Power Sensitive Routing Algorithm for ZigBee Wireless Networks

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List of Acronyms

AODV	Ad hoc On-Demand Distance Vector
GTS	Capability of Management Timeslot
MAC	Medium Access Control
MCU	Micro Controller Unit
OSI	Open System Interconnection
PANs	Personal Area Networks
PHY	Physical Layers
PS-AODV	Power Sensitive Ad hoc On-Demand Distance Vector
RERR	Route Error Message
RF	Radio Frequency
RREP	Route Reply Message
RREQ	Route Request Message
TTL	Time to Live
WSNs	Wireless Sensor Networks
ZC	ZigBee Coordinator
ZED	ZigBee End Device
ZR	ZigBee Router

LIST OF PUBLICATIONS

1- Abla Hussein and Ghassan Samara, “Mathematical Modeling and Analysis of ZigBee Node Battery Characteristics and Operation, **MAGNT Research Report (ISI Thomson Reuters Indexed)**, Already Published in, Vol. 3 (6). PP: 99-106, 2015, (DOI: dx.doi.org/14.9831/1444-8939.2015/3-6/MAGNT.09)

2- Abla Hussein and Ghassan Samara, “Coordinator Location Effects in AODV Routing Protocol in ZigBee Mesh Network, **International Journal of Computer Applications**, Already Published in, Vol. 127 (8), pp. 1-7, October 2015.

خوارزمية تحويل ذات حساسية للطاقه خاصة بشبكات ZigBee اللاسلكيه

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الملخص

تطبيقات ZigBee هي تطبيقات لاسلكيه مفتوحة وعالمية، تعتمد على معيار IEEE 802.15.4، يتم استخدامها للإستشعار والتحكم عن بعد في العديد من المجالات الدفاعيه والتجارية والصناعية والطبية. وبسبب ارتفاع الطلب على إطاله عمر الشبكه في صناعه العديد من شبكات ZigBee وتطبيقاتها التي تعمل بهذة التقنيه، وحيث أن عمر الشبكة يعتمد على قوة البطاريات للعقد المستخدمه، أصبح من الضرورة القصوى وضع خطه أو منهجيه لدعم إدارة الطاقه في تلك الشبكات وإطاله عمر بطارياتها المستخدمه.

في هذا العمل البحثي، تم اقتراح خوارزميه حساسه تجاه الطاقه (PS-AODV) لتطوير مخطط البروتوكول ومنهجية التوجيه من خلال تطوير خوارزمية توجيه الموجهات عند الطلب (AODV) المعروفه، لتقوم بإدارة العمليات في شبكة ZigBee وبناء المسار من العقد الموثوق بأنها عقد نشطة. علاوة على ذلك تم بحث العديد من جوانب البروتوكول على الشبكات المتداخلة مع التركيز على اكتشاف المسار، صيانة المسار، جدول العقد المجاورة، أقصر مسار وذلك باستخدام الخوارزميه المقترحه PS-AODV على شبكتين مختلفتين في موقع منسق الشبكة الاولى في الوسط والثانيه على الطرف. النتائج أظهرت تقدم للشبكه في أداء العمليات عندما يكون موقع منسق الشبكه في المركز، كما أظهرت النتائج زيادة بعمر الشبكه بواقع 20% وانخفاض التاخير بنسبة 32.7% مقارنه بخوارزميه AODV .

أيضا سيتم التركيز على تأسيس صيغة متعدده الحدود لتعبر عن خصائص البطارية والعمليات في عدة أحمال باستخدام منحنى تقنية مناسب تم تطبيقه على بيانات عملية مقدمه من قبل شركه Free Scale و Farnell Technology، لتساعد المصممين والباحثين على تقدير قوة البطاريه وتوقع عمر البطاريه في عقد الشبكه.

POWER SENSITIVE ROUTING ALGORITHM FOR ZIGBEE WIRELESS NETWORKS

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ABSTRACT

ZigBee applications are open and global wireless technology that based on IEEE 802.15.4 standard, it is used for sense and control in many fields like, military, commercial, industrial and medical applications. Extending ZigBee lifetime is a high demand in many ZigBee networks industry and applications, and since the lifetime of ZigBee nodes depends mainly on batteries for their power, the desire for developing a scheme or methodology that support power management and saving battery lifetime is of a great requirement.

In this research work, a power sensitive routing Algorithm is proposed (PS-AODV) to develop protocol scheme and methodology of existing on-demand routing protocols (AODV), by introducing an algorithm that manages ZigBee operations and construct the route from trusted active nodes. Furthermore, many aspects of routing protocol in ZigBee mesh networks have been researched to concentrate on route discovery, route maintenance, neighboring table, and shortest paths. PS-AODV routing algorithm is used in two different ZigBee mesh networks, with two different coordinator locations, one used at the center and the other one at the corner of the networks. The extracted results conclude a better network operation for the coordinator located at the center with an increase in the network lifetime around 20% percentage, and saved about 32.7% of delay time compare to AODV.

Also, an optimized polynomial formula has been established for battery characteristics and operations at different loads, using curve fitting technique of practical data that are provided by Free Scale semiconductor and Farnell technology. The optimized formula will help system designers and hardware developers to estimate the battery capacity requirements and study the expectation of the battery lifetime for ZigBee-based nodes.

Chapter 1

Introduction

1.1 Overview

Wireless communication is the largest and dominant contributor to communication technology for commercial and industrial applications where signals are transmitted and received at distances ranging from few centimeters to thousands of kilometers. Radio waves propagation carrying the signal takes place through air or free space, without the need of wires, cables, or any transmission lines, examples of wireless technology are: Cordless phones, TV reception, microwave application, satellite communications, and wireless sensors such as ZigBee and home automation *(Sohraby et al., 2007)*.

Wireless sensor becomes very popular application nowadays since it is inexpensive, low power application, and had great wireless communication capabilities, where the nodes in Wireless Sensor Networks (WSNs) transmits/ receives data within the network via radio, infra-red or other electromagnetic radiation to monitor physical or environment condition such as sound, motion or pollutants, vibration, pressure, and temperature at different locations. WSN end nodes are responsible for sensing and reporting to the central processing unit but WSN is constrained in memory, energy and processing speed *(Sohraby et al., 2007)*

WSNs were developed for military purposes since it has low power consumption and widely adopted for control military applications, in today's technology, the expansion of applications are used in commercial mainstream with monitoring, home automation, control application, and fire protection *(Sohraby et al., 2007)*. WSN applications are deployed usually in large area or in unreachable places like dangerous environment and disaster places where there is no human access, and due to dangerous situations it is difficult to replace or recharge their batteries. Since the battery has a limited capacity, it will discharge completely, and a failure of one node or more can lead to a failure of the whole network. In this situation; the battery recharge will be carried out to serviceability the network *(Piyare and Lee, 2013)*.

However, power consumption awareness and therefore long-living networks are a challenging issues in designing WSNs, where energy consumption and reliability has been studied intensively by researchers; they employed different types of networks topologies and routing protocols at which most of the nodes in WSNs follow ZigBee routing protocols because of the high level of communication that is designed for low power consumption, self-organizing and large scale network *(Akyildiz et al., 2002)*.

ZigBee is a targeted application in which it has been researched extensively for a long battery operation, low data rate, secure network and it is based on IEEE 802.15.4 standard with mesh network [*(Ergen, 2004)*, *(Daintree, 2010)*]. Despite this target, the current network formation and routing protocols in the ZigBee specification do not fully addresses the power consumption issues. Our research works concentrate on this kind of application in mesh network.

1.2 Problem Definition

ZigBee node battery power consumption and discharge due to transmit and receive activities is the main issue in ZigBee network and since network life depends mainly on battery life time, many researchers studied and analyze procedures and techniques that could support the longevity of ZigBee network throughout the development of routing protocols for different kinds of network topologies *(Peng et al., 2009)*.

For ZigBee mesh network topology the AODV routing protocol lacks in rout discovery process and maintenance which leads to eliminate the life time of battery powered ZigBee network. These short life time batteries affect the connectivity of the network while transmitting which leads to network partitions, path failure and delays.

To keep the network active and running, care must be taken about routing algorithms that considered necessary steps toward a considerable reduction of battery power consumption and consequently a longer life of the ZigBee network.

Furthermore, the location of ZigBee coordinator and battery characteristics and operation, should be taken into account by system designers and hardware developers in order to estimate battery capacity requirements and study the expectation lifetime for ZigBee-based nodes.

1.3 Research Objectives

This research aims to achieve the following objectives:

- To optimize battery voltage decaying formulas that analyzes ZigBee node battery characteristics and behavior as a function of time or number transmission.
- To determine the better coordinator location for routing performance.
- To propose a new power sensitive routing algorithm for ZigBee Wireless Networks, and evaluate it.

1.4 Thesis Outline

The reminder of this thesis is organized as follows:

- **Chapter 2** covers the concept of ZigBee technology with brief introduction to AODV routing protocol in ZigBee mesh network. Finally more illustration of related work is presented from different perspectives.
- **Chapter 3** covers the methodology frame work and lists the phases of the proposed Algorithm.
- **Chapter 4** presents detailed description of proposed algorithm phases that congregate the expected results of saving network life, and explains the method that used to establish a formula for battery voltage behavior, which was used for setting up power management scheme for each node in the network.
- **Chapter 5** shows the simulation and results of proposed algorithm in MATLAB programming for two different kind's network in regard to coordinator location.
- **Chapter 6** concludes the research work along with some of the future works.

Chapter 2

ZigBee Technology and Related work

2.1 Introduction

This chapter gives an overview of ZigBee technology and the underlying IEEE 802.15.4. standard, it covers ZigBee network devices and protocol stacks also it covers the key component of AODV routing protocol for mesh ZigBee network and illustrates the different drawback in AODV protocol that are exist during the route establishment to destination. Finally, presents an overview of the related work from different perspectives.

2.2 ZigBee Technology

ZigBee is one of the newest technologies developed by ZigBee Alliance; its characteristics depend mainly and operated on IEEE 802.15.4 standards which consist of both Medium Access Control (MAC) layer and physical layers (PHY). ZigBee protocols have been designed to communicate data through Radio Frequency (RF) environments that are used commercially and in Industry applications, where this standard completes the communication protocol stack which defined and used by WSN applications *(Daintree, 2010)*.

The ZigBee Alliance is an association of over 300 companies including, module stack, semiconductors, and software developers that came together to maintain, and published the ZigBee standards for varieties of applications *(Daintree, 2010)*.

ZigBee technology has been used widely in different commercial, medical, industrial and home automation, and the importance of keeping the network operating a longer time was the main objective of ZigBee manufacturers who design and manufacture transceivers, coordinators and end unit modules. ZigBee applications are expected to provide low power and low cost connectivity for equipment that needs to be operated on batteries *(Sohraby et al., 2007)*. They are required to operate from several months to several years for a transmission of low bit rate applications in wireless networks as shown in Figure 2.1. There are many that are ideal for redundant, self-healing, and mesh network capability, key ones include *(Daintree, 2010)*. ZigBee technology is based mainly on IEEE 802.15.4 standard.

2.2.1 ZigBee Typical Applications

1- Home automation that provide flexible services for security, healing and cooling and home entertainment for anywhere in the home.

2- Building automation to amalgamate and centralized management of lighting, heating and security.

3- Industrial automation to provide reliability and process control system.

4- Military, Medical, consumer products and agriculture applications.

Figure 2.1 Zigbee Application *(Daintree, 2010)*

2.2.2 IEEE 802.15.4 Standard

IEEE 802.15.4 is a wireless network protocol which has become an industry-standard for implementing radio-based Personal Area Networks (PANs). IEEE 802.15.4 is a standard defined by the IEEE committee for low-rate. IEEE 802.15.4 defines two layers, the physical and MAC layer. The OSI model has been adapted in the 802.15.4 standards as shown in Figure 2.2, which is limited to the PHY and MAC Layers [*(Dash, 2014)*, *(IEEE, 2006)*].

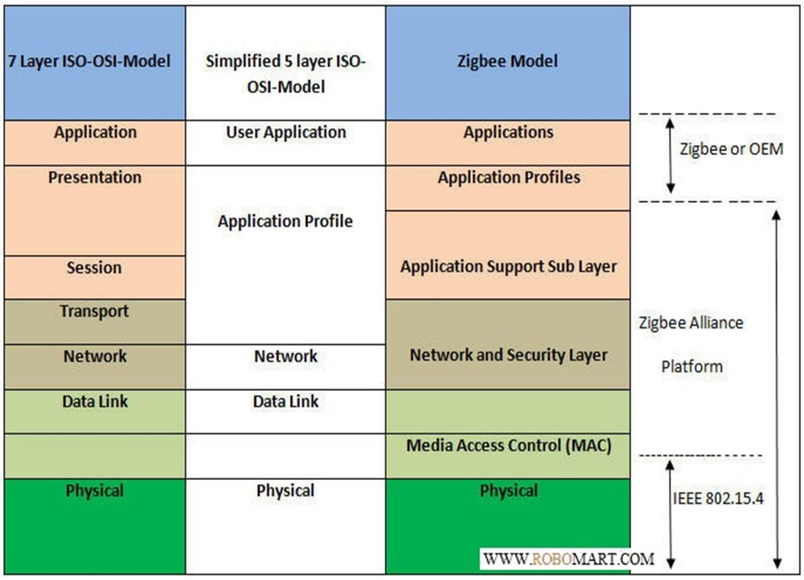

Figure 2.2 OSI Model to ZigBee Stack *(Dash, 2014)*.

2.2.2.1 Physical Layer (PHY)

The physical layer defines low-power spread spectrum radio operating at 2.4 GHz with basic bit rate of 250 kb/s, additional frequency bands are being made available in various countries like 915 MHz is common in North America and Australia, and 868 MHz is only used in Europe. The data rate for the above frequencies is shown in Table 2.1*(Baronti et al., 2007)*.

Table 2.1 IEEE 802.15.4 RF Bands.

Frequency	Channel	Region	Data rate
868-868.6 MHz	0	Europe	20 kbit/s
902-928 MHz	1-10	USA	40 kbit/s
2400-2483.5 MHz	11-26	Global	250 kbit/s

2.2.2.2 MAC Layer

The main responsibilities of the MAC sub-layer are:

1- Providing a reliable communications between node and its immediate neighbors.

2- Providing an access control to share channels.

3- Help to avoid collisions and improve efficiency.

4- Responsible for assembling and decomposing data packets and frames.

5- Capability of Management Timeslot (GTS).

6- Providing services for associating / disassociating devices with network.

7- The coordinator generates the network beacons.

8- Conserve energy by allowing devices to go to a sleep and idle modes *(Baronti et al., 2007)*.

2.2.3 Power Management in IEEE 802.15.4

IEEE 802.15.4 includes many features like energy detection and interference avoidance between radio communication channels, where the channels are selected according to the best frequency channel initialization in cases of channel problems due to many factors that affect a reliable communication *(IEEE, 2006)*. Also, IEEE 802.15.4 achieves low power consumption by autonomous low-powered devices. Such devices that go to sleep or shut down due to low battery power where many applications required these kinds of devices.

Battery power has a certain advantages such as:

1- easy and low-cost

2- used for flexible location devices

3- easy to be modified for scalable network

4- low duty cycle: duty cycle is the propagation of time interval between transmissions, most of power consumption of wireless network devices corresponds to transmission time. The battery is very effective using IEEE 802.15.4 standard due to its extremely low duty cycle. The transmission will be in a very small fraction of time and when there are no transmissions, the device will revert to low-power sleep mode to minimize power consumption.

2.3 ZigBee Protocol Stacks

Figure 2.3 shows the typical ZigBee protocol stack architecture which defines the different layers *(Baronti et al., 2007)*, networking, and security has been defined by the ZigBee Alliance. Where the lower portion of MAC layers and the PHY layer has been define by IEEE. 802.15.4.

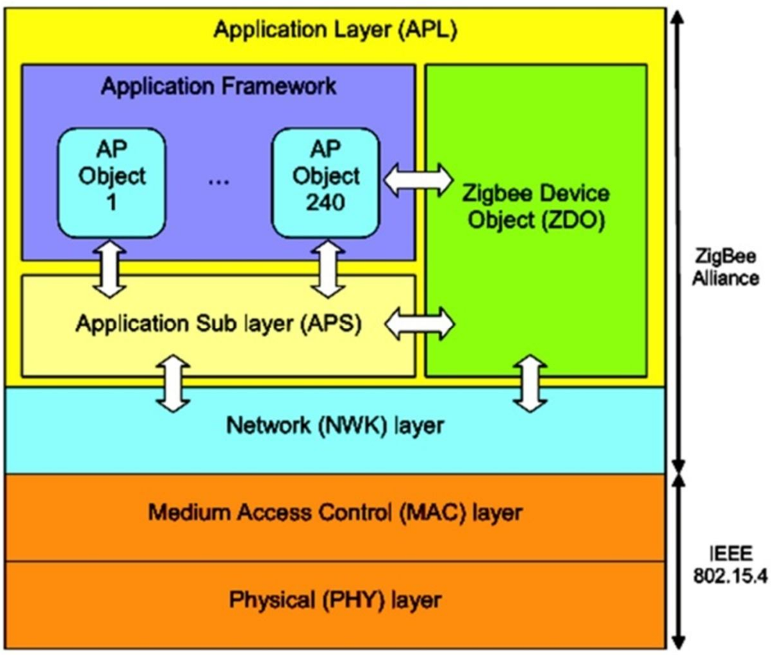

Figure 2.3 ZigBee Protocol Stack Architecture *(Baronti et al., 2007)*.

2.3.1 Network Layer

The network layered responsible for switching and routing technologies, addressing and managing network problems such as packet switching and data congestion. Self-healing is also implemented at this layer, if there is any node failure, the network re-routes the message to alternative route paths that are available; both the discovering and the neighbor information on the routing tables between devices is done at this layer. The ZigBee coordinator is responsible for assigning 16-bit network address to new devices that joining the network [*(Yusuf, 2014)*, *(Malhotra, 2015)*]. It is important to notice that ZigBee Alliance defined network capabilities that are out of the scope of IEEE standards 802.15.4.

2.4 Types of ZigBee Devices

There are three different types of ZigBee devices as shown in Figure 2.4

2.4.1 ZigBee Coordinator (ZC)

ZC starts up the network initialization; it is the most important device in ZigBee network that able to store information about nodes and mange network nodes. ZC device needs a maximum memory as well as high computing power because it does not sleep but it helps end devices to sleep*(Inc, 2012)*. Every ZigBee network has only one coordinator that selects a personal area network identifier (PAN ID) and also assets the routes messages between paired nodes, ZC acting as the trusted center that responsible for security keys [*(Kinney, 2003)*, *(Yusuf, 2014)*].

2.4.2 ZigBee Router (ZR)

ZigBee Router (ZR) extends network area coverage, connect the coordinator and other routers and also support end nodes; act as a link between routers by relays messages from one node to another. It provides backup router in case of device failures or network congestion by storing and maintaining network information. The information provided from ZR routers used to select the most efficient routes for packets. Also, ZR considered as a full function device that can act as coordinators of network and can talk to any other device [*(Kinney, 2003)*, *(Yusuf, 2014)*].

2.4.3 ZigBee End Device (ZED)

ZED devices transmit and receive massages; they have limited functions as compared with coordinator and routers. ZED cannot perform any routing operations. This characteristic is done to allow the ZED devices to be sleep and prolong the battery life. They require fewer amounts of memory and energy to reduced complexity and cost. Therefore, many ZigBee sensors are only ZEDs due of the lower power consumption compared to ZRs but also ZRs are needed to integrate ZED into a ZigBee network [*(Kinney, 2003), (Yusuf, 2014)*].

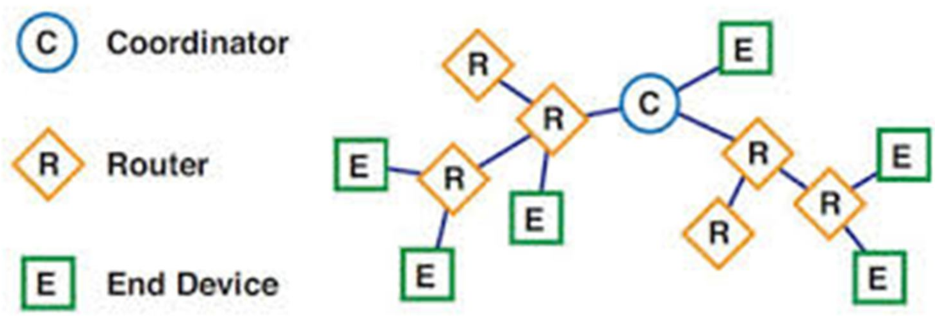

Figure 2.4 Types of ZigBee nodes *(Yusuf, 2014)*.

2.5 Network Topology

ZigBee device classified according to the tasks assigned to the specific application. Different topologies can be build up from ZigBee devices such as star, cluster tree, and mesh topologies *(Sun et al., 2007)*. As illustrated in Figure 2.5 each ZigBee network required at least one ZC to initiate the ZigBee network, If ZED associated with one ZC it will build up point to point network. At least two ZEDs and one ZC can build up a star network and additional ZRs build up a tree network where ZEDs can communicate by using ZR or ZC devices.

In star topology networks, ZC is responsible for network initiation. All other devices are ZED devices which communicate with the ZC, at least two ZEDs and one ZC can build up a star topology. Hence, any exchange of packets between the ZED devices and routers ZR should reach the ZC devices. The ZC device in star topology is powered by power supply while most of ZED devices are battery operated *(Sun et al., 2007)*. The star topology is mainly designed for a simple communications from one node to several nodes, it will be suitable for a time critical applications and centralized device *(Li et al., 2010)*.

In cluster tree topology ZC is responsible for network initiation and maintenance; but ZRs can be used for network extension. ZRs can act as coordinator and provides services to other devices, ZRs controls messages across the network by using hierarchical routing strategies. Any node failure in this type of network topology could causes dead zones and a lot of communication overhead will be needed for communication recovery. Cluster tree topology is the combination of both star and the mesh networks *(Yusuf, 2014)*.

Mesh network will be more complex, ZRs will provide more than one path due to multiple connections through the network; also it will provide more levels of reliability and scalability. weak signals and dead zones can be eliminated by adding more routers to the network *(Sun et al., 2007)*. Mesh topology is a form of ad-hoc network support self-healing, self-organizing, more robust, and high fault tolerance *(Yusuf, 2014)*. Industrial control and monitoring application would benefit from such a topology.

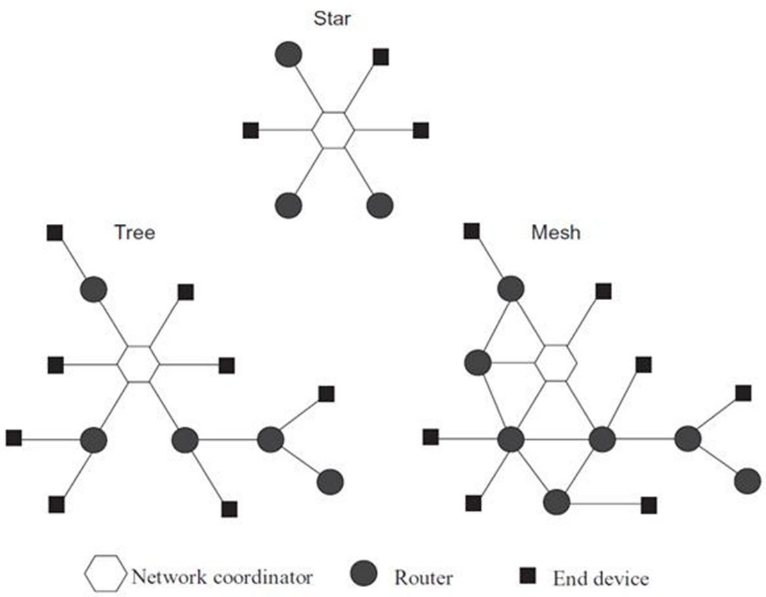

Figure 2.5 Zigbee Network Topologies *(Baronti et al., 2007)*

2.6 AODV Routing Protocol for ZigBee Mesh Networks

ZigBee is a version of AODV routing protocol, where the routes are discovered through RREQ source broadcasting and the reception of RREP acknowledgment back from destination *(Al-Gabri et al., 2014)*. Mesh topology is best suited with AODV routing protocol which is a destination-based reactive protocol, the name claims from its nature on demand that the route created only when it is needed, which employs reactive discovery process to route data through networks, this implies no nodes participation until it takes part in the discovery route process, and the communication link will be removed after routing, the intermediate nodes only needs to be saved until after data reaches its destination [*(Ortiz et al., 2011)*, *(Al-Gabri et al., 2014)*, *(Malek et al., 2013)*]. One hop communication will be refreshed automatically via neighboring tables messaging that presumes a symmetric links between neighboring nodes, which is the links have same properties in both directions *(You et al., 2011)*. AODV routing protocol discover process is used to maintain links that uses different routing messages *(Ali and Akbar, 2009)*:

2.6.1 Route Request Message (RREQ)

A route request packet is flooded broadcast messages through the network whenever a new route from source to a destination is required where its frame format contains fields which specify destination sequence number, destination address, source address, hop count, and some other data.

2.6.2. Route Reply Message (RREP)

It is a reply message acknowledgment sent back by destination to the source or it is a valid route to destination when message delivered. RREP frame format contains fields which specify source address, destination sequence number, hop count, life time.

2.6.3 Route Error Message (RERR)

When a message has not been delivered to destination or destination could not locate, an RERR message will be issued, and the route will be deleted.

2.6.4 Hello Messages

Hello messages are broadcasted in order to inform the neighbors about the activation of the link in AODV maintenance process where the neighbor's nodes are ready for communication.

The protocol consists of two basic processes *(Group, 2003)*:

1. Route discovery process.
2. Route maintenance when some link disappears in the mesh.

2.6.5 Route Discovery Process

A route discovery is the process at which an unknown route to destination is determined; the process starts by broadcasting RREQ packets from source to destination, consider the network in Figure 2.6 where node A (ZC node) sends data to node G (ZED node) and does not have a route information for this destination node.

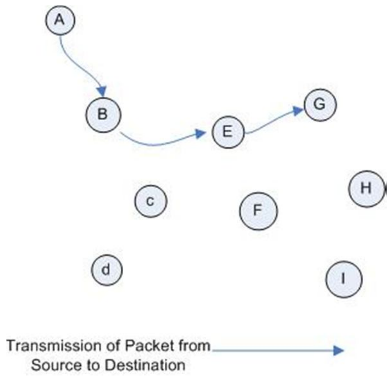

Figure 2.6 Transmission of Packet from Source to Destination.

First node A will initiate route discovery process by broadcasting a RREQ packet to its immediate neighbors (in our case node B). When an intermediate node receives the packets, it will rebroadcast it to the next intermediate node within the route, all intermediate nodes repeat this process either rebroadcasting or timing out until RREQ reaches its destination, then the destination node unicast acknowledgment packets RREP to the source acknowledging the recipient of packets through reverse path setup.

2.6.5.1 Reverse Path Setup

The reverse path to source is illustrated by each node during the broadcasting of RREQ messages. In Figure 2.7 RREQ travels from node A to various active intermediate nodes and finally reaches the destination node G, the reverse path will be setup automatically, by recording the address of the active neighbors in routing table from which it received the RREQ packet, in our case node (B and E), then RREP message travels along this path from node G to A as indicated by dashed arrows while the solid arrows represent the forward direction in Figure 2.7.

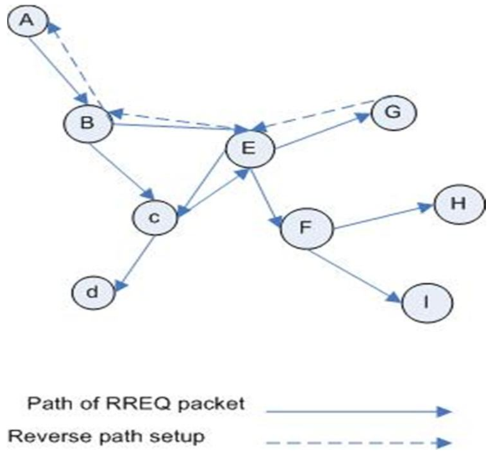

Figure 2.7 Reverse Path Setup in AODV.

2.6.5.2 Forward Path Setup

A forward path is setup during the transmission of RREP message, each node along this reverse path setup a forward pointer to the node from which the RREP is received, forward path means that it is reveres to the reverse path, the data transmission as soon as this forward path is setup. In Figure 2.8 solid arrow indicates the forward path from node A to G.

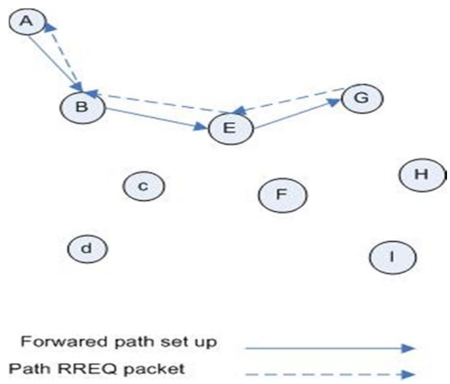

Figure 2.8 Forward Path Setup in AODV.

2.6.6 Route Maintenance

Routing process is not an easy task as we think and there are many factor influences. This process and delay the establishment of an active route, like number of hops, Time to Live (TTL) of the packets, transmitting power, receiver sensitivity and nodes locations. If one node detects this type of failure then the source can re-initiate a route discovery process if a route to the desired destination is still required. On the other hand, an intermediate node of an active route lose large amount of its power which affect to node then failure path. As shown in Figure 2.9 node E fail it will breaks the link between B and G, and A tries to send again. In this case B will inform A that E fail and should be deleted from entry in the routing table and establish a new route discovery process.

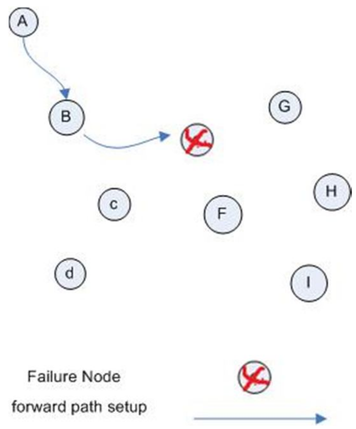

Figure 2.9 Failure Nodes and Maintenance Path.

2.6.7 Routing Table Management

Route table management is a primary goal of routing protocols that used by coordinator or routers to store temporary information used during route discovery*(Shob . S. and Rajeswari, 2014)*. The forwarding and reverse routes are saved and kept stored for short time and it is updated periodically. In Figure 2.7, nodes C, D, F, I and H purge there entries after route expiration time. The routing table also stores routes and metrics information that was associated with routes establishment to a particular destination, metrics can be any value that could be used by routing algorithm to determine whether one route better than another

(Group, 2003). AODV generally deals with routing table that contains information which is updated periodically and has a specific TTL.

Route table entry for AODV routing has the following fields:

- Destination address.
- Destination sequence number.
- Next hop.
- Number of hops.
- TTL.

The node chooses the higher sequence number if more than one route entry for a specific destination, then if the sequence numbers are the same less number of hop is chosen *(Group, 2003)*.

2.6.8 AODV Routing Protocol Drawback

Due to the on demand nature for AODV routing protocol, there are several problems associated to high routing overheads and high packet drop *(Ortiz et al., 2011)*. Also, power consumption issue is one of the main problems that do not fully addressed in ZigBee specification for routing protocol description. However, the nature of both discovery and maintenance processes will produce several problems that leads to nodes power consumption, which affects the life of the network. Obviously, the selected shortest route provided by discovery and maintenance of AODV routing protocol can effectively reduce the transmission delay but with little overhead *(Li et al., 2010)*.

The following factors contribute to AODV routing protocol drawback during route establishment to destination:

- *Deficient metric*: The preference of hop numbers as a metric for AODV routes and ignoring other important metrics *(Sun et al., 2007)*.
- *Duplicated Messages*: Sometimes intermediate node may receive from the source same RREQ with a lower number of hops. RREQ message have to be forwarded again, that contribute to flood and increase the transmission delay and node battery power consumption *(Ortiz et al., 2011)*.
- *High route discovery delay*: the route discovery process can take more time when nodes send message randomly, as a result a waiting period is needed until second path setup; therefore a longer AODV routing delays will be generated*(You et al., 2011)*.

2.7 Related work

The importance of network power consumption was of great interest to many researchers, the following will illustrate this side of research work from different perspectives.

2.7.1 Battery Consumption

Most of the power conservation research work has studied the development of the different types of routing protocols aiming to extend node battery life and not so much study focused on battery characteristics, features and operation. This section focused on research work that aiming to extend the node battery life by studying the battery characteristics and activates cycled that used in ZigBee nodes.

An experiment has been carried out to observe the activity cycle and power consumption in battery energy for a ZigBee network node during start-up, packet transmission, and during sleep-mode on Texas Instruments CC2520 transceiver and the Freescale MC1322x platform *(Casilari et al., 2010)*.

Extensive study has been presented on energy consideration based on IEEE 802.15.4 technology where many experiments carried out on a node prototype powered by Lithium batteries, and the concluded results states that lifetime as announced by hardware manufacturer was not studied well specially for network nodes, also variable loads on battery chemistry impacted the reduction of the node life time, and the life time was dependent of node receiving state time which considered the worst case of power consumption *(Fourty et al., 2012)*.

Other researchers looked and examined different battery capacity models that describe battery capacity utilization based on battery discharged by the different parts of circuits and loads that could consume battery power. Their study reflects a qualitative insight into how a battery's capacity is influenced by multiple factors *(Inc., 2011)*.

Models to estimate the energy requirements based on application activities has been proposed in order to extend the battery life time, a generic low duty-cycle ZigBee used as a case study. Experimental results has been carried for a proposed models with 3% error in average compared with estimated values of those obtained from experimentations, and their conclusion was based on the fact that battery-driven system design solution is the base to address energy challenges *(Zarrabi et al., 2011)*.

Temperature is another factor that affects the performance of batteries in general, and since batteries are composed of many chemical materials, warmer temperatures will decrease battery life time because heat can cause chemical reactions that produce corrosion in the internal electrodes *(Park et al., 2001)*.

Jennic technology has provided guidance when using coin cell to power devices based on the Jennic JN513x wireless microcontroller. An extensive study has been carried out to study average current consumption, desired battery life, and maximum current consumption for Sanyo CR2032 coin battery *(JennicTechnology, 2008)*.

2.7.2 Routing Protocols

Routing protocols had the share to support the longevity of the network and the varieties of approaches that have been implemented for conserving power, using different kinds of routing protocols for different network topologies, some of which have been studied carefully, and a developed protocols have been surveyed and its performances was evaluated [*(Narmada and Rao, 2011)*, *(Saraswala, 2013)*].

Some authors focused on reducing energy consumption by using a fussy logic based metric in AODV algorithm for ZigBee mesh network which has been considered as decision making for the discovery process, the simulation results displayed a reduction in energy consumption by cutting down the number of messages sent; thus reducing collision and overhead *(Ortiz et al., 2011)*.

ZigBee AODV mesh network has been researched to send and receive route request, by dividing the network into several logical clusters for the purpose of reducing flooding route requests. Their simulations results show improvements in battery capacity and computing power limitation, the authors concentrate on ZigBee topology but do not concentrate on battery capacity in each node *(Al-Gabri et al., 2014)*.

A priority energy aware protocol is proposed where a residual energy field has been added to RREQ frame format message using AODV routing protocol. This generated EAODV protocol procedure which selects the shortest path and minimum energy level for routing each RREQ request packet, but this process of minimum energy path will deplete the energy of the nodes that are selected during the routing process; this procedure will rapidly drain node batteries and may cause poor routing *(Samundiswary and Bhardwaj, 2013)*.

An energy awareness algorithm has been proposed in order to use limited energy in order to extend the lifetime of ZigBee networks. EA-AODV Algorithm grouped the nodes on routing discovery process into three levels where each level depends on its own energy. This classification will support route discovery processes to count the total energy consumption of the path, authors in their algorithm do not consider the energy threshold value for nodes' battery which is a critical problem for node's lifetime *(Peng et al., 2009)*.

In another set of routing protocols, authors' aim was to reduce problems in ZigBee tree routing algorithm where some of the nodes use large amounts of energy in the process of using neighbors table, node depth and residual energy will be considered to avoid selecting nodes of low residual energy. As such the power threshold will be saved and maintained in ZigBee coordinator tables, a procedure leads to an excess of data exchange and avoid exhaustion of some nodes *(Tao et al., 2010)*.

STR algorithms protocol for ZigBee tree routing (ZTR) has been proposed which follows the tree topology for transmission and used one hop neighboring table information. Authors lead was to solve the problem of the severe collision of packets, congestion, and network performance degradation *(Kim et al., 2014)*.

Another research work has been proposed, that based on limitation of flooding in broadcasting of Route Request (RREQ) packets in AODVjr algorithms, which depends on tree routing aiming to reduce the consumption of power and extend ZigBee network lifetime *(Zare et al., 2013)*

Authors in *(Lee et al., 2006)* divided ZigBee network into several logical clusters nodes to share network resource but this process does not solve problems of RREQ group flooding, and will lead to excessive energy consumption. Authors in *(Zhang et al., 2009)*combine AODVjr with residual energy to balance between the shortest path routing and energy aware routing.

2.7.3 Coordinator Location Effects in AODV Routing Protocol

A considerable number of research works have been published on the mobile coordinator in WSNs, and most of them concluded that mobile coordinator improves WSNs network performance [*(Liang et al., 2006)*, *(Shakya et al., 2007)*, *(Bi et al., 2007)*]. None of them concentrated on effective positioning of the nodes in ZigBee network which is particularly important in improving the performance of ZigBee network. In this research work, fixed positioning of coordinator in different spots of the network will be researched and analyzed.

Dhaka et al. performed an extensive evaluation study using OPNET to study the impact of coordinator mobility on ZigBee mesh network routing. The results indicate that the best performance had been achieved when the trajectory of the sink (coordinator) movement along fixed path, other way the throughput is minimum for diagonals or square trajectories, also the best result achieved for minimum hops counts from the static sink *(Dhaka et al., 2010)*.

Other researchers have concentrated on investigating the ZigBee network performance when using static coordinator and random mobility coordinator in star, tree and mesh topology. The authors concludes that random sink mobility will provide more performance than static sink because of neighboring nodes will consume their energy faster than far away from the sink, also mesh topology is more efficient energy than star and tree *(Aziz et al., 2012)*.

For tree network topology, an experiment has been carried out to determine the effectiveness of positioning nodes among the network for the purpose of better throughput. The study was performed using OPNET simulator testing different mobility models, the authors concluded, that group mobility model has the best performance among other suggested model such as random waypoint, random walk, and pursue mobility model *(Dhillon and Sadawarti, 2014)*. From the literature, it had been concluded that various researchers have not taken into consideration the routing strategies and its optimization.

Jiasong Mu and Kaihua Liu in their research was to simulate network performances by experimenting different route strategies such that Enable Route Discovery (ERD), Force Route Discovery (FRD) and a Suppress Route Discovery (SRD) by means of changing node mobility and network dimension using the evaluation tool of OPNET simulator. Their conclusion proves that ERD and AODV have the most efficiency and suitable for dynamic environments, FRD has always the worst performance, and SRD is the most suitable for static networks, and the positioning of the node and mobility coordinators need to be considered in improving the performance of ZigBee network *(Mu and Liu, 2010)*.

2.8 Summary

From the previous survey of related work in network power consumption, we have concluded that tree network topology have been dominated in most of the research work, and less work on Mesh network topology, despite the fact that most of ZigBee networks are mesh networks.

Most of the proposed algorithms did not concentrate on the threshold power level of nodes, since below this level the functionality of the node will be reduced dramatically, and the sent discovery packets will consume nodes power; neighbor table should play major part in this process, because dead node information should be removed from the table, that way routes will not be generated within these dead nodes.

In this research work, many factors are taken into consideration such as; effects of coordinator location in AODV routing protocol, node battery power consumption, dead nodes, neighbor table, distances calculation between nodes, and switching paths.

Chapter 3

Research Work Methodology

3.1 Introduction

As we have discussed later in previous chapter, we found that existing mechanism for AODV routing process only gives the shortest path based on the minimum number of hops, which is not sufficient always in route mechanism process. In case when a node is selected in shortest path and always the communication going through the same node, then the power battery is getting down for this node early than original lifetime and may suddenly causes failure or delay data received. Therefore, monitoring the energies for these shortest path nodes and their neighbor's node will survive the network form failures and delay.

However, in order to extend the life time of network, a Power Sensitive Routing (PS-AODV) Algorithm is proposed to facilitate the adjustment of AODV operation downside, where the adjustment depends mainly on nodes battery power consumption, neighboring table, and dynamic path switching using Dijkstra's algorithms for shortest paths.

In this chapter, methodology frame work and descriptive methods used is covered to simplify the understanding of the whole work of this research. Started with intensive research work on coin battery characteristics and feature in order to obtain formula for battery voltage decaying which plays part in generating routes and the simulation process. Also, the enhancement of AODV routing protocol is illustrated by listing phases and the procedures. Finally, the flowchart of improved route discovery and maintenance mechanism that contains the main enhancement phases is shown in section 3.2.3.

3.2 Methodologies Frame Work

Methodology frame work of the research is divided into four main steps as shown in Figure 3.1.

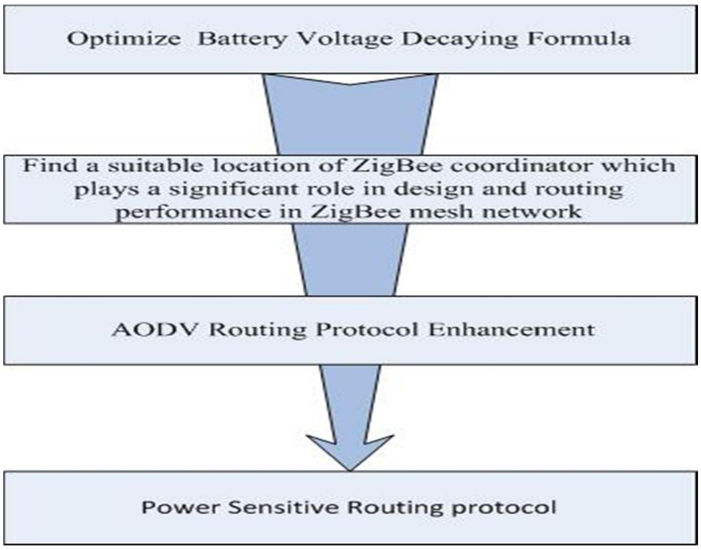

Figure 3.1Methodology Frame Work and Descriptive Methods.

3.2.1 Method used to Obtain Battery Voltage Decaying Formula

The method used to produce an optimized voltage decaying formula as a function of time is shown below:

1. On line intensive search has been carried on to find coin battery characteristics data, since coin batteries used in ZigBee devices.
2. Farnell and Free scale battery datasheets have been selected since the data were clear and the curves are measured at different loads (15 Kohms and 7.5 Kohms) [*(Povalac and Ligertwood, 2012), Hk. Co, (2011)*].
3. The voltages of the data given were measured in second and for convenience it has been converted to hours.
4. Regression technique used for curve fitting the practical data for the purpose obtaining formula that could represent voltage decaying as a function of time.

5. Curve fitting done three times for three cases of different loads.

6. Three formulas have been concluded as a result of the fitting technique.

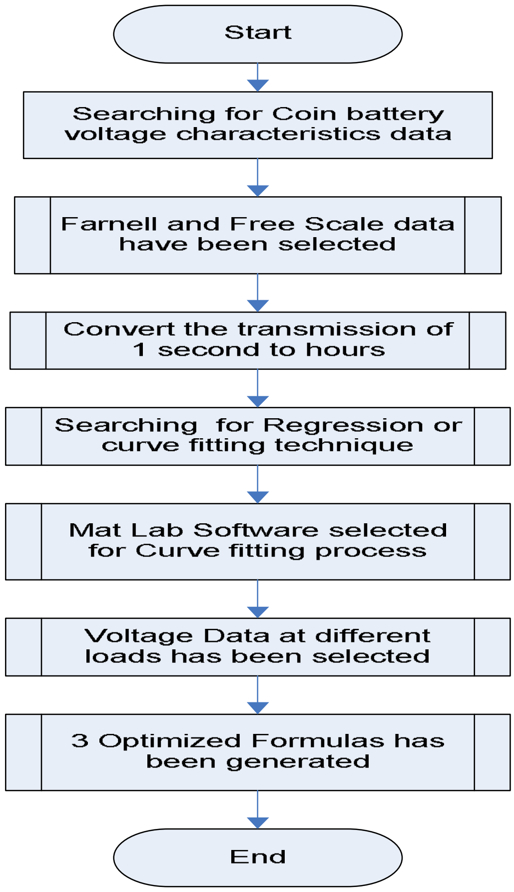

Figure 3.2 Methodology used for Creating Voltage Decaying Formulas.

3.2.2 Coordinator Location Effects in Routing Protocol

The location of ZigBee coordinator plays a significant role in network design and routing performance, the following steps have been used to perform more appropriate coordinator location for lifelong batteries and AODV routing performance:

1- Fixed positioning of coordinator in two different spots of ZigBee mesh network.

2- All results (voltage decline and energy map routes curves) have been analyzed and studded carefully for the best coordinator location that provides good communication with less power consumption.

3- The best coordinator location selected with shortest route that could generate communication with less power consumption.

3.2.3 AODV Routing Protocol Enhancement

The enhancements are done in three phases as shown below to improve both route discovery and route maintenance process of AODV to make it more sensitive and dynamic power protocol:

1- Setting up power management scheme for each node in the network and the threshold value of nodes voltage decline to 50% of the voltage initial value, at which the node is considered inactive and will be removed from tables. Freescale datasheet *(Povalac and Ligertwood, 2012)*, shows the concept of battery voltage decline, where 3.2V was the initial value and after node power consumption, the voltage value declines fast below 2V where the battery will be considered as an un-functional device. At level of 50% (voltage = 1.6 V), this value is called threshold value which is considered the level of un-functional battery.

2- Developing the neighboring table by adding nodes battery voltage and distances between nodes using Dijkstra's algorithms, with the fact that the table is updated continuously with battery voltage.

3- Dynamic switching to path where all nodes within the route having voltages above the threshold value to prevent early death of nodes that having low energy and to switching the path to best quality route without explicit route discovery.

The flowchart of the discovery route process and modification shown in Figure 3.3 where contains the main modification phases that improved AODV routing protocol.

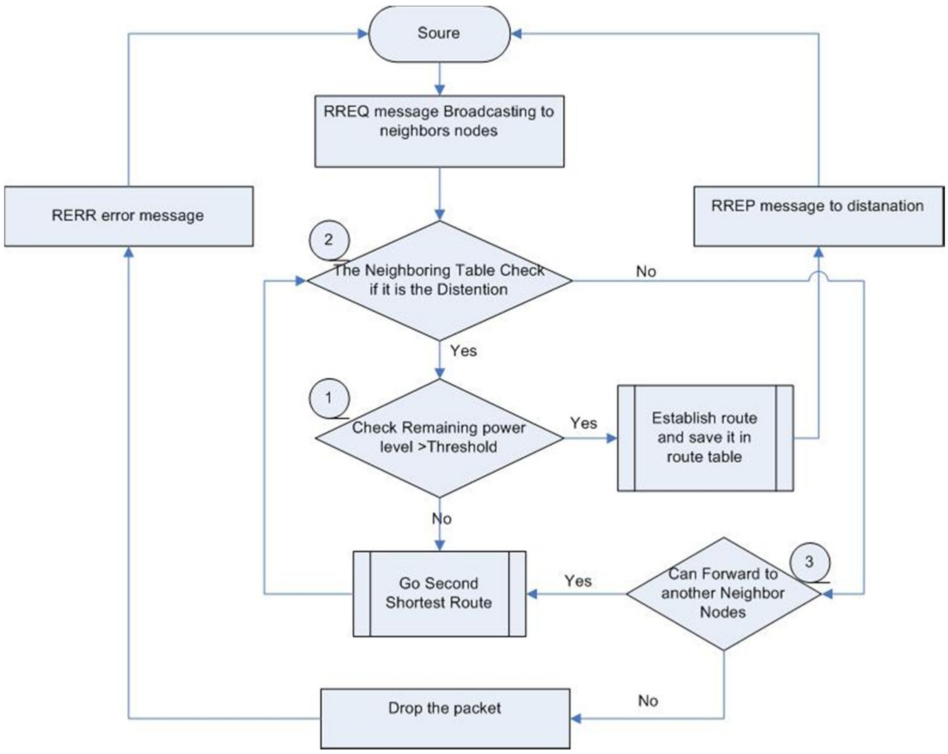

Figure 3.3 Discovery Route Process and Modification

3.3 Summary

This chapter covered the methodology and descriptive method used in this research work. It introduced the method used to obtain battery voltage decaying formula and it also illustrated the steps that used to perform more appropriate coordinator location for lifelong batteries and AODV routing performance. In addition, the enhancement of AODV routing protocol has been illustrated with flow chart for route discovery and maintenance.

Chapter 4

Node Power Management and Proposed PS-AODV Protocol Design

4.1 Introduction

In this chapter, the details phases of the proposed PS-AODV routing algorithm and procedure are presented and discussed, along with neighboring table and dynamics path switching, started with ZigBee nodes power management which plays an important role in the proposed routing protocol that produces an optimized voltage decaying formula, followed by the location of ZigBee coordinator and its impact on routing protocol process throughout the study of battery voltage decaying.

4.2 ZigBee Nodes Power Management

Most of small devices nowadays are powered by batteries, ZigBee devices are an example of this kind, in this technology when the battery voltage go low beyond the threshold value (for this research work threshold voltage =1.6 V as mentioned in section 3.2.3), a small module within the device will detect the low voltage and notify the Micro Controller Unit (MCU) which is equipped in most of the latest technology of ZigBee devices, at which the MCU will send the device to change condition, the MCU could be programmed to perform any necessary activity regarding the discharge of the battery *(Povalac and Ligertwood, 2012)*.

In the simulation process of this research work, the detection of low voltage is carried out and the battery decline in voltage information could be saved in the neighboring table.

4.2.1. Battery Power Consumption

Battery power of ZigBee network nodes will be consumed and exhausted as a function of time in the various electronic components of the different nodes of the network as a result of transmitting signals, receiving signals, and sleeping of the node or during node idle condition, the following analysis will discuss the major component that contributes to energy consumption and voltage decline.

The following formula represents the battery total power consumption of one node of ZigBee network:

$$P_{con} = P_{tx} + P_{rx} + P_{Sleep} + P_{idle} \tag{4.1}$$

Where:

P_{Con} = total power consumption,

P_{tx} = power consumption due to transmitted signal,

P_{rx} = power consumption due to received signal,

P_{Sleep} = power consumption during sleep state, where the router is in sleep mode, and

P_{idl} = power consumption due to Idle state, where there is no packets are transmitted or received.

The relationship between energy and power is represented by*(Paynter and Boydell, 2005)*:

$$P = E/t \tag{4.2}$$

Where P is power measured in Watts, E is energy measured in Joules, and t is time measured in hours, so the E_{con} is *(Paynter and Boydell, 2005)*:

$$E_{con} = P_{con} * t \tag{4.3}$$

The following formula represents power left in battery after some power consumption,

$$P_{res} = P_{int} - P_{con} \tag{4.4}$$

Where P_{res}= Remaining power in battery,

P_{int} = Battery initial power condition and *Pcon* = power consumed

The voltage of the battery is given by the following formula *(Paynter and Boydell, 2005)*

$$V = \sqrt{P * R} \tag{4.5}$$

Where *R* is the load in *ohms* and *P* power in *watts(Paynter and Boydell, 2005)*

and

$$V = I R \tag{4.6}$$

Where *I* is the current in *mA*

4.2.2 Battery Life Time Calculation

The battery lifetime in hours could be calculated using the following formula:

$$T = I_C / I^n \tag{4.7}$$

Where:

T = Battery life time in Hours

I_C = Battery Capacity in *mAH*, I^n = Load current in *mA*

n= Peukert's exponent, it ranges from 1 to 1.3, where 1 is the best. (W. Peukert is German scientist (1897) expressed the battery capacity in terms of the rate at which it is discharged, as the rate increases, the battery's available capacity decreases) *(Doerffel and Sharkh, 2006)*. Equation (4.7) will be used to calculate the battery life time at n=1 for Freescale practical data *(Povalac and Ligertwood, 2012)*. Table 4.1 shows the data required and calculation of the numbers of hours of coin battery as compared with free scale data, where theoretical battery life equals 887 hours and the number of hours that is provided by Freescale data sheet was 848 hours.

Table 4.1 Comparison between Calculated and Measured Battery Lifetime

Characteristic	Value
Peukert's exponent "n"	1
The Battery capacity	220mAH,
The standard load current which is used for transmission and reception	0.2 mA
The load current that is used due to sleeping and idle states	0.048 mA,
The total current	0.248 mA.
Theoretical Battery Life (in Hours)	220 mAH / 0.248 mA= 887 hours,
The number of hours that is provided by Freescale data sheet	848 hours.

The theoretical battery life value shown in the table will increase if the load current is reduced in value which reflects less battery power consumption *(Gears, 2009)*.

4.2.3 Mathematical Modeling of Battery Characteristics

An optimized mathematical formula has been proposed for battery characteristics in which it represents the voltage decaying (battery power consumption behavior) as a function of time, where a 4th degree order polynomial has been proposed for this purpose as shown in Equation (4.8).

In this research work curve fitting technique has been to predict the formula that fits the practical data, where all coefficients have been calculated using Freescale, and Farnell battery practical data for this purpose at different loads, which shows a good fitting between the practical data and the proposed 4th degree order polynomial.

$$V_{out} = a_0 + a_1 t^1 + a_2 t^2 + a_3 t^3 + a_4 t^4 \qquad (4.8)$$

Where a0, a1, a2, a3, a4 are coefficient constants that could be evaluated with the aid of practical values of battery operation using any regression or curve fitting technique. In this study, MatLab has been used for this purpose. Equation (4.9) shows the polynomial formula that fits Freescale data.

$$V_{out} = 3.16 + 0.00309\, t^1 + 1.125E\text{-}5 t^2 - 1.36E\text{-}8\, t^3 + 4.255\, E\text{-}12\, t^4 \qquad (4.9)$$

Curve fitting of Farnell practical data at 15k ohms with the polynomial equation represented in Equation (4.10). While Equation (4.11) represents the curve fitting formula of Farnell practical data at 7.5k ohms.

$$V_{out}=3.292 -0.0012\, t^{1}-2.464E\text{-}6t^{2}+8.92E\text{-}9\, t^{3} - 6.3E\text{-}12\, t^{4} \quad (4.10)$$

$$V_{out}= 3.292 -0.0015\, t^{1} + 1.32E\text{-}5t^{2} +4.63E\text{-}9\, t^{3} - 4.17E\text{-}11\, t^{4} \quad (4.11)$$

Equation (4.10) has been used within MatLab Program to simulate the battery voltage decline and the resulted values will be saved in the neighboring table, since it suits our simulation condition.

4.3 Coordinator Location Effects in Routing Protocol

In section 2.4 ZigBee devices were classified in three different categories, a coordinator that initiate the transmission, routers that build up routes between nodes and an end units which considered as final destination. ZigBee was manufactured according to specific application where each network required at least one coordinator to initiate the network operation in which a personal area network identifier (PAN ID) will be assigned and routes will be established to communicate among the different nodes of the network, therefore the coordinator considered the most important device in ZigBee network which has the ability to store nodes information and mange network routes.

Although, the location of ZigBee coordinator plays a significant role in design and routing performance; most published papers did not concentrate in this issue and researcher's interest was on network topology *(Al-Gabri et al., 2014)*. In this section an extensive evaluation study has been performed to study the impact of coordinator location on routing process activities from different aspect:

- The distances between the coordinator and all nodes.

- The number of surrounded routers to the coordinator that could be surviving through routing process.
- Appropriate coordinator location for lifelong batteries by analyzed the battery voltage decaying.
- The impact of coordinator location on AODV and PS-AODV process that generate communication with less power consumption and have a shortest route to the distention which leads to less delay in route request and route maintenance.

These aspects were taken into account during the design of ZigBee mesh network with proper coordinator location that could sustain PS-AODV protocol. The following steps were followed to choose the suitable location for coordinator location:

1- Two different networks were analyzed; the first where the coordinator was located at the center of the network, and the second where the coordinator was located at the corner of the network while each network represent a different scenario.

2- Each network had two different route connections; the work depends mainly on AODV as a routing protocol that communicates between routers and broadcast packets to destination and PS-AODV routing protocol used for the same purpose.

3- Analyzed results based on graphs for the two network were discussed intensively using voltage decline curves to mentoring the battery lifetime, energy map to determine the survive routers, neighboring table which have battery power level and shortest path that have active routers.

4- Choosing the best results that achieve our aspects that have been mentioned above.

4.4 Proposed PS-AODV Routing Protocol

In this section, the phases of a proposed PS-AODV routing protocol discussed and explained in detail. Firstly, explain the power management scheme, secondly give details of the development and updates of the neighboring table. Finally, demonstrate the dynamic path switching with an example.

4.4.1 Power Management Scheme

Since ZigBee node batteries have been the core objective of this research work, a power management scheme will be one of the phases in the proposed protocol that could facilitate the increase in network life. Firstly, a voltage decaying formula used to estimate the battery capacity requirements and study the expectation of battery lifetime for ZigBee-based nodes. The decline of 50% of battery voltage capacity will be used as a power level threshold (1.6 Volts). Finally, has been discussed the avoidance of nodes that didn't have enough power to participate in routing process (less than 1.6V as explained in section 3.2.3).

4.4.2 Neighboring Table

The neighboring tables for each node contain information about other neighbor nodes in one hop transmission, the neighboring table used is already defined in ZigBee specification, where each node can collect and store the environmental information and communicate with neighboring nodes to support PS-AODV multi hop routing. The information contents of neighboring table are the identifier of network's personal area network (PAN), networks addresses, device types, and nodes extended addresses. In this research work, some additional information included, the distance between neighboring nodes and nodes battery voltage level. Initially each node has assigned with maximum power of battery level and it is updated periodically per each information transmission. The distance used by Dijkstra's algorithms to estimate the cost of the shortest paths in route discovery process in order to use it in forwarding the packet during transmission. Table 4.2 shows neighboring table fields.

Table 4.2 Neighboring Table Fields

Node ID	Neighbors ID	Distances	Battery voltage level

4.4.2.1 Efficient Neighbor Selection

Neighbor's node which has enough power for transmitting the packets from source to destination will be selected, and this is the key approach used in this research work, this strategy has been adopted on one hop neighboring table information which has many advantages especially when focusing on the remaining voltage value in node batteries, whenever a node voltage decline in value will be prevented or isolated from the participation in route discovery process and will be discarded from the neighboring table, the efficient neighbors with better status of battery voltage will be selected.

The route discovery process begin the coordinator broadcasting RREQ message to the next neighbor's node after checking its neighbors for batteries voltage level from its neighboring table. The reverse path will be setup automatically, by recording the address of the active neighbors in routing table from which it received the RREQ packet. It is clear that, by using neighbor's table information the flooded of RREQ messages will be reduced and the paths well be coming always from trusted nodes that acts in active routes all the time. Thus the route should be optimized for improved lifelong network.

4.4.3 Dynamic Path Switching

Finding the path between source and destination is one of common challenges in communication networks that routing algorithms and protocols face. The path should be always short and exist in any case of network, it means in case of path failure an alternative second shortest path provided to the network.

As we have mentioned in previews section the node that didn't have enough energy will be discarded from the neighboring tables for the nodes, then RERR message will be sent if this node in the first shortest path lose its energy and the periodic hello messages are used to maintain a list of neighbors in the neighboring table. The path must serve fewer delays, and the cost for the path maintain continuously by using Dijkstra's algorithm with aids of refreshed neighboring table without explicit route discovery process. Figure 4.1 shows the flow chart for switching path when the first path failed, and the necessary steps which required for increasing the network life time.

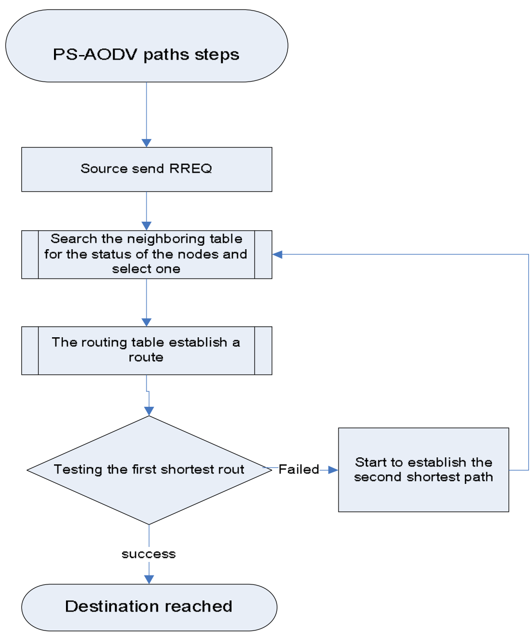

Figure 4.1 Flow Chart Dynamic Path Switching.

Figure 4.2 shows an example of broadcast process and switching path where node 1 (ZC) will broadcast message to node 5 (ZED), when node 2 (ZR) receives the message and check its neighboring table for destination node, if it is exist in the neighbor table, the routing table will establish a route and deliver message to node 5 (ZED), as seen node 2 is an intermediate node which has enough battery power to do its job to be part of the route to destination 1- 2- 5, if node 2 fails to be part of the process due to battery problems, a second shortest route will take place either 1-4-5 route or 1-3-5 route.

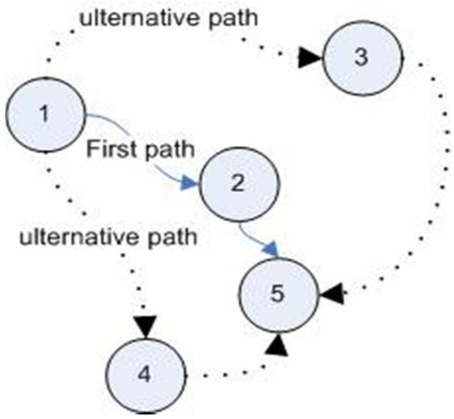

Figure 4.2 Path Switching Technique.

Taking into consideration the main difference of path length, the long paths are more vulnerable to breaking and require a high control and maintenance.

4.5 Summary

This chapter introduced the most important phases in PS-AODV routing protocol in detailed and provided a discussion of the primary development in neighboring table and switching paths with aid of Dijkstra's algorithm for shortest path. The development depends on the fact that the neighbor table contains information about the battery power status for each node besides saving the distances in meters between nodes, and the information is updated from time to time, this feature could help the selection of the node with proper battery power and avoid using node goes down that node could disturb the transmission and could lead to looping process which will exhaust node battery.

Also, this chapter explained the details of the study of ZigBee nodes power management along with mathematical modeling of battery characteristics that optimized battery voltage decaying formulas that used in PS-AODV protocol to analyze ZigBee node battery characteristics and behavior. In addition, analyses steps of effects of coordinator location in routing protocol and network lifetime have been introduced in order to estimate the appropriate coordinator location in designing ZigBee mesh networks.

Chapter 5

Simulation Process and Results

5.1 Introduction

This chapter presents and discusses a wide range of results of inclusive simulation process to evaluate the performance in two routing protocol (AODV and PS-AODV), and their impact on ZigBee network performance and operation for two different kinds of networks. Firstly, an introduction of simulation software and flow chart of Matlab code structure and steps were introduced followed by the evaluation metrics that performed to analysis the system; Finally, an analysis of the results were presented with intense discussion.

5.2 Simulation Software

In this research work, Matlab® commercial software version R2013b *(Mathworks, 2015)* has been used to implement and simulate AODV routing protocol in ZigBee Mesh network. The simulation performed on hp® PC, Intel® Core™ i3 CPU, M380 2.53GHz, RAM is 3 GB to implement the routing process activities from different aspect of the problems assigned. Many factors have been taken into consideration which played big part in the assigned scenarios.

The choice of MATLAB was made because of its powerful features and flexibility enough to adjust the variables and network parameters, where the concluded results were comparable to real situation results in ZigBee network technology. MatLab was more reliable and suitable for this kind of research work, since MatLab has features of high-level language programming and its interactive environment that help scientist and engineers to come across solutions to problem with adapting programming language. MatLab is used widely for science disciplines of algorithms development, modeling energy consumption, data analysis and visualization *(Etter and Kuncicky, 2011)*. Also, MatLab has powerful graphic tools that visualize graphs in both 2D and 3D dimension, which represents the most important tools in this research work, where Graph Theory Toolbox has been used to simulate ZigBee mesh network and visualize the shortest route using Dijkstra's algorithm, the goal to simulate (PS-AODV) discovery process and maintenance. Also MATLAB programming code has been written to research battery power consumption in ZigBee mesh network, and an optimized formula has been created which has been implemented in AODV routing protocol to evaluate discovery process and maintenance that establish links between routers and share information about best route and neighbor nodes.

5.2.1 Simulation Scenarios and Assumptions

The proposed mesh network was composed of 1 (ZC), 6 (ZR) transceivers and 8 (ZED) as implemented in *(Hammoodi et al., 2009)*, each node was recognized by specific color for the purpose of illustration, AODV will be selected as routing protocol in the proposed algorithm. Due to the constrains of laptop CPU speed, the number of transmission was limited to 20000 transmissions; each transmission time is assigned to be 0.02 seconds for a total transmission time of 400 seconds until a shortest path will be established, during all this process, the battery power for each node will be calculated using an optimized formula related to section 4.2.3. The complete simulation input data and parameters have been organized according to OPNET software package procedures of designing ZigBee networks, through the process of selecting the attributes of each node in the network *(Hammoodi et al., 2009)*. The input data were presented in Table 5.1.

Table 5.1 ZigBee Network Parameter.

Parameter	Value
Network scale size	Fixed area (600×600 m).
Type of Technology	ZigBee / IEEE 802.15.4
Network Topology	Mesh network
Routing Protocol used	AODV Routing Protocol
Operating Voltage Range	3.292 -1.65 Volts
Power Supply	Power supply for Coordinator and Coin battery for end units and routers
Threshold	1.6 Volts
Frequency	2.4 GHz
Number of Bits per packet	2000 Bits
Modulation type	On/ Off Keying Modulation scheme
Transmit power	0.01w
Received power	- 60 dbm
No. of Nodes	one coordinator, six routers and 8 end units

5.2.2 Evaluation Metrics

The metrics used during this research includes the following:

1- Network Lifetime: The numbers of dead nodes (inactive) where its voltages decline to less than 50% of its original values, this process could be achieved during less time due to the facts that an update of battery voltage strength will take place periodically in the neighboring table in PS-AODV, this process of voltage decline could be detailed in energy map where voltage values were represented in colors to indicate remaining voltage per each node in terms of voltage initial value. Also, the percentages of live and dead nodes which present the number of transmission that could be achieved before the first node die in the network.

2- End to end delay: is defined as the time required for packets to transfer from the source to destination. This includes all possible delays affected route discovery and route maintenance latency.

5.2.3 Simulation Steps

Simulation process has been carried on and applied precisely for the purpose of achieving best results as planned, the steps are summarized in Figure 5.1:

- *Step 1*: Input data shown in Table 5.1 were selected, tabulated and applied collectively on two different scenarios of ZigBee mesh network, the first scenario of mesh network with the coordinator located at the center of the network and the second scenario for a network with the coordinator located at the upper left corner of the network for a span area of 600m x 600m.
- *Step 2:* Run two version for each two scenarios the first version using AODV routing Algorithm without modification, only each node will be equipped with battery that provides an operating voltage of 3.2 Volts. MatLab code is designed to show battery threshold voltage of the all node. The second version after using our proposed algorithm will be analyzed after the modification added to the Algorithm related to section 4.4.
- *Step 3:* Simulation results show a variety of plotted graphs and tables using the assigned metrics for two different kinds of networks topology with different coordinator location.
- *Step 4*: Test results were analyzed for both scenarios of the first and second version, power management and switching path were added to the program for the purpose of updating the neighboring table in order to select a second route if the first route fail.

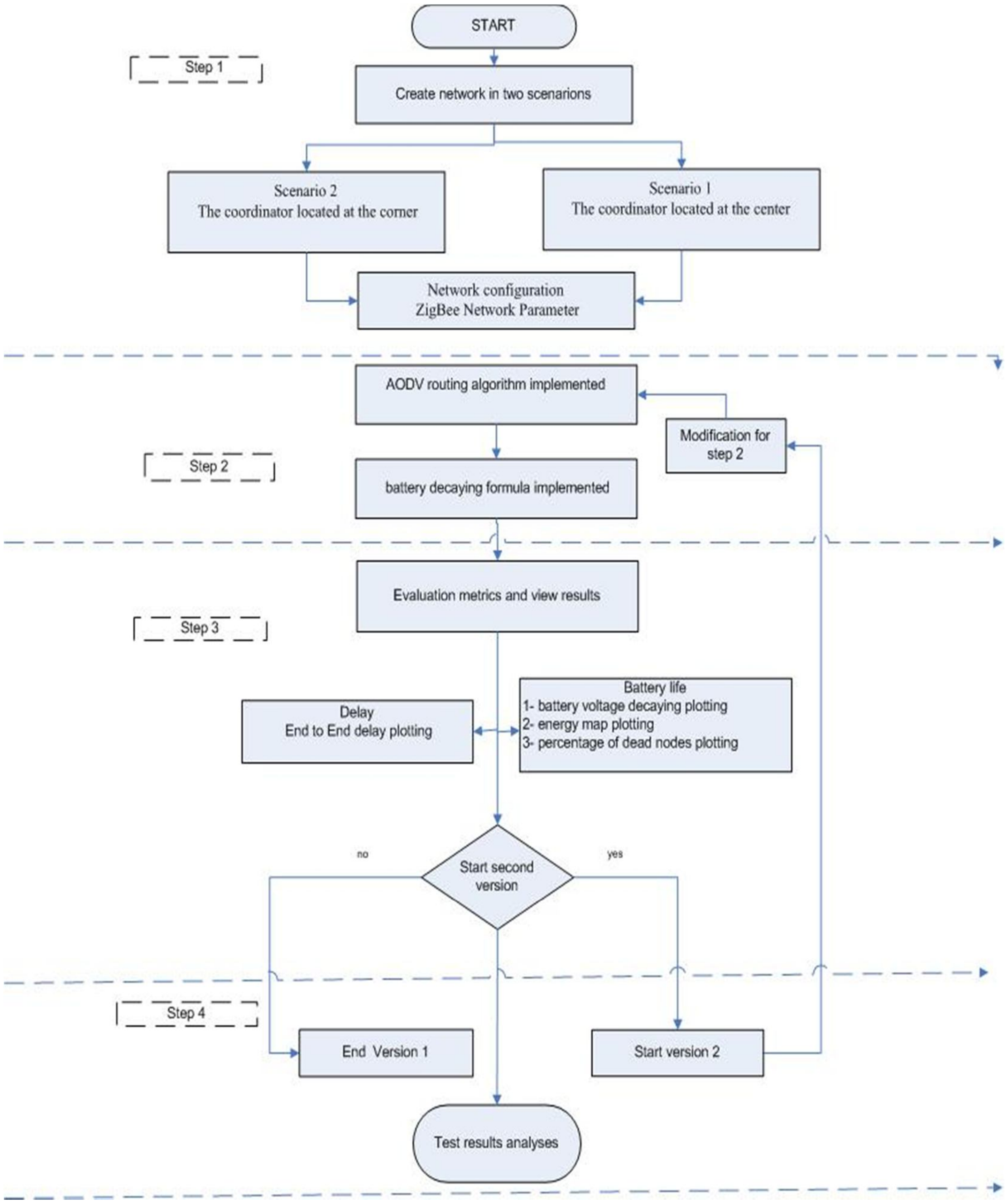

Figure 5.1 Implementation structure & steps.

5.3 Simulation Analysis and Results

The simulation results that illustrate the impact of using two scenarios for different locations of the coordinator in ZigBee mesh networks, with two version of AODV routing protocol implementation, will be analyzed and results are detailed in the following sections.

5.3.1 The Coordinator at the Center of the Network (Scenario1)

The first mesh network where the coordinator in red color located at the center of the network surrounded by 6 routers in green color, then surrounded by 8 end units in yellow color as shown in Figure 5.2.

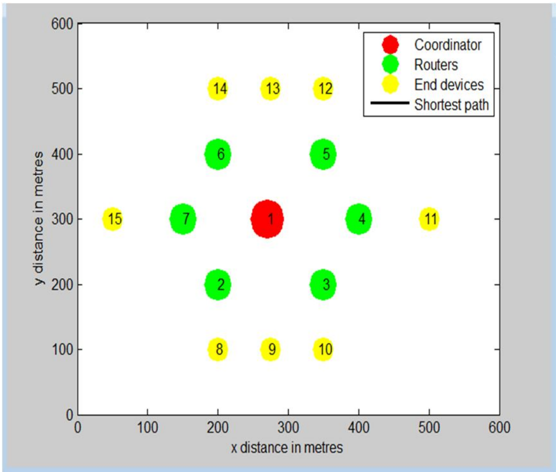

Figure 5.2 First Scenarios the Coordinator in the Center.

5.3.1.1 First Scenario Networks using AODV Routing Protocol (Version 1)

Version 1 is the case study of the shortest route establishment using AODV routing when broadcasting packets to destination will start, during this process there will be no changes to the neighboring table updates, and as communications between routers continue, some of the router battery voltages will start getting exhausted through routing discovery process until shortest route to destination will be achieved and a link will be connected between coordinator and destination, the whole process is shown in Figure 5.3, as seen the mesh network has its coordinator positioned at the center of the network surrounded by 6 routers which is considered as the first hop, then surrounded by 8 end units, where node number 8 is the destination where the black line represent the minimum hop account (shortest path), where the packets will be broadcasted to all nodes, until the route 1-2-8 will be established.

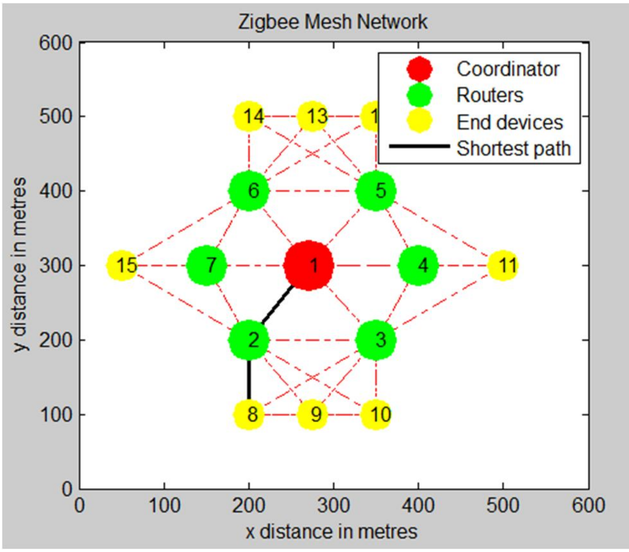

Figure 5.3 First Scenario Networks using AODV Routing Protocol (Version 1).

During all this process, the battery power for each node will be calculated through discovery routing process as shown in Figure 5.4. As seen in figure, node 1 is the coordinator where its voltage remain intact because it is powered by power supply, node 2 is the first node for the shortest route, its voltage decayed more than other nodes, since it participated in routing discovery process, the destination which is node 8 will suffer less decay since it is an end unit don't work hard like routers. Routers 3, 4, 5, 6, 7 will suffer more decay in its battery voltage due to the participation in relaying packets during routing process, which support the connection between source and destination during route discovery process. AODV routing protocol is used to provide maintenance and discovery routes for all routers. Nodes numbers 9,10,11,12,13,14,15 suffer less decay in battery voltage since they are end units operate less than routers. The complex part of using AODV routing algorithm that select the route based only on the minimum hop account (shortest path) whatever the status of the power battery for the nodes especially the routers. In Figure 5.4 node 2 has been exhausted its battery power since it has been used for 1^{st} shortest route connection, its voltage value reduced less than the threshold value this condition was considered a boundary for non-active node and a service is required for these node, also the voltage decline was heavily for nodes 3, 4, 5, 6, 7 their voltage values always become close to threshold value (1.6 V) after a period of time which may will suddenly interruption paths and caused failure or data drops.

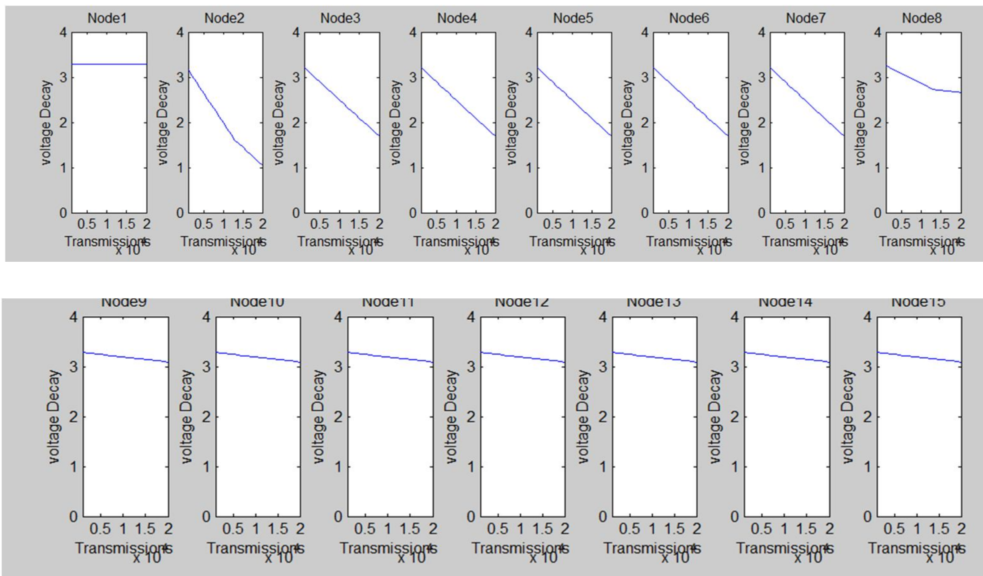

Figure 5.4 Version 1: Voltage Decaying for All Nodes using AODV Routing Algorithm.

Figure 5.5 represents the energy maps for all nodes in the network; each color has its own battery percentage of the maximum battery voltage (3.3 V), where the legend on the figure shows the percentages values, for example the pink color for routers nodes has 60% left of its battery voltage and could be calculated as 60% x 3.3 V= 1.98 V.

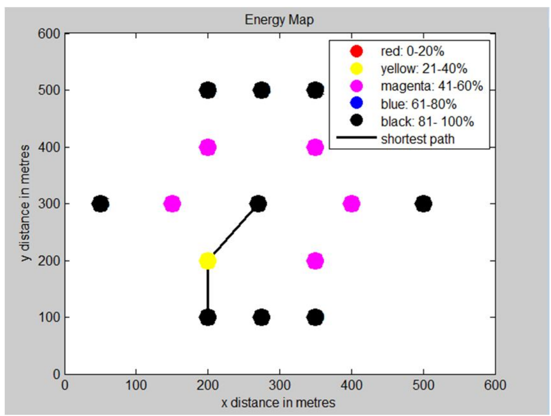

Figure 5.5 Energy Maps for all Nodes in Version 1(scenario 1).

Figure 5.6 and Figure 5.7 represent percentage of live and dead nodes during of broadcast of 20000 transmissions of version 1 when the coordinator in the center, as seen at the end of transmitting 12000 transmission 15% nodes became dead and only 85% nodes are left alive.

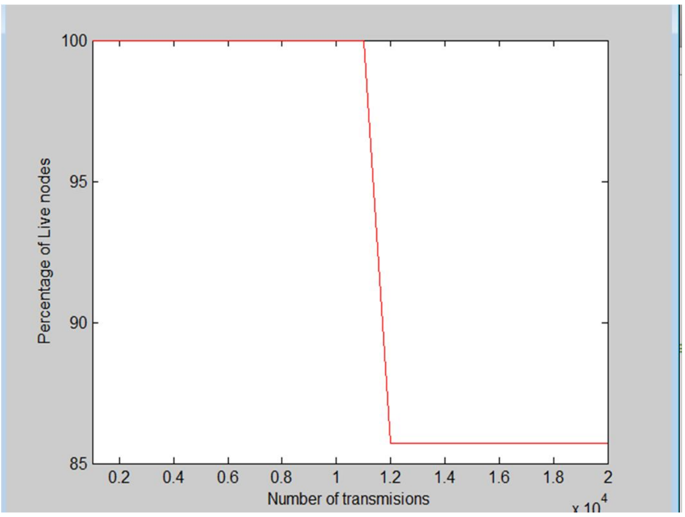

Figure 5.6 Percentages of Live Nodes in Version 1(Scenario 1)

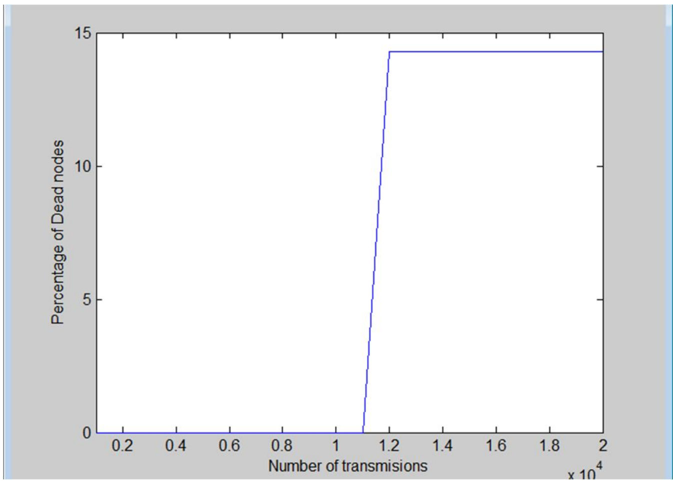

Figure 5.7 Percentages of Dead Nodes in Version 1(Scenario 1)

5.3.1.2 First Scenario Network using PS-AODV (Version 2)

Since the main objective of this research work is to reduce battery power consumption and increase network lifetime, a modification has been carried on AODV protocol which depends on power management scheme, updates of the neighboring table with batteries voltage decaying and dynamic path switching as mentioned in section 4.4. The previous steps in section 5.3.1 were repeated using proposed PS-AODV for the same scenario networks shown in Figure 5. 2.

Version 2 the case where the first shortest route fails to reach its destination due to battery voltage decline, a second route will be established to reach its destination to achieve its goal, during all this process a neighboring table will be created which contain all distances between nodes and power remaining in batteries, that updating periodically as a function of transmission as shown in Figure 5.8.

Command Window

'NODE'	'NEI'	'DIS'	'ENERGY'
[1]	[2]	[122.0656]	[3.2920]
[1]	[3]	[128.0625]	[3.2920]
[1]	[4]	[130]	[3.2920]
[1]	[5]	[128.0625]	[3.2920]
[1]	[6]	[122.0656]	[3.2920]
[1]	[7]	[120]	[3.2920]
[2]	[1]	[122.0656]	[1.6383]
[2]	[3]	[150]	[1.6383]
[2]	[7]	[111.8034]	[1.6383]
[2]	[8]	[100]	[1.6383]
[2]	[9]	[125]	[1.6383]
[2]	[10]	[180.2776]	[1.6383]
[2]	[15]	[180.2776]	[1.6383]
[3]	[1]	[128.0625]	[2.3329]
[3]	[2]	[150]	[2.3329]
[3]	[4]	[111.8034]	[2.3329]
[3]	[8]	[180.2776]	[2.3329]

Figure 5.8 Snapshots from the Neighboring Table in Version 2.

The coordinator starts initiating the operation of the ZigBee network using PS-AODV routing protocol to provide communication between routers, since it has the capability of discovery process and maintenance. Figure 5.9 shows both routes, the route with black line is the first shortest route, and the blue route is the second shortest route. As seen in the Figure, the route link is the same as for the previous case but with better performance when node 2 battery power is getting down, if the battery voltage of node 2 reduced below the threshold value which is 1.6 V, the first shortest will fail and dynamic switching to second shortest route will be established through router number 3. Table 5.2 shows the distance in meters for the first, second and some other different routes that used by Dijkstra's algorithm for switching first and second paths.

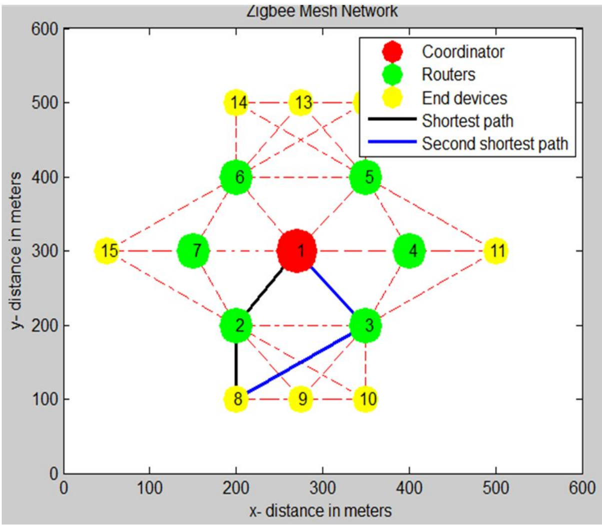

Figure 5.9 Version 2 Dynamic Switching Path in Scenario 1.

Table 5.2 1st, 2nd, and other Routes Distances Calculated in Meter (Scenario 1)

Node	**Distance**
1-2	122.0656
2-8	100
Sum	222.0656 (First Route)
Node	**Distance**
1-3	128.0625
3-8	180.2776
sum	308.3401 (Second Route)
Node	**Distance**
1-2	122.0656
2-3	150
3-8	180.2776
Sum	452.3432 (Other Routes)

Figure 5.10 represents the voltage decaying of all nodes as a function of packet transmission for the Version 2. The Comparison between voltages of nodes 4, 5, 6, 7, in Figure 5.4 of version 1 using AODV and the same nodes in Figure 5.10 of version 2 using PS-AODV was noticeable, the improvement was 0.4 V in which the nodes voltages of version 2 voltage was 2.2 V while the nodes voltage of version 1 was 1.8 V, gives a difference of 0.4 V, which reflect gains of 20%. Nodes 2 and 3

voltage declines more due to its participation in routing process, node 8 voltages will decline little more since it has been used for both routes.

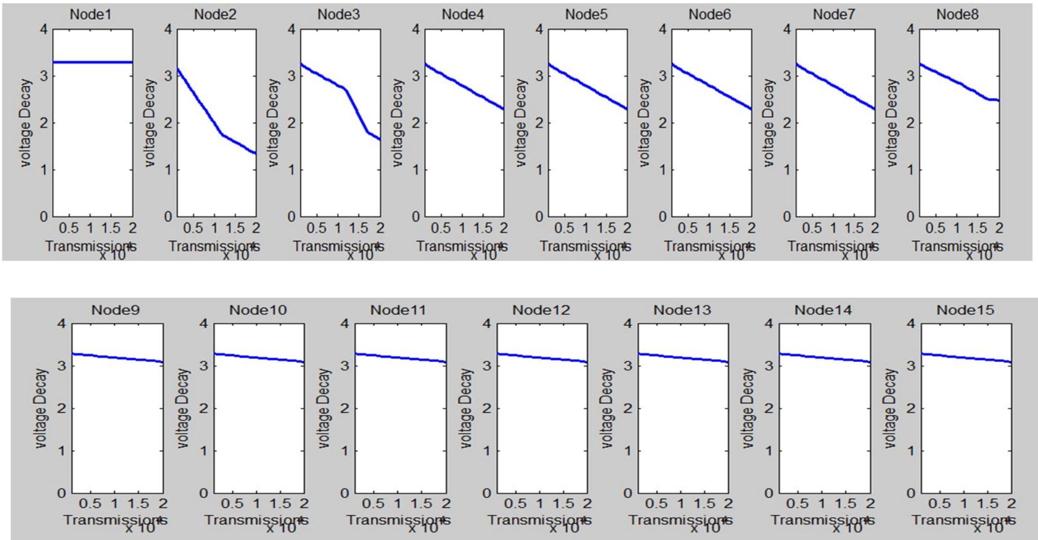

Figure 5.10 Version 2: Voltage decaying of all Nodes as a Function of Packet Transmission.

Figure 5.11 shows the energy map for version 2 and Figure 5.12 represent the percentage of live nodes during transmission of version 2 where 85% of nodes stay alive when it reaches 14,000 transmissions, due the fact that each node can collect and store the environmental information and communicate with neighboring nodes that support route discovery process in PS-AODV, the live nodes after that will be reduced to 72% by the end of transmission process. Figure 5.13 shows the opposite in term of dead nodes.

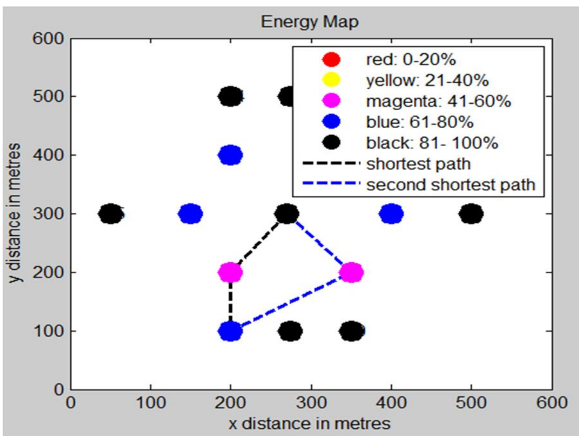

Figure.5.11 Version 2: Network Energy Map for (Scenario 1)

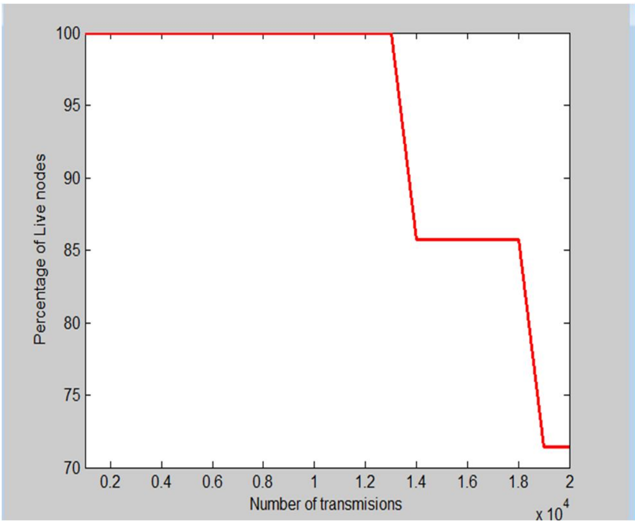

Figure 5.12 Percentages of Live Nodes of Version 2

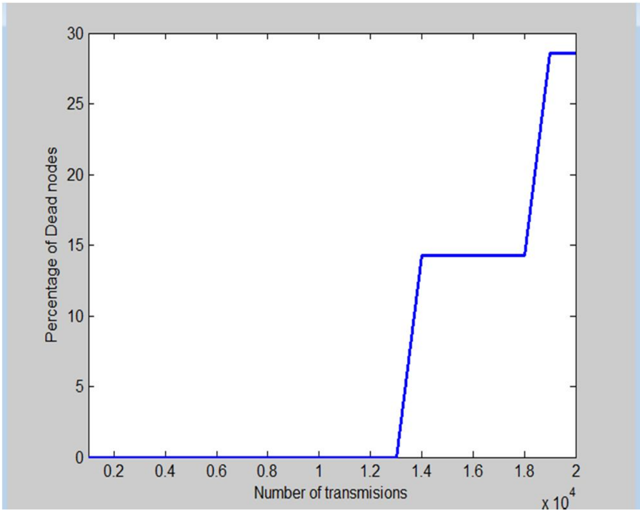

Figure 5.13 Percentages of Dead Nodes for Version 2

5.3.2 The Coordinator at the Corner of the Network (Scenario 2)

The same description as mentioned in section 5.3.1 will be carried in to the network where the coordinator is located at the corner of the network as shown in Figure 5.14.

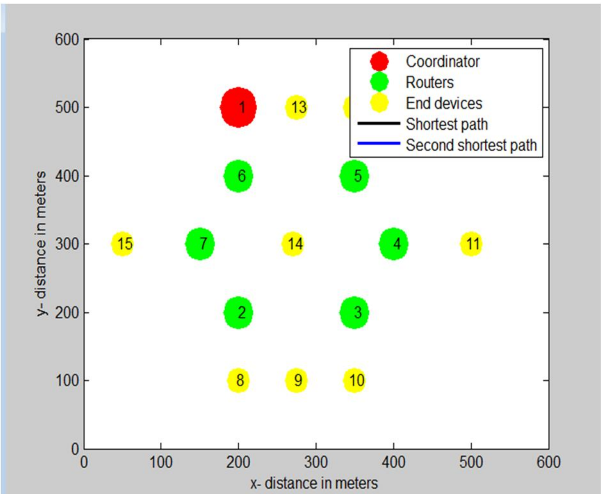

Figure 5.14 Second scenario the Coordinator is Located at the Corner of the Network.

5.3.2.1 Second Scenario Networks using AODV Routing Protocol (Version 1)

The black line in the Figure 5.15 shows the shortest route connection (1-6-7-2-8) using AODV routing protocol, the route connection starts from the coordinator (node 1) through route 6 (first hop), router 7(second route), route 2 (third route) until it reaches its destination at end unit node 8. As seen the shortest route is long, AODV routing process passes through 4 hops until it reaches its destination.

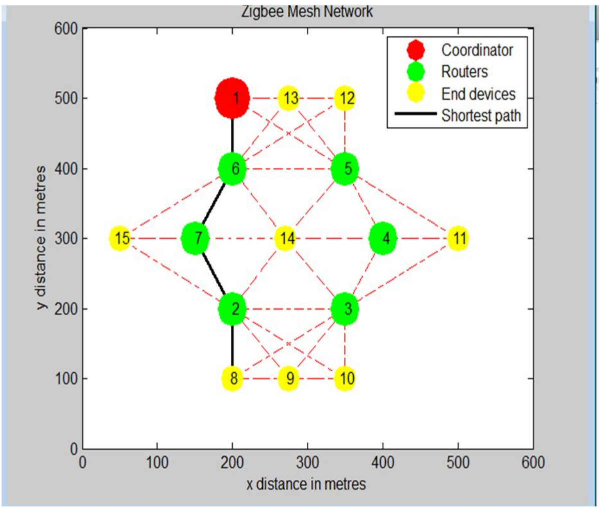

Figure 5.15 Second Scenario Networks using AODV Routing Protocol (Version 1)

Figure 5.16 shows the results for voltage decline as a time for the second network where the coordinator is located at the corner of the network, as seen coordinator (node 1) voltage remains unchanged due to the fact that its voltage supplied by power supply, and due to many broadcast by the coordinator using AODV protocol, the voltage decline was heavily for nodes 6, 7, 2 and their voltage values went below threshold value (1.6V) as shown in Figure 5.17 which was considered a boundary for non-active nodes and a service is required for these nodes. The other nodes suffer small voltage decline since its participation in routing was limited.

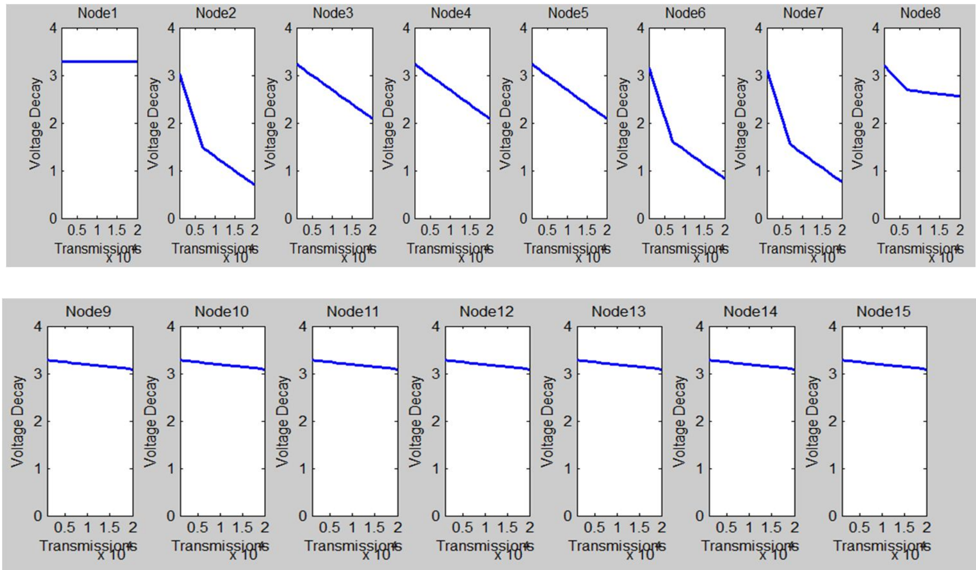

Figure 5.16 Version 1: Voltage Decaying for All Nodes using AODV Routing Algorithm (scenario 2)

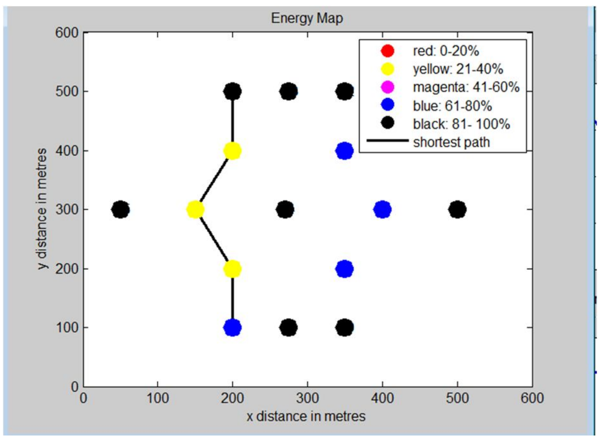

Figure 5.17 Energy Maps in Colors for all Nodes in Version 1(scenario 2).

Figure 5.18 and Figure 5.19 represents percentage of live and dead nodes during of broadcast of 20000 transmissions of version 1 at the coordinator in the corner, as seen at the end of 8000 transmission 45% nodes became dead and only 55% nodes are left alive.

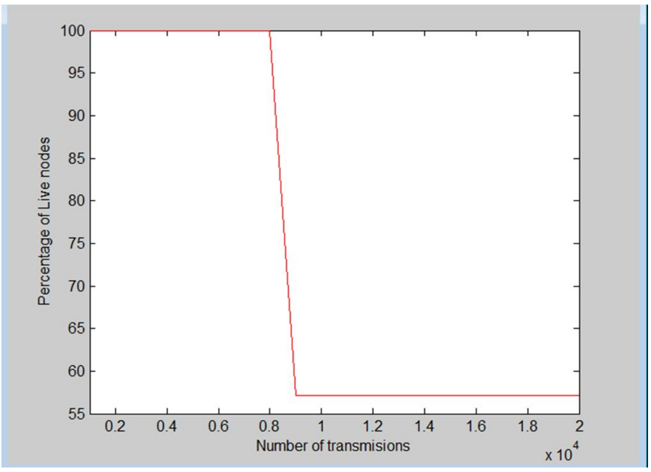

Figure 5.18 Percentage of live nodes in version 1(scenario 2)

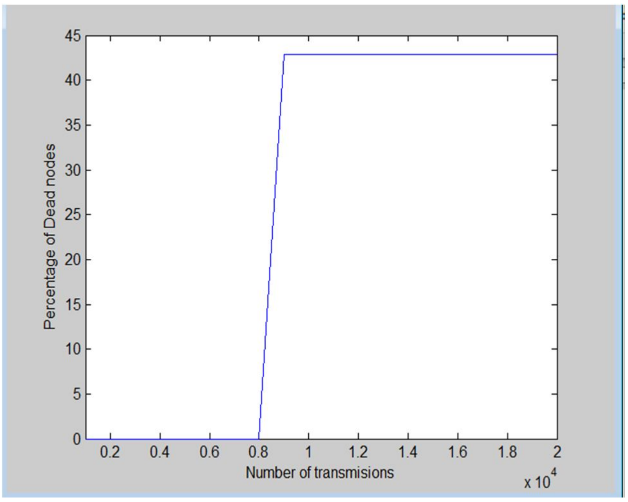

Figure 5.19 Percentage of dead nodes in version 1(scenario 2).

5.3.2.2 Second Scenario Networks using PS-AODV (Version 2)

The previous steps in section 5.3.2 were repeated using proposed PS-AODV for the same network shown in Figure 5.14. In Figure 5.21 a route connection was established (1-6-7-2-8) as represented by a black line which is the first shortest route, the route link is the same as for the previous case (Figure 5.15) with better performance when node 6 battery power is getting down, if the battery voltage of node 6 reduced below the threshold value which is 1.6 V, the first shortest will fail and dynamic switching to second shortest route will be established as represented by a blue line through router number 5, a modifications added to the program to establish a second route connection using Dijkstra’s algorithm for shortest path (1-5-4-3-8), in case the first shortest route fails, as seen the second route is longer and both routes spanning through 4 hops .Table 5.3 represent the 1st, 2nd and other route distances.

Figure 5.20 shows the battery voltage decline for this case, the coordinator voltage remain unchanged because its voltage supply coming from power supply, nodes 2, 6, 7 voltages were better than the previous case (Figure 5.16) by 20% of voltage value (the same procedure of voltage analysis and calculation will apply for the second network as shown in section 5.3.1.1 and 5.3.1.2), node 8 suffer little decline also since it is an end node and does not participate in routing process. Nodes 3, 4, 5 has some voltage decline since the process carried out after the second shortest was established.

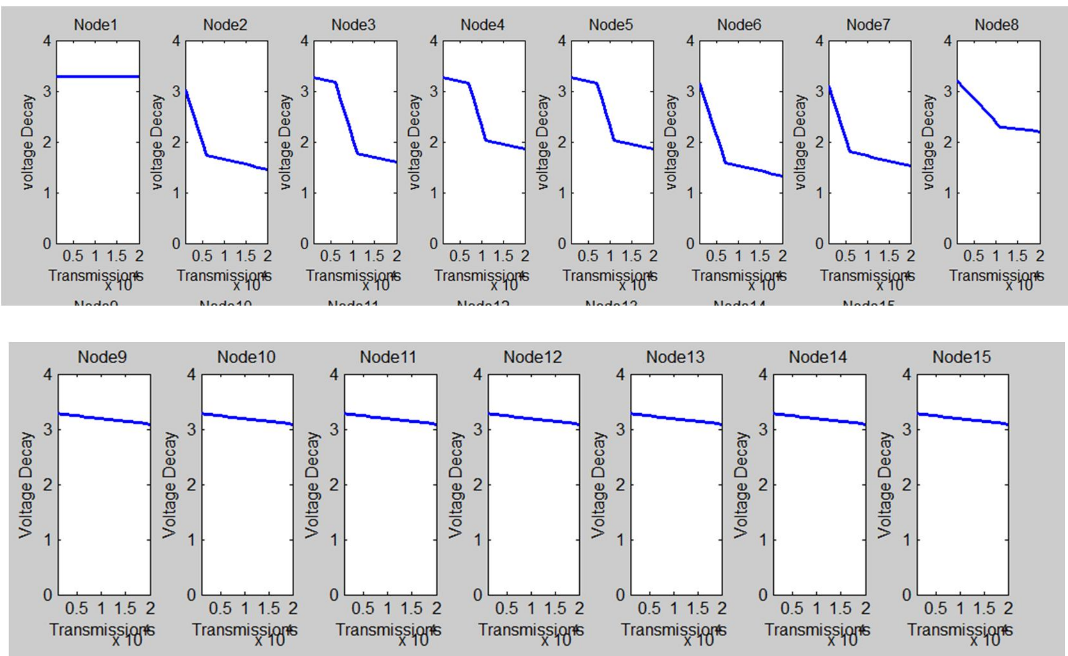

Figure 5.20 version 2: Voltage Decaying for All Nodes using PS-AODV in Scenario 2.

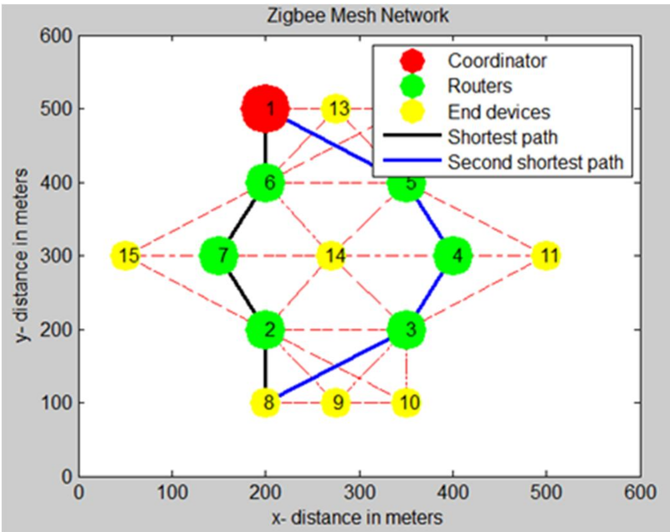

Figure 5 .21 Version 2 Dynamic Switching Path in Scenario 2.

Table 5.3 1st and 2nd Routes Distance Calculations in Meters (Scenario 2).

Node	Distance
1-6	100
6-7	111.8034
7-2	111.8034
2-8	100
Sum	423.6068 (First Route)
Node	**Distance**
1-5	180.2776
5-4	111.8034
4-3	111.8034
3-8	180.2776
Sum	584.16 (second route)
Node	**Distance**
1-6	100
6-5	150
5-4	111.8034
4-3	111.8034
3-8	180.2776
Sum	473.081 (Other Routes)

Figure 5.22 shows the energy maps for all nodes after the 2nd shortest path takes place, the legend show the percentage of remaining voltages in different colors and Figure 5.23 shows the percentage of live nodes and since the route is

longer, the live nodes reduce rapidly at 9000 transmission to 55%, then it will stay at this level until the end of the simulation process. Figure 5.24 shows the opposite for dead nodes.

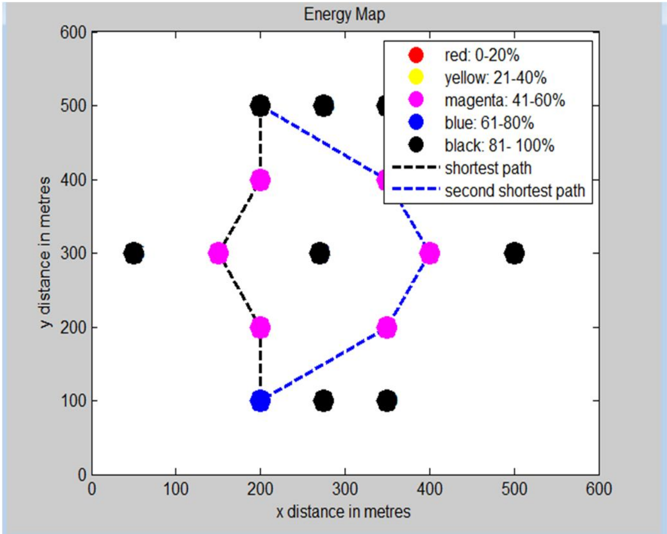

Figure 5.22 Network Energy Map for (version 2) Coordinator in the Corner.

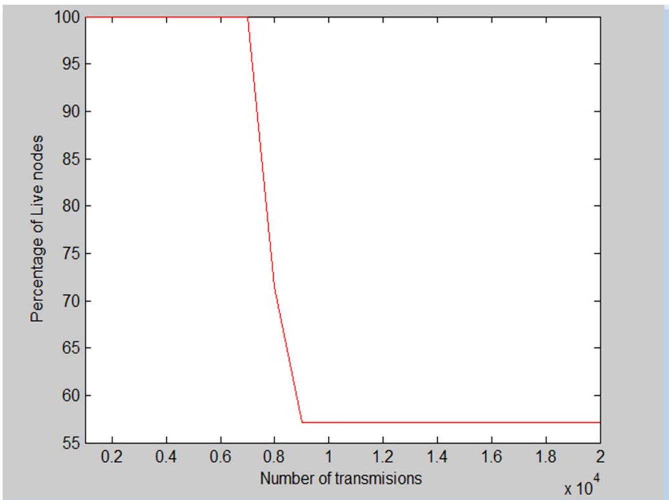

Figure 5.23 Percentages of live nodes for version 2

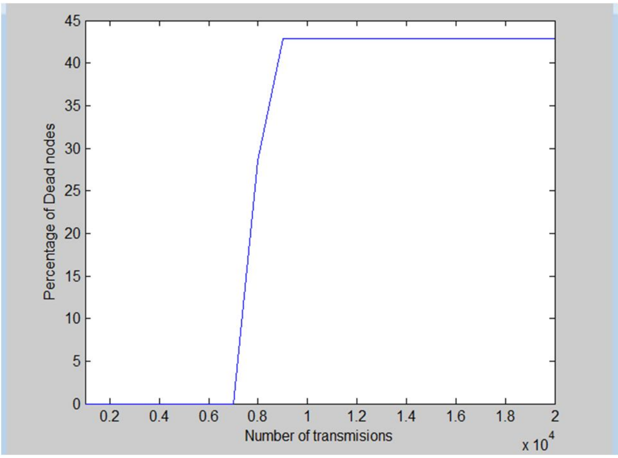

Figure 5.24 percentages of Dead Nodes of Version 2

5.4 Summary/Observation

In this chapter the simulation results are analyzed and discussed, two scenarios with two different coordinator positions were researched to study the necessary metrics and steps that could support the establishment of a connection between source and destination. The two different routing protocols were implemented a well-known AODV and PS-AODV in each scenarios to evaluate their performance dependent the main metrics that are considered in this chapter in order to achieve planned goal to extend battery lifetime and reduce power consumption by introducing a power sensitive routing algorithm. PS-AODV was great success using these metrics to build 1st and 2nd shortest route between the coordinator and end unit, since distances between nodes and voltage decline was updated in neighboring table during transmission process of packets and switching fails paths. The results based on graphs of each protocol, according to the scenario wise observations are given below:

5.4.1 First Scenario (Coordinator at the Center): Voltage Decaying for all Nodes AODV vs PS –AODV

Figure 5.25 shows the results of voltage decline as a function of transmission for first scenario where the coordinator located at the center of the network using

AODV and PS-AODV routing protocols, the red color results represent voltage decline using AODV routing protocol and the blue color results are for the voltage decline using PS-AODV. For the first shortest route (1-2-8) , node 1 (Coordinator) , voltage level remain the same for both cases since its voltage has been provided by a power supply, which keeps the voltage constant since electricity is its main supply, the voltage level of node 2 is 0.5 V more using PS-AODV than using AODV, for node 8, there is slight difference between the red and blue results, and this due to the fact that PS-AODV exhausted node 8 in first and second route in receiving more packets. Node 3 is used in PS-AODV for the second shortest route and which the blue line did not decline fast, in the middle way of the transmission, its voltage was more for apply PS-AODV than AODV shown by the red line. Nodes 4, 5, 6, 7 in PS-AODV the blue line was way better than AODV the red line by 0.4 V, this difference came from the lack of AODV routing process mechanism only gives the shortest path based on the minimum number of hops, which is not sufficient always in route mechanism process. Nodes 9,10,11,12,13,14,15, the voltage looks like the same, since end units operate when needed.

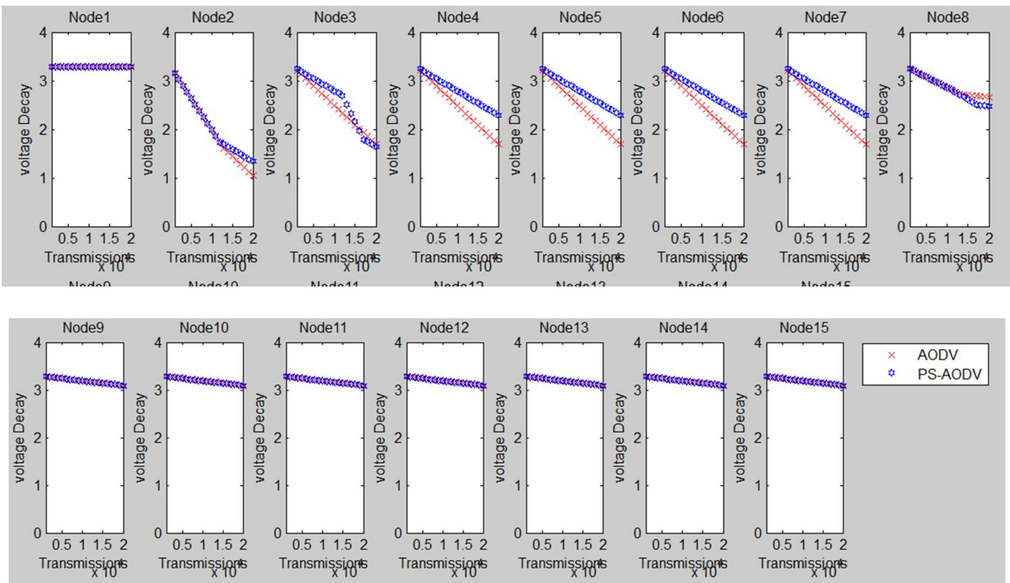

Figure 5.25 Voltage decaying for all nodes AODV Vs PS –AODV in First Scenario.

5.4.2 First Scenario (Coordinator at the center): End to End Delay AODV vs PS –AODV

As seen in Figure 5.26, the delay for link establishment using PS-AODV was better than using AODV routing protocol especially after 14000 transmissions, as shown in section 5.3.1.2, the percentage of living nodes is 85%, since there are 15% of dead nodes and according to the features of PS-AODV there is a better chance for fast connection between source and destination. Accordingly a lower delay will be resulted which produce the lower dip in time delay since it was faster possibility of route establishment which saved 32.7 of delay time compared to AODV, the accomplishment of saving played major part in increasing network life time.

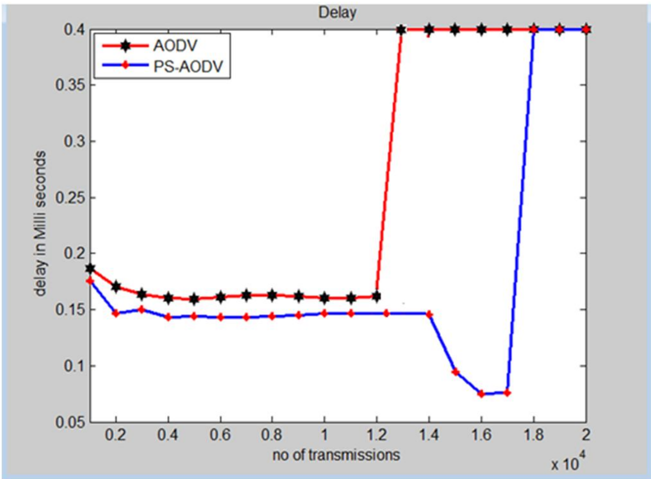

Figure 5.26 End to End Delay AODV Vs PS –AODV in First Scenario.

5.4.3 Second Scenario (Coordinator at the corner): Voltage decaying for all nodes AODV vs PS –AODV.

Figure 5.27 represents the results of voltage decline as a function of transmission for second scenario where the coordinator located at the corner of the network using AODV and PS-AODV routing protocols, the red line results represent voltage decline using AODV routing protocol and the blue line results are for the voltage decline using PS-AODV. The first shortest route represented by 1-6-

7-2-8 route, where the packet will span through 3 hops which is a long distance route. Node 1 voltage for both cases stay the same since its voltage is provided by power supply, router nodes 6, 7, 2, their voltage decline during the application of PS-AODV routing protocol represented by blue line is better than of the AODV. The difference in voltage for both cases is about 0.7 v, that means using PS-AODV routing protocol could consume less battery power and this due to the fact that all nodes voltages are saved periodically in the neighboring table, so during the routing process, less exhaustion will be resulted for the connection link. For node 8, there is slight difference between the red and blue results, due to the fact that PS-AODV process exhausted node 8 twice during both routes.

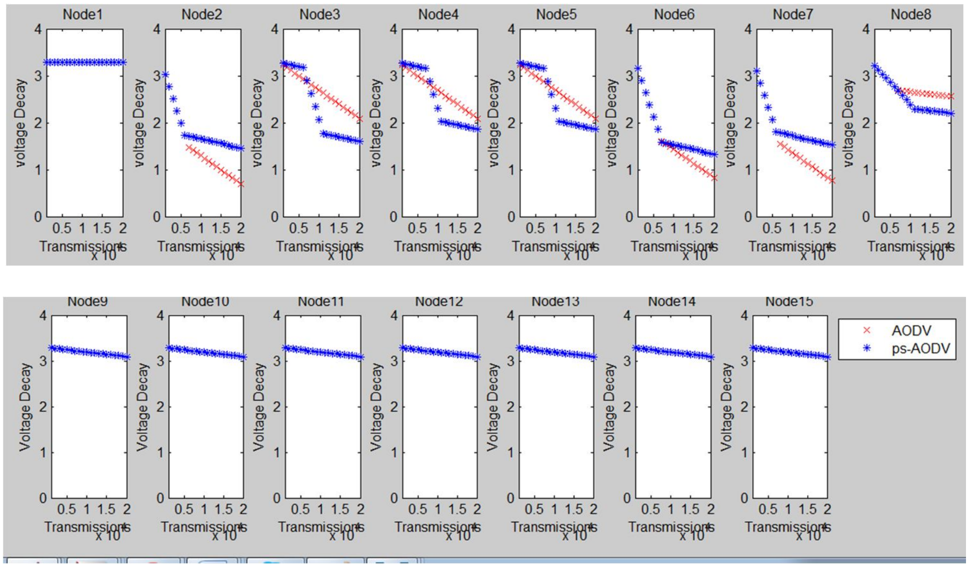

Figure 5.27 Voltage decaying for all nodes AODV Vs PS –AODV in First Scenario.

5.4.4 Second Scenario (Coordinator at the Corner): End to End Delay AODV vs PS –AODV

As seen in Figure 5.28, the delay for link establishment using PS-AODV was better than of the AODV routing protocol especially after 8000 transmissions, PS-AODV algorithms saved about 23.2% of delay time compared to AODV, due to the fact that 43 % of the nodes became inactive, and since the distance is long, the delay was reasonable until 12,000 transmission, which considered as better performance than AODV which provide higher delay after 8,000 transmission.

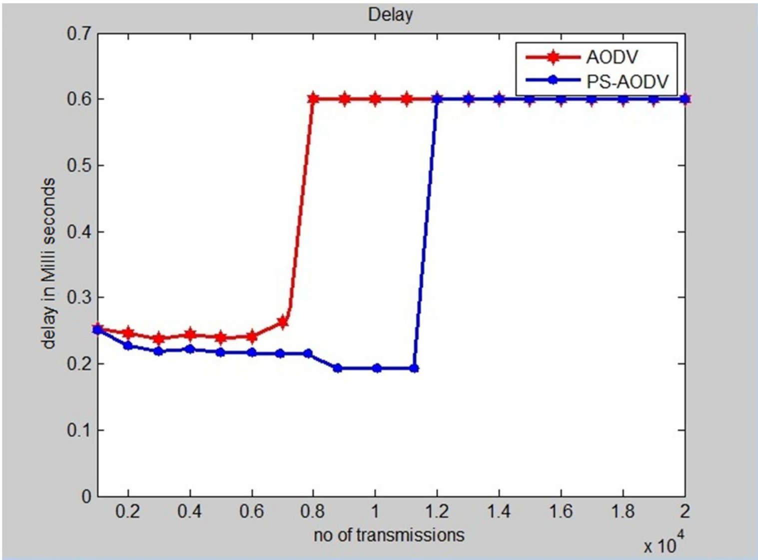

Figure 5.28 End to End Delay AODV Vs PS –AODV in Second Scenario.

Chapter 6
Conclusion and Future Work

The aim of this work was to investigate the several factors; "characteristic of battery nodes, power sensitive routing algorithm, and appropriate coordinator location" that affect and reduce battery power consumption and therefore prolong lifetime of ZigBee mesh networks. In conclusion, our investigation in this research work remarkably achieved the following results:

1- A mathematical optimized formula played a big role in describing battery characteristic and voltage behavior as a function of time. As a result of such the optimized mathematical model, was accurate enough to reflect the minimal difference between the mathematical model values and the practical data; which is considered as a reference to calculate voltage discharge value as a function of time, and the optimize formula could be used by system designers and hardware developers to estimate battery capacity requirements and study the expectation lifetime for ZigBee-based nodes. In addition, a decline in battery voltage below 50% of battery capacity could influence and degrade ZigBee network performance and delay the establishment of routes between source and destination

2- The location of the coordinator within approximate equal distances to all nodes and using PS-AODV routing algorithms is more appropriate for lifelong batteries and routing performance. Also, it is more appropriate for reliable communications between nodes, since the shortest route could be generated fast which lead to fast communication and less power consumption which will lead to save 23.3 % of nodes voltage than the coordinator location on the corner.

3- In PS-AODV algorithm neighboring table considered as the foundation ground that affected the whole process of increasing network life by saving power consumption and reduces path delays. PS-AODV algorithm also, a achieve on an average 20% in network life time better than AODV routing algorithm, that means using PS-AODV routing protocol consumed less battery power, and this due to the fact that proposed protocol. PS-AODV was provided with immense feature using battery threshold value (1.6V) to discard and eliminate the weak nodes that go below the threshold value and update the neighboring table with this information that have decrease the time of route discovery and maintenance.
4- PS-AODV was very efficient using dynamic switching technique to ease looking for the shortest route in very short time with the aid of dijkistra algorithm.

For future work, many factors could be taken into consideration such as scalability, coordinator mobility. Also, security issues can be considered for study because of AODV vulnerable to several kinds of attacks.

REFERENCES

Akyildiz, F., Su, W., Sankarasubramaniam, Y. and Cayirci, E. (2002). **A Survey on Sensor Networks**. Communications magazine, IEEE, vol. 40, no. 8, pp. 102-114.

Al-Gabri, M., Chunlin, L. and Li, L. (2014). **Improving ZigBee AODV Mesh Routing Algorithm Topology and Simulation Analysis**. TELKOMNIKA Indonesian Journal of Electrical Engineering, vol.12, no. 2, pp. 1528-1535.

Ali, A. and Akbar, Z. (2009). **Evaluation of AODV and DSR Routing Protocols of Wireless Sensor Networks for Monitoring Applications**. MSr Thesis, Blekinge Institute of technology, Department of Electrical Engineering with emphasis on Telecommunication, Karlskrona, Sweden.

Aziz, A., Qureshi, A., Soorage, U., Kashif, N. and Hafeez, A. (2012). **Evaluation of ZigBee Based Wireless Sensor Network with Static Sink and Random Sink Mobility**. International Journal of Computer and Electrical Engineering, vol. 4, no. 4, pp. 562-566.

Baronti, P., Pillai, P., Chook, V. W., Chessa, S., Gotta, A. and Hu, Y. F. (2007). **Wireless Sensor Networks: A Survey on the State of the Art and the 802.15. 4 and ZigBee Standards**. Computer communications, vol. 30, no. 7, pp. 1655-1695.

Bi, Y., Sun, L., Ma, J., Li, N., Khan, I. and Chen, C. (2007). **HUMS: An Autonomous Moving Strategy for Mobile Sinks in Data-Gathering Sensor Networks**. EURASIP Journal on Wireless Communications and Networking, vol. 2007, no. 1, pp. 1-15.

Casilari, E., Cano-Garcı́a, J. M. and Campos-Garrido, G. (2010). **Modeling of Current Consumption in 802.15. 4/ZigBee Sensor Motes**. Sensors, vol.10, no. 6, pp. 5443-5468.

Daintree (2010). **Getting Started with ZigBee and IEEE 802.15.4**. Retrieved 28 September, 2015, from www.daintree.net/downloads/whitepapers/ZigBee_primer.pdf.

Dash, S. K. (2014). **ZigBee/XBee Technology**. Retrieved 28 September, 2015, from http://novudux.blogspot.com/.

Dhaka, H., Jain, A. and Verma, K. (2010). **Impact of coordinator mobility on the throughput in a ZigBee mesh networks**. IEEE 2nd International conference on Advance Computing Conference (IACC), pp. 279-284.

Dhillon, P. and Sadawarti, H. (2014). **Impact Analysis on the Performance of Zigbee Protocol Under Various Mobility Models**. International Journal of Engineering Trends and Technology (IJETT), vol. 9, no. 11, pp. 550-562.

Doerffel, D. and Sharkh, S. A. (2006). **A Critical Review of using the Peukert Equation for Determining the Remaining Capacity of Lead-Acid and Lithium-ion Batteries**. Journal of Power Sources, vol. 155, no. 2, pp. 395-400.

Ergen, S. C. (2004) **ZigBee/IEEE 802.15.4 Summary**.

Etter, D. M. and Kuncicky, D. C. (2011). **Introduction to MATLAB**, Prentice Hall.

Fourty, N., Van Den Bossche, A. and Val, T. (2012). **An Advanced Study of Energy Consumption in an IEEE 802.15. 4 Based Network: Everything but the Truth on 802.15. 4 Node Lifetime**. Computer communications, vol. 35, no. 14, pp. 1759-1767.

Gears, (2009). **Battery Basics**, Retrieved 14 December, 2015, From http://gearseds.com/files/determining_battery_cabacity3.pdf

Group, I. M. W. (2003). **Ad Hoc On-Demand Distance Vector (AODV) routing, (RFC 3561)**. IETF-Draft, IETF.

Hammoodi, I. S., Stewart, B. G., Kocian, A., and McMeekin, S. G. (2009). **A Comprehensive Performance Study of OPNET Modeler for ZigBee Wireless Sensor Networks.** IEEE, Third International Conference on Next Generation Mobile Applications, Services and Technologies. pp. 357-362.

Hk. Co.(2011). **Specification for Lithium Battery Model: CR2032** Specs. sheet

IEEE, S. (2006). **IEEE Standard for Information technology-Telecommunications and information exchange between systems-Local and Metropolitan Area Networks-Specific Requirements-Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (WPANs)**

Inc, D. (2012). **XBee/XBee-Pro ZB RF Modules**, Minnetonka: Digi International Inc.

Inc., C. S. (2011). **Power supplies Application Note, Code: 5-F, Revision: 11**.

JennicTechnology, A. N. (2008) **Using Coin Cells in Wireless PANs**.

Kim, T., Kim, S. H., Yang, J., Yoo, S.-e. and Kim, D. (2014). **Neighbor table based shortcut tree routing in zigbee wireless networks**. IEEE, Transactions on Parallel and Distributed Systems, vol. 25, no. 3,pp. 706-716.

Kinney, P. (2003). **Zigbee Technology: Wireless Control that Simply Works**. Communications design conference, pp. 1-7.

Lee, K., Kim, H., Choi, S. and Park, S. (2006). **A Mesh Routing Protocol using Cluster Label in the ZigBee Network**. IEEE, International Conference on Mobile Adhoc and Sensor Systems (MASS), pp. 801-806.

Li, J., Zhu, X., Tang, N. and Sui, J. (2010). **Study on ZigBee Network Architecture and Routing Algorithm**. IEEE, 2nd International Conference on Signal Processing Systems (ICSPS), pp. 389- 393.

Liang, C., Chen, C., Sun, T., Yang, G., Chen, J. and Gerla, M. (2006). **Impact of Node Heterogeneity in ZigBee Mesh Network Routing**. IEEE, International Conference on,Systems, Man and Cybernetics, pp. 187-191.

Malek, A. G., Li, C. L., Liu, Y. C., Liu, Y. P. and Wleed, A. M. (2013). **Performance Analysis of Improving ZigBee Wireless Network Using AODV Mesh Routing Model**. Advanced Materials Research, Trans Tech Publ, pp. 828-832.

Malhotra, J. (2015). **Simulation Analysis of Tree and Mesh Topologies in Zigbee Network**. International Journal of Grid and Distributed Computing, vol. 8, no. 1,pp. 81-92.

Mathworks .(2015**)**. **MATLAB and Simulink for Technical Computing**, Retrieved 14 December, 2015, from. http://www.mathworks.com/?requestedDomain=www mathworks.com.

Mu, J. and Liu, K. (2010). **Effect of Node Mobility and Network Dimension to the Zigbee Routing Method**. IEEE, 6th International Conference on Wireless Communications Networking and Mobile Computing (WiCOM), pp. 1-5.

Narmada, M. A. and Rao, P. S. (2011). **Performance Comparison of Routing protocols for ZigBee wpan**. International Journal of Computer Science Issue (IJCSI), vol. 8, no. 6, pp. 394-402.

Ortiz, A. M., Royo, F., Olivares, T. and Barbosa, L. O. (2011). **Intelligent Route Discovery for ZigBee Mesh Networks**. IEEE, International Symposium on a World of Wireless, Mobile and Multimedia Networks (WoWMoM), pp. 1-6.

Park, S., Savvides, A. and Srivastava, M. (2001). **Battery Capacity Measurement and Analysis using lithium Coin Cell Battery**. Proceedings of the 2001 international symposium on Low power electronics and design, ACM, pp. 382-387.

Paynter, R. T. and Boydell, T. (2005). **Electronics Technology Fundamentals**, Pearson/Prentice Hall.

Peng, Y., Li, Y., Lu, Z. and Yu, J. (2009). **Method for Saving Energy in Zigbee Network**. IEEE, 5th International Conference on Wireless Communications, Networking and Mobile Computing (WiCom'09), pp. 1-3.

Piyare, R. and Lee, S. r. (2013). **Performance Analysis of XBee ZB Module Based Wireless Sensor Networks**. International Journal of Scientific & Engineering Research, vol. 4, no. 4, pp. 1615-1621.

Povalac, K. and Ligertwood, P. (2012) **Low Power Considerations for ZigBee Applications Operated by Coin Cell Batteries**. Freescale Semiconductor, Application Note.

Samundiswary, P. and Bhardwaj, H. (2013). **Performance Analysis of Energy Aware AODV Routing Protocol for IEEE 802. 15. 4 Enabled WSN**. International Journal of Computer Applications, vol. 63, no. 19, pp. 32-35.

Saraswala, P. (2013). **A Survey on Routing Protocols in ZigBee Network**. International Journal of Engineering Science and Innovative Technology (IJESIT), vol. 2, no. 1, pp. 471-476.

Shakya, M., Zhang, J., Zhang, P. and Lampe, M. (2007). **Design and Optimization of Wireless Sensor Network with Mobile Gateway**. IEEE, 21st International Conference on Advanced Information Networking and Applications Workshops (AINAW'07), pp. 415-420.

Shob . S. and Rajeswari, R. (2014). **An Efficient Backbone Aware Shortest Path Selection Protocol in Zigbee Wireless Networks**. International Journal of Engineering Trends and Technology (IJETT), vol. 11, no. 3, pp. 127-132.

Sohraby, K., Minoli, D. and Znati, T. (2007). **Wireless Sensor Networks: Technology, Protocols, and Applications**, John Wiley & Sons.

Sun, J., Wang, Z., Wang, H. and Zhang, X. (2007). **Research on Routing Protocols Based on ZigBee Network**. IEEE, Third International Conference on Intelligent Information Hiding and Multimedia Signal Processing (IIHMSP) pp. 639-642.

Tao, L., Qiao-lin, C., Deng-di, W. and Yan-li, B. (2010). **ZigBee Tree Routing Optimize Based on Energy-Balanced**. IEEE, 2010 Ninth International Symposium on Distributed Computing and Applications to Business Engineering and Science (DCABES), pp. 301-307.

You, P., Huixian, Y. and Sha, M. (2011). **An ACO and Energy Management Routing Algorithm for ZigBee Network**. Information and Automation, Springer, pp**.** 185-191.

Yusuf, O. (2014). **Determination of Optimal Power for ZigBee-based Wireless Sensor Networks**. M.A.Sc.Thesis, Electrical and Computer Engineering, University of Windsor, Ontario, Canada.

Zare, A., Taheri, H., Moghaddam and Nesary, M. (2013). **Using Limited Flooding in on-demand Distance Vector Junior for Reduction Power Consumption in ZigBee Networks**. Mobile communication and power engineering, Springer, pp**.** 103-108.

Zarrabi, H., Al-Khalili, A. and Savaria, Y. (2011). **Activity Management in Battery-Powered Embedded Systems: a Case Study of ZigBee® WSN**. 18th IEEE International Conference on, Electronics, Circuits and Systems (ICECS), pp. 727-731.

Zhang, F., Zhou, H. and Zhou, X. (2009). **A Routing Algorithm for ZigBee Network Based on Dynamic Energy Consumption Decisive Path**. IEEE, International Conference on Computational Intelligence and Natural Computing(CINC'09.), pp. 429-432.