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Investigation and performance optimization of mesh networking in Zigbee

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ABSTRACT

The aim of this research paper is to perform a detailed investigation and performance optimization of mesh networking in Zigbee. ZigBee applications are open and global wireless technology that are 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 Power Sensitive Ad hoc On-Demand (PS-AODV) to develop protocol scheme and methodology of existing on-demand routing protocols, 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, neighbouring 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 centre and the other one at the corner of the networks. The extracted results conclude a better network operation for the coordinator located at the centre with an increase in the network lifetime around 20% percentage, and saved about 32.7% of delay time compare to AODV.

Keywords: ZigBee, Ad-hoc, PS-AODV, WSN, RREQ

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1. Introduction

In this paper, we have developed and investigate performance optimization of mesh networking in Zigbee. 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 [1]. 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 [2]. WSN end nodes are responsible for sensing and reporting to the central processing unit but WSN is constrained in memory, energy and processing speed 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 [3]. 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 [4].

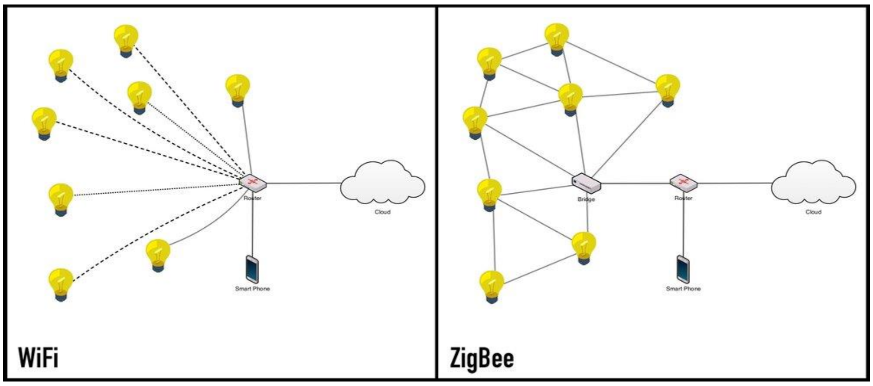

Figure 1. Architectural comparison of two data transmission systems with the network components [4]

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 [5].

1.1. Problem Statement

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. 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.

1.2. Research Contribution

This research work aims 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 optimized routing algorithm for ZigBee Wireless Mesh Networks, and evaluate its performance as well as to optimize it to greater extent.

In this study, we investigate the performance optimization of mesh networking in Zigbee from different aspect:

- The distances between the coordinator and all nodes of mesh network.
- 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 in mesh network.
- 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 optimization.

2. Related Work

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 [6]. 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 [7]. AODV routing protocol discover process is used to maintain links that uses different routing messages.

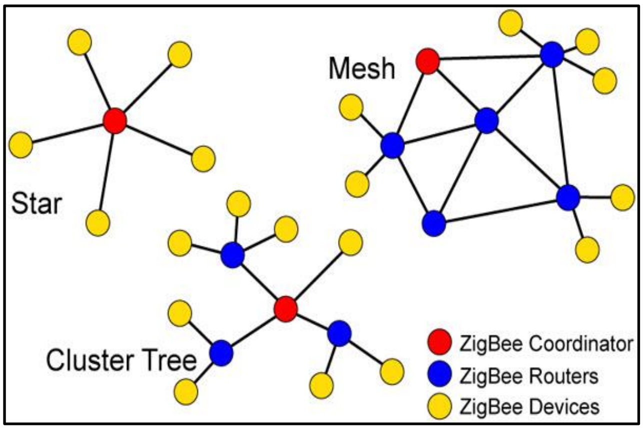

Figure 2. Different types of Zigbee topologies are displayed while Zigbee mesh network is represented on the top right corner [7]

From the previous survey of related work in network power consumption, we have concluded that tree network topology has 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 [8]. 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 [9]. 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.

2.1. Drawbacks of Routing Protocols

Due to the on-demand nature for AODV routing protocol, there are several problems associated to high routing overheads and high packet drop. Also, power consumption issue is one of the main problems that do not fully addressed in ZigBee specification for routing protocol description [10]. 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.
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.
• **Duplicated Messages:** Sometimes intermediate messages have to be forwarded again, that contribute to flood and increase the transmission delay and node battery power consumption.
• **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.

2.2. Zigbee Energy Consumption

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.
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 [11]. 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. Energy consumption for ZigBee tree routing (ZTR) has been proposed which follows the tree topology for transmission and used one hop neighboring table information [12]. Authors lead was to solve the problem of the severe collision of packets, congestion, and network performance degradation [13]. Another research work has been proposed, that based on limitation of flooding in broadcasting of Route Request (RREQ) packets in AODV algorithms, which depends on tree routing aiming to reduce the consumption of power and extend ZigBee network lifetime [14].

3. Methodology

In this research work, 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 section, 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 figure.

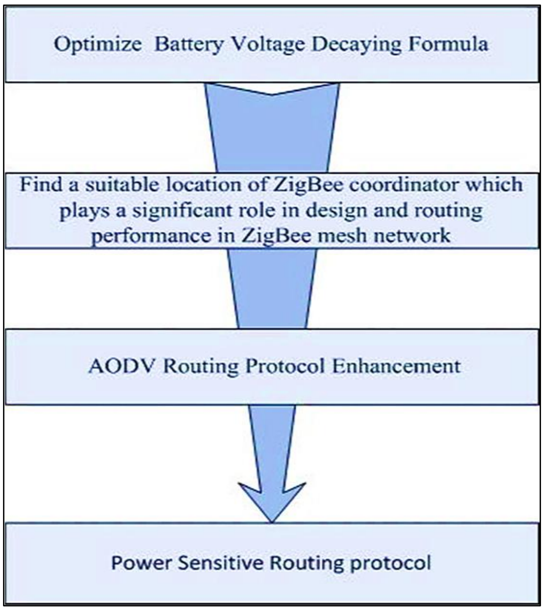

Figure 3. Methodology framework and descriptive methods for the implementation

3.1. 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:

- On line intensive search has been carried on to find coin battery characteristics data, since coin batteries used in ZigBee devices.
- Farnell and Free scale battery datasheets have been selected since the data were clear and the curves are measured at different loads.

- The voltages of the data given were measured in second and for convenience it has been converted to hours.
- Regression technique used for curve fitting the practical data for the purpose obtaining formula that could represent voltage decaying as a function of time.
- Curve fitting done three times for three cases of different loads.
- Three formulas have been concluded as a result of the fitting technique.

3.2. 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:

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, 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.

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.

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 4, where contains the main modification phases that improved AODV routing protocol.

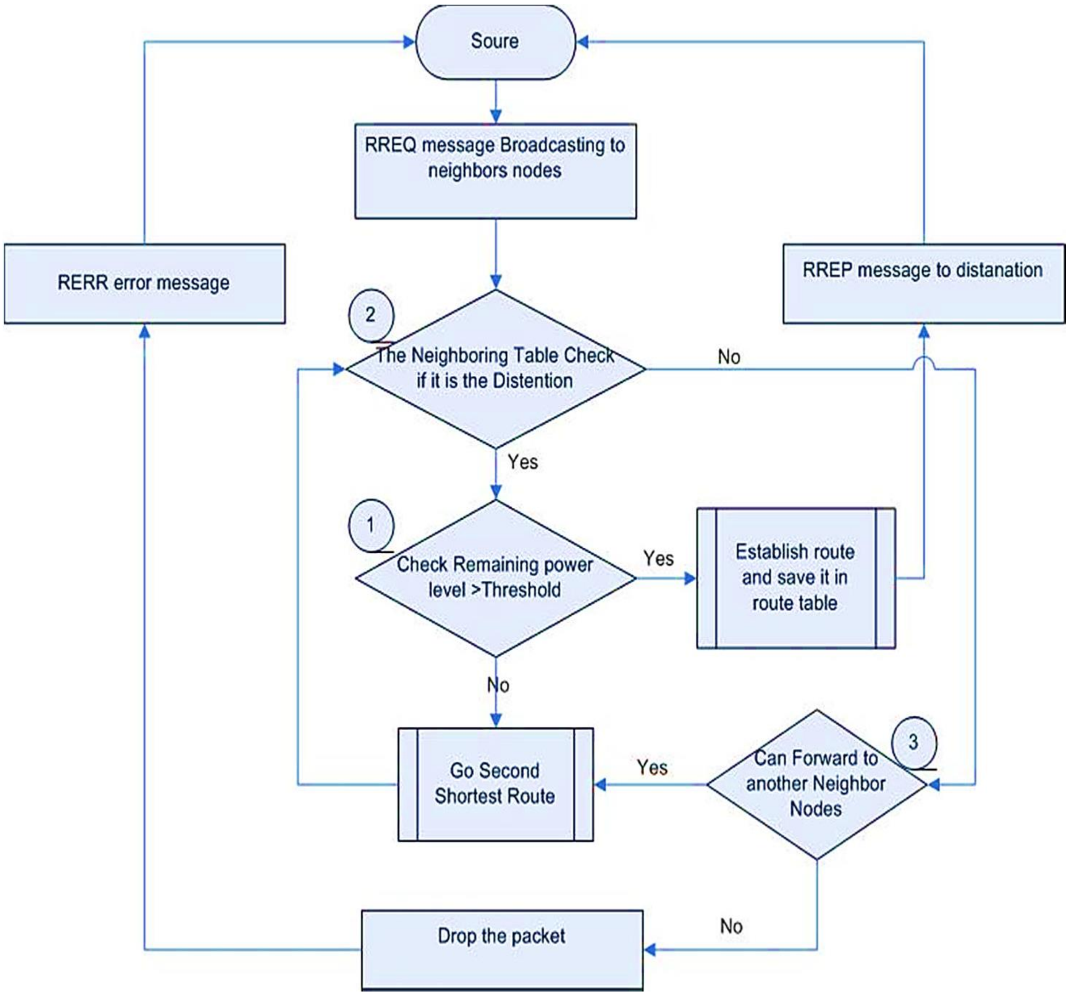

Figure 4. Flowchart of discovery route process for the optimization of mesh network

3.3. Method

3.3.1. Zigbee 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.

3.3.2. Zigbee 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 address, 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.

Table 1: Zigbee neighboring table fields

Node ID	Neighbors ID	Distances	Battery voltage level

3.3.3. Zigbee 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 -- shows the flow chart for switching path when the first path failed, and the necessary steps which required for increasing the network life time.

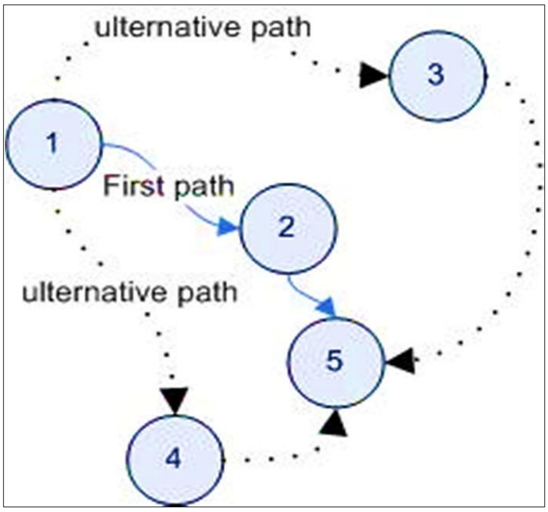

Figure 5. Path switching technique [15]

3.4. Summery

This methodology 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 [15]. 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 paper 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.

4. Results

This section presents 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.

4.1. Simulation Tool

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. 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.

4.2. Performance and Optimization

Since the main objective of this research work is to investigate performance and increase optimization of Mesh networking in Zigbee as well as 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 3.4.

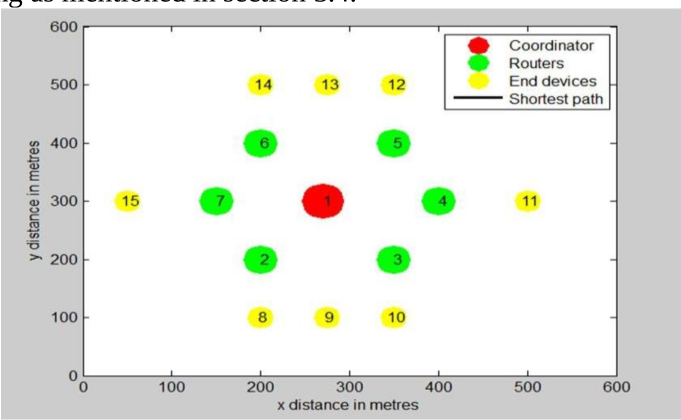

Figure 6. Estanlishment of 15-nodes in a Zibee mesh network

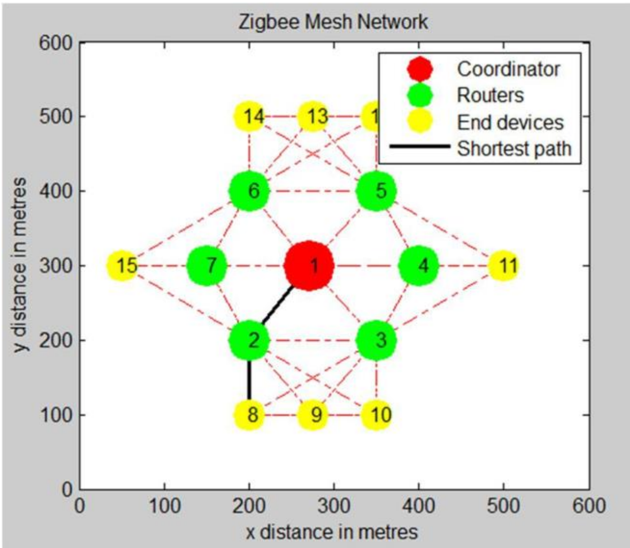

Figure 7. Connecting the nodes and finding the shortest path between the nodes using the algorithm for a proposed Zigbee mesh network using PS-ADOV

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 1st 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.

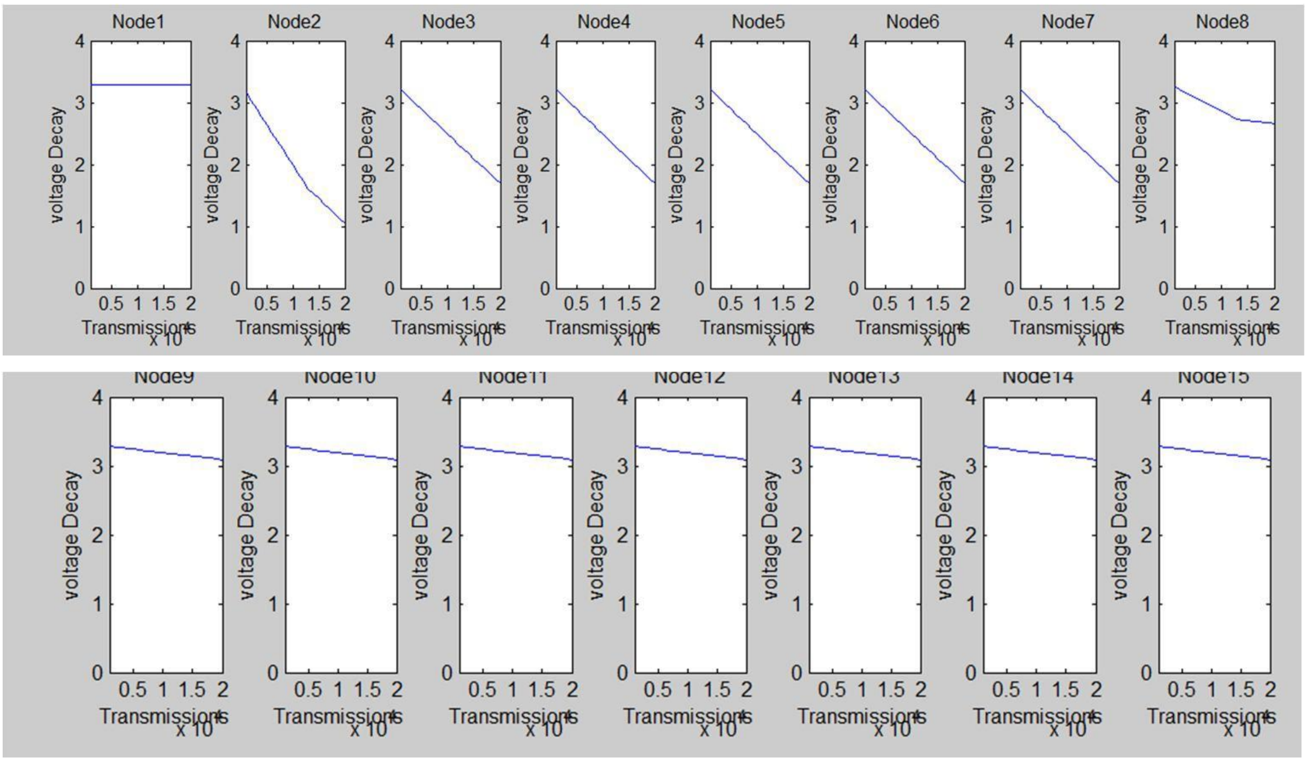

Figure 8. Estimating and deducing the transmission and voltage decay for all the nodes in a Zigbee mesh network

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.

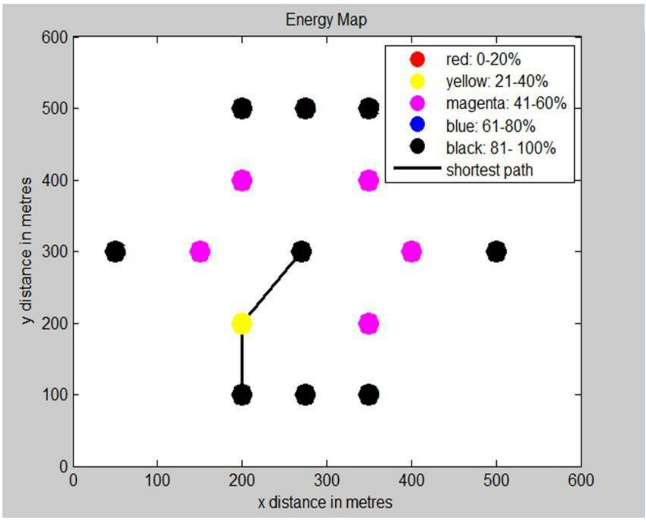

Figure 9. Energy map of Zigbee mesh network for all the 15-nodes with shortest path using PS-ADOV

Figure 10 and Figure 11 represent percentage of live and dead nodes during of broadcast of 20000 transmissions of data and energy 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.

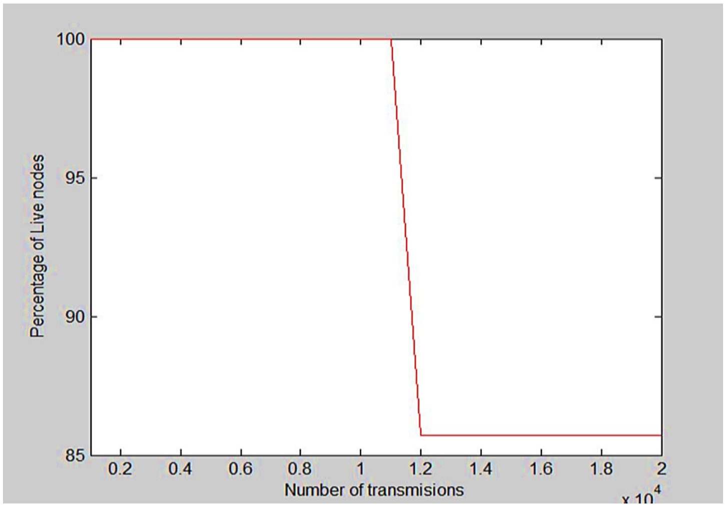

Figure 10. The percentage of live during of the transmission

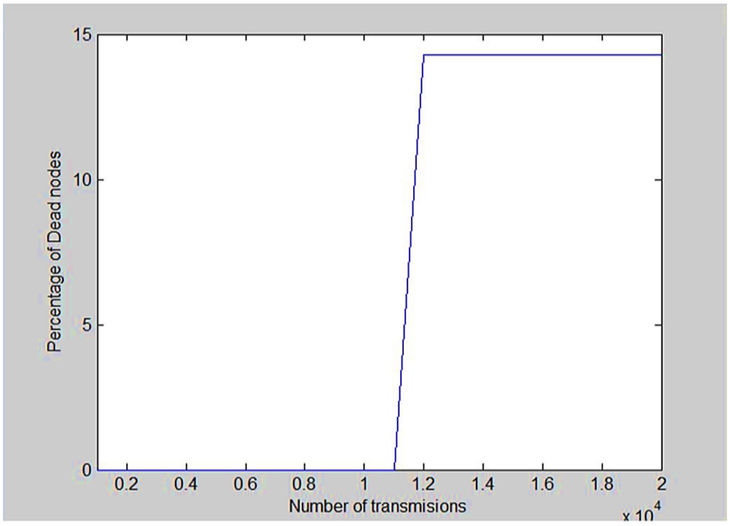

Figure 11. The percentage of dead nodes during of the transmission

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.

'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 12. The neighboring table on the command window of Matlab after the Zigbee mesh network has given an optimized performance in terms of low decay and high transmission

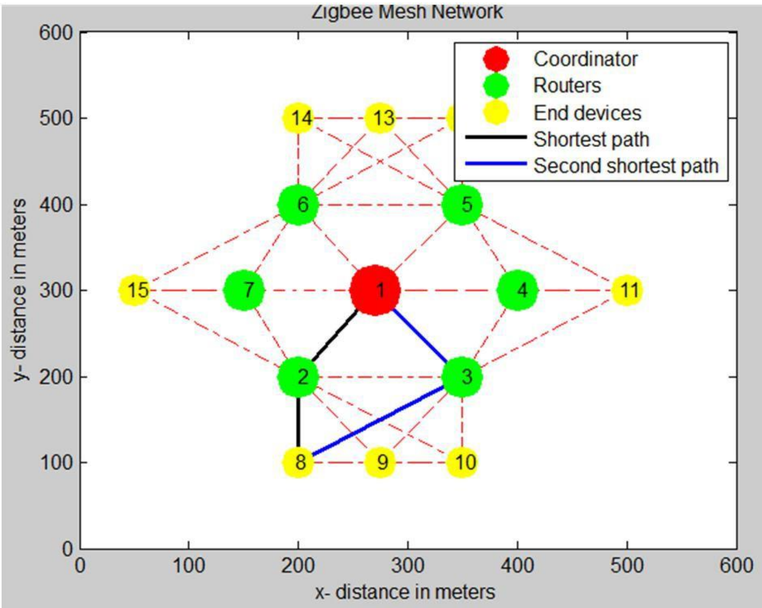

Figure 13. The second optimized shortest path for the Zigbee mesh network with 15-nodes using PS-ADOV

5. Discussion

In this work, we have seen the tests performed to our application. As seen in Figure 14, 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.

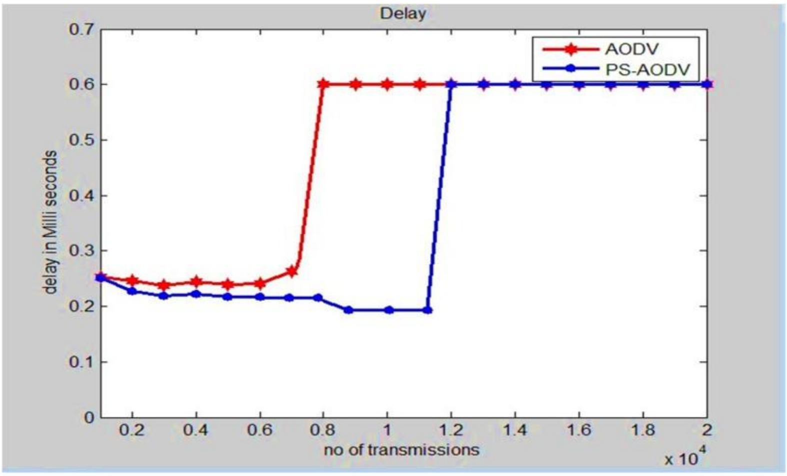

Figure 14. Comparison of transmission delay AODV vs PS –AODV

6. Conclusion

In this paper, the aim of this work was to investigate the performance and increase the optimization of mesh network in Zigbee after considering several factors; "characteristic of mesh network, power sensitive routing algorithm, and appropriate coordinator location" that affect and reduce battery power consumption and therefore prolong lifetime of ZigBee mesh networks. In PS-AODV algorithm neighboring table considered as the foundation ground that affected the whole process of increasing mesh network life by saving power consumption and reduces path delays. PS-AODV algorithm also achieve on an average 20% in mesh 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 optimized 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 optimized the mesh network performance in Zigbee.

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