the event to the cluster head of the cell. The cluster head will examine all the possible paths. Since Cluster head knows the location of the sink ahead during initial sink broadcasting. It, therefore, determines which out of eight possible paths, the cluster heads select three using equation 3.3.

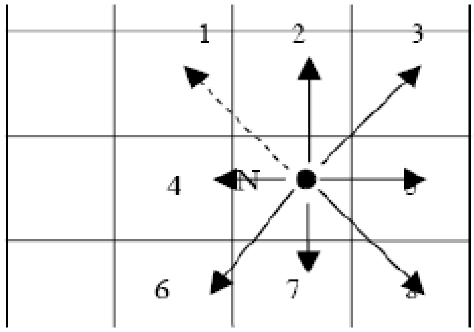


Figure 3.4: Eight possible paths

Figure 3.4 shows the sources cluster head may have eight, 1 up to 8, possible alternatives paths to the destination. The proposed algorithm finds three out of eight paths using proposed algorithm based on the direction of the sink. Once the three possible paths are determined in horizontal, vertical and diagonal direction, then the next thing will be to compare each other using a metrics of energy and transmission distance. However, one path, which costs less, will be favoured using equation 3.1. We know that each cell offers cluster head which has maximum energy value compare to its cell members. During path searching, when there no cluster head inside the next adjacent cell then cluster head set the paths to maximum value or infinity so that the chance to be elected becomes null. The minimum cost path will take responsibility to act as source agent so it plays the same role as the previous cluster head recursively until the packet reaches the sink.

Figure 3.5 shows the steps WSN initialization took place. At the first setup phase, the sink node initiates grid construction and determine the size of the cell and the origin of grid where it starts to construct when the sensor node receive broadcast message from the sink then start to calculate its grid id based on equation x next the sensor node broadcast the message to its neighbours. Similarly, when neighbour sensor nodes sends broadcast message within the grid then sensor node add to neighbour list otherwise the message is going to be rejected.

Flowchart of the Sensor Network Initialization

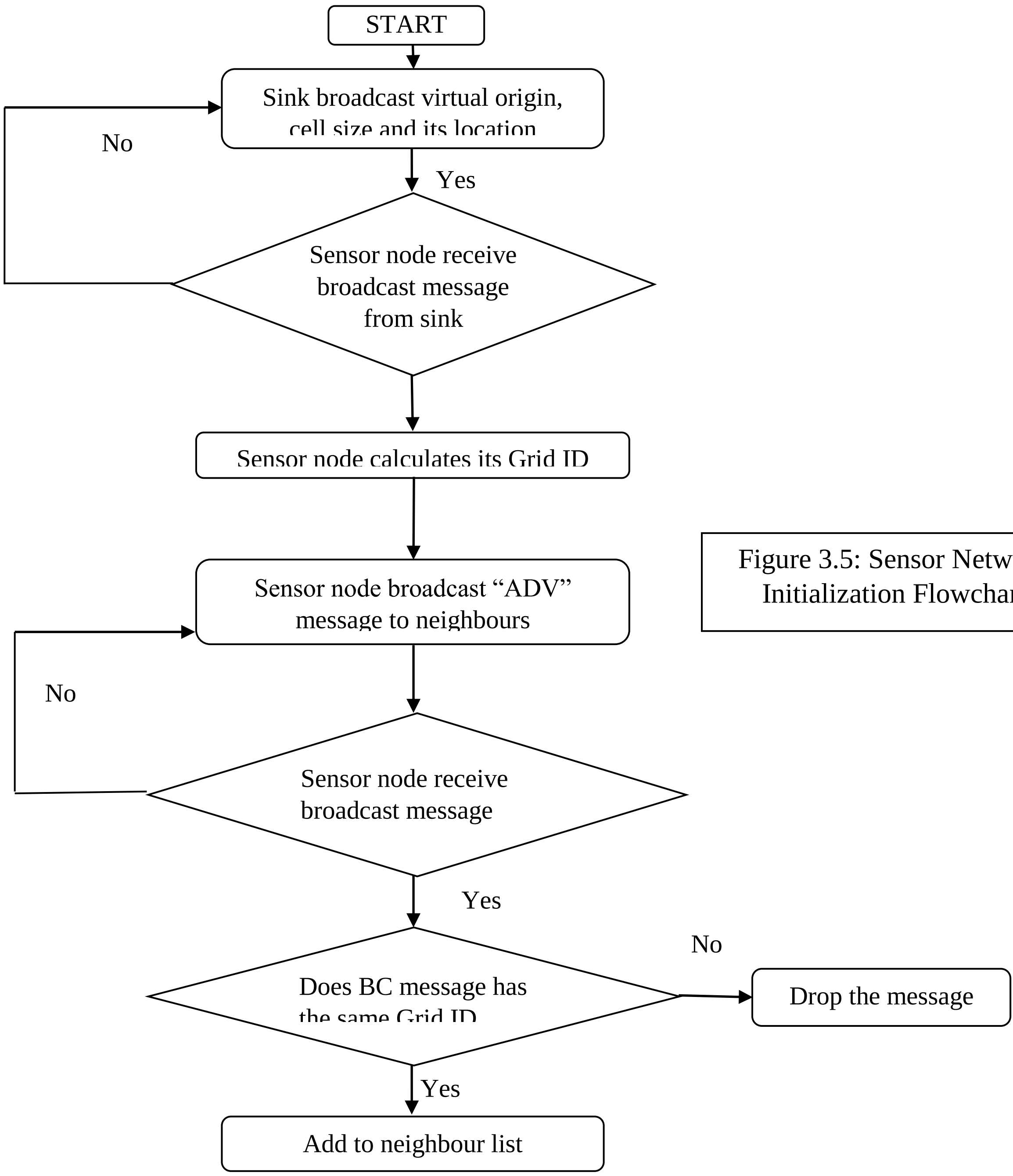


Figure 3.5: Sensor Network Initialization Flowchart

Flowchart of the Cluster Head Formation

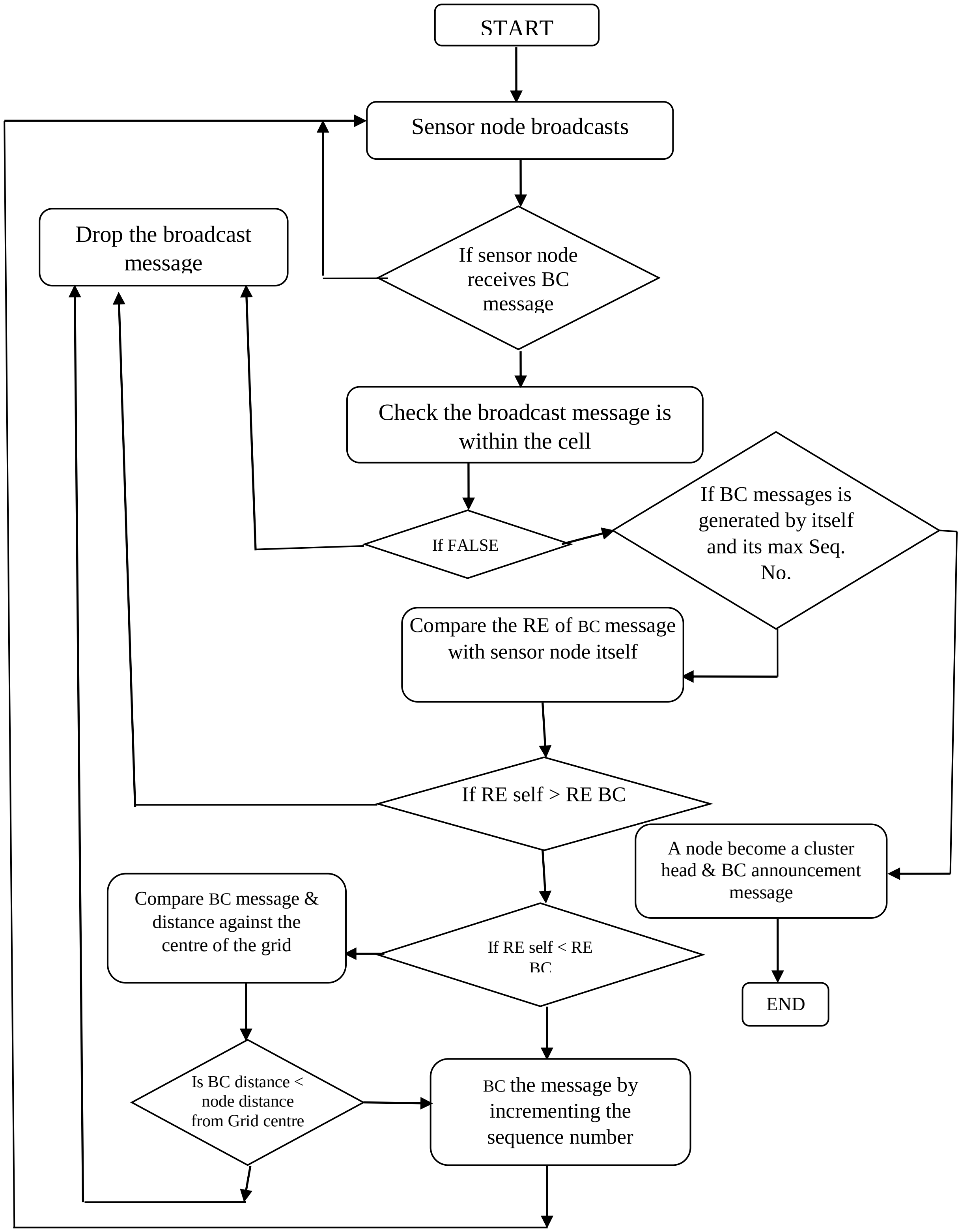


Figure 3.6: Cluster Head Formation Flowchart

The flow chart shown in Figure 3.6 depicts how cluster head is going to be created. After grid constructed, the next initial phase will be electing cluster head based on each grid based on the residual energy level and the distance to the centre of their grid during initialization phase and at a time two or more sensor nodes have the same level of residual energy. During this phase each sensor node within the grid broadcast message with different time interval. If the sensor node receives broadcast message, it first checks whether the message is within the same grid or not, if it is not in the same grid it will be immediately discarded. Otherwise it starts processing the message. If the broadcast message generated from itself check sequence number if it has max sequence number then the node becomes cluster head and broadcast to announce becomes a cluster head. Otherwise check the broadcast message residual energy and compare with its residual energy. If broadcast message has the maximum residual energy then the message is rebroadcast by increment the sequence number. By chance if both have the same residual energy level in this case the closest node to the centre of the grid will be elected. Cluster head nodes keep maintaining their cluster until their energy levels go down below a certain threshold value. If battery power of the cluster head has fallen below a specific value, the election process of new cluster heads will occur again locally in order to distribute energy dissipation evenly. Cluster head reconstruction is handled by cluster head itself.

CHAPTER FOUR

SIMULATION IMPLEMENTATION AND ANALYSIS OF RESULTS

4.1. Introduction to Java Simulator (J-SIM)

J-Sim is an open-source, component-based compositional network simulation environment that is developed entirely in Java. J-Sim is implemented on top of component-based software architecture, called the autonomous component architecture (ACA). The basic entities in the ACA are components, which communicate with one another via sending/receiving data at their ports. How components behave (in terms of how a component handles and responds to data that arrive at a port) is specified at system design time in contracts, but their binding does not take place until the system integration time when the system is being "composed." With the separation of contract binding (at system design time) from component binding (at system integration time), J-Sim provides loosely-coupled component architecture, i.e., a component can be individually designed, implemented and tested independently. By closing the gap between hardware and software ICs, the ACA enables new components to be included into J-Sim in a plug-and-play fashion. On top of the ACA, a generalized packet-switched internetworking framework (called INET) has been laid based on common features extracted from the various layers in the protocol stack. Both the ACA and the INET have been implemented in Java, and the resulting code, along with its scripting framework and GUI interfaces, is called J-Sim. Finally, an essential suite of wire line and wireless network components and protocols have been implemented in J-Sim. J-Sim possesses several desirable features. The fact that J-Sim is implemented in Java, along with its autonomous component architecture, makes J-Sim a truly platform-independent, extensible, and reusable environment. J-Sim provides a script interface that allows its integration with different script languages such as Perl, Tcl, or Python. (In particular, the latest release of JSim (version 1.3) has been fully integrated with a Java implementation of Tcl interpreter, called Jacl, with the Tcl/Java extension.) Therefore, similar to ns-2 (ns version 2), J-Sim is a dual language simulation environment in which classes are written in Java (for ns-2, in C++) and "glued" together using Tcl/Java. However, unlike ns-2, classes/methods/fields in Java need not be explicitly exported in order to be accessed in the Tcl environment. Instead, all the public classes/methods/fields in Java can be accessed (naturally) in the Tcl environment.

4.2. Overview of the J-SIM Simulation Framework

As mentioned in Section 4.1, a major objective of wireless sensor networks is to monitor, and sense events of interests in a specific environment. Upon detecting an event of interest (e.g., change in the acoustic sound, seismic, or temperature), sensor nodes send reports to sink (user) nodes (either periodically or on demand). Events (or termed as stimuli) are generated by target nodes. For instance, a moving vehicle may generate ground vibrations that can be detected by seismic sensors. From the perspective of network simulation, a wireless sensor network typically consists of three types of nodes: sensor nodes (that sense and detect the events of interest), target nodes (that generate events of interest), and sink nodes (that utilize and consume the sensor information). J-Sim simulation framework for WSNs is derived from the SensorSim simulation framework. In a nutshell, sensor nodes detect the stimuli (signals) generated by the target nodes over a sensor channel and forward the detected information to the sink nodes over a wireless channel. Figure 4.1 depicts the top-most view of the proposed simulation framework. It should be noted that the nature of signal propagation between target nodes and sensor nodes over the sensor channel is inherently different from that between sensor nodes and sink nodes over the wireless channel. Two different models for signal propagation are therefore included: a sensor propagation model and a wireless propagation model. A sensor node is equipped with (1) a sensor protocol stack, which enables it to detect signals generated by target nodes over the sensor channel, and (2) a wireless protocol stack, which enables it to send reports to the other sensor nodes (and eventually to sink nodes) over the wireless channel. On the other hand, a target node has only a sensor protocol stack and a sink node has only a wireless protocol stack. A sensor node also has a power model that embodies the energy-producing components (e.g., battery) and the energy-consuming components (e.g., radio and CPU). Finally, in order to enable simulation of mobile nodes (e.g., moving tanks), a mobility model is included. Figures 4.1— 3 depict, respectively, the internal view of a target/sink/sensor node defined and implemented in the proposed simulation framework. All these nodes are constructed by sub-classing key classes in J-Sim [32].

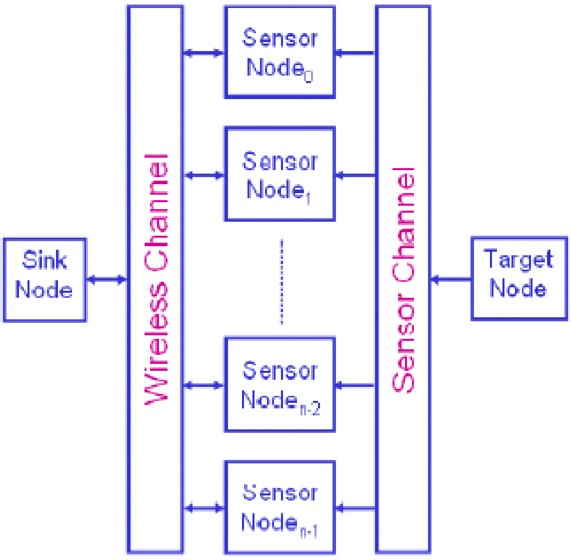
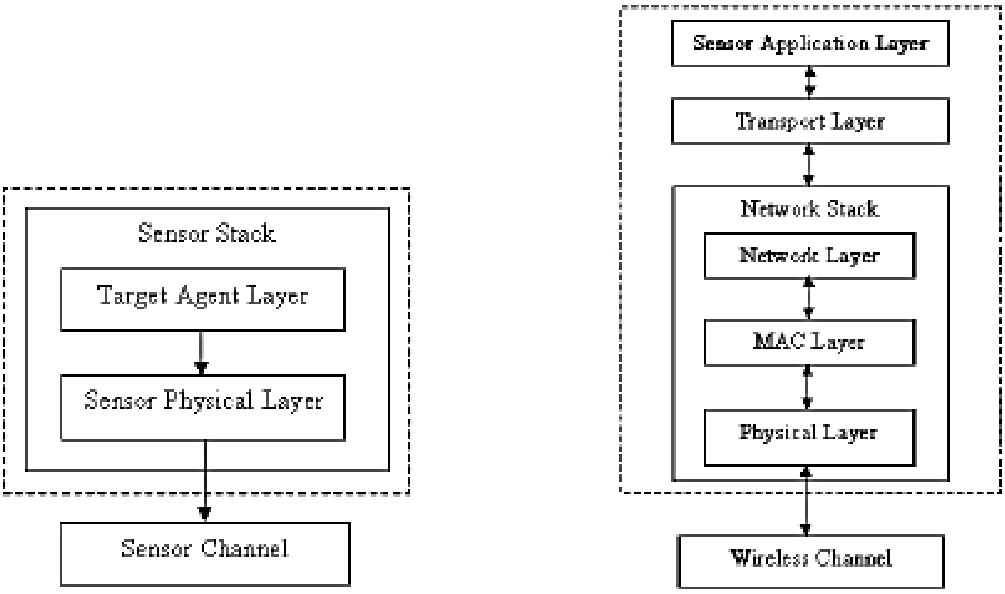


Figure 4.1: A typical WSN environment model of J-Sim.

The operation of the proposed simulation framework can be illustrated by considering a fairly simple event-to-sink transport protocol: A stimulus is periodically generated by a target node and propagated over the sensor channel. It should be noted that, as shown in Figure 4.2 (a), a target node can only send (but not receive) data packets over the sensor channel. The neighbouring sensor nodes (e.g., sensor nodes that are within the sensing radius of the target node) will then receive the stimulus over the sensor channel.



a) Internal view of a target node (b) Internal view of a sink node

Fig. 4.2: An Internal views of a target node and a sink node

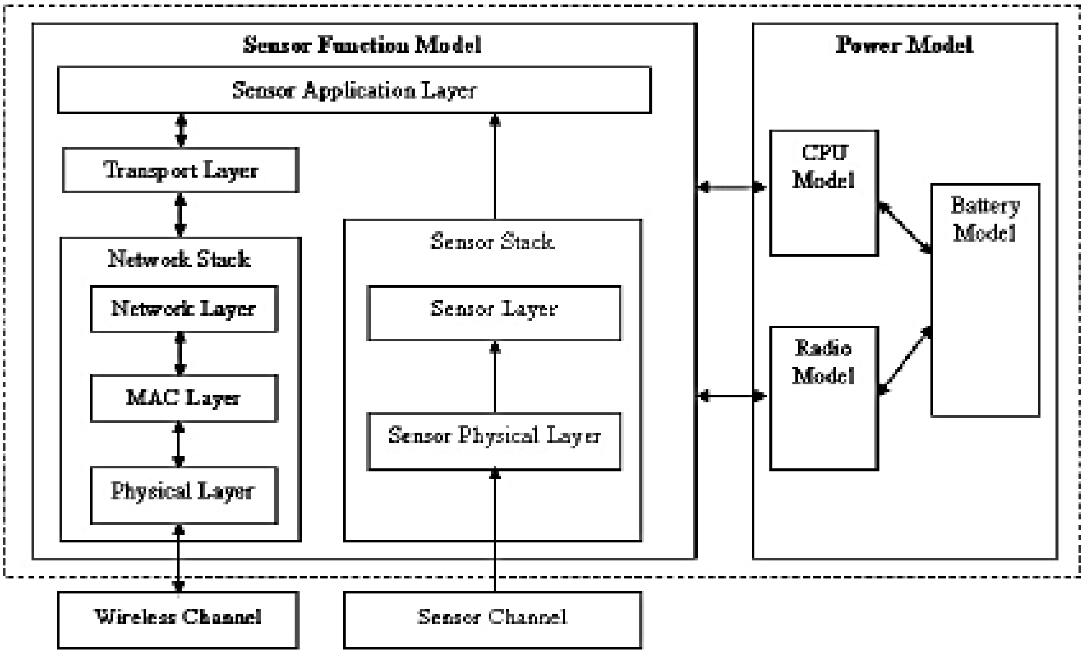


Figure 4.3: Internal view of a sensor node (dashed line) in J-Sim.

As shown in Figure 4.2, a sensor node can only receive (but not send) stimuli over the sensor channel. However, due to the fact that the signal may be attenuated in the course of being propagated over the sensor channel, a sensor node receives and detects a stimulus only if the received signal power is at least equal to a pre-determined receiving threshold. The calculation of the received signal power is determined by the sensor propagation model used in the model (e.g., seismic or acoustic).

As mentioned above, each sensor node that receives and detects over the sensor channel has to forward its sensing result to one or more sink nodes over the wireless channel. Inside a sensor node (Figure 4.2), the coordination between the sensor protocol stack and the wireless protocol stack is done by the sensor application and transport layers. For instance, depending on the application for which the sensor network operates, a sensor node may either forward data packets as soon as they detects the stimuli, or process them first (e.g., compute the average temperature measured within a few minutes) and then forward processed data (e.g., the average temperature) to the sink node. Any in-networking processing mechanism such as that discussed in where can be implemented in the sensor application layer.

As the sink node may not be in the vicinity of a sensor node, communication over the wireless channel is usually multi-hop. Specifically, in order to send a packet from a sensor node s_i to a sink node snk_j , intermediate sensor nodes between s_i and snk_j have to serve as relays (routers) to forward that packet along the route from the source (s_i) to the final destination (snk_j). This illustrates why sensor nodes have to be able to both send and receive data packets over the wireless channel (as shown in Figure 4.2). As sensor nodes may fail or die of power depletion, the network topology of a WSN may change dynamically and the multi hop routing protocol has to adapt to the topology change (e.g., ad hoc routing such as Ad-hoc On-demand Distance Vector routing (AODV) or geometric routing such as Greedy Perimeter Stateless Routing (GPSR)). The latest version of J-Sim includes classes for AODV, and GPSR. Similar to signal propagation over the sensor channel, a sensor/sink node receives, and will further process, a data packet from the wireless channel only if the received signal power exceeds a pre-determined receiving threshold. Calculation of the received signal power is determined by the wireless propagation model used in the model. The latest release of J-Sim includes classes for three wireless propagation models: the free space model, the two-ray ground model, and the irregular terrain model.

The information received at the sink node over the wireless channel can be further analysed by a control server and/or a human operator. Based on the content of the information, the sink node may have to send commands/queries to the sensor nodes. This explains why, as shown in Figure4.2 (b), sink nodes have to be able to both send and receive data packets over the wireless channel. As shown in Figure 4.2, the power model in a sensor node includes both the energy producing components (e.g., battery) and the energy-consuming components (e.g., CPU and radio).

The sensor function model (i.e., combination of the sensor protocol stack, the network protocol stack and the sensor application and transport layers) is subject to the power model. For example, the energy incurred in handling a received data packet is dictated by the CPU model, and the energy incurred in sending and/or receiving data packets is dictated by the radio model. In the proposed simulation framework, both the CPU and radio models can be in one of the several different operation modes. For example, the radio model can be in one of the following operation modes: idle, sleep, off, transmit or receive. The amount of energy consumed by an energy consumer depends on the operation mode in which the power model operates. The CPU and radio models can report their operation mode to the sensor function model, and the sensor function model can also change the operation mode of the CPU and radio models.

4.3. Simulation Study and Results

4.3.1. Simulation Model

In this section, the performance of proposed protocol will be evaluated the using simulations. We first describe our simulation metric and experimental setup in section 5.2 and 5.3. Then we evaluate the performance of our method in section 5.4.

4.3.2. Simulation Metric

Different metrics are chosen to compare the performance of proposed protocol. They include Energy consumption, Life time, Delay, Success rate, and Impact of node density.

The energy consumption is defined as the sum of each node's energy consumption for transmitting and receiving only. We do not take the energy consumption in idle mode into account, since it largely depends on the data generation interval. Delay is defined as the average time between the time a source transmits a packet and the time a sink receives the packet and transfer times excluding buffering and queuing. We define the network lifetime as the number of nodes alive over time. The success rate is the ratio of the number of successfully received packets at a sink and the total number of packet generated by a source.

Table 4.1: Shows the simulation parameters

Parameter	Value
Simulator	J-Sim
Simulation Time	Max-simulation time 600sec
Number of nodes	100
Node distribution	Random distribution
Sink mobility	Random way-point model
MAC	IEEE 802.11 DCF
Area	1000mx 1000m
Power range	200m
Radio propagation model	Two-ray ground
Antenna	Omni-directional
Transmitting Power	0.66W
Initial Energy/node	300J

4.3.3. Simulation Results

In this section, we present the results of each of our simulation experiments together with an explanation of the resulting trends. In this experiment, we examine the performance of such as energy consumption, success rate and network lifetime of the proposed routing algorithms when increasing the number of network nodes. In reality, it is expected that many sensor network applications will require deploying a large number of sensor nodes randomly over a certain geographical area of interest. We ran simulation experiments with the default simulation parameters given in Table 4.1 but with varying the number of network nodes (20 and 200 nodes) to check the effect of increasing the network size on protocol performance, and lifetime.

A. Impact of Nodes Density

Energy Consumption

Figure 4.4 shows the effect of changing the node density on the network Energy vs. Time graph and observe the energy consumption. It observed that the lower the number of sensor nodes to 20 nodes, the much average energy drop compared with 100 nodes. Effect of varying the number of nodes results in the changing life time of the network, increased lifetime of the network as sensor nodes density is increased. We do believe that when the node density is higher, the lifetime of CBR-WSN will be prolonged much more than other protocols. The simulation result shows that 22% average energy difference between 20 and 100 nodes. Thus the proposed protocol is much more effective when sensor network are deployed densely.

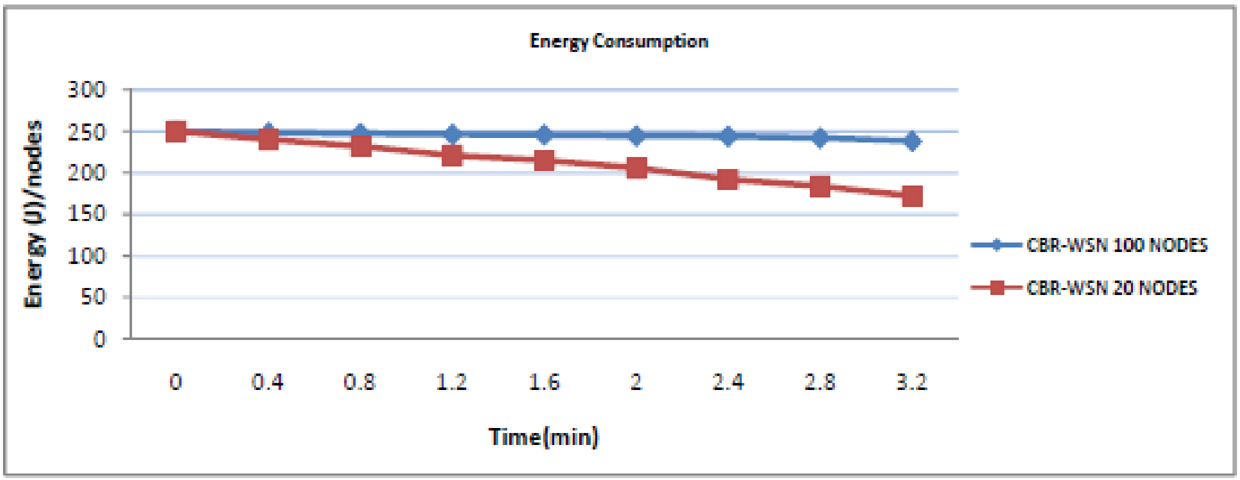


Figure 4.4: Remaining energy level of nodes.

Success Rate

Changing Sensor node density has slight effect on total packet delivered. Figure 4.5 shows regardless of the nodes density the total packets received by sink is almost the same.

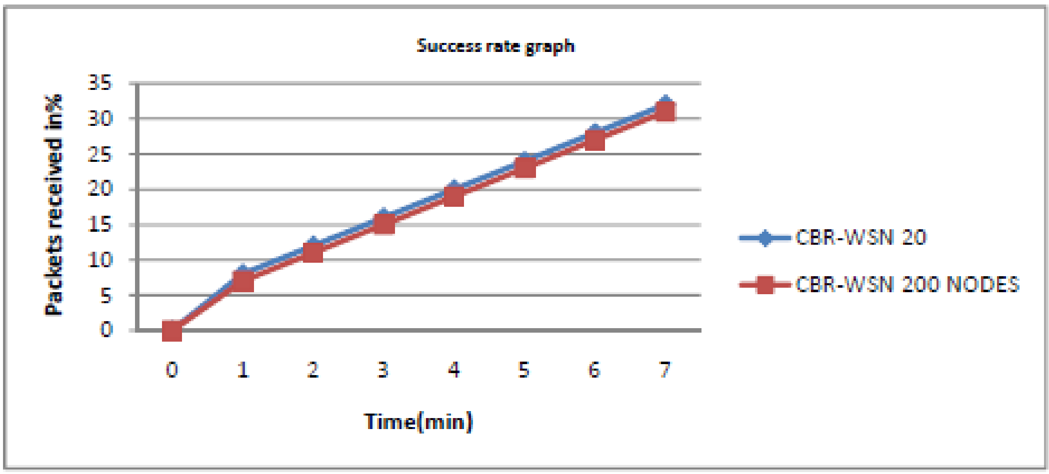


Figure 4.5: Packets Received vs. Time

Success rate or average data delivery ratio gives an indication of the ability of the proposed protocol to deliver the data that was detected at source sensors to data sink. We notice from this figure that the packet delivery ratio for CBR-WSN remains almost unchanged as the network population increases and is almost 100% for these simulation conditions. The lifetime of the network is the only difference.

B. Resilience to Sensor Node Failures

Success rate

We further study how node failures affect CBR-WSN. In the default simulation setting 100 nodes, we allow 10% randomly chosen nodes to experience sudden, simultaneous failures at a given time. However, Figure 4.6 shows that the success rate ratio drops slightly. What we conclude from this is that the proposed protocol is effective in handling node failures.

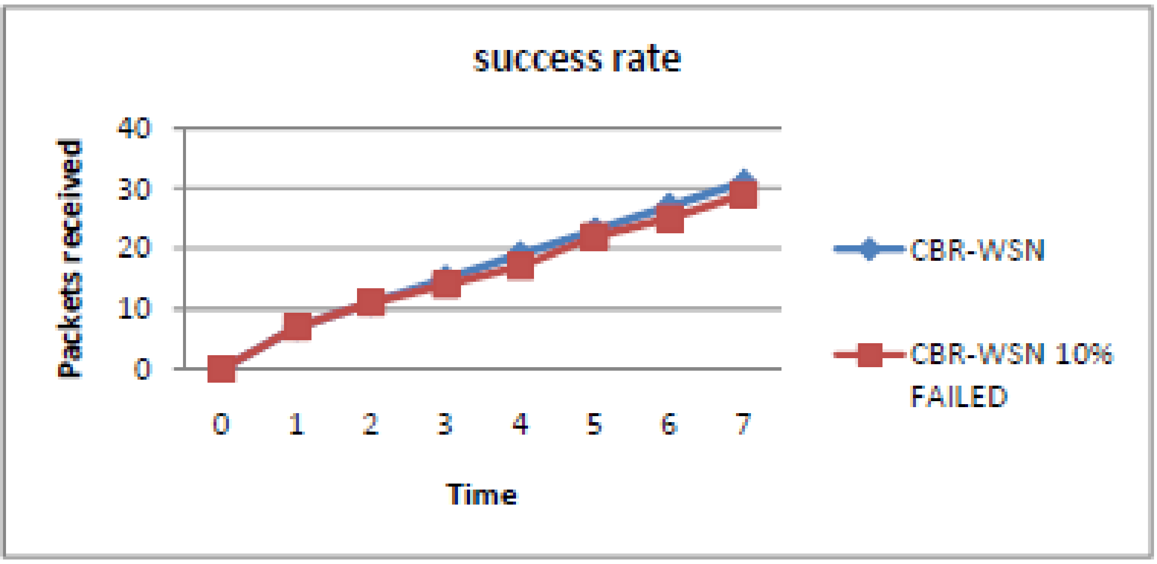


Figure 4.6: Success rate ratio when 10% nodes failed

Delay

As Figure 4.7 shows that the average latency between CH-SINK increases during the initial period and becomes nearly constant for long period of time. The figure depicts there is trade-off between energy with time.

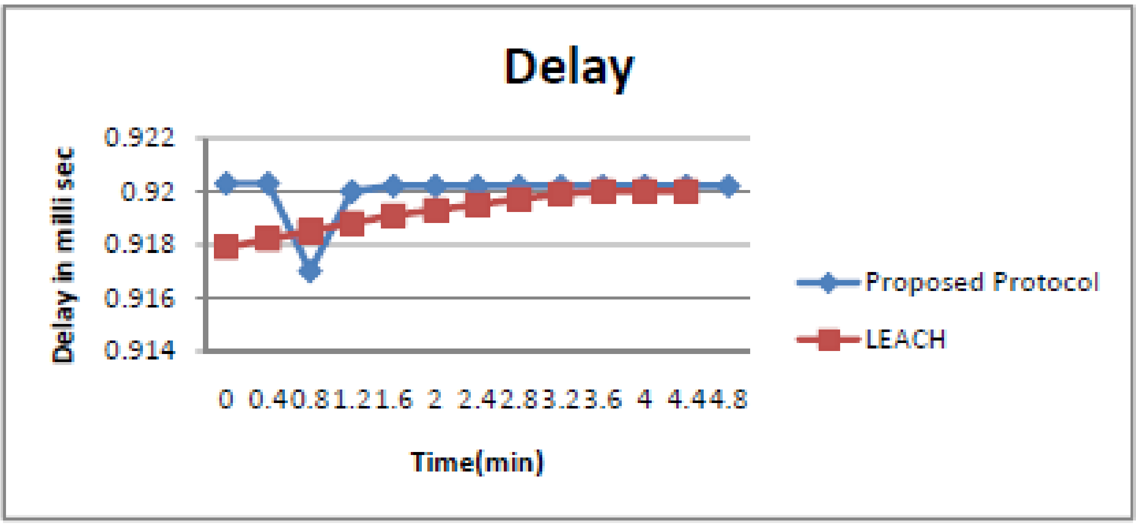


Figure 4.7: Average latency between cluster heads

Lifetime and Residual Energy

To study the network operational lifetime we consider the average energy of the network at different instances of time. To obtain the average energy of the network at a given simulation time we consider the summation of the energy of all the nodes at that instant of time. The number of sensor nodes is 100. A node is considered as a dead node if its energy is not enough to send or receive a packet. Figure 4.8 shows that number of nodes alive at a time t. CBR-WSN the nodes alive for longer period of time than LEACH which is 2% as the time goes by the difference becomes large. This is because of two reasons. The first is that CBR-WSN focus on energy efficiency. The second is that cluster head in a grid change when its energy level below the threshold level hence distributes energy consumption to other nodes, thus nodes will not quickly deplete its energy like LEACH. In nutshell, the fairness of energy utilization in cell is balanced. This is depicted in Figure 4.9

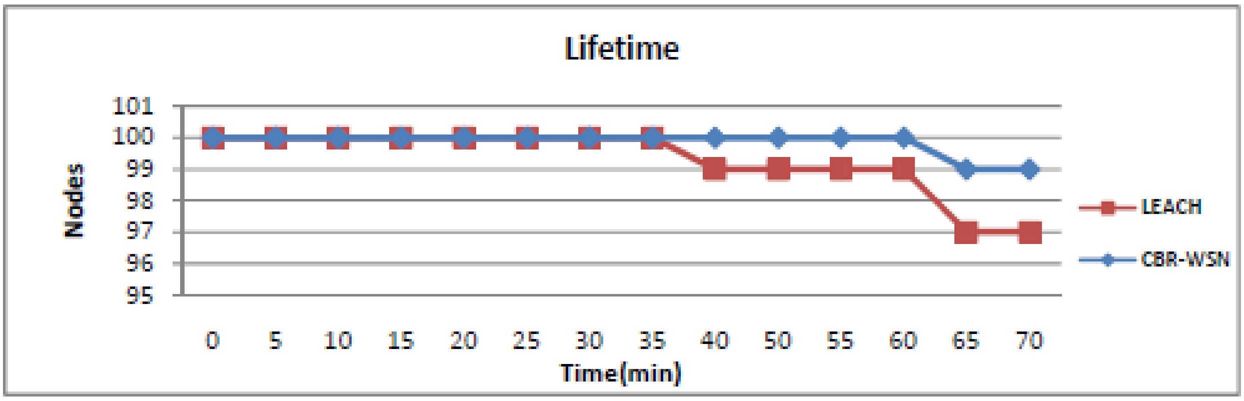


Figure 4.8: Shows number of nodes alive

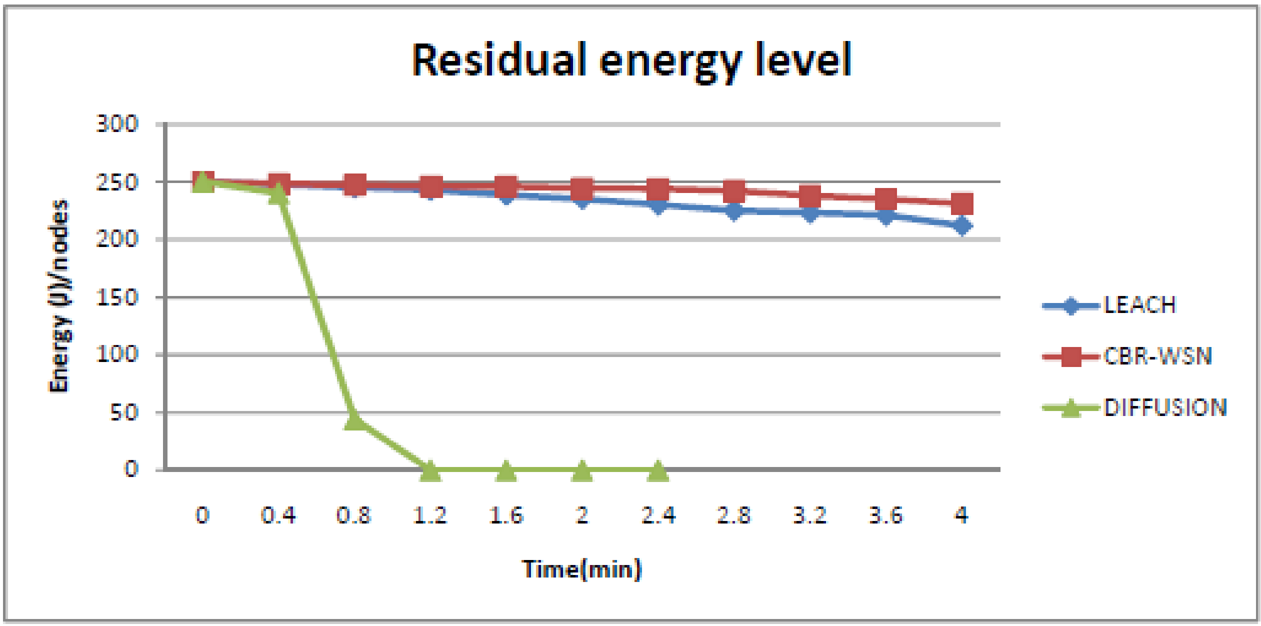


Figure 4.9: Comparison of energy consumption of LEACH, CBR-WSN and DD protocols.

The major objective of this thesis work is to minimize the energy consumption during data transmitting. In this respect, comparing the proposed protocol with other similar protocols has been made. In light of this, CBR-WSN improves the energy consumption rate against LEACH and Direct Diffusion (DD). DD protocol doesn't have energy efficient utilization mechanism at all; hence the energy level drops drastically. LEACH uses cluster mechanism to minimize energy consumption thus relatively; it improves the energy efficiency with respect to traditional DD protocol. However, as it can be seen from the graph LEACH drops more energy as time goes by. CBR-WSN has brought 8.16% improvement. The main reason that the proposed protocol has got better energy efficient mechanism for instance, cluster head is selected on the bases of the available high energy compared to other cell member nodes and moreover when cluster head energy level below the threshold value then another cluster head will takes over.

CHAPTER FIVE

CONCLUSIONS AND FUTURE WORKS

6.1. Conclusions

This thesis proposed a routing protocol for wireless sensor networks called Cell Based Routing Protocol (CBR-WSN). A detailed design, verification and performance analysis of the protocol were provided in this thesis. The capability of preserving energy is crucial for routing protocols in wireless sensor networks. CBR-WSN routing protocol proposed with view to increase the energy efficiency and extend the wireless sensor network lifetime. The proposed protocol uses algorithms to search paths towards the sink from three possible paths by selecting one optimal path in terms of energy consumption. The proposed protocol has been evaluated against DD, and LEACH protocols. Based on the simulation result the CBR-WSN has enhanced the energy efficiency by 8.16 % comparing to LEACH protocol in fact, still possible to improve the energy efficiency by handling idle time energy waste and computation energy. The reason that leads to reduction of energy consumption is that due to the fact that algorithm is focusing on communication cost on grid based approach and clustering a node which has maximum energy in the cell. Moreover only cluster heads are responsible for data dissemination, coordination and schedule nodes activities inside a cell. Further, the proposed routing protocol distributes the energy consumption. Simulation result also shows that by varying network size increases from 20 up to 200 nodes density of the proposed protocol. Regardless of the nodes density the total packets received by sink is almost the same. However the difference is that the lifetime of the network having more nodes the longer it stays. Comparing the lifetime the proposed protocol against LEACH with similar simulation parameters, proposed protocol has improved at least 2%. We further study how node failures affect proposed protocol, the simulation result shows that, the protocol is resilience to node failures.

6.2. Future Works

The proposed protocol is effective in reducing the energy consumption due to communication cost which is the major energy consumption factor. However, to increase the lifetime of WSN nodes more energy needed to be saved as per the works of [33] [34] and [35]. To achieve that one approach could be to include other energy consumption parameters such as idle time energy and computation energy waste. In our work the nodes are assumed to be stationary. Mobility may be added to the nodes in the network and the working of the protocol can be observed.

Other future extensions in this area could be to enable nodes harvest energy through vibrations, heat and solar sources.

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