Deanship of graduate studies

Al-Quds University

Normalized Efficient Energy Routing in Wireless Sensor Network (NEER)

Mahmoud Ismail Arda

M.Sc Thesis

Jerusalem – Palestine

April - 2014

Normalized Efficient Energy Routing in Wireless Sensor Network (NEER)

Prepared by

Mahmoud Ismail Arda

B.Sc : Computer Systems Engineering, Birzeit University

Palestine

A thesis submitted to Najjad Zeenni Facultyof Engineering, Al-Quds University in partial fulfillment of the requirement for the degree of Master of Electronic and Computer Engineering

Supervisor: Dr. Rushdi Hamamreh

Al-Quds University

April 2014

Electronic and Computer Engineering MasterProgram

NajjadZeenniFacultyof Engineering

Al-Quds University

Thesis Approval

Normalized Efficient Energy Routing in Wireless Sensor Network (NEER)

By

Student Name: Mahmoud Ismail Arda

Reg. No: 21011064

Supervisor: Dr. RushdiHamamreh

Master thesis submitted and accepted. Date: 1/7/2014

0The names and signatures of examining committee members are as follows:

1- Head of committee : Dr. RushdiHamamreh ____________
2- Internal Examiner : Dr. Samer Bali ____________
3- External Examiner : Dr. RaedZaghal ____________

Dedication

This thesis is dedicated to my beloved family, who raised me to be the person I am today

My friends and colleagues

Thank you all, I love you!!!

Declaration

I certify that this thesis submitted for the degree of master is the result of my own research, except where otherwise acknowledged, and that this thesis (or my part of the same) has not been submitted for higher degree to any other university or institution.

Signed: ______

Mahmoud Ismail Arda

Date: 25/6/2014

Acknowledgments

I would like to express my greatest gratitude to the following people that helped me to turn my dream to reality; to be through scientific as well as moral support, without their guidance and help the work presented in this thesis would not have been possible.

The first person that comes to mind is my adviser Dr. Rushdi Hamamreh who believed in me from the beginning and allowed to develop professionally as well as individually. With his patience, guidance, deep vision, support, constant encouragement, this thesis has been done what it is today.

I am very glad and it has been an honor to work with him over the past year.

Thanks go out to all my teachers at Al-Quds University who did their best to provide me with their help, support and encouragement.

Also, I would like to express my gratitude to all those who gave me the possibility to complete higher studies, especially my colleagues at AL- Quds University.

Abstract:

Wireless Sensor Networks (WSNs) consist of thousands of tiny nodes having the capability of sensing, computation, and wireless communications.WSN is used for wide range of applications such as habitat and environmental monitoring, military surveillance, inventory tracking, medical monitoring smart spaces and process monitoring. Unfortunately these devices are a limited energy device, that's means we must save energy as much as possible since it is impossible to change or to recharge battery to those nodes in some critical applications.

Researches and studies showed that most power of a sensor node is consumed through communication rather than sensing or computation. As a result the most important technique to save energy of a WSN is to save energy through communication between different nodes.

Routing algorithms could be classified in different ways, according to topology of WSN to be flat routing protocol or hierarchal, it could be classified also according to initiator of communication between source and destination, finally it could be classified according to path establishment, it could be reactive, proactive or hybrid. In Proactive protocol each node in the network has routing table for the broadcast of the data packets and want to establish connection to other nodes in the network. These nodes record for all the presented destinations, number of hops required to arrive at each destination in the routing table. Reactive Protocol has lower overhead since routes are determined on demand. It employs flooding (global search) concept. Constantly updating of route tables with the latest route topology is not required in on demand concept. In some cases there is a state called hybrid algorithms that takes features from reactive and proactive protocols. The routing is initially established with some proactively prospected routes and then serves the demand from additionally activated nodes through reactive flooding.

In this thesis we propose NEER protocol, normalized energy efficient routing protocol that increases network lifetime through switching between AODV protocol that depends on request-reply routing, and MRPC that depends on residual battery in routing. Simulation results and analysis showed that NEER protocol could save energy and could increase network lifetime in comparison with other different protocols.

NEER protocol proved its ability to save energy through communication phase of wireless sensor network, and proved its capability to increase network lifetime without affecting other metrics such as total number of sent packets or the energy per packet.

تطبيع التوجيه الأمثل لإستخدام الطاقة في نقل البيانات

إعداد الطالب: محمود إسماعيل عارضة

إشراف الدكتور: رشدي حمامرة

الملخص:

شبكة الإستشعار اللاسلكية Wireless Sensor Networks تتكون من مجموعة أجهزة إستشعار تستخدم لنقل المعلومات التى تجمعها من البيئة التى تتواجد بها من خلال قنوات إتصال لا سلكية فيما بينها.

إن هذه الأجهزة تستخدم في كثير من التطبيقات و المجالات و أهمها التطبيقات العسكرية و الطبية و الصناعية إضافة إلى الأبحاث العلمية. تكمن أهمية أجهزة الإستشعار إلى قدرتها على العمل في ظروف يصعب على الإنسان العمل بها أو الوصول إليها دون التعرض للخطر.

تواجه شبكات الإستشعار اللاسلكية مشاكل جمة أهمها أن هذه الشبكات تتكون من أجهزة ذات إمكانيات محدودة من حيث الحجم و الذاكرة والطاقة. تعتبر الطاقة من أهم الصفات التى تميز شبكات الإستشعار اللا سلكي و ذلك لصعوبة الحفاظ على مستوى الطاقة بها نتيجة لكثرة عددها و البيئة اللتى تعمل بها. إن نتائج البحث العلمي تعطي دلالات واضحة أن النسبة الأكبر من الطاقة في شبكات الإستشعار اللاسلكي يتم إستخدامها خلال نقل البيانات من أجهزة الإستشعار إلى الهدف بالطرف الاخر للشبكة, إن عملية تحديد المسار الذي يتم من خلاله إرسال البيانات من المصدر Source إلى الطرف الاخر Destination من الشبكة يلعب دورا حاسما في تحديد فترة عمر الشبكة Lifetime . إن إستخدام نفس المسار خلال عملية نقل البيانات من المصدر إلى لهدف في الطرف الاخر يؤدي إلى

إنهاك أجهزة الإستشعار التى تمر من خلالها البيانات بشكل سريع و بالتالى إلى فقدان هذه العقد Nodes من المسارات, مما يؤدى الى موت الشبكة و إنهاء مهمتها.

تُصنَف بروتوكولات التوجيه في شبكات الإستشعار اللاسلكية إلى: Proactive (استباقي) حيث يتم بناء المسار قبل طلب الإرسال, و Reactive (رد الفعل) الذي يبني المسار عند طلب الإرسال. و تعتبر Reactive protocols الأقل إستهلاكا للطاقة, و منها AODV .

لذلك قمنا باقتراح نموذج جديد يعمل على توزيع إستخدام الطاقة بين جميع أجهزة الإستشعار التى تشكل الشبكة من خلال الاعتماد على عاملين مهمين و هما: إستخدام المسار الأقل إستهلاكا للطاقة Minimum Energy Route بين جميع المسارات Route , و زيادة إستخدام أجهزة الإستشعار Sensor Nodes التى لم تخسر الكثير من طاقتها قبل ذلك, إن الجمع بين هذين العاملين يؤدي إلى توزيع إستخدام الطاقة على جميع المجسات الموجودة بالشبكة.

إن البروتوكول المقترح (NEER) Normalized Efficient Energy Routing " تطبيع التوجيه الأمثل لاستخدام الطاقة في نقل البيانات" يعتمد على بروتوكولين AODV و MRPC . ان NEER يعمل على نقل البيانات بمسار Route ينتقل الى مسار آخر عند الوصول إلى مستوى طاقة محدد Threshold, وبذلك نحافظ على وجود الشبكة.

إن البروتوكول الجديد NEER يعمل على زيادة عمر شبكة الإستشعار اللاسلكي مقارنة مع أنظمة اخرى إستخدمت مسبقا, دون التأثير على حجم البيانات المنقولة خلال فترة عمر الشبكة.

Table of Contents

Table of Figures

Table of Tables

Table of Equations

Chapter 1: Introduction

Contents

1 Introduction

1.1 Motivation

The emergence of wireless sensor networks (WSNs) is essentially toward the miniaturization and ubiquity of computing devices. Sensor networks are composed of thousands of resource constrained sensor nodes and also some resourced base stations are there. In WSN environment, network lifetime is vital issue in design of these networks. Network lifetime depends on the lifetime of individual nodes that form wireless sensor network, which depends on many factors.

The first factor is the coverage area of that node, in other words as coverage area of a node increases, the power consumption of that node increases, as a result network lifetime decreases. In typical environments nodes distribution of wireless sensor network plays an important role in wireless network lifetime. The second factor is transmission; network lifetime depends on the transmission rate of that node. As transmission rate increase the power consumption increase, this leads to decrease network lifetime. The third factor that interest researcher is the topology of that network, whether it was flat topology or it was hierarchal. Finally, network lifetime depends on the routing protocol used. Routing protocols could be classified according to topology of the wireless sensor network wither it was flat or hierarchal; it depends on the initiator of communication between source and destination. Power consumption in wireless sensor network and network lifetime depends on the routing algorithm used, hence researchers seeks to improve routing protocols that save energy and power of wireless sensor network, to extends network lifetime as long as possible.

Research results showed that most power ***P*** of wireless sensor is consumed through initial construction, sensing, processing, or during transmission, but power consumed through transmission is more than that consumed during through other factors, the route of each message destined to the base station is really crucial in terms network lifetime, we should use the best path to save power and to increase network lifetime as long as possible, If we take the same path each packet we send, then nodes in that path would be powered off earlier.

In this thesis, we aim to introduce a new routing algorithm to be used in wireless sensor network environment that could increase network lifetime, the idea is to present a new algorithm that doesn't only take the power consumed through that path, but also it takes the residual battery of nodes in that path. In other words, we want to use energy threshold to switch routing path during network lifetime to increase network lifetime as long as possible. We would use Ad-hoc On Demand Distance Vector Routing **AODV** routing protocol in the beginning of simulation until the first node's battery reaches threshold, after that routing protocol would use Maximize Network Lifetime for Reliable Routing in Wireless Environments (**MRPC**) protocol for the rest time of simulation.

1.2 Objectives

We aim to introduce a new routing algorithm in wireless sensor networks, the new routing algorithm could be considered a new hybrid algorithm that switch between two different algorithms. In this algorithm we use to check residual battery continuously, until the first node reaches the threshold. After that it switches the routing algorithm to different protocol. We need to get advantages of two different protocols, the least energy protocols that save energy during transmission and the MRPC protocol that depends on residual battery of nodes, that it the other protocol distribute load between different nodes and paths, in that protocol we could save power and energy of nodes that have the least energy. In this way we aim to increase network lifetime by using all nodes during simulation. And not to use the same path all the time until its node would die.

1.3 Problem Statement

Sensor networks are composed of thousands of resource constrained sensor nodes and also some resourced base stations are there. Communication in wireless sensor networks occurs in different ways depending on application used, in general there are three different types, clock driven, event driven and query driven. In clock driven mode, nodes sense their environment to gather data and periodically send that data to sink, the other modes are event and query driven are triggered by an event in their environment or by a query fro sink node or base station, in the same environment one or more modes could be used at the same time.

Network lifetime is the most important metric to evaluate wireless sensor network, in resource constrained environments, energy consumption should be considered. Network lifetime depends mainly on the lifetime of the individual nodes in that network. The lifetime of a sensor node depends basically on two factors: how much energy it consumes over time, and how much energy is available for its use. Network lifetime and energy consumption came up because of battery recharging or replacing is not suitable in many applications since some environments are hostile and may it have too many nodes. As a result, network lifetime should be discussed from different view, how to save power of wireless sensor network during simulation time. The route of each message destined to the base station is really crucial in terms network lifetime. This thesis introduces a new routing algorithm based on minimum energy and residual battery algorithms using energy threshold to switch routing path.

1.4 Contribution

Wireless sensor network (WSN) consists of hundreds or thousands nodes, these nodes have the ability to sense, process, and communicate. On the other hand these nodes are small and limited capabilities. The most important and critical issue is to create wireless sensor applications that save power of these nodes as long as possible since it is impossible to change or to recharge battery to those nodes in some applications.

- We proposed a new routing algorithm that saves energy and increases network lifetime.
- We developed new routing algorithm based on two different algorithms, residual battery algorithm MRPC and power consumed algorithm AODV.
- We have implemented a new routing protocol that improved throughput of the network through path switching.
- Benefited from NEER protocol that it increased network lifetime without affecting other network metrics.

1.5 State of Art

Wireless sensor node has the ability to sense, compute and to communicate through transmission, with the state of the art, limited capability sensor node could be alive as long as possible. Wireless sensor network usually consists of hundred or sometimes thousands of sensors. Sensors usually consumes energy through processing or during transmission, but most energy is consumed though transmission [MTY06]. In most cases these sensors gather information through sensing, process them and aggregate these data to transmit them to the base station that would retransmit data the concerned user [CKT01].

WSN have common challenges, the first one is the type of service that wireless sensor network provide to its user, on the other hand node deployment wither it was deployed randomly or it was deployed in a pre-determined manner. Furthermore, data reporting model became a challenge and design issue, it could be time driven or event driven or query driven or it could be a hybrid of these methods, on the other hand data should be aggregated before sending, that is, to reduce the amount of data to be sent, which leads to save power and energy consumed through transmission [GHA10].

Although scalability, through design of wireless sensor network we should take in consideration that our network could be scaled and routing algorithm to be suitable for that change. The most important issue to take into account is energy consumption, as mentioned above sensor node is a device with limited capabilities, memory, processor and power, the power is related directly to network lifetime. In many scenarios, nodes will have to rely on a limited supply of energy (using batteries) [STZ04]. Replacing these energy sources in the field is usually not practicable, and simultaneously, a WSN must operate at least for a given mission time or as long as possible. Hence, the lifetime of a WSN becomes a very important figure of merit. Evidently, an energy-efficient way of operation of the WSN is necessary.

As an alternative or supplement to energy supplies, a limited power source (via power like solar cells, for example) might also be available on a sensor node. Typically, these sources are not powerful enough to ensure continuous operation but can provide some recharging of batteries. Under such conditions, the lifetime of the network should ideally be infinite. The lifetime of a network also has direct trade-offs against quality of service: investing more energy can increase quality but decrease lifetime. Concepts to harmonize these trade-offs are required.

Researches and studies of WSN showed that most power in WSN consumed through communication. We aimed in this thesis to introduce a new routing algorithm that save energy and increase network lifetime. Our routing algorithm is based on two different routing algorithms (AODV, MRPC) using switching procedure.

1.6 Thesis Outline

We have organized the thesis into six chapters which includes Introduction; Wireless sensor networks; Power aware routing; NEER protocol, Simulation, and conclusion in chapter six.

- Chapter one: we already presented an introduction that describe wireless sensor network in general in terms of motivation, objectives, problem statement, contribution, state of the art and thesis outline.

- Chapter two: literature review of wireless sensor networks, challenges and design issues of WSN, goals of routing in WSN, flat and hierarchal routing in WSN, it introduces some wireless sensor network power consumption in general in addition to routing algorithm protocols used for wireless sensor networks.

- Chapter three: discuss problem statement of our research. In this chapter we study energy routing protocols that concern with energy saving protocols that increase network lifetime as long as possible.

- Chapter four: study protocol development, in which we would study NEER protocol that we developed to increase wireless sensor network lifetime.

- Chapter five: introduce our protocol implementation in terms of software installation, simulation, design and analysis.

- Chapter six: study results and conclusion about our developed protocol and comparison of our results with other protocols, it also presents future work could be done.

Chapter two: Wireless Sensor Network

Contents

2 Wireless Sensor Network

Wireless sensor network usually consists of hundreds or thousands sensing nodes scattered and deployed in interested area, the applications of these networks ranging from simple applications into very complex applications such as disaster relief applications, environment control, intelligent building, machine surveillance and preventive maintenance, medicine and health care.

2.1 Sensor Node

A sensor is a small, cheap, energy efficient device; these devices should have necessary computation and memory resources, and suitable communication facilities. A basic sensor consists of the following components:

1. Power supply: energy is the most important part of sensor devise since sensor lifetime usually depends on battery, in most cases battery isn't rechargeable. Most energy is consumed through transmission. To save power and increase node lifetime, we should control energy consumption as long as possible.
2. Communication: the presence of node within a network required its ability to send and receive data from/to other nodes in its environment.
3. Memory: in sensor node, memory needed to store intermediate data received from other nodes, and to store routing table used in some routing algorithms
4. Controller: controller to process all the relevant capable to execute arbitrary code.
5. Actuators: in some applications; sensor nodes should have the ability to act in its environment.

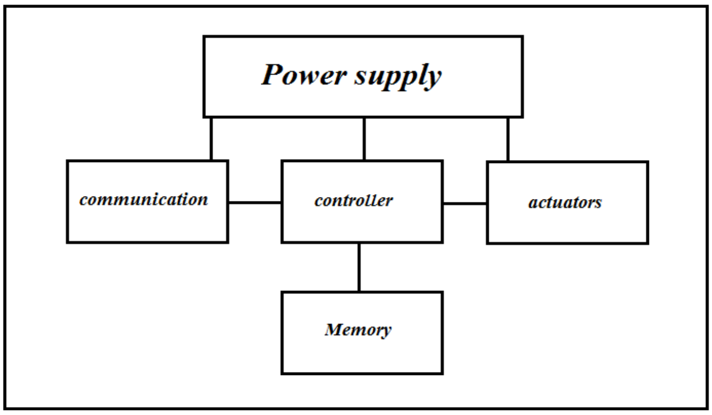

Figure 2-1: Sensor Node

In last few years, sensor nodes have many changes and improvements [CHN03], these changes affected wireless sensor nodes directly in many factors, the following table explains the changes that affected sensor nodes in many variables, the improvement of wireless sensor nodes is divided into three generations, that is; invention of sensor node, improved nodes, and finally current sensor.

Table 2-1: Sensor Development

	1980-2000	**2000-2010**	**2010- now**
Size	Large shoe box	Small shoe box	dust particles
Weight	Kilograms	Grams	Negligible
Architecture	Separating sensing, processing and communication	Integrated sensing, processing and communication	Integrated sensing, processing and communication
Topology	Point to point, star	Client server, peer to peer	Peer to peer
Power supply	Large battery, hours or days	AA battery days or weeks	Solar, month or years
Deployment	Vehicle placed	Hand placed	Embedded.

As shown above, there were much work has been done to improve sensor node power supply, on one hand researchers improved battery used as a power supply to sensor node, on the other hand they improved power consumption, these two factors enabled them to increase sensor node lifetime, in 1980's these nodes were active for hours or days, while recent sensor nodes have the ability to be active for long times.

2.2 Wireless Sensor Network Structure

A wireless sensor network (WSN) in its simplest form can be defined as a network of (possibly low-size and low-complex) devices denoted as nodes that can sense the environment and communicate the information gathered from the monitored field through wireless links; the data is forwarded, possibly via multiple hops relaying, to a sink that can use it locally, or is connected to other networks (e.g., the Internet) through a gateway.

Traditional wireless communication networks like Mobile Ad hoc Networks (MANET) differs from WSN; however sensor network WSN have unique characteristics such as

1. Dense level of node deployment,
2. Higher unreliability of sensor nodes and severe energy,
3. Computation and storage.

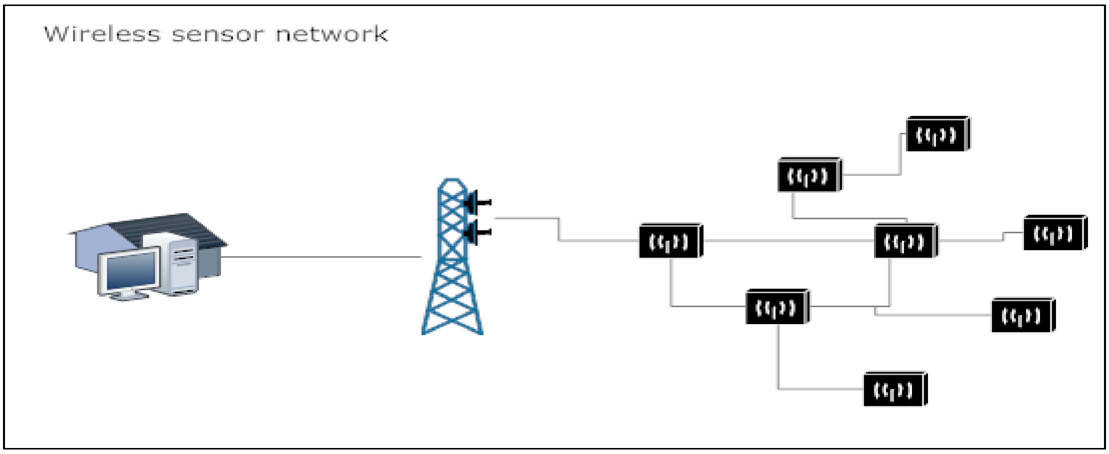

Figure 2-2: Wireless Sensor Network

Research has been made to explore and find solutions for various design architecture and application issues and significant advancement has been made in the development and deployment of WSNs. Usually the sensor nodes are deployed randomly over geographical location and these nodes communicate with each other to form a network.

The node gathers data from its environment, after that node processes data and sends it to the base station. These nodes can either route the data to the base station (**BS**) or to other sensor nodes such that the data eventually reaches the base station. In most applications, sensor nodes suffer from limited energy supply and communication bandwidth. These nodes are powered by limited batteries that couldn't be changed or recharged; hence network life-time depends on the battery consumption. Creative techniques are developed to efficiently use that limited energy and bandwidth resource to maximize the lifetime of the network as long as possible. These techniques work by careful design and management at all layers of the networking protocol. For example, at the network layer, it is highly desirable to find methods for energy efficient route discovery and relaying of data from the sensor nodes to the base station or sink node Routing methods in WSNs have to deal with a number of challenges and design issues we would summarize them next section.

2.3 Challenges and Design Issues

There are many characteristics that should be taken in to account during design of wireless sensor networks. The first one is the type of service that wireless sensor network provide to its user, on the other hand node deployment wither it was deployed randomly or it was deployed in a pre-determined manner. Furthermore, data reporting model became a challenge and design issue, it could be time driven or event driven or query driven or it could be a hybrid of these methods, on the other hand data should be aggregated before sending, that is, to reduce the amount of data to be sent, which leads to save power and energy consumed through transmission.

Although scalability, through design of wireless sensor network we should take in consideration that our network could be scaled and routing algorithm to be suitable for that change. The most important issue to take into account is energy consumption, as mentioned above sensor node is a device with limited capabilities, memory, processor and power, the power is related directly to network lifetime.

In many scenarios, nodes will have to rely on a limited supply of energy (using batteries). Replacing these energy sources in the field is usually not practicable, and simultaneously, a WSN must operate at least for a given mission time or as long as possible. Hence, the lifetime of a WSN becomes a very important figure of merit. Evidently, an energy-efficient way of operation of the WSN is necessary.

As an alternative or supplement to energy supplies, a limited power source (via power like solar cells, for example) might also be available on a sensor node. Typically, these sources are not powerful enough to ensure continuous operation but can provide some recharging of batteries. Under such conditions, the lifetime of the network should ideally be infinite. The lifetime of a network also has direct trade-offs against quality of service: investing more energy can increase quality but decrease lifetime. Concepts to harmonize these trade-offs are required.

2.4 Goals of Routing Algorithm

In multi-hop networks, intermediate nodes have to relay packets from source to destination, such node has to take a decision to which neighbor to forward incoming packet. As shown in figure 2.3 below, source node (**S**) couldn’t send packets to destination node (**D**) directly. It has to decide wither it send packets to node (B) or to send them through node (E).

[HED88] presented the simplest forwarding rule, is to flood the network, in other words, a node should forward incoming packets to all neighbors, as long as source and destination nodes are connected through intermediate nodes, we could be sure that packet would arrive to its destination. To avoid packet duplicating, a node identifier and packet sequence number should be added to packet, if node has seen that packet before, it could discard it.

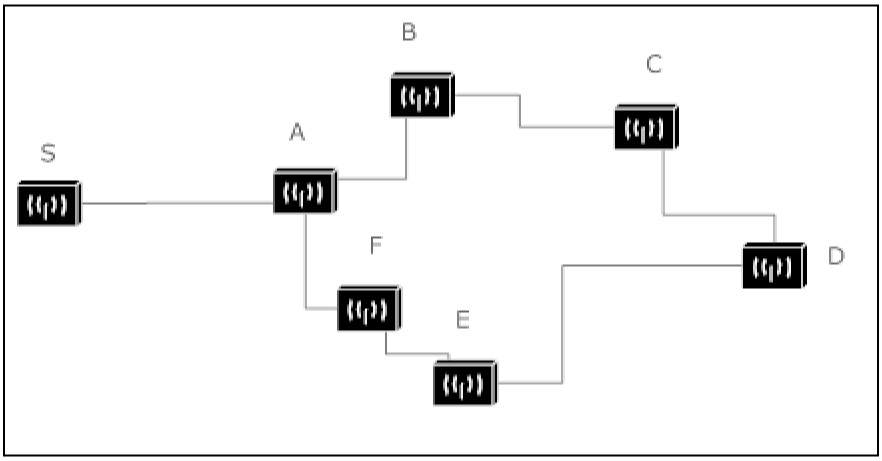

Figure 2-3: Routing In Multi-hop Network

The simplest forwarding rule, is to flood the network, in other words, a node should forward incoming packets to all neighbors, as long as source and destination nodes are connected through intermediate nodes, we could be sure that packet would arrive to its destination. To avoid packet duplicating, a node identifier and packet sequence number should be added to packet, if node has seen that packet before, it could discard it.

Routing algorithms generally could be classified into two groups; the first one is table driven or proactive, while the other group is reactive routing protocols. In table driven protocols, are “conservative” protocols in that they do try to keep accurate information in their routing tables, while reactive protocols are do not attempt to maintain routing tables at all times but only construct them when a packet is to be sent to a destination for which no routing information is available. In some cases, some algorithms are hybrid; they take characteristics from both groups.

On the other hand, routing algorithm could be classified according to structure of wireless sensor network into three groups, data centric, hierarchal based and location based routing. Table1 shows routing algorithm protocols.

Table 2-2: Routing Algorithm Protocols

	WSN Routing Protocol		
Path Establishment	**Network Structure**	**Protocol Operation**	**Initiator of Communication**
Proactive	Flat	Multipath Based	Source
Reactive	Hierarchical	Query Based	Destination
Hybrid	Location Based	Negotiation Based	
		QoS Based	
		Coherent & Non-coherent	

2.5 Flat WSN Routing Algorithms

Flat wireless sensor network could be defined as a network in which each node plays the same role in performing sensing tasks, and all nodes in flat topology wireless sensor network appear to be peer. We would study SPIN, direct Diffusion and rumor routing protocols designed for flat topology WSN.

2.5.1 Sensor Protocols for Information via Negotiation

Sensor Protocols for Information via Negotiation (**SPIN**): [HNZ00,SZW01] proposed a family of adaptive protocols called Sensor Protocols for Information via Negotiation (SPIN) that disseminate all the information at each node to every node in the network assuming that all nodes in the network are potential base-stations. This enables a user to query any node and get the required information immediately. These protocols make use of the property that nodes in close proximity have similar data, and hence there is a need to only distribute the data that other nodes do not posses. The SPIN family of protocols uses data negotiation and resource-adaptive algorithms.

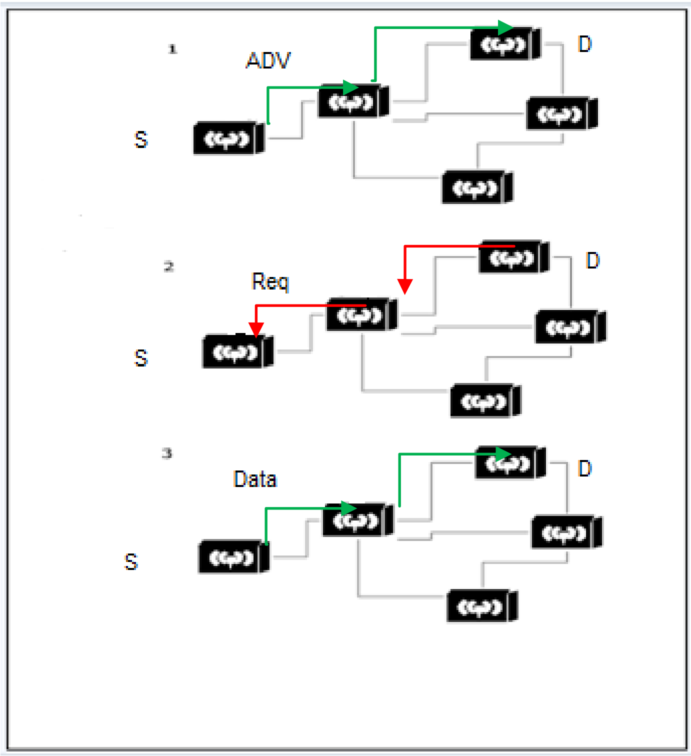

Figure 2-4: SPIN Protocol

Nodes running SPIN assign a high-level name to completely describe their collected data (called meta-data or Meta content that is defined as data providing information about one or more aspects of the data, such as: Means of creation of the data, Purpose of the data, Time and date of creation, Creator or author of data, and Location on a computer network where the data was created) and perform meta-data negotiations before any data is transmitted. This assures that there is no redundant data sent throughout the network. The semantics of the meta-data format is application-specific and is not specified in SPIN. For example, sensors might use their unique IDs to report meta-data if they cover a certain known region. In addition, SPIN has access to the current energy level of the node and adapts the protocol it is running based on how much energy is remaining. These protocols work in a time-driven fashion and distribute the information all over the network, even when a user does not request any data. SPIN's meta-data negotiation solves the classic problems of flooding, and thus achieving a lot of energy efficiency. SPIN is a 3-stage protocol as sensor nodes use three types of messages ADV, REQ and DATA to communicate. ADV is used to advertise new data, REQ to request data, and DATA is the actual message itself. The protocol starts when a SPIN node obtains new data that it is willing to share. It does so by broadcasting an ADV message containing meta-data. If a neighbor is interested in the data, it sends a REQ message for the DATA and the DATA is sent to this neighbor node. The neighbor sensor node then repeats this process with its neighbors. As a result, the entire sensor area will receive a copy of the data.

[HKP00] SPIN-2 is a version of SPIN-1 that backs-off from communication at low energy threshold. Such resource adaptive approach holds the key to the future of routing in WSNs. SPIN keeps up the promise of achieving high performance at low cost in terms of complexity, energy, computation and communication.

[HSC02] presented a new version to modify SPIN protocol SPIN-PP: This protocol is designed for a point to point communication. While SPIN-EC: This protocol works similar to SPIN-PP, but with an energy constraints added to it.

[HCB02] modified a new version of SPIN to save energy and to cope with diverse environment as following

- SPIN-BC: This protocol is designed for broadcast channels, in this protocol all nodes become in range of a sensor node. If channel is busy, then nodes couldn't transmit and must wait. On the other hand if a node received an ADV it couldn't request data, it uses a random timer and it should wait until this timer expires.
- SPIN-PP: PP stands for point to point communication, in this modified protocol, any two nods could communicate if there is no interference from other nodes. In SPIN-PP when a node announce that it has data and send ADV, the neighbor of this node which interested in this data would send RREQ, when this node receives actual data it would send new announcement to its neighbor, in this way SPIN protocol is working point to point or hop by hop. In figure 5-2, we investigate the work flow of SPIN-PP protocol.
- SPIN-EC: it is hop by hop SPIN protocol, in which a node couldn't participate in communication unless it has the capability to complete transmission process, to do so; its energy must be above a certain threshold.
- SPIN-RL: it was developed for loosely channels in which packets could be lost during transmission phase.

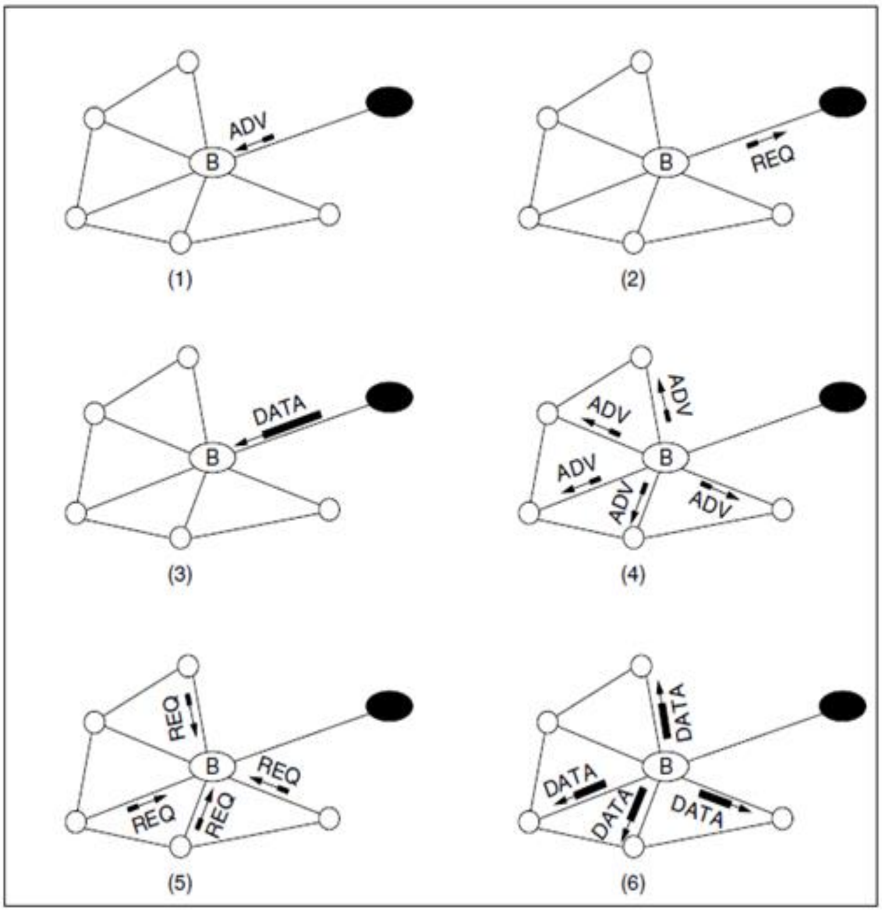

Figure 2-5: SPIN-PP

2.5.2 Direct Diffusion

[IGE03] introduced directed diffusion routing algorithm in which a sink node would send an interest message, in that message the sink node would specify a set of features to describe the desired data. This message is disseminated into the network. On the other hand, nodes that could produce sensor data that match the interest are called source nodes. A data packet produced by a source node travels through intermediate nodes to the sink. An intermediate node stores the interest along with (set of) possible upstream neighbors in the interest cache. When an intermediate node receives a data packet, it would search its cache for an interest matching the data and forwards the data packet to the associated upstream neighbor.

Directed diffusion algorithm has many advantages such as it allows on demand data queries while SPIN allows only interested nodes to query. On the other hand, direct diffusion doesn't need to maintain global network topology in directed diffusion. But it has disadvantage because it may not be applied to applications (e.g., environmental monitoring) that require continuous data delivery to the BS.

[HDZ04] presented a new modification for direct diffusion using passive clustering model to improve the energy efficiency of directed diffusion.

2.5.3 Rumor Routing

[BDE02] proposed Rumor routing algorithm based on the fact that each node maintains a list includes its neighbors and a table event, when this node triggered by an event, it would generate an agent that would travel all over the network to inform other nodes about event. Any node has a query that match this event would transmit to get data.

Rumor routing algorithm has an advantages, the important advantage is that it could save power in comparison with flooding and direct diffusion, on the other hand Rumor routing technique fails in case of large number of nodes since the cost of maintaining agents and event-tables in each node becomes infeasible.

[CLZ01] presented a new routing algorithm for flat topology wireless sensor networks, called minimum forwarding cost algorithm, in which nodes doesn't have any unique ID and also it doesn't have any routing table, but it has least cost estimated path to base station or sink, when this node want to forward a packet, it sends data to its neighbors, when neighbor nodes receive a packet, it would check if it was on the least-cost path or not, if yes it would forward packet, if no it would discard it.

2.5.4 Ad-hoc On Demand Vector Routing Protocol (AODV)

AODV [PEM99, PMR98, PRD00, PBR03, GMR07, ZMS02, and JNS10] is the simplest and widely used algorithm either for wired or wireless network. It is one of the most efficient routing protocols in terms of establishing the shortest path and lowest power consumption. AODV builds routes between nodes on-demand i.e. only as needed. Messages to other nodes in the network do not depend on network-wide periodic advertisements of identification messages to other nodes in the network.

It broadcasts “HELLO” messages to the neighboring nodes. It then uses these neighbors in routing. Whenever any node needs to send a message to some node that is not its neighbor, the source node initiates a Path Discovery, by sending a Route Request (RREQ) message to its neighbors. Nodes receiving the RREQ update their information about the source.

Set up a backward link to the source in their routing tables. Each RREQ contains the source node’s address (IP address) and a Broadcast ID that uniquely identifies it. It also has a current sequence number that determines the freshness of the message. The RREQ also contains a hop count variable that keeps track of the number of hops from the source. On receipt of the RREQ, the node checks whether it has already received the same RREQ earlier. If it has received the same RREQ earlier, it drops the RREQ. If it is an intermediate node without any record of a route to the final destination, the node increases the hop count and rebroadcasts the RREQ to its neighbors. If the node is the final destination, or an intermediate node that knows the route to the final destination, it sends back the Route Reply (RREP). This RREP is sent back via the same route traversing which the node had received the message from the source. When the source node receives the RREP, it checks whether it has an entry for the route.

We should take in consideration another control message; that's it, RERR that is used if a node detect that there is a link break on the next hop of an active route, or if it gets a data packet destined to a node for which it does not have an active route and is not repairing. Finally if a node receives a RERR from a neighbor for one or more active routes it sends a RERR message.

[STZ04] presented A Robust AODV Protocol with Local Update, to improve AODV routing protocol, in this protocol, multiple backup routes are built with different priorities, and the highest priority route would become active route when the current path would become less proffered.

[XWQ08] proposed The Energy-Saving Routing Protocol Based on AODV, the power controlled mechanism is adopted to adjust the emission power of node dynamically and to improve the energy saving performance of AODV routing protocol in mobile Ad Hoc networks. ES-AODV protocol focuses on the local repair and minimizes the probability of using source node for the route rebuild. ES-AODV protocol comprehensively evaluates excess energy of nodes; each node in the link calculates its weight which is in inverse proportion with its energy. The routing protocol always chooses the smallest cost link for data transmission. Energy consumption of nodes in the network could be effectively balanced and the average survival time of nodes in the network can be improved. The ES-AODV protocol makes full use of the backup route information which is cached during the stages of route optimization to repair the broken link.

[MPR10] Presented a paper called "Load Balancing and Route Stability in Mobile Ad Hoc Networks base on AODV Protocol" To introduce a new routing algorithm based on AODV protocol, they aimed to increase stability and lifetime of wireless sensor network using modified AODV protocol, they suggested to create alternate backup route, in LBAODV protocol; all discovered paths are used for transmitting data. In this way, load and energy consumption would be balanced and distributed on all nodes and paths in network. When a node create route request RREQ, they would receive RREP from different paths, each RREP is given count number, this number is correlated to its priority, each packet sent would be on different path, to distribute load. This would lead to balance power consumption.

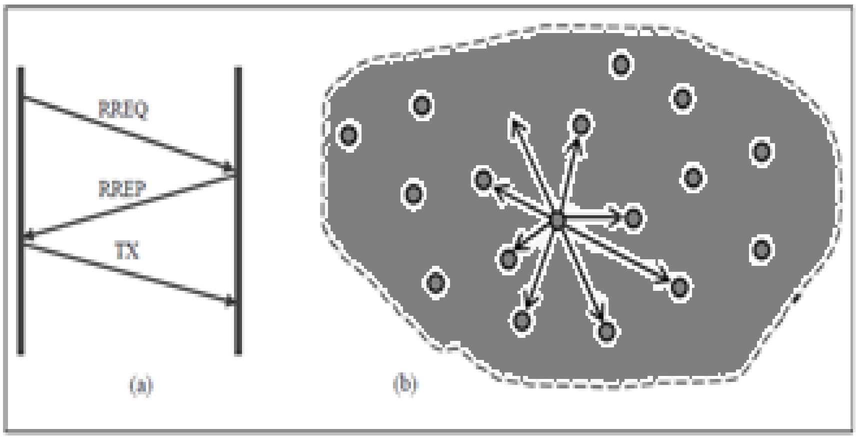

Figure 2-6: a) Timing diagram b) Hello packet

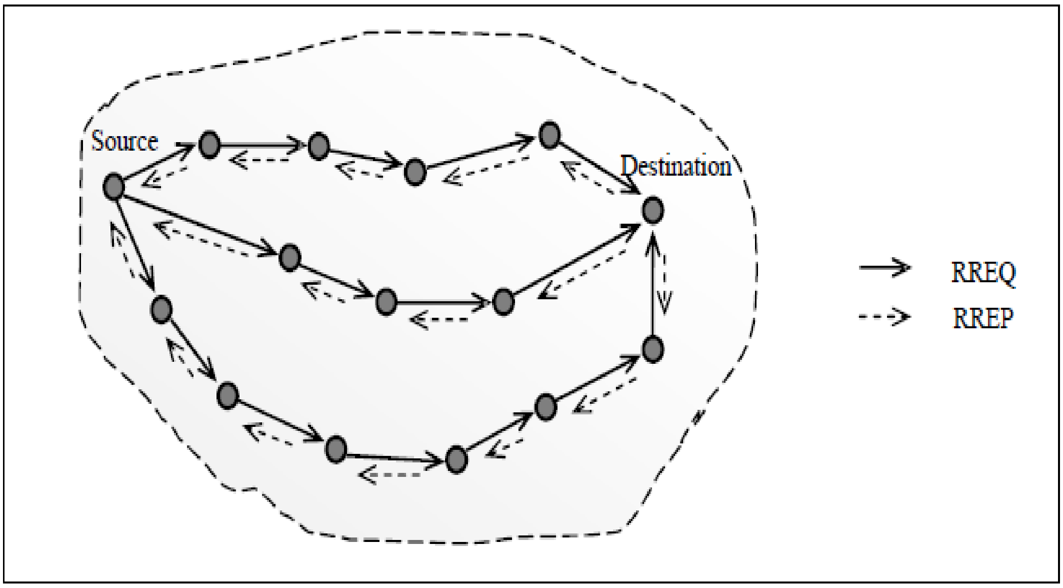

Figure 2-7: AODV Protocol- Path Discovery

In figure 2-6 we summarize the process of AODV control packets and data according to time between sender and receiver. While in figure 2.7 we summarize the process of AODV protocol in terms of control packets sent between source and destination,

Based on AODV, used in MANET [AGH10] environment, in which nodes may join or leave network at any time, as a result the topology, would change constantly, the Dynamic MANET on (DYMO) demand. DYMO is a successor of the AODV routing protocol, It operates similarly to AODV.

DYMO does not add extra features or extend the AODV protocol, but rather simplifies it[NSJ09], while retaining the basic mode of operation. As is the case with all reactive ad hoc routing protocols, DYMO consists of two protocol operations: route discovery and route maintenance. Routes are discovered on-demand when a node needs to send a packet to a destination currently not in its routing table. A route request message is flooded in the network using broadcast and if the packet reaches its destination, a reply message is sent back containing the discovered, accumulated path. Each entry in the routing table consists of the following fields: Destination Address, Sequence Number, Hop Count, Next Hop Address, Next Hop Interface, Is Gateway, Prefix, Valid Timeout, and Route Delete Timeout [ICP06].

2.6 Hierarchal Topology

Hierarchal topology is a new topology that differs from flat topology in which not all nodes have the same role, in which sensor node is the core of wireless sensor network, it could sense, process and send data. Clusters could be defined as organizational unit of for wireless sensor network; they are used to simplify communication process. Each cluster has a special node called cluster heads; they are responsible for cluster activities.

Clustering faces many challenges such as clustering cost, selecting cluster heads and clusters, real time operations, synchronization and data aggregations. It should take in consideration repair mechanism and quality of service.

2.6.1 Low Energy Adaptive Clustering Hierarchy

LEACH Low energy adaptive clustering hierarchy LEACH [HCB99, HCB00] randomly selects a few sensor nodes as cluster heads (CH) to distribute the energy load among the sensors in the network. CH nodes compress data arriving from nodes that belong to the respective cluster. CH sends an aggregated data to the base station to reduce information that must be sent to the base station. Operation of LEACH is separated into two phases Setup phase: clusters organized steady state phase and CH are selected. In steady state phase: actual data transfer to the base station take place.

$$\boldsymbol{t(n) = \frac{p}{1-p\left(r \bmod \left(\frac{1}{p}\right)\right)}} \qquad \textbf{(2-1)}$$

Where

P: fraction, cluster heads fraction

And ***r***: random number *0<r<1,*

If $r < t(n)$ a node becomes CH. After that CH broadcast advertisement message to the rest of nodes in the network that they are new CH. Other nodes, decide on the cluster on the cluster on which they want to belong to. The nodes inform appropriate **CH** that they will be a member of the cluster. The cluster head node create **TDMA** schedule, and assign each node a time slot when it can transmit. In steady state phase, sensor can begin sensing and transmitting data to **CH** node, **CH**-node aggregate data before sending it to base station. Each cluster communicates using different **CDMA** codes to reduce interference. After a certain time, which is determined before, network goes back into setup phase. **LEACH** has many disadvantages it assumes that all nodes can reach **BS** with the same power. It is not applicable to networks deployed in large area. Also the idea of dynamic clustering brings extra overhead.

Finally, the protocol assumes that all nodes begin with the same amount of energy, assuming that **CH** consumes same energy like other nodes.

[CDT02, YSF04] Modified typical **LEACH** protocol and presented a new algorithm based on it, called weighted clustering algorithm. They believed that nodes parameters such as identifier, node degree and node speed couldn't express node weight individually, they determined the cluster size that should not exceed particular value, and also node speed should be taken in consideration , in fact they preferred slow nodes. On the other hand they took in consideration the closeness of neighbors, the short distance is preferred.

The actual algorithm is then essentially identical to the ones discussed above where small weights take precedence (ties are broken arbitrarily). An interesting aspect of this algorithm is that it will, all else being equal; rotate the role of cluster heads among several nodes to ensure sharing of the load between several nodes.

[CAP04] proposed a new algorithm in which each node may be cluster member or a cluster head or may be not clustered node, in other word, it doesn't follow any cluster. The interesting idea in this algorithm is that cluster heads can concede if there is a nonhead node that could work a better cluster head, for example, one that would have more followers and less overlap with other clusters. Such a superior node will be promoted to cluster head status by the old, abdicating cluster head. In effect, the cluster head role moves around in the network. Nodes terminate the algorithm after a predefined time.

2.7 Power consumption

Usually wireless sensor node [HZR09] passes through many states, power consumption differs according to this states. A sensor node may be in idle state, running state or in sleep state; these states and transition between them shown in details in figure below, in this section we would study the Beauvoir of sensing node, we would study power consumption at different states mentioned above. In figure 5 below we could note that sensor node consumes most energy in running statr, while it consumes less energy in idle state, on the other hand sensor node doesn't consume approximatly Zero at sleep state.

Table 2-3: Comparison between different protocols

	Routing Protocol			
	SPIN	LEACH	Direct diffusion	AODV
Optimal route	NO	NO	Yes	Yes
Network lifetime	Good	Very good	Good	Excellent
Resource awareness	Yes	Yes	Yes	Yes
Use of meta data	Yes	NO	Yes	No

In table 2-3 above we summerize comparison between different protocols (SPIN, LEACH and direct diffusion) according to different metrics such as optimal route, network lifetime, resource awareness and the use of meta data. It is abvios that AODV is the best protocol in saving energy despite the fact that it is the only one that doesn't use meta data. While direct diffusion is the best protocol that select optimal path. In general, we could see that AODV protocol was the best according to network lifetime, also it uses the optimal route without ignoring resource awareness[SSS10,SSS11].

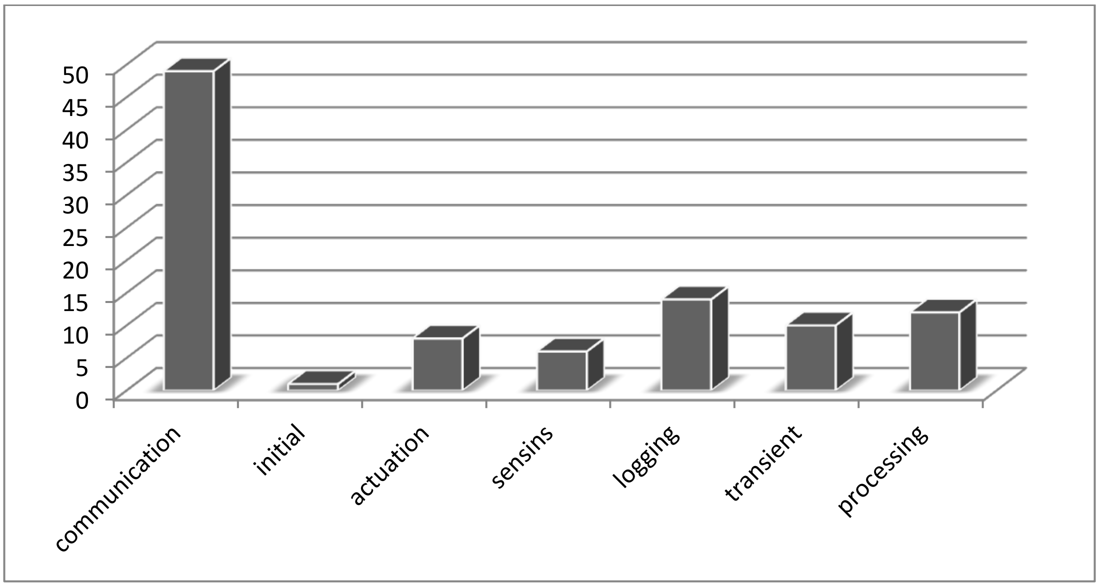

Figure 2-8: Power consumption in wireless sensor node

As shown above in figure 2-8 we could note that most power consumed in sensor node is lost through communication stage, approximately one half of sensor node power (49%). We could see also that if we could save power through communication, then we could increase the whole sensor node lifetime. This elimination of power consumption is gotten through suitable routing of message from source to destination.

We could save power also through data aggregation, if we minimize message length, or if we decrease data rate in which we could send data over wireless sensor network. In most vases mobile agent is used to aggregate data before sending [MTY06].

Chapter 3: Power Aware Routing Protocols

Contents

3 Power Aware Routing

3.1 Introduction

Several algorithms had been developed for routing in wireless sensor network, some of these algorithms and protocols are energy based algorithms. In these algorithms we take the network graph, assign to each link a cost value that reflects the energy consumption across this link, and pick any algorithm that computes least-cost paths in a graph. An early paper along these lines is reference [KNP96], which modified Dijkstra's shortest path algorithm to obtain routes with minimal total transmission power.

One of the most important algorithms used is known as minimum energy per packet or per bit. The most straightforward formulation is to look at the total energy required to transport a packet over a multi hop path from source to destination (including all overheads). The goal is then to minimize, for each packet, this total amount of energy by selecting a good route. Minimizing the hop count will typically not achieve this goal as routes with few hops might include hops with large transmission power to cover large distances – but be aware of distance-independent, constant offsets in the energy-consumption model. Nonetheless, this cost metric can be easily included in standard routing algorithms. It can lead to widely differing energy consumption on different nodes [CKT01]**.** To understand these different algorithms we present figure 3-1 as an example to simplify our idea, in figure 3-1 we could see two different values related to the residual battery of that node, while the other represents the amount of energy consumed to send a single packet between two nodes.

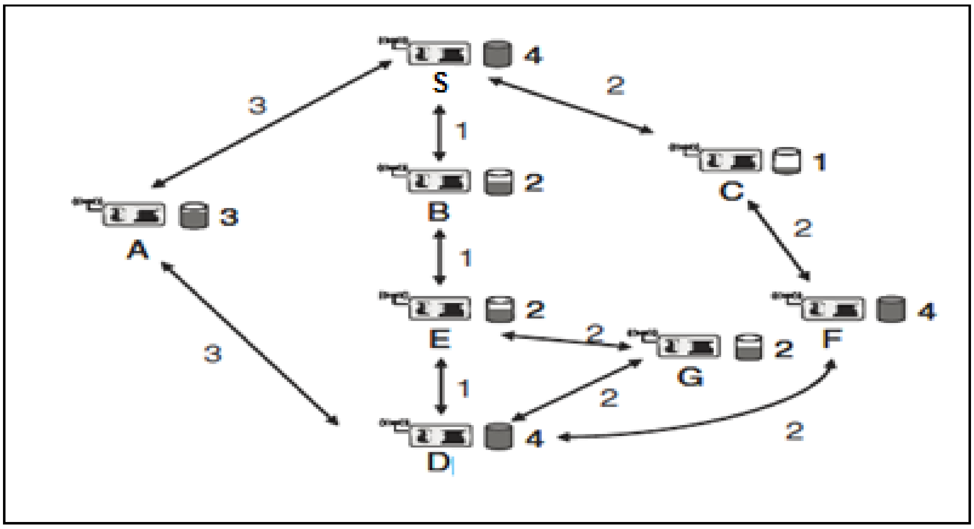

Figure 3-1: Example Model

3.2 Network Lifetime

A WSN's task is not to transport data, but to observe (and possibly control). Hence, energy-efficient transmission is at best a means to an end and the actual end should be the optimization goal: the network should be able to fulfill its duty for as long as possible. Which event to use to demarcate the end of a network's lifetime is, however, not clear either.

Several options exist:

1. Time until the first node fails.
2. Time until there is a spot that is not covered by the network (loss of coverage, a useful metric only for redundantly deployed networks).
3. Time until network partition (when there are two nodes that can no longer communicate with each other).
4. Until all nodes in the network die.

In our research we will use the final definition, in which we wait until all nodes in the network die.

3.3 Energy Based Algorithms

3.3.1 Maximum Total Available Battery Capacity (MTAB)

Some researches went to routing considering available battery energy, as the finite energy supply in nodes' batteries is the limiting factor to network lifetime, it stands to reason to use information about battery status in routing decision. Some of the possibilities are **Maximum Total Available Battery Capacity** Choose that route where the sum of the available battery capacity is maximized, without taking needless detours (called, slightly incorrectly, "maximum available power" in reference [ASC02]. In this algorithm we would find different paths from source to destination, and then find we find total residual battery in all nodes of that path. Table 3-1 below would summarize packet routing from source (S) to destination (D).

Mathematically:

If Network = ***N***

Path = ***P***

Battery = ***Bi***

Consumed Energy = ***Eij***

$\forall \quad P \in N$

$|P| = \sum Bi$

Then,

$$\boldsymbol{P}_{\boldsymbol{candidate}} = \boldsymbol{Max}\ (|\boldsymbol{P}|) \qquad \textbf{(3-1)}$$

Table 3-1: Maximum Available Battery

Path number	Path name	Total residual battery
1	(S -> A -> D)	3
2	(S -> B -> E -> D)	2+2=4
3	(S -> B -> E -> G -> D)	2+2+2=6
4	(S -> C -> F -> D)	1+4=5

As expected we would choose path number 3 since it has maximum available battery. Despite the fact that this path would exhaust this path and it would exhaust the nodes that form it.

3.3.2 Minimum Energy Path (MAP)

Some researchers concentrate on minimum energy path to save energy and to maximizes network lifetime in other words if we look at figure 3-1 below we could see that there are four paths from **source (S)** to **destination (D)**, the first on is (S -> A -> D) which consumes 6 power units to send a single packet from source to destination. The second path is (S -> B -> E -> D) consumes 3 energy units to send a single packet from source to destination.

The third path is that (S -> B -> E -> G -> D) would consumes 6 energy units, the last path is (S -> C -> F -> D) that would consume 6 energy units. Table 3 below would summarize this algorithm. As a result we would choose path number 2 (S -> B -> E -> D). if energy need to send a packet from source to destination was equal in two or more paths, then we could depend on another factor, we may use minimum hop count to use the path that have less number of hops, or we may use another important factor such as the maximum residual battery in that path.

If $P \in N$

$|P| = \sum Eij$

Then,

$$P_{candidate} = Min\ (|P|) \qquad (3\text{-}2)$$

Table 3-2: Minimum Energy Routing

Path number	Path name	Power
1	(S -> A -> D)	6
2	(S -> B -> E -> D)	3
3	(S -> B -> E -> G -> D)	6
4	(S -> C -> F -> D)	6

3.3.3 Minimum Battery Cost Routing (MBCR)

Instead of looking directly at the sum of available battery capacities along a given path; MBCR instead looks at the "reluctance" of a node to route traffic [SWR98, CKT01] .This reluctance increases as its battery is drained; for example, reluctance or routing cost can be measured as the reciprocal of the battery capacity. Then, the cost of a path is the sum of this reciprocals and the rule is to pick that path with the *smallest* cost. Since the reciprocal function assigns high costs to nodes with low battery capacity, this will automatically shift traffic away from routes with nodes about to run out of energy. Route S-C-F-D is assigned a cost of 1/1 + 1/4 = 1.25, but route S-A-D only has cost 1/3. Consequently, this route is chosen, protecting node C from needless effort. Table 5 below would explain how the algorithm would work to get best results.

Table 4 below find minimum battery cost routing algorithm. We could see that we take intermediate nodes in path only, since source and destination nodes exist in all paths, if we take minimum value, then we would take path number 1 (A -> D -> H).

If,

$$\forall \quad P \in N$$

$$|P| = \sum 1/Eij$$

The

$$P_{candidate} = \mathit{Min}\ (|P|)$$
(3-3)

Table 3-3: MBCR Algorithm

Path number	Path name	MBCR
1	(S -> A -> D)	1/3 = 0.33
2	(S -> B -> E -> D)	1/2 +1/2 = 1
3	(S -> B -> E -> G -> D)	1/2 +1/2 +1/2 =1.5
4	(S -> C -> F -> D)	1 +1/4 = 1.25

3.3.4 Min–Max Battery Cost Routing (MMBCR)

This scheme [SWR98, CKT01] follows a similar intention, to protect nodes with low energy battery resources. Instead of using the sum of reciprocal battery levels, simply the largest reciprocal level of all nodes along a path is used as the cost for this path. Then, again the path with the smallest cost is used. In this sense, the optimal path is chosen by minimizing over a maximum. The same effect is achieved by using the smallest battery level along a path and then maximizing over these path values [ASC02]. This is then a maximum/minimum formulation of the problem. Minimize variance in power levels to ensure a long network lifetime, one strategy is to use up all the batteries uniformly to avoid some nodes prematurely running out of energy and disrupting the network. Hence, routes should be chosen such that the variance in battery levels between different routes is reduced.

Table 6 would explain how the algorithm would work; in first step we would find all different paths as shown in figure 3-1 we have only 4 paths from source to destination. Then we would find minimum battery in each path. Finally, we would take maximum value of all paths; the path with maximum value would be taken. In this algorithm it is clear that we would protect nodes with low batteries. Mathematically,

$$\forall \qquad P \in N$$

Then,

$$\boldsymbol{P}_{\boldsymbol{candidate}} = \boldsymbol{Max}\,(\boldsymbol{Min}\,(|\boldsymbol{Bi}|)) \qquad \textbf{(3-4)}$$

Table 3-4: MMBCR Algorithm

Path number	Path name	Minimum node energy
1	(S -> A -> D)	3 (A)
2	(S -> B -> E -> D)	2 (B,E)
3	(S -> B -> E -> G -> D)	2 (B,E,G)
4	(S -> C -> F -> D)	1 (C,F)

If we take maximum value, then we would choose path 1 (S -> A -> D).

3.3.5 Minimize Variance in Power Levels (MVPL)

In this algorithm we aim to reduce variance in nodes battery between different nodes as long as possible, we aim in this way to be sure that load is distributed uniformly between different nodes, and not to disrupt our network through the dead nodes.

3.3.6 Maximize Network Lifetime for Reliable Routing in Wireless Environments (MRPC)

[MSB02] used to Maximize Network Lifetime for Reliable Routing in Wireless Environments (MRPC), they depended on the fact that selecting the path with the least transmission energy for reliable communication may not always maximize the lifetime of the ad-hoc network. On the other hand since the actual drain on a node's battery power will depend on the number of packets forwarded by that node, it is difficult to predict the optimal routing path unless the total size of the packet stream is known during path-setup. MRPC works on selecting a path, given the current battery power levels at the constituent nodes, that maximizes the total number of packets that may be ideally transmitted over that path, assuming that all other flows sharing that path do not transmit any further traffic.

Another important algorithm is called as MRPC which stands for maximum residual packet capacity. It tries to select the rout that maximizes the residual capacity currently at the most critical node.

As the number of hops is increased, the resultant increase in the total number of re-transmissions, needed to ensure reliable packet delivery over the large number of hops, can negate the reduction achieved using short-range hops. It suggested using a battery cost function

$$\boldsymbol{f(Bi) = \frac{1}{Bi}} \qquad (3\text{-}5)$$

Where

Bi : is the residual battery capacity of node.

While the cost of a path could be is given as:

$$\boldsymbol{Cp = \sum_{node\ i\epsilon P}^{n} f(Bi)} \qquad (3\text{-}6)$$

Selecting the path with the least transmission energy for reliable communication mayn't always maximize the lifetime of the ad-hoc network. Assume that the residual battery power at a certain instance of time at node $\boldsymbol{i}$ is$\boldsymbol{Bi}$.

Also, let us assume that the transmission energy required by node i to transmit a packet over link$(\boldsymbol{i}, \boldsymbol{j})$, to node $\boldsymbol{j}$ is$\boldsymbol{Eij}$.

Then the maximum number of packets that node I can forward over this link is clearly:

$$\boldsymbol{Cij = \frac{Bi}{Eij}} \qquad (3\text{-}7)$$

Clearly, the maximum "lifetime" of the chosen path P defined by the maximum number of packets that may be potentially forwarded between $S$and D using P is determined by the *weakest intermediate node– one with the smallest value* of $\boldsymbol{Cij}$ accordingly, the "maximal lifetime" associated with route

$$\text{Life P=}\mathbf{Min}_{I,J\,\in P}\{\,\boldsymbol{Cij}\} \qquad (3\text{-}8)$$

The MRPC algorithm then selects the route **P** candidate that maximizes the "maximal lifetime" of communication between **S** and **D**

As a result:

$$\text{P candidate} = \mathbf{Max}\{\mathbf{life}_{\,P} \mid \boldsymbol{P} \in \boldsymbol{all\ possibl\ routs}\} \qquad (3\text{-}9)$$

Simulation of this algorithm gave very good results, for example the use of this routing algorithm increased network lifetime and the total number of packets received. Now we have to compare between different algorithms according to network lifetime, energy per packet and throughput.

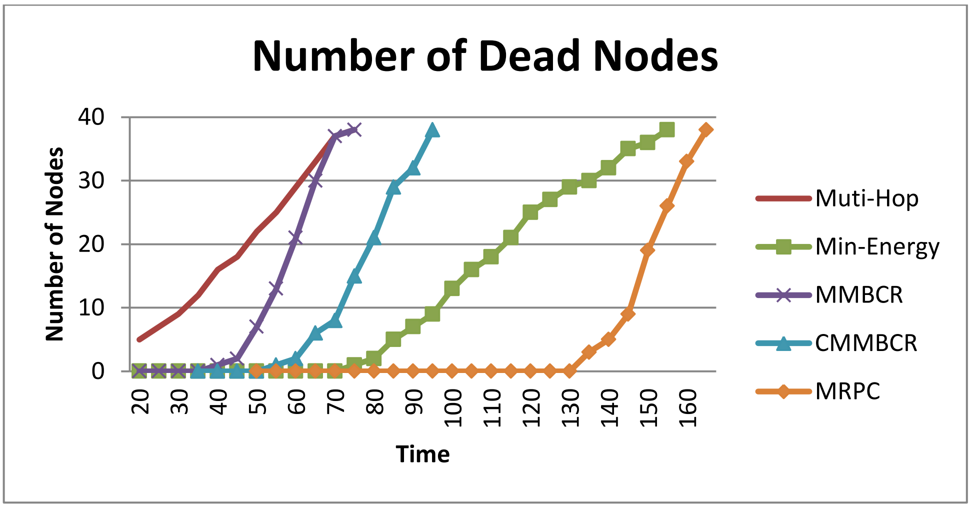

Figure 3-2: Comparison Between Different Algorithms

Simulation results [MSB02] of different algorithms showed that MRPC was the best algorithm that increase network lifetime as long as possible, on the other hand if we compare between different algorithms according to total number of sent packets we find that MRPC was very good. In general we find that MRPC works fine for WSN. In this thesis we will introduce new routing algorithm to be successor to MRPC and AODV.

Chapter 4: NEER

Contents

4 Normalized Energy Efficient Routing (NEER)

4.1 Introduction

In this chapter we would study **MRPC** algorithm in details, according to MRPC disadvantages problems, on the other hand we would study **NEER** algorithm that depends directly on MRPC and **AODV** algorithms, we would finally introduce a flow chart summarize NEER algorithm.

4.2 MRPC Disadvantages

MRPC algorithm has a problem in that it uses a path that consumes much power. Simulation results showed that the transmission power per packet was higher than that of minimum energy algorithm.

Figure 4-1 below shows that MRPC algorithm would take path *P1* (S -- C -- F -- D) because it would send 3 packets from A to H while it would send only 2 packets through *P2* (S –B – E -- D) despite the fact that sending a packet through *P1* (6 units) consumes much more power than *P2* (only 3 units). We proposed a new algorithm called NEER (Normalized Energy Efficient Routing). As shown in table 4-1 we could send 3 packets through path 4, but we should note that this packet to be sent through path 4 would consume 8 energy units. While if we take another path; such as path 2 (S -> B -> E -> D) would consume less energy to deliver a packet from source to destination.

Table 4-1: MRPC Example

Path number	Path name	C = B/E	Min
1	(S -> A -> D)	8/3=2 ,7/3=2	Min (2,2) =2
2	(S -> B -> E -> D)	8/1=8 ,2/1 =2, 4/1=4	Min (8,2,4)= 2
3	(S -> B -> E -> G -> D)	8/1=8,2/1=2,4/1=4,2/2=1	Min(8,2,4,1)=1
4	(S -> C -> F -> D)	8/2=4,6/2=3,8/2=4	Min(4,3,4)=3

From table 4-1, we could recognize that MRPC algorithm doesn't choose the shortest path all the time, or it doesn't save energy during communication phase, but it chooses the path that could send more packets through. MRPC algorithm distribute load of energy consumption on all paths that available from source to destination.

On the other hand AODV algorithm and shortest path algorithms in general select the same path all the time, this behavior would in face exhaust nodes that form shortest path. Our idea came from the fact that we would use the shortest path as long as possible, until the most exhausted node reaches threshold, after that NEER would switch to MRPC instead AODV algorithm discussed above.

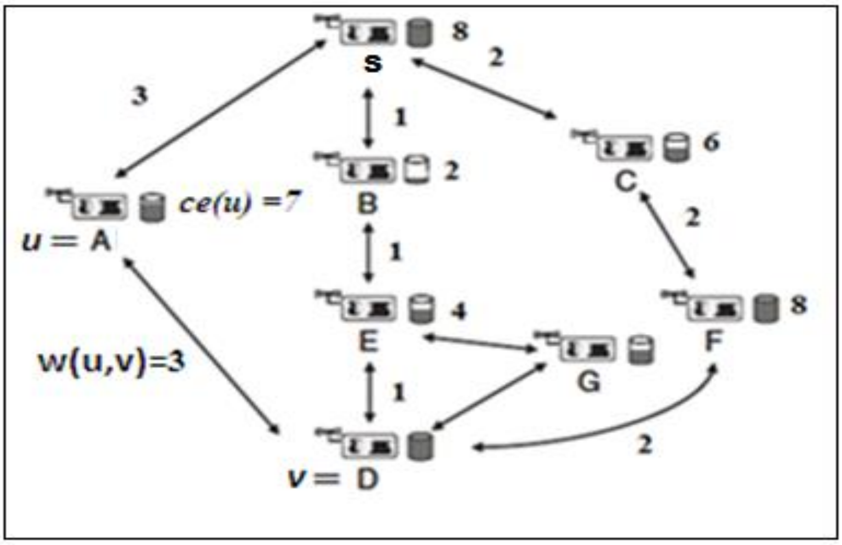

Figure 4-1: NEER Example

4.3 Normalized Efficient Energy Routing NEER

NEER algorithm was developed to save energy in wireless sensor network and to increase network lifetime, without affecting other factors and metrics. In this section we introduce **NEER** in details and its sudu code

Our algorithm could be summarized as following:

Let ***G*** represent sensor network graph

$$\boldsymbol{c(u,v)} = \frac{\mathbf{Ce(u)}}{\mathbf{W(u,v)}} \qquad \textbf{(4-1)}$$

Where

u,v represents nodes.

Edge ***(u,v)*** is the link between ***u*** and ***v***

ce(u) is residual battery of node ***u***

w(u,v) is the weighted cost of edge(***u,v***)

Step 1: [Initialize]

Eliminate from G every edge *(u, v)* for which

$$\mathbf{ce(u) < w(u,v)} \qquad \textbf{(4-2)}$$

This condition is used to ensure we could send at least one packet through this path.

For every remaining *edge (u, v)* let

$$\boldsymbol{C(u,v)} = \frac{\boldsymbol{Ce(u)}}{\mathbf{W(u,v)}} \qquad \textbf{(4-3)}$$

Let *L* be the list of distinct *c(u, v)* values.

Step 2: [Binary Search]

Do a binary search in *L* to find the *maximum* value max for which there is a path *P* from Source to destination that uses no edge with

$$\mathrm{C(u,v)} < \mathrm{max.} \quad C(u,v) < Max \qquad \textbf{(4-4)}$$

For this, when testing a value *q* from *L*, we perform a depth- or breadth-first search beginning at source. The search is not permitted to use edges with

$$\mathrm{C}(\mathbf{u},\mathbf{v}) < q \qquad \textbf{(4-5)}$$

Let *P* be the source-to-destination path with lifetime max.

Simultaneously we should find minimum energy path using Dijkstra's algorithm as following:

$$x = \sum_{i=1}^{i=n} w(u,v) \forall\, w(u,v) \epsilon\, P \qquad \textbf{(4-6)}$$

Step 3: [Wrap Up]

If no path is found in Step 2, the route isn't possible. Otherwise, use P for the route.

Also find

$$\mathrm{Min(x)}, \forall\, \mathrm{x}\, \epsilon\, P \qquad \textbf{(4-7)}$$

Our new algorithm; **power aware routing we** need to: use a new hybrid algorithm that takes the advantages of both. Here we use the following equation

$$Z = \begin{cases} AODV \Big| & Bi \geq 0.2 * Initial\ Battery \\ MRPC \Big| & Bi < 0.2 * Initial\ Battery \end{cases} \qquad \textbf{(4-8)}$$

Where ***Z*** *is the used function or protocol*

AODV*: **AODV** protocol*

MRPC*: **MRPC** Protocol*

Bi= *current Battery level.*

B = *initial battery*

If ***Z*** was above a certain value (threshold) we would use **MRPC**, if ***Z*** was less than that threshold, then we use minimum energy approach.

4.4 NEER Flow Chart

In figure 4-2 below we could see our proposed algorithm flow chart that explain our algorithm steps in details. In NEER algorithm we take two factors in consideration. The total power consumed through that path and the residual battery in all nodes of that path. NEER algorithm starts with AODV protocol, until the first node of network reaches the threshold value, in such a case the NEER algorithm switches to MRPC algorithm.

Figure 4.2 below shows that NEER at first check battery at all nodes, if all nodes above threshold, then AODV would work. It sends request to send and waits for clear to send control packet, when source node receives clear to send control packet it sends data. Each iteration; NEER would check battery at all nodes until it reaches threshold at least at one node. After that our algorithm would switch to MRPC, it finds the path that could be used to send more packets from source to destination. If nodes becomes out of energy or turned off, NEER would stops.

In chapter 5 we would simulate NEER algorithm to compare it with other different algorithms to measure its ability to extend network lifetime, on the other hand we would use simulator to find best value of threshold (α).

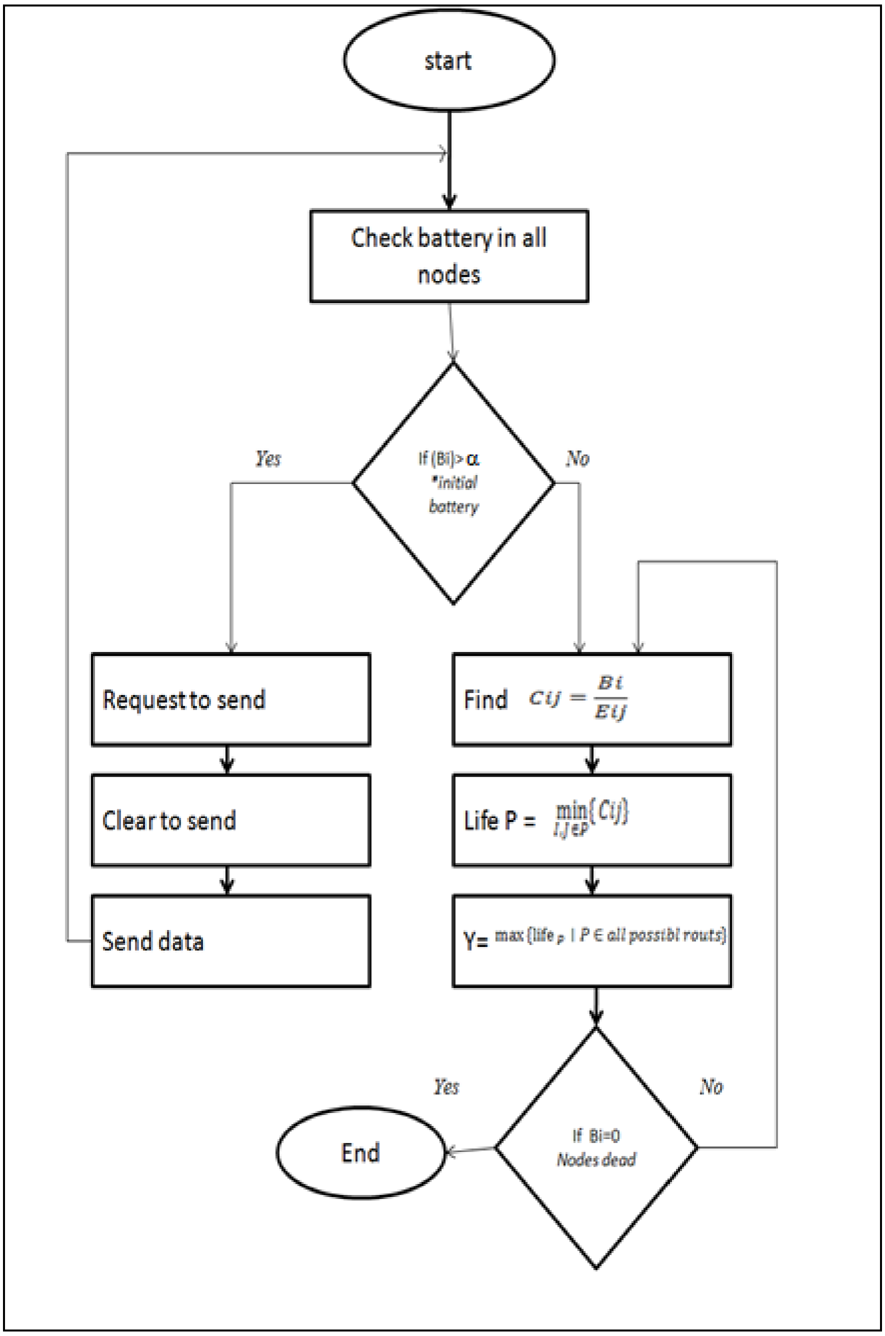

Figure 4-2: NEER flow chart

Chapter 5: Simulation

Contents

5 Simulation

In this chapter we would get an overview about environment we used for simulation, it includes Ubuntu operating system, network simulation NS-3.16 and wire shark needed for analysis of simulation results; we need to take an overview about nodes and energy.

5.1 Simulation Parameters

The following table summarizes parameters that used in simulation, simulation continues until all nodes become dead. As shown, there is one source node and one destination node. While all nodes starts with the same energy level.

Table 5-1 : simulation parameters

Parameter	Description
Channel type	Wireless channel
Mac protocol	Mac/802_11
number of nodes	40
routing protocol	AODV, MRPC and NEER,
grid size	800 X 800
packet size	64
simulation time	To die
Topology	Random , Flat
Initial energy	3 joule
Source node	1
Destination node	1

5.2 AODV Simulation

We did simulation for AODV protocol by adding energy parameters to our code, to study the behavior of AODV algorithm according to energy. We used WireShark software to analyze simulation results; we used simulation time to be 10000 mS, to guarantee that all nodes become dead.

In AODV, any node needs to send a message to some node that is not its neighbor; the source node initiates a Path Discovery, by sending a Route Request (RREQ) message to its neighbors. Nodes receiving the RREQ update their information about the source. Set up a backward link to the source in their routing tables. Each RREQ contains the source node's address (IP address) and a Broadcast ID that uniquely identifies it. It also has a current sequence number that determines the freshness of the message. The RREQ also contains a hop count variable that keeps track of the number of hops from the source. On receipt of the RREQ, the node checks whether it has already received the same RREQ earlier.

We should study some variables in our simulation; these variables should be number of nodes used in simulation, and the distance between different nodes. In this section we would study the behavior of AODV protocol according to number of nodes used in simulation. We used 10 nodes simulation, 20 –nodes, 30 nodes, 40 nodes, and 50 nodes. We want to examine wither expiration time of nodes during simulation would change if we increase number of nodes in simulation or not.

Table 5-2 below summarizes simulation results. If we study results in details we could see that number of nodes in simulation doesn't have direct impact on the expiration time. When we used 10 nodes, all nodes died at 90 seconds, we tried to add 10 additional nodes in simulation, and we could see that all of them died within the same duration. In each iteration; we added ten additional nodes in simulation to study the behavior of these nodes. The expiration time of them was the same approximately.

These results could be illustrated. Simply, the distance between nodes doesn't change, so energy needed to transport packet still the same and fixed. But energy per packet would increase as the number of nodes increase. In next simulation we would use 40 nodes to compare between different protocols.

Table 5-2 : Expiration Time of different nodes

Time	Number of dead nodes				
	10	20	30	40	50
10	0	0	0	0	0
15	0	0	0	0	1
20	0	0	0	1	2
25	1	4	5	8	12
30	2	6	8	16	23
35	4	9	14	22	29
40	4	11	16	24	33
45	5	12	17	23	34
50	5	13	18	26	35
55	7	14	21	29	38
60	7	15	24	33	42
65	8	16	26	36	45
70	10	16	26	38	46
75	10	17	26	38	46
80	10	17	27	38	47
85	10	17	27	39	48
90	10	18	28	40	49
95	10	19	28	40	50
100	10	20	30	40	50

Figure 5-1 below represents simulation results of table 5-2, on X- axis we could see time series of simulation, while Y- axis define number of dead nodes as a function of time. It seems that number of nodes used in simulation doesn't affect the number of dead nodes, because percentage of dead nodes seems to be the same for all results.

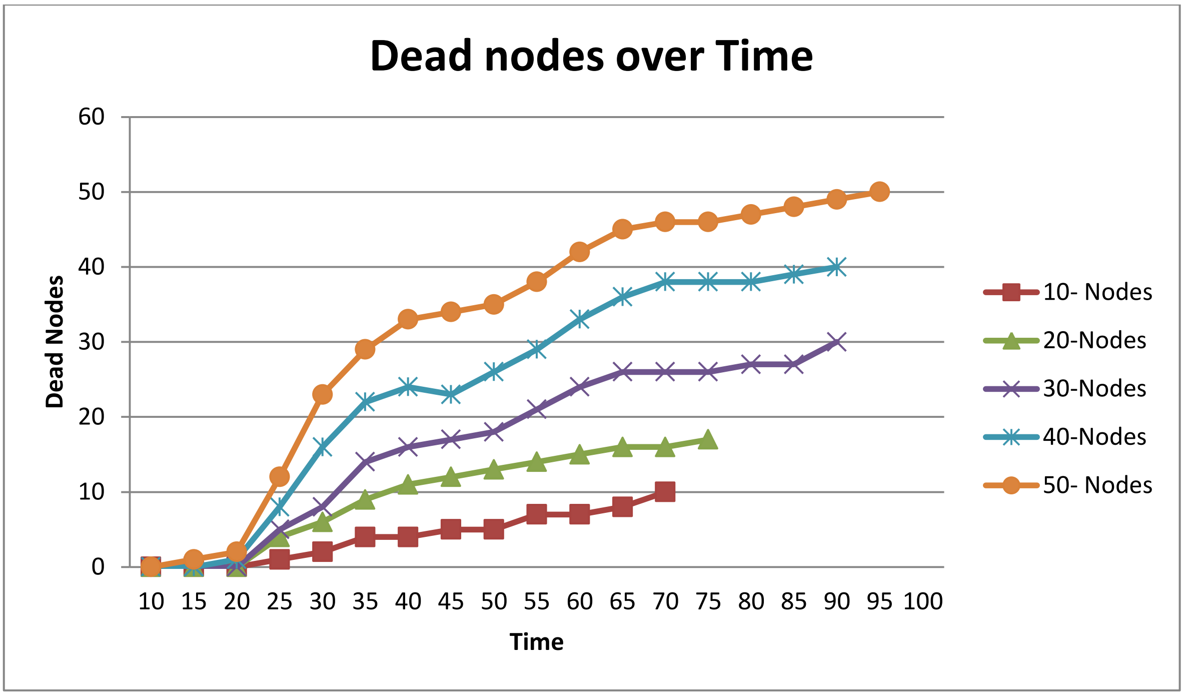

Figure 5-1 : Expiration Time

In this section we would study the impact of distance on expiration time of nodes over time, in this factor we would use distance of 20 meters, 40 meters, 60 meters, 80 meters and finally we would use 100 meters distance between each two nodes. (We would use 40 nodes as standard in this simulation).

Table 5-3: Expireation Time to Distance

Time	Distance				
	20	40	60	80	100
5	0	0	0	0	0
10	0	0	0	3	4
15	0	0	1	5	6
20	0	0	8	6	7
25	0	1	16	9	11
30	1	8	22	14	16
35	8	16	24	20	20
40	16	22	23	27	29
45	22	24	26	29	31
50	24	23	29	32	34
55	23	26	33	36	38
60	26	29	36	38	40
65	29	33	38	39	Dead
70	33	36	38	40	Dead
75	36	38	38	Dead	Dead
80	38	38	39	Dead	Dead
85	38	38	40	Dead	Dead
90	38	39	Dead	Dead	Dead
95	39	40	Dead	Dead	Dead
100	40	Dead	Dead	Dead	Dead

As expected, if we increase distance, energy consumed would increase, and expiration time would decrease, since power would consumed in faster manner. If we increase distance other factors also would differs , such as energy per packet, and the other important factor the throughput, the packet loss ratio would also increase , which would affect the whole system.

In our next simulation, we would use 60 meters distance for all protocols, to compare between them, figure 4-5 below illustrate the behavior of AODV protocol according to distance.

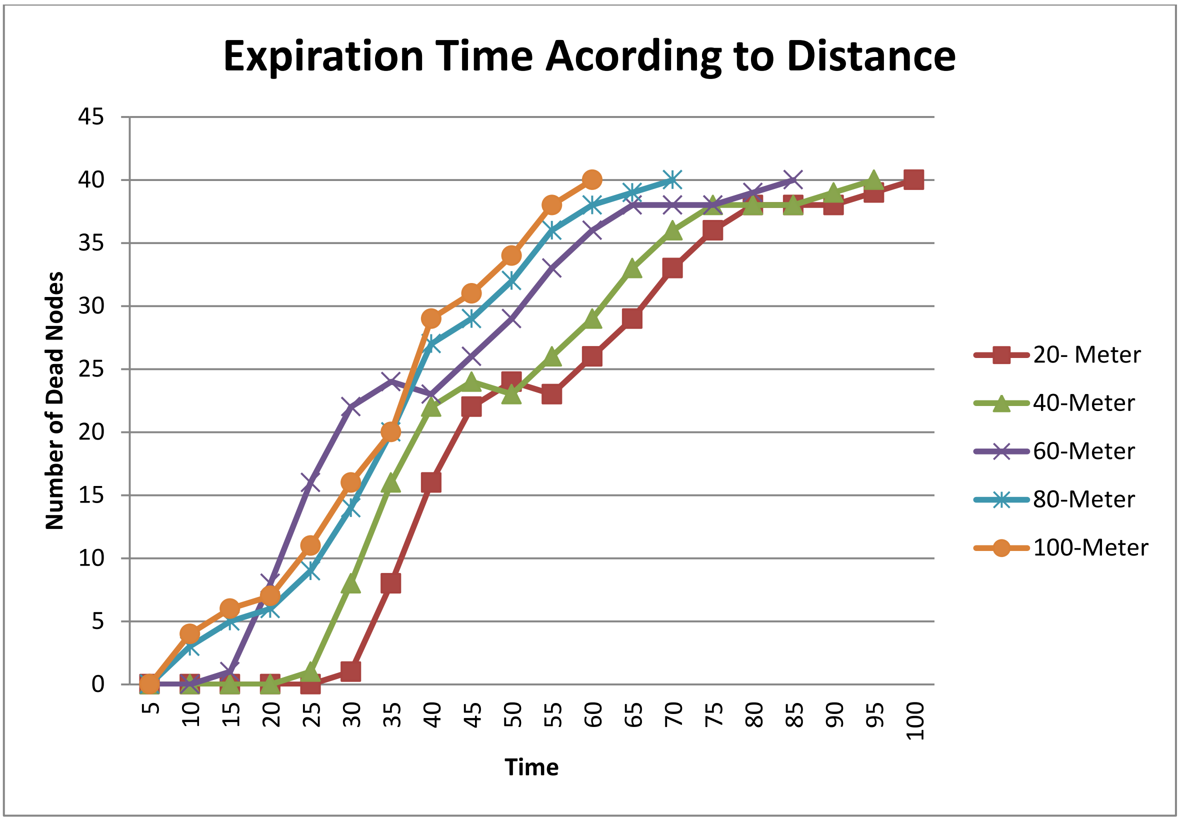

Figure 5-2: Expiration Time Acording to Distance

Now, we would study AODV protocol results in details, table 5-4 shows simulation results of AODV protocol, the first column shows time, and the second column is the number of nodes died before that time, while the last column is the node number died at that time.

Table 5-4: simulation results

Time	# of nodes	node dead	Time	# of nodes	node dead
18.59	1	31	33.84	20	22
20.9	2	0	34.32	21	2
21.86	3	28	34.37	22	10
21.94	4	32	36.44	23	11
22.46	5	30	39.01	24	6
22.75	6	15	44.28	25	3
23.42	7	18	46.07	26	7
24.75	8	12	51.07	27	8
26.09	9	17	53.5	28	9
26.51	10	5	54.82	29	25
27.86	11	35	57.66	30	13
28.16	12	37	58.53	31	23
28.46	13	29	58.84	32	16
28.75	14	34	59.98	33	9
29.28	15	39	62.08	34	19
29.56	16	33	62.83	35	36
30.83	17	26	63.33	36	20
31.59	18	4	93.04	37	1
32.9	19	14	33.84	20	22

A wireless sensor network is supposed to be did when

- Until the first node fails.
- Time until there is a spot that is not covered by the network (loss of coverage, a useful metric only for redundantly deployed networks).
- Time until network partition (when there are two nodes that can no longer communicate with each other).

As mentioned above AODV protocol would continue until all nodes become dead. Table 5-5 shows number of dead nodes according to time. We would find number of nodes dead each period to simplify study of its behavior.

On the other hand table 5-6 shows total energy consumed during simulation time. We calculated that value by multiplying number of nodes by the initial energy of that nodes, it is important to find that value to compare between different protocols in used in this thesis. After that we have to study energy per packet which could be found by division total consumed energy with total sent packets during simulation.

Table 5-5: Number of dead nodes

	time	dead nodes
1	5	0
2	10	0
3	15	1
4	20	3
5	25	8
6	30	14
7	35	18
8	40	22
9	45	25
10	50	27
11	55	30
12	60	33
13	65	36
14	70	37
15	75	40

Table 5-6: Total Energy Consumed

Energy per node	Total energy mJ
30009.6	1200384

Here we have to find energy per packet value, this value could be found by finding the total consumed energy and the total number of packets sent, and after that the total consumed energy should be divided by total number of packets sent during simulation. This value is very important metric to compare between different algorithms.

Table 5-7 : Total Sent Packets

Total consumed energy	Number of Packets
1200384	2728

Energy per packet value =1200384/2858

= 4.2 mJ/Packet

In figure 5-3, it shows the number of dead nodes as a function of time according to table 5-5 above. In figure 5-3 we could find that in **AODV** algorithm nodes dies in all periods of time, since in AODV it choose the path and use it until it becomes broken. And it doesn’t distribute load over all nodes that form **WSN**.

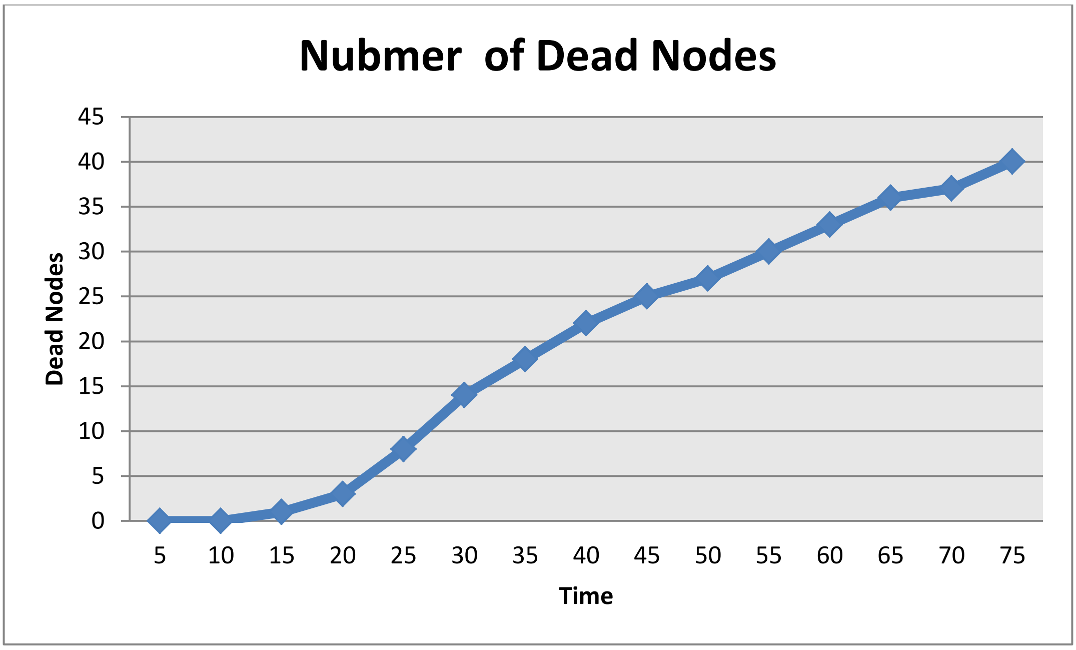

Figure 5-3: Number of Dead Nodes Over Time

5.3 MRPC Simulation

MRPC stands for maximizing network life-time for reliable routing in wireless environments, it takes in consideration two factors, the residual battery in each node, and also the channel characteristics. It is similar to MMBCR mentioned previously in chapter

3; it tries to select the route that maximizes the residual capacity currently available in the most critical node. In MRPC we choose the path or link that could send maximum number of packets through it.

In MRPC routing protocol discussed in chapter three, we notice that this algorithm is power aware routing algorithm. In other words, this algorithm take in consideration the total number of packets could be sent through available paths. In this algorithm, we try to use paths that have most residual battery despite the fact that this path may consume much energy that other paths, but on the other hand this algorithm guarantee load distribution of energy.

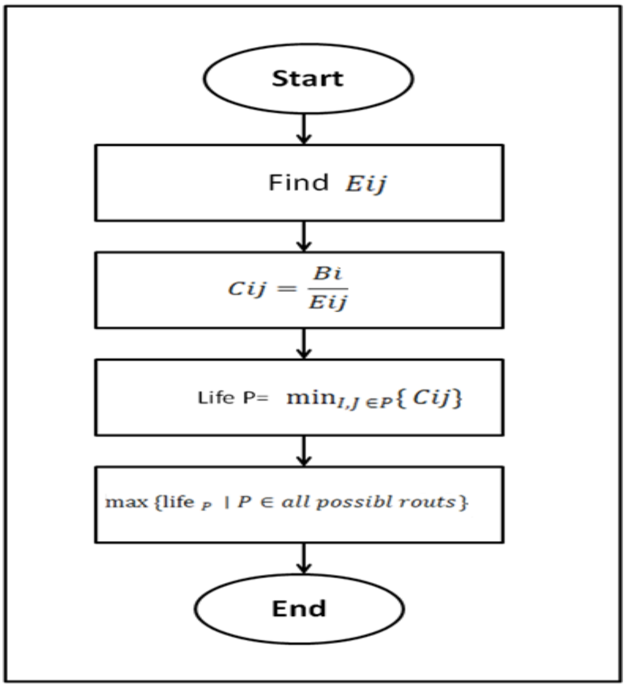

Figure 5-4: MRPC Flow Chart

In figure 5-4 we show the flow chart of MRPC protocol, in which we would choose the path through which we could send the maximum number of packets. First of all, we would find haw many packets we would send through each path, this number represents the minimum number of packets could be sent in each hop through the whole path. After that we should choose the path with maximum number of packets, between all different paths.

Table 5-8: MRPC Simulation

Index	Time	Node Dead	Index	Time	Node Dead
1	57.82	8	**21**	106.81	39
2	62.54	11	**22**	106.99	27
3	64.45	0	**23**	107.44	18
4	73.24	3	**24**	108	2
5	86.43	22	**25**	109.33	16
6	87.45	14	**26**	109.56	29
7	89.95	13	**27**	109.97	5
8	94.53	15	**28**	110.02	4
9	97.22	24	**29**	110.46	20
10	99.74	25	**30**	110.87	26
11	100.54	32	**31**	111.03	28
12	102.43	36	**32**	111.98	33
13	102.78	7	**33**	112.34	19
14	103.94	12	**34**	113.45	34
15	104.01	17	**35**	114.43	31
16	104.56	9	**36**	114.7	36
17	105.01	23	**37**	114.78	6
18	105.34	1	**38**	114.96	30
19	105.97	37	**39**	115.76	10
20	106.22	38	**40**	115.87	35

As expected and mentioned before, most of nodes suddenly died, in figure 4-8 we could see that load is distributed on all nodes, we don't use the same path and the same nodes all the time until they are exhausted as in AODV. We could summarize simulation results of MRPC protocol as following in table 5-9, by finding number of dead nodes every 5 seconds.

Table 5-9: MRPC Simulation

Time	Number of Dead nodes
5	0
10	0
15	0
20	0
25	0
30	0
35	0
40	0
45	0
50	0
55	0
60	1
65	3
70	3
75	4
80	4
85	4
90	7
95	8
100	10
105	17
110	28
115	40

Table 5-9 above could be transformed to figure 5-5 to show the behavior of MRPC algorithm, in X- axis we can see time, while number of dead nodes is shown on Y-axis. In figure below we can see that most nodes died in the end of simulation since load is distributed among all nodes form network. It is obvious that all nodes expired at the same time.

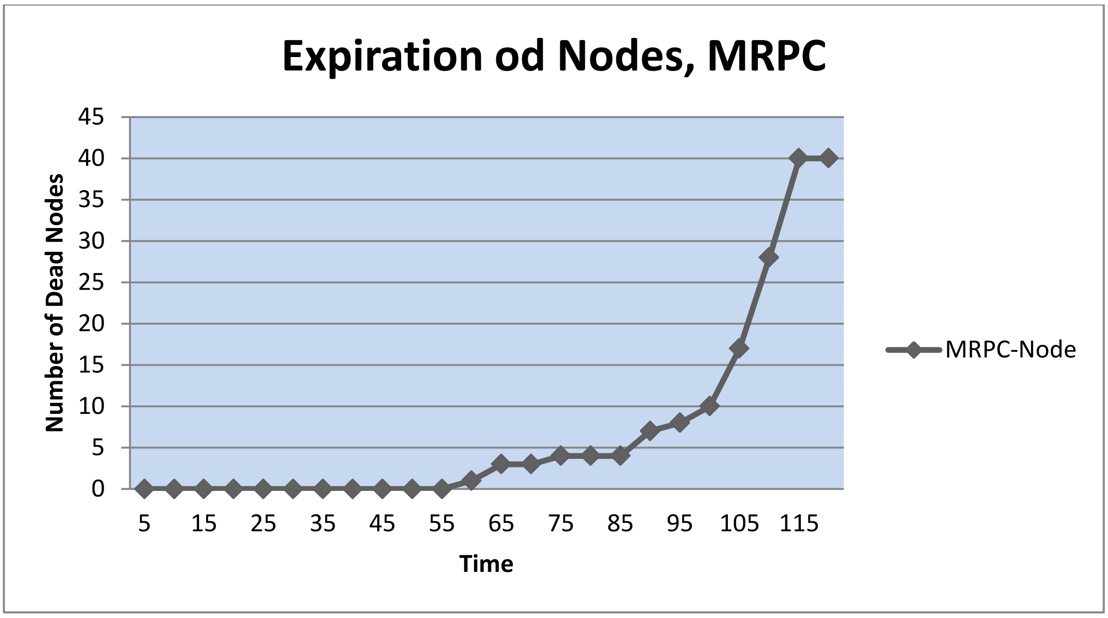

Figure 5-5 : MRPC Simulation

After simulation, we have to find the initial energy of each single node and the total energy of all nodes, in table 5-10 we can see the initial energy per node and the total energy consumed during simulation. The total energy could be simple calculated by multiplying energy per node (30009.6 mJ) multiplied by total number of nodes (40).

Table 5-10:Initial Energy of all Nodes

Energy per node mJ	Total energy mJ
30009.6	1200384

In MRPC simulation 1364 packets sent from source to destination, which is less than total number packets sent using AODV protocol. Now, we have to find energy per packet metric for MRPC protocol as shown in table 5-11 below.

Table 5-11: Energy per packet

Total consumed energy	Total number of Packets
1200384	1348

Energy per packet= Total consumed energy / Total number of Packets

= 1200384/1364

= 8.8 mJ /Packet

5.4 NEER Simulation

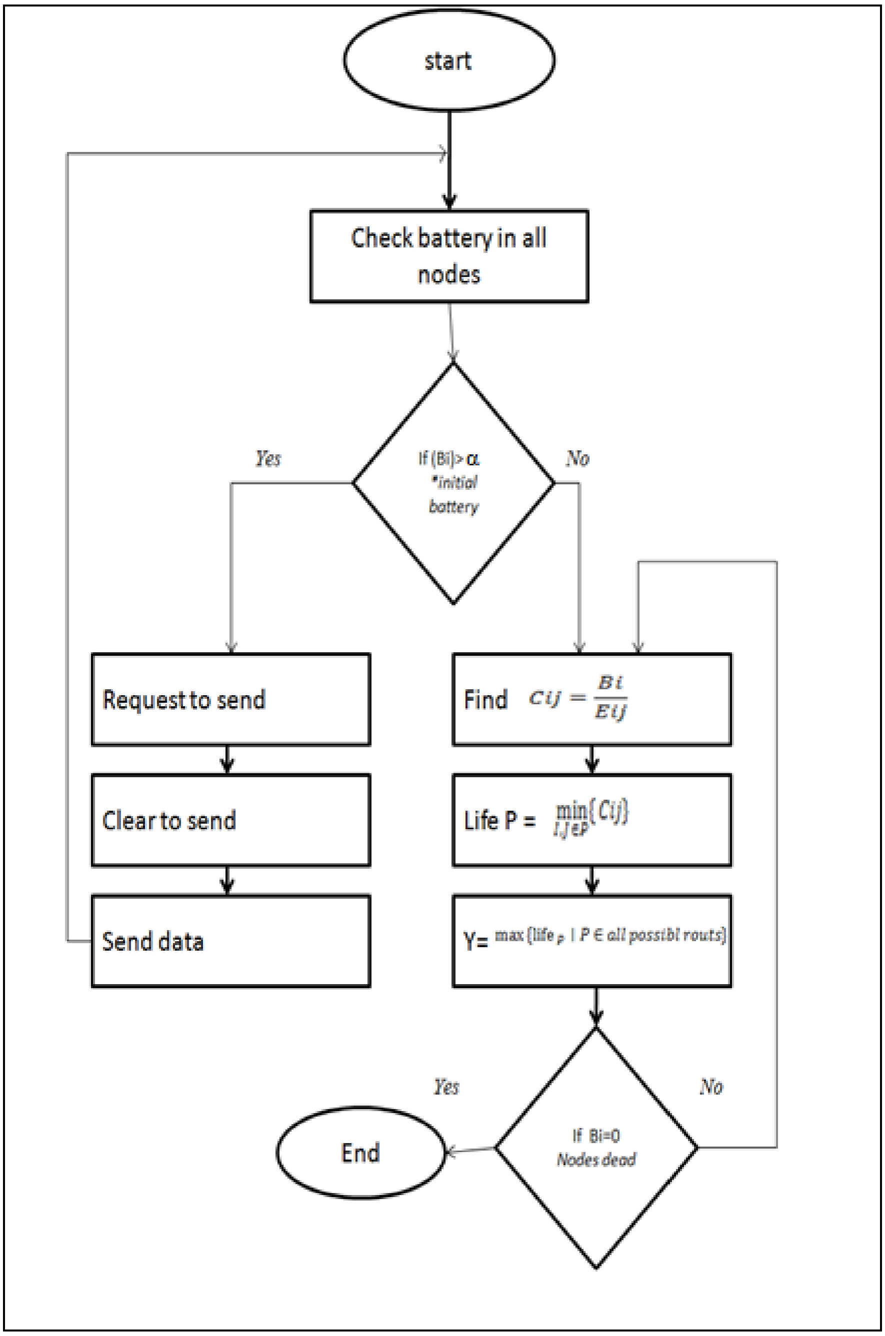

Figure 5-6: NEER flow chart

In figure 5-6 above we could see that NEER algorithm depends on (α) threshold value, we have to find that value to find the best results of NEER algorithm. In our experiment we chose the value of α to be 0, which means we would use AODV algorithm all the time; never switch to MRPC algorithm, after that we increased α value by 0.1 each iteration.

Table 5-12: NEER Threshold Value

Time	MRPC	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	AODV
5											0
10											0
15											1
20											3
25											8
30										1	14
35										3	18
40										6	22
45										7	25
50					1	1	1	2		8	27
55		0	1	2	3	4	3	5		9	30
60	1	1	3	4	5	7	5	7		12	33
65	3	4	4	7	8	8	8	9		18	36
70	3	4	7	9	12	13	12	13	2	22	37
75	4	5	11	13	17	13	17	15	2	25	40
80	4	9	16	16	20	16	21	18	5	28	
85	4	13	18	18	25	18	24	22	8	32	
90	7	16	23	23	28	22	25	27	13	37	
95	8	21	29	29	32	27	28	31	18	40	
100	10	27	37	35	36	31	31	34	22		
105	17	33	40	37	37	38	35	37	27		
110	40	36		39	40	40	37	40	29		
115		40		40			40		32		
120									40		

In table 5-12 we summarized threshold value table, in which we found the total number of dead nodes every 5 seconds, if threshold α =0 then NEER algorithm would behave like AODV protocol. After that we increased α by 0.1. In table 5-12 we see that when α==0.2 * initial battery, then the network lifetime was the best, since last node died after 120 seconds. This is better than MRPC and AODV.

Figure 5-7 below summarize simulation results of table 5-12 above, on X-axis it shows time, while on Y-axis it shows total number of dead nodes. All of them have 40 nodes, but each one died on different time. AODV has the worst network lifetime, while MRPC improved that value by distributing load over all nodes of the network. Finally, NEER with α=0.2 * initial battery was the best value since it improved network lifetime.

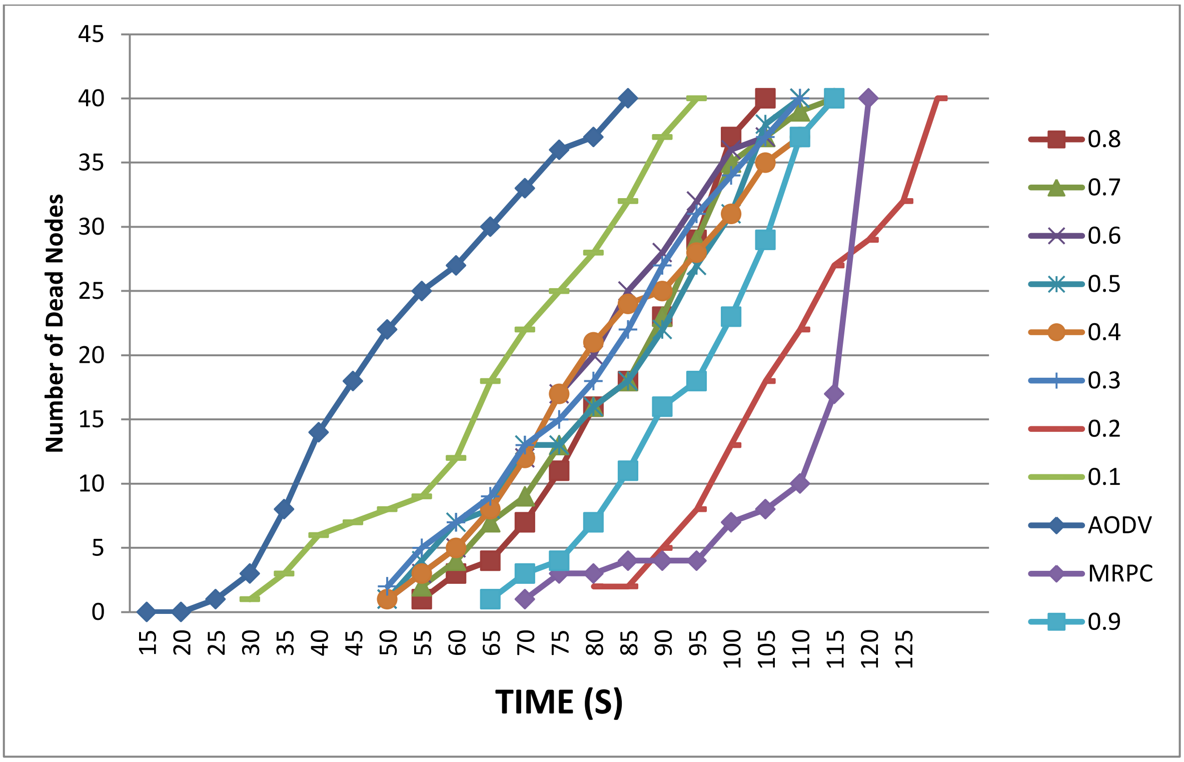

Figure 5-7: NEER Threshold

After that, we changed threshold value to be more precise that .2 * initial battery, we got four values as following, 0.15 * initial battery, 0.18* initial battery, 0.22* initial battery and 0.25* initial battery. As we note we can find that all new threshold values tested were around 0.2 * initial battery since this value gave us the best network life time. As shown in table 5-13 below.

Table 5-13: Network Life Time (with Precise α)

Time	0.2	0.25	0.22	0.18	0.15
5					
10					
15					
20					
25					
30					
35					
40					
45					
50					1
55		2			2
60		3		2	3
65		5	2	2	7
70	2	8	4	5	13
75	2	12	5	8	18
80	5	16	8	13	21
85	8	22	14	18	27
90	13	27	18	22	29
95	18	29	22	27	32
100	22	32	27	29	34
105	27	36	29	32	40
110	29	40	34	37	
115	32		40	40	
120	40				

We can see new values of α at table 5-13 as shown above to simplify comparison between different values, also we added the new values of α the same figure 5-8 as shown below, this will help us to study the behavior of NEER protocol. As shown in table 5-12 and figure 5-7 related to it, we could see that the best value of α was 0.2 * initial battery gave us the best value of highest network life time.

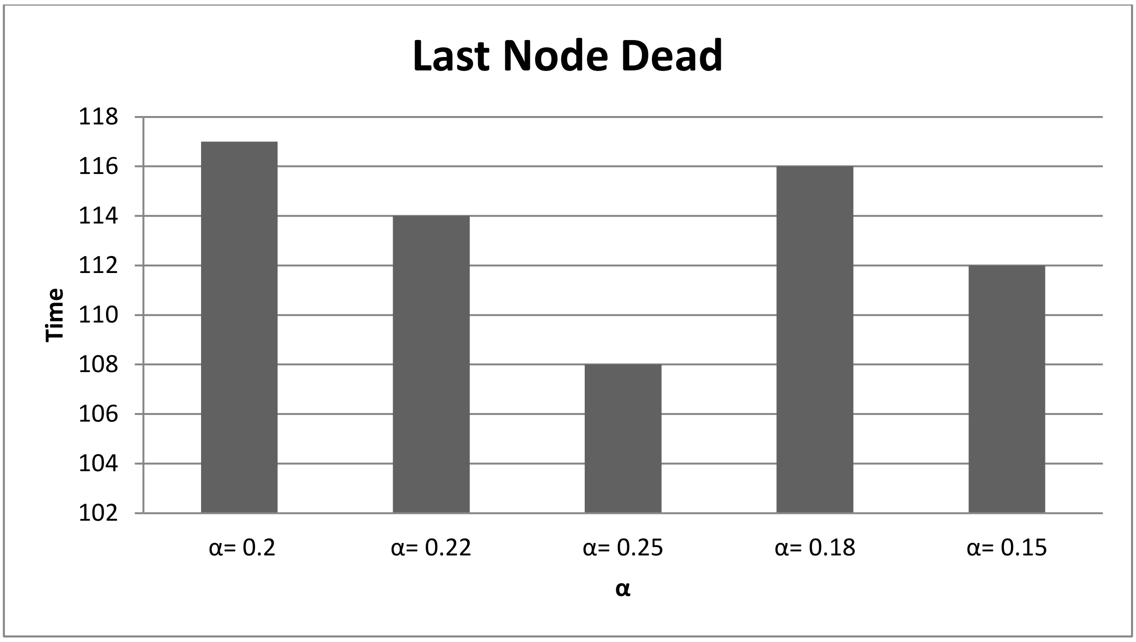

Figure 5-8 : Last Node Dead

We could see that best behavior of NEER algorithm was when α=0.2 * initial battery. We have study the behavior of NEER algorithm when α=0.2 * initial battery, we would study network lifetime, total packets sent and energy per packet. Now we want to test our New Algorithm NEER in the same environment of 40 nodes, 60 meters apart, to check network lifetime.

Table 5-14: NEER expiration Time

Time	Node Dead	Total number of dead nodes
55.54	16	1
57.62	5	2
61.34	14	3
64.67	25	4
65.65	3	5
67.02	6	6
71.22	26	7
73.34	15	8
74.58	1	9
77.78	31	10
79.43	9	11
82.33	27	12
82.67	22	13
84.5	7	14
86.45	33	15
88.23	12	16
89.26	36	17
90.02	13	18
92.12	24	19
92.89	11	20
93.01	37	21
93.23	32	22
94.45	2	23
96.31	8	24
98.76	4	25
99.06	17	26
101.23	21	27
102.45	30	28
103.67	18	29
104.87	34	30
105.21	20	31
108.32	35	32
109.77	19	33
110.34	38	34
112.43	39	35
114.23	28	36
114.32	40	37
114.54	29	38
116.45	23	39
118.32	10	40

Table 5-14 above summarize simulation results of NEER protocol with (α=0.2 * initial battery) in the first column it shows time stamp, while the second column is define the node died, while the last one is the total number of nodes died. For simplification, we figure 5-8 describe the total number of dead nodes as a function of time, on X-axis we defined time while Y-axis we defined number of died nodes. In table 5-15 we summarized simulation result shown in table 5-14 above, we find the total number of dead nodes in each 5 seconds period, these values would be used for line chart shown in figure 5-8 below.

Table 5-15: Number of Dead Nodes

TIME	**Total Number of Dead Nodes**
0	0
5	0
10	0
15	0
20	0
25	0
30	0
35	0
40	0
45	0
50	0
55	0
60	2
65	4
70	6
75	9
80	11
85	14
90	17
95	22
100	25
105	29
110	32
115	36
120	40

In figure 5-9 we see that first node died on 60 seconds while the last one died at 120 and all nodes died through the second period of simulation time. Its behavior was better than AODV according to network lifetime since it increased network lifetime. But on the other hand it doesn't distribute load over all nodes of WSN. After that we have to check the other metrics than network lifetime such as the total number of sent packets and energy per packet value. These values would be used for comparison with other protocols and algorithms used for routing in WSN.

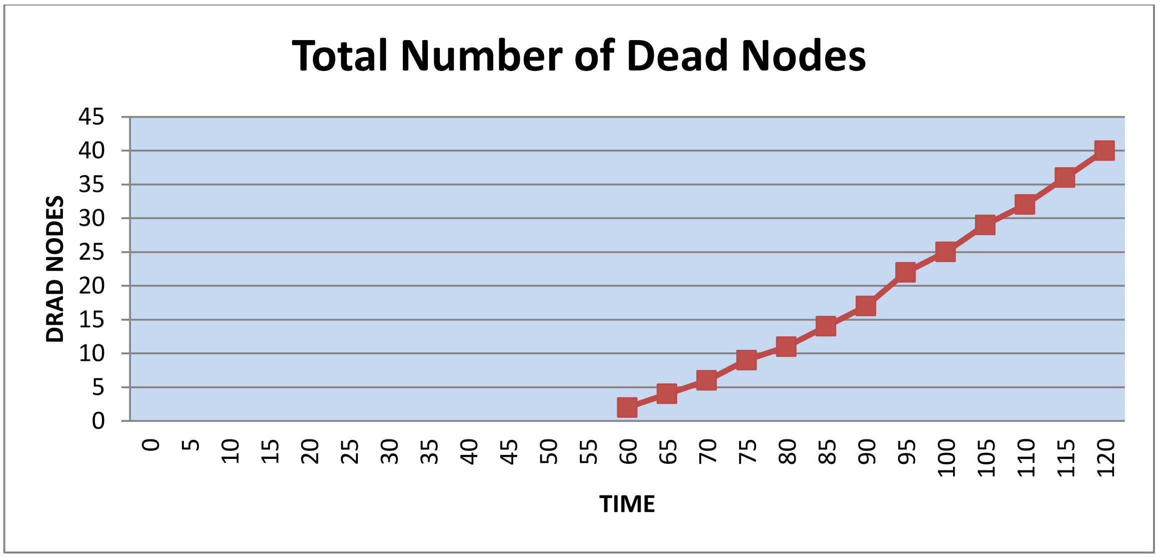

Figure 5-9: Expiration Time of Network

Table 5-16: Total Energy Consumed

Energy per node mJ	Total energy mJ
30009.6	1200384

Total energy consumed equals the initial energy of each node multiplied by the total number of nodes used, after that we want to find energy per packet value.

Table 5-17: Energy per Packet

Total energy mJ	Total sent Packets
1200384	2697

Energy per packet= total consumed energy / total sent packets

= 1200384/2308

= 5.2 mJ/Packet

Now we have to compare between different algorithms (AODV, MRPC and NEER) for all metrics such as network lifetime, total sent packets and energy.

5.5 Algorithm Comparison

The first metric to study is network lifetime, we have to compare between different algorithms shown below in table 5-18, in which we found the number of dead nodes each 5 seconds, in first column we defined time intervals, while the second one is AODV, while the third one is MRPC and the last one is NEER protocol.

Table 5-18 : Comparison between different algorithm (Lifetime)

Time	AODV	MRPC	NEER
5	0	0	0
10	0	0	0
15	0	0	0
20	0	0	0
25	1	0	0
30	4	0	0
35	9	0	0
40	15	0	0
45	19	0	0
50	23	0	0
55	26	0	0
60	29	1	2
65	33	3	4
70	36	3	6
75	38	4	9
80	38	4	11
85	38	4	14
90	39	7	17
95	40	8	22
100	Dead	10	25
105	Dead	17	29
110	Dead	28	32
115	Dead	40	36
120	Dead	Dead	40

In figure 5-10 below defines line chart of that protocols, it shows the total number of dead nodes as a function of time. On X-axis we will see time while on Y-axis we have to see the total number of Dead nodes. These numbers are given in detail in table 5-18 above.

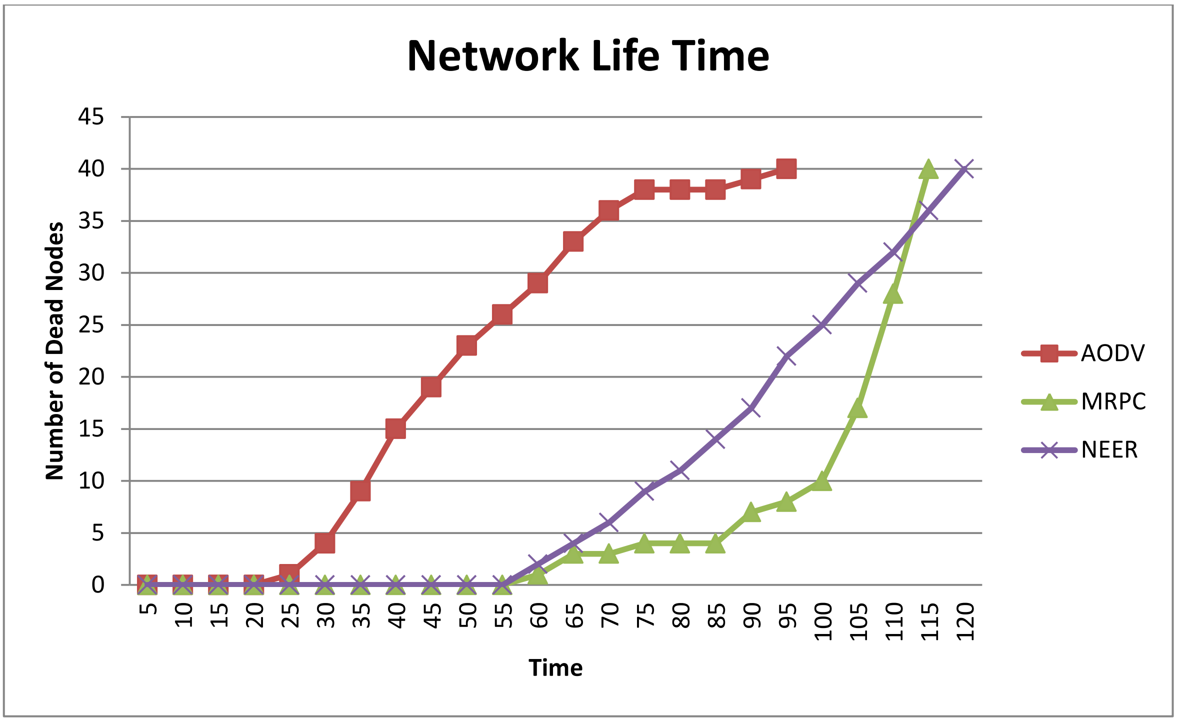

Figure 5-10: Network Lifetime Comparison

As shown in figure 5-10 above, we compared network lifetime of 3 different protocols; the first one was AODV, in which network nodes gradually, because AODV protocol chooses the same path all the time until this path becomes useless; since some nodes would become out of energy. After that AODV would choose different path and so on until all nodes become dead.

On the other hand, MRPC would choose path that would send higher number of packets from source to destination, in other words; it would distribute load on all paths and nodes during simulation. As a result; most nodes dies in the same time.

Table 5-19: Comparison between Algorithms

	Sent Packets	Energy per Packet
AODV	2858	4.42
MRPC	1364	8.87
NEER	2308	4.44

In NEER algorithm we used threshold value to switch between two different approaches; that is, between AODV and MRPC, its behavior was similar to MRPC according to network lifetime, most nodes died at the same time, and network lifetime was similar to MRPC.

Now we have to study energy per packet. Figure 5-11 shows the differences between three algorithms according to energy per packet metric, as shown in this figure below, we can see that NEER algorithm improved the energy per packet metric in MRPC algorithm; it was approximately similar to AODV.

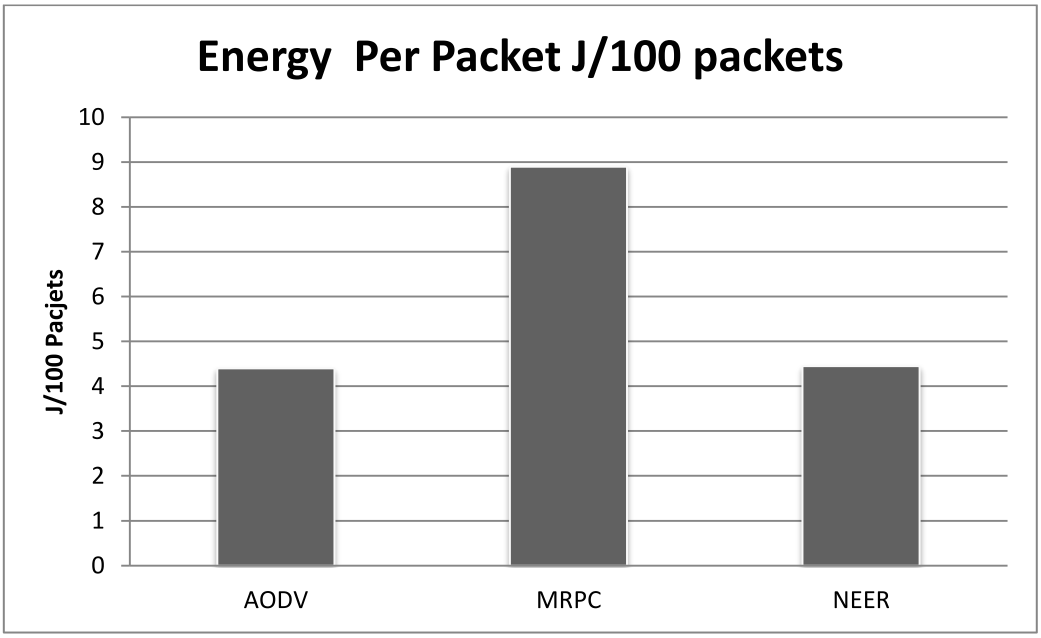

Figure 5-11: Energy per Packet Comparison

We need to study number of packets could be sent during simulation time, figure 5-12 illustrates energy per packet for different three algorithms, it obvious that AODV and NEER protocols are better than MRPC protocol, since it is always use the same path, and doesn't need to recalculate for every packet, on the other hand it uses the least energy path.

While MRPC uses the path that could sent more packets during it, despite the fact that it would consume more energy than other paths. That is it; it would consume much energy for each packet as shown in figure 5-12 below. On the other hand we could see that NEER algorithm reduced energy per packet value of MRPC, but still higher than that of AODV, since it use AODV until it reaches threshold and then switches to MRPC algorithm.

Figure 5-12 above investigate comparison between the different protocols used in simulation, it shows that AODV protocol sent about 2.6 thousand packet, while MRPC sent approximately 1.8 thousand. On the other hand NEER could send a number of packets more than AODV and less than MRPC.

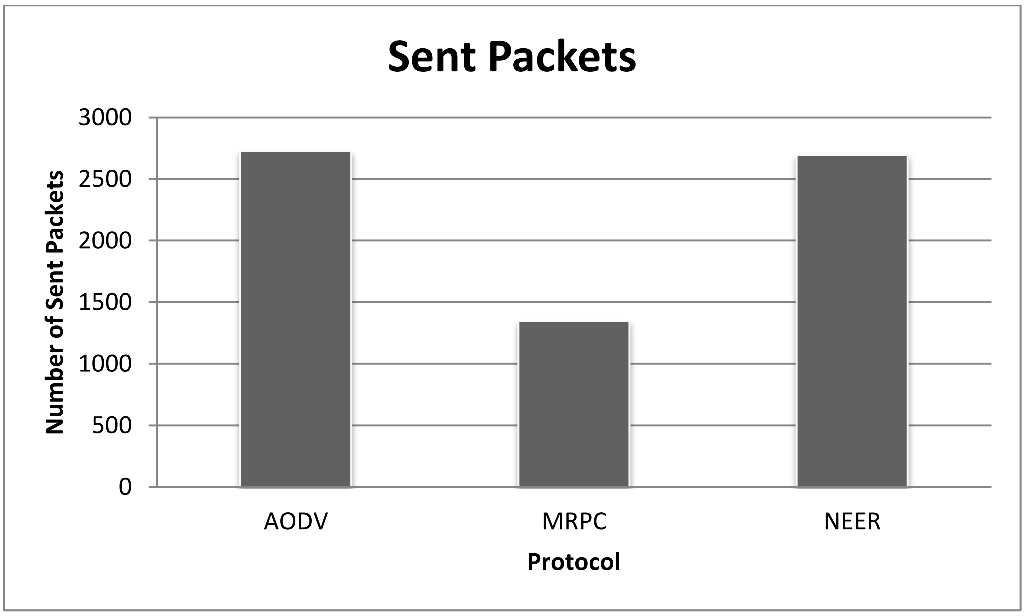

Figure 5-12: Number of Sent Packets Comparison

Throughput:

Time delay is defined as the amount of data transferred from source to destination or the amount of data processed in a period of time. As a result we could find throughput by finding the total data transferred divided by time at which data sent.

Table 5-20: Throughput

Protocol	Packets sent	Data size KB	time	throughput
AODV	2858	234.4453	92	2.548319
MRPC	1364	111.8906	114	0.981497
NEER	2803	229.9336	119	1.932215

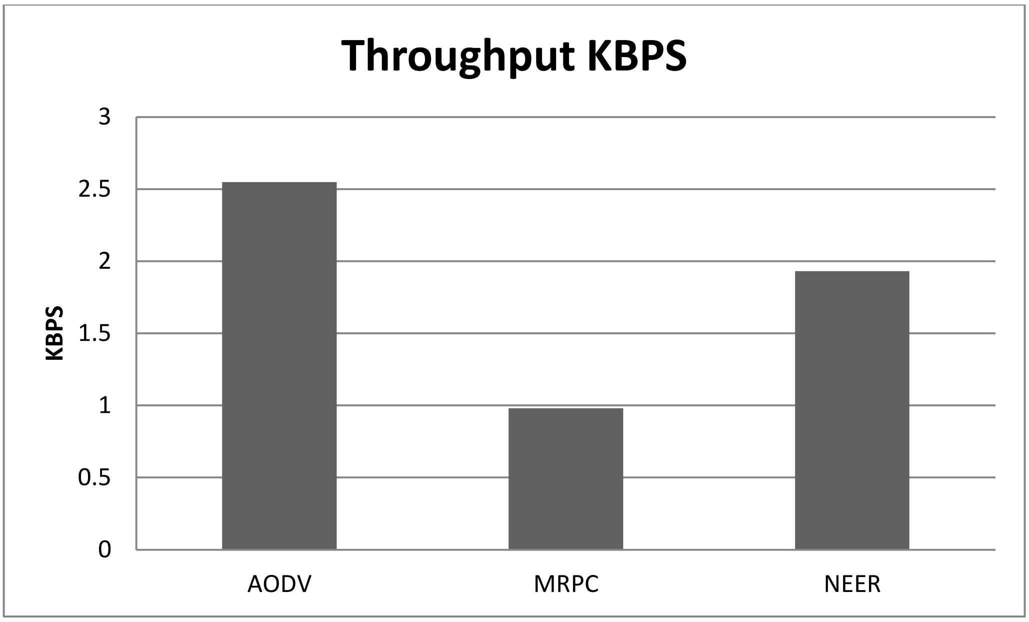

Figure 5-13: Throughput

Latency:

This metric have to be found by calculating average time needed to send one packet from source to destination, table 5-21 would investigate how to find this value, while figure 5-14 would find comparison between the different three protocols.

Table 5-21: Latency

Protocol	Time	Total sent Packets	Time latency (S)	Time Latency (mS)
AODV	92	2858	0.03219	32.19034
MRPC	114	1364	0.083578	83.57771
NEER	119	2803	0.042455	42.45451

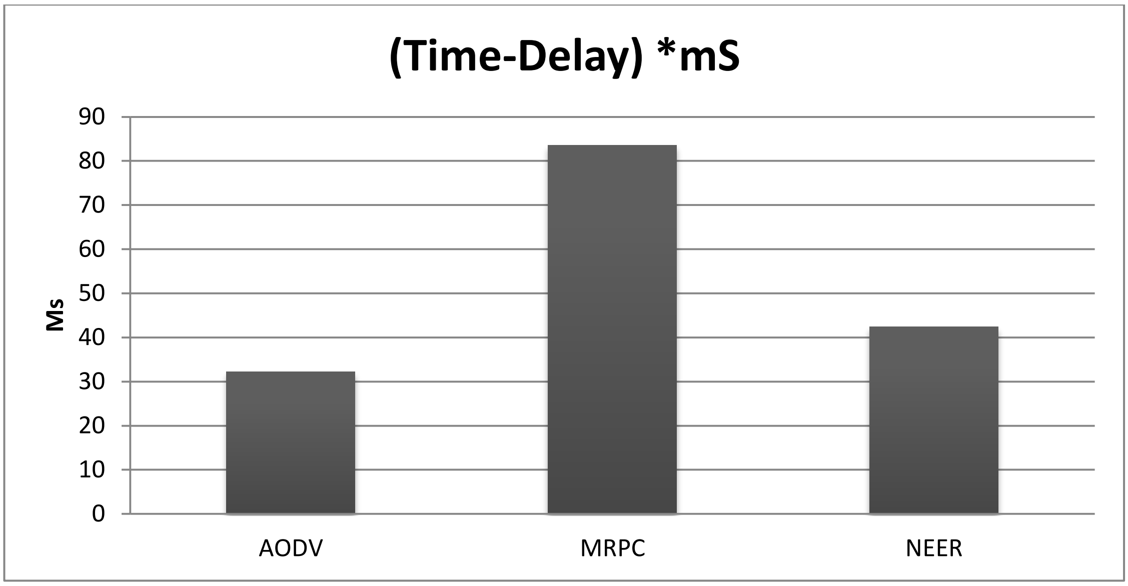

Figure 5-14: Latency

Table 5-22: Comparison

	AODV	MRPC	NEER	CHANGE % AODV,NEER	CHANGE % MRPC,NEER
NLF	92	114	119	0.293	0.0438
TSP	2858	1364	2803	-0.019	1.054
EPP	4.42	8.87	4.44	0.004	-0.499
T-D	3.22	8.35	4.24	0.318	-0.492

As seen above in table 5-22 we could see comparison between different protocols according to different metrics, if discuss the network lifetime we could see that NEER protocol improved the AODV by 30% while it improved MRPC by 5% only, on the other hand we should note that other metrics such as total sent Packets it was less than AODV by 2% approximately, while it was better than MRPC by 105% improvement.

On the other hand energy per packet factor, we see that NEER was the same as AODV but it was much better than MRPC since it improved it by 49%. According to time delay we see that it was higher than AODV but still less than MRPC.

Chapter 6: Conclusion

Contents

6 Conclusion

6.1 Introduction

In last few years, huge advance in low cost, limited power and multi-functional wireless sensor network occurred. Wireless sensor network consists of hundreds or thousands wireless nodes; these nodes have the ability of sensing, processing and communicating. WSN in general has common features such as self organizing capability, short range broadcasting, multi hop routing, dense deployment, frequent changing topology and limitation in energy.

WSN are used in many applications such as agricultural and environment monitoring, civil engineering, military applications, and health monitoring and surgery.

6.2 Conclusion

NEER routing algorithm was used to increase network lifetime and to save energy in WSN. Simulation results could be summarized as following:

1- Simulation results of NEER protocol showed that best threshold valueto α=0.2 * initial battery. In which NEER network lifetime was the highest.

2- Network lifetime: in NEER algorithm, we were able to increase network lifetime in comparison with other techniques such as AODV and MRPC, since NEER depends on both algorithms, NEER takes advantages of using shortest path until the first node reaches threshold, after that NEER switches to MRPC algorithm to distribute load over all nodes in WSN. In such case we take advantages of both algorithms.

3- Total sent packets: NEER algorithm improved the total sent packets metric of MRPC, since it was able to send more packets than MRPC could, in comparison with AODV, it is approximately the same as AODV could send. Because AODV uses the paths that consumes less energy than other protocols.

4- Energy per packet: this metric could be found by dividing total energy consumed on the total sent packets. NEER algorithm was able to improve this factor in comparison with MRPC, since they start with the same initial energy but NEER was able to send more packets than MRPC, this would decrease energy per packet value, on the other hand energy per packet value for AODV was less than NEER protocol.

5- Quality of service QOS: NEER algorithm was able to send 81% of the packets correctly, they are received on destination. With loss rate of 19%. In comparison with other algorithms; NEER was approximately the same as AODV and MRPC since they use the same variables through simulation time.

6- End-to-End latency: NEER algorithm was able to improve this metric in comparison with MRPC, because time delay variable for NEER protocol was less than that of MRPC. On the other hand time delay for NEER protocol was approximately the same for AODV algorithm.

As mentioned above, our new algorithm NEER is able to improve network lifetime of WSN and switching between AODV and MRPC using threshold of 0.2 * initial battery achieved advantages of both protocols. But unfortunately it was not able to improve total sent packets and energy per packet values.

6.3 Future Work

In WSN environment, the power consumption is the challenge that faces its lifetime. The route of each message from source to destination is playing a critical role in network lifetime. Since most power is consumed through communication phase of WSN. There are too many algorithms used to save energy in WSN.

The first factor that could be used to improve network lifetime is to use hop by hop decision to choose the suitable routing algorithm. In this way we get a guarantee to use least energy path as long as possible. On the other hand hierarchal topology could be used instead of flat topology. In clustering technique would enable us to save energy through using cluster heads for routing.

On the other hand we could use data compression techniques in routing to minimize data sent in WSN to minimum. Finally, Mobile agents can be used to greatly reduce the communication cost, especially over low bandwidth links, by moving the processing function to the data rather than bringing the data to a central processor. MAWSN proposes better performance than client / server communication in terms of energy consumption and packet delivery ratio. But on the other hand it has a high end- to –end latency.

7 Appendix A: Set of Abbreviation:

NEER	Normalized Energy Efficient Routing
WSN	Wireless Sensor Network
BS	Base Station
P	Power
AODV	Ad-hoc On demand distance Vector Routing
MANET	Mobile Ad-hoc Network.
DYMO	Dynamic MANET On-demand
MRPC	Maximize Network Lifetime for Reliable Routing in Wireless Environments
MANET	Mobile Ad hoc Networks
SPIN	Sensor Protocols for Information via Negotiation
LEACH	Low energy adaptive clustering hierarchy
TDMA	Time division multiple access
CDMA	Code Division Multiple Access
MMBCR	Min–Max Battery Cost Routing
MBCR	Minimum battery cost routing
MTAB	Maximum total available battery
MAP	Minimum Energy Path
MVPL	Minimum Variance in Power Level
NS	Network simulation
ADV	Advertisement
RREQ	Route Request
RREP	Route Reply
CH	Cluster Head
IP	Internet Protocol
LBAODV	Load Balancing Ad-hoc On demand distance Vector Routing
ESAODV	Energy Saving Ad-hoc On demand distance Vector Routing
S	Source
D	Destination
E	Energy
RERR	Route Error

TX	Text data
SPIN-PP	Sensor Protocols for Information via Negotiation – point to point
SPIN-BC	Sensor Protocols for Information via Negotiation – broadcast channel
SPIN-EC	Sensor Protocols for Information via Negotiation – energy below certain threshold
$\mathbf{B}_i$	Battery level at node i
$\mathbf{E}_{ij}$	Energy to send a packet from node *i* to node *j*
$\mathbf{C}_{ij}$	Number of packet could be sent from node *i* to node *j*
$\mathbf{C}_p$	Cost of path
MAWSN	Mobile Agent Wireless Sensor Network

8 References:

[CHN03]C. Chong and S. P. Kumar, “Sensor Networks: Evolution, Opportunities, and Challenges”, in Proceedings of the IEEE, vol. 91, no. 8, Aug. 2003.

[HED88] S. Hedetnieme and A.Liestman “a survey of gossiping and broadcasting in communication networks”. IEEE networks, vol 18. NO.4 1988 pp319,349

[HNZ00] W. R. Heinzelman, A. Chandrakasan, and H. Balakrishnan. Energy-Efficient Communication Protocol for Wireless Microsensor Networks. In Proceedings of the 33rd Hawaii International Conference on System Sciences, pages 174–185, Hawaii, HI, January 2000.

[SZW01]A. Perrig, R. Szewczyk, V. Wen, D. Culler, and J. D. Tygar. SPINS: Security Protocols for Sensor Networks. In Proceedings of the 7th Annual International Conference on Mobile Computing and Networking (ACM MobiCom), pages 189–199, Rome, Italy, July 2001.

[HKP00] W. Heinzelman, J. Kulik, and H. Balakrishnan, “Adaptive Protocols for Information Dissemination in Wireless Sensor Networks“ in: Proc . of 5The ACM/IEEE Mobicom Conference (MobiCom ’99), Seattle, WA

[HSC02] Wendi Rabiner Heinzelman, Amit Sinha, Alice Wang, and Anantha P. Chandrakasan ENERGY-SCALABLE ALGORITHMS AND PROTOCOLS FOR WIRELESS MICROSENSOR NETWORKS Massachusetts Institute of Technology 2002

[GHA10] Anuj K. Gupta, Dr. Harsh Sadawarti, Dr. Anil K. Verma, “Performance analysis of AODV, DSR and TORA Routing Protocols”, International Journal of Engineering & Technology (IJET), ISSN: 1793-8236, Article No. 125, Vol.2 No.2, April 2010, pp. – 226-231

[SKJ09] Narendran Sivakumar, Satish Kumar Jaiswal, “Comparison of DYMO protocol with respect to various quantitative performance metrics”, ircse 2009

[ICP06] Ian D. Chakeres and Charles E. Perkins. Dynamic MANET on demand (DYMO) routing protocol. Internet-Draft Version 17, IETF, October 2006, (Work in Progress). http://tools.ietf.org/html/draft-ietf-manet-dymo-17

[HCB02] W.R. Heinzelman, A. Chandrakasan , and H. Balakrishfnan, “An Application- Specific Protocol Architecture For Wireless Microsensor Networks,” IEEE Transactions on Wireless Communications, Vol. 1, No. 4, October 2002, pp. 660–670.

[IGE03] [6] C. Intanagonwiwat, R. Govindan, D. Estrin, J. Heidemann, and F. Silva. Directed Diffusion for Wireless Sensor Networks. IEEE/ACM Transactions on Networking, 11(1): 2–16, 2003.

[HDZ04] [7] V. Handziski, A. K¨opke, H. Karl, C. Frank, and W. Drytkiewicz. Improving the Energy Efficiency of Directed Diffusion Using Passive Clustering. In H. Karl, A. Willig, and A. Wolisz, editors, Proceedings of the 1st European Workshop on Wireless Sensor Networks (EWSN), volume 2920 of LNCS, Springer, pages 172–187, Berlin, Germany, January 2004.

[BDE02] [8] D. Braginsky and D. Estrin. Rumour Routing Algorithm for Sensor Networks. In Proceedings of the 1st Workshop on Sensor Networks and Applications, Atlanta, GA, September 2002.

[CLZ01] . Ye, A. Chen, S. Lu, and L. Zhang, “A scalable solution to minimum cost forwarding in large sensor networks,” in Proc. IEEE 10th Int. Conf. Computer Communications and Networks, Scottsdale, Arizona, Oct. 2001, pp. 304–309.

[HCB99]W. B. Heinzelman, A. P. Chandrakasan, and H. Balakrishnan. An Application-Specific Protocol Architecture for Wireless Microsensor Networks. IEEE Transactions on Wireless Networking, 1(4): 660–670, 2002.

[HCB00]W. R. Heinzelman, A. Chandrakasan, and H. Balakrishnan. Energy-Efficient Communication Protocol for Wireless Microsensor Networks. In Proceedings of the 33rd Hawaii International Conference on System Sciences, pages 174–185, Hawaii, HI, January 2000.

[CDT02] M. Chatterjee, S. Das, and D. Turgut. WCA: A Weighted Clustering Algorithm for Mobile Ad Hoc Networks. Cluster Computing Journal, 5: 193–204, 2002.

[YSF04] O. Younis and S. Fahmy. Distributed Clustering in Ad-hoc Sensor Networks: A Hybrid, Energy-Efficient Approach. In Proceedings of IEEE INFOCOM, Hong Kong, March 2004.

[CAP04] H. Chan and A. Perrig. ACE: An Emergent Algorithm for Highly Uniform Cluster Formation. In H. Karl, A. Willig, and A. Wolisz, editors, Proceedings of 1st European Workshop on Wireless Sensor Networks (EWSN), volume 2920 of LNCS, pages 154–171. Springer, Berlin, Germany, January 2004.

[SSS10] S.K. Singh, M.P. Singh, and D.K. Singh, “A survey of Energy-Efficient Hierarchical Cluster-based Routing in Wireless Sensor Networks”, International Journal of Advanced Networking and Application (IJANA), Sept.–Oct. 2010, vol. 02, issue 02, pp. 570–580

[PEM99]C. E. Perkins and E. M. Royer. Ad-Hoc On-Demand Distance Vector Routing. In Proceedings of the 2nd IEEE Workshop on Mobile Computing Systems and Applications, pages 90–100, New Orleans, LA, February 1999.

[SSS11] S.K. Singh, M.P. Singh, and D.K. Singh, "Energy-efficient Homogeneous Clustering Algorithm for Wireless Sensor Network", International Journal of Wireless & Mobile Networks (IJWMN), Aug. 2010, vol. 2, no. 3, pp. 49-61.

[PMR98]C_ E_ Perkins and E_ M_ Royer_ Ad Hoc On Demand Distance Vector _AODV Routing_ draft_ietf_manet_Aodv,02.txt, Nov1998.

[HKF04] V. Handziski, A. K¨opke, H. Karl, C. Frank, and W. Drytkiewicz. Improving the Energy Efficiency of Directed Diffusion Using Passive Clustering. In H. Karl, A. Willig, and A. Wolisz, editors, Proceedings of the 1st European Workshop on Wireless Sensor Networks (EWSN), volume 2920 of LNCS, Springer, pages 172–187, Berlin, Germany, January 2004.

[STZ04] Suhua TANG’and Bing ZHANG’, A Robust AODV Protocol with Local Update, 10th dsia-pacific Conference on Camrmnications and 5th International Symposium an Multi Dimensional Mobile Communications , 2004

[XWQ08] Xinsheng Wang, Qing Liu and Nan Xu, The Energy-Saving Routing Protocol Based on AODV, Fourth International Conference on Natural Computation 2008

[MPR10] Mehdi Effat Parvar, Mohammad Reza Effat Parvar, Amir Darehshoorzadeh, Mehdi Zarei, Nasser Yazdani “Load Balancing and Route Stability in Mobile Ad Hoc Networks base on AODV Protocol” 2010

International Conference on Electronic Devices, Systems an Applications (ICEDSA2010)

[PRD00]. Perkins CE, Royer EM, Das SR. Ad Hoc on Demand Distance Vector (AODV) routing. Available from: http://www.ietf.org/internetdrafts/draft-ietfmanet-aodv-06.txt, IETF Internet Draft, work in progress, 2000.

[PBR03]. Perkins C, Belding-Royer E, Das S. Ad hoc On- Demand Distance Vector (AODV) routing. Network working group, IETF RFC,RFC 3561, 2003.

[GMR07]. Gallissot M. Routing on ad hoc networks, Project, Supervisor,Maurice Mitchell Date, 2007.

[ZMS02]. Zygmunt J Haas, Marc R. Pearlman, and Prince Samar, "The Zone Routing Protocol (ZRP) for Ad Hoc Networks", draftietf- manet-zone-zrp-04.txt,july,2002

[JNS10] Jaisankar N, Saravanan R. An extended AODV protocol for multipath routing in MANETs. Int J Eng Technol 2010;2(40).

[MTY06] Min Chen, Taekyoung Kwon, Yong Yuan, and Victor C.M. Leung Mobile Agent Based Wireless Sensor Networks , Journal of Computers, Vol 1, No 1 (2006), 14-21, Apr 2006

[HZR09] M. N. Halgamuge, M. Zukerman, K. Ramamohanarao and H. L. Vu, “An Estimation of Sensor Energy Consumption,” Progress in Electromagnetic Research B, Vol. 12, 2009, pp. 259-295.

[KNP96] K. Scott and N. Bambos. Routing and Channel Assignment for Low Power Transmission in PCS. In Proceedings International Conference on Universal Personal Communications, pages 469–502, Cambridge, MA, September 1996.

[CKT01] C. K. Toh. Maximum Battery Life Routing to Support Ubiquitous Mobile Computing in Wireless Ad Hoc Networks. IEEE Communications Magazine, 39: 138–147, 2001

[ASC02] I. F. Akyildiz, W. Su, Y. Sankasubramaniam, and E. Cayirci. Wireless Sensor Networks: A Survey. Computer Networks, 38: 393–422, 2002.

[SWR98]S. Singh, M. Woo, and C. S. Raghavendra. Power-Aware Routing in Mobile Ad Hoc Networks. In Proceedings of the 4th ACM/IEEE International Conference on Mobile Computing and Networking (MOBICOM'98), Dallas, TX, October 1998.

[ASC02]I. F. Akyildiz, W. Su, Y. Sankasubramaniam, and E. Cayirci. Wireless Sensor Networks: A Survey. Computer Networks, 38: 393–422, 2002.

[MSB02] Archan Misra and Suman Banerjee Maximizing Network Lifetime for Reliable Routing inWireless Environments, Department of Computer Science University of Maryland College Park, MD 20742, USA.2002.