Effect of Number of Nodes and Distance between Communicating Nodes on WSN Characteristics

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Abstract—Wireless Sensor Networks (WSNs) are increasingly used in many applications. However, issues like topology, routing, energy, nodes distribution and density, and connection reliability are affecting their deployment. In this work, investigation into such parameters using shortest path first routing technique is carried out using MATLAB simulation in free space with ransom uniform nodes distribution. The principle of simulation is to select the best route based on node's location and available energy to carry out data transmission. The investigation proved that as the number of WSN nodes grows, the number of discovered routes grows in a power relationship with the overall time of route discovery, which is accompanied by a decrease in the number of hops per route. The research also showed that as the distance between the source and destination nodes increases, the number of routes identified increases in an exponential relationship, as does the overall route discovery time and the number of hops per route. Also, the simulation results shows that there is a relationship between path loss and both distance, and number of WSN nodes, with exponential relationship between path loss and distance and power relationship between path loss and number of nodes. The work also established a logarithmic relationship between distance and number of WSN nodes. By relating path loss to both distance and nodes, energy consideration is being covered in this work as an indirect parameter that is affected by routes, distance, communication medium and number of nodes. The mathematical modeling indicates that there is a need to dynamically correlate distance between nodes, communication medium, node's energy, and topology to enhance routing of exchanged messages and to enable lower energy consumption.

Index Terms—WSN, routing, hops, path loss, topology, random uniform

I. Introduction

Wireless Sensor Networks (WSNs) increasingly becoming important in many industrial, military, and civil applications, for the purpose of monitoring industrial and manufacturing processes, surveillance process, and medical process and most recently in automotive and traffic management monitoring process. In addition, smart cities and smart homes can also benefit from WSNs, which is part of the ongoing intelligent automation and smart environments [1]-[6].

Locations of WSN nodes is critical in the process of communication and data transmission, as nodes are placed in a uniform random manner, specifically in difficult environments and access critical positions. Thus, WSN nodes deployment is carried out after considering their physical and logical connectivity, coverage, path loss, hops count, energy consumption, and nodes discharging rate among others. So, nodes are selected and placed so that they are able to sense and detect events within coverage range and communicate their data through other nodes to a destination or sink node, such that there is access to the destination or sink node under all conditions with emphasis on each node lifetime. To guarantee coverage and a path to a destination or sink node, an optimum number of nodes in a WSN should be specified [7]-[11].

Energy and power limitations of WSN nodes is regarded as a very decisive factor when choosing nodes deployment and number of nodes, such that paths are available under nodes power fading and energy discharge conditions and nodes lifetime. Thus performance can be affected if optimum number of nodes is not determined with consideration to nodes life time [12]-[16]

Node deployment, data exchange, and energy efficiency are regarded as main challenges to WSN topological deployment. Thus, WSN density is crucial as it affects the WSN performance and energy consumption, which can result in higher power consumption. The distance between WSN nodes and the distance between nodes and sink with their varying transmission rates would end in a power inequality between the nodes. Thus it is natural that some nodes will discharge and fade earlier than others, with other nodes still possess most of their power. Multi-hop process and clustering are used to resolve some of the energy issues [17]-[20].

Sensor node location and deployment topology are important factors in constructing a WSN. Determining node. Position depends on many factors such as, application, construction time, cost, region under consideration. Wireless sensor nodes can be affected to a great extent by node distribution, topology and

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deployment, which can affect nodes life time, transmission reliability and routing approach. A graph model can be used to assess the performance of nodes and to enable better and optimum designs for real world systems. Using graphs, geometric position of vertices and edges in a WSN can be considered with each edge weighted by the distance between its ends [21]-[25].

One of the most important aspects of the WSN's design is its energy efficiency. Providing energy sources or recharging facilities is not always possible because WSN is used in many combative and difficult conditions. The built-in batteries present a challenge to the entire network. Because a few nodes dying due to low battery power might trigger a full network failure known as network partitioning, extending the WSN's existence is one of the most crucial components. WSNs use a variety of energy-saving techniques, and built-in energy technologies and batteries are increasing all the time. The clustering mechanism of the WSN can be employed to save energy. The effect of WSN size and distance between source and destination nodes can be used as part of a design process that supports clustering techniques. Multi-hop wireless networks in general, including WSN, can benefit from energy-efficient routing, as multi-hop wireless networks exchange information among nodes. Effective routing algorithms are required for proper WSN architecture in terms of future growth and energy efficiency [26]-[28].

Important part of WSN nodes localization and energy management is the use of path loss and Received Signal Strength Indicator (RSSI) using radio signals. Such techniques, are affected by topological status and environmental changes, which affect routing and energy consumption in WSN nodes. This relationship can be affective in supporting design of WSN nodes communication including clustering [29]-[30].

Performance optimization of WSN connectivity is approached by different researchers in terms of topology, consumed energy, and routing efficiency. Work is carried that considers mobile nodes in addition to static nodes [31]. The use of mobile nodes affected both distance between sending and receiving node, and routes travelled by the transmitted packets of data. In addition mobile nodes affects the available number of routes for data transmission. The use of mobile nodes positively affected efficiency and energy saving.

Strategic location arrangement is also considered by researchers [32], where WSN is deployed to achieve connection reliability using the shortest path search technique combined with Steiner approximation algorithm to achieve path optimization, thus energy saving and stable connectivity.

Different WSN topologies are researched to establish the optimum efficiency, connectivity, lifetime, [33]. Researchers considered uniform, random, and circular topologies in terms of First Node Dead (FND), Half Nodes Die (HND), Last Node dead (LND) and Cluster Heads (CHs) count. The authors found that uniform and circular topologies have better energy efficiency compared to random topology.

As routing is closely related to energy efficiency and distance between nodes, researchers looked into various routing algorithms and techniques [34]-[35]. Researchers considered optimizing algorithm to protect weak nodes, which has limited transmission capability and low energy. This is carried out through network modeling and energy optimization in relation to WSN infrastructure.

This paper studies effect of WSN nodes density in terms of network coverage and transmission efficiency as a function of available nodes, distance between source node and destination node, and routes.

II. Methodology

Connectivity modeling in WSN networks with random uniform topology is not an easy task, due to nodes trying to preserve their energy and the imperfect radio links between nodes. For a single hop transmission, the condition for successful communication is that the distance between source node and destination node should be less than the transmission radius.

Establishing connectivity within the network is the main objective in WSNs to achieve data transmission. A node can connect to other nodes through direct (single hop) or indirect (multi-hop) path. A WSN can be described as fully connected if all nodes are connected and no node is isolated. Thus the probability of any node to be isolated is a function of the number of nodes within a WSN and a function of neighboring nodes to a node under consideration. In addition, each node needs to have at least N number of neighbors in order to have N chances of being connected.

The approach here is to investigate through MATLAB simulation the effect of WSN density on network connectivity, and efficiency. The MATLAB simulation of random uniform WSN nodes is carried out to achieve three objectives:

1. To investigate effect of WSN nodes density on routes discovery time.
2. To study effect of number of WSN nodes on discovered routes (route length, maximum hops)
3. To correlate path loss to distance between source node and destination node.

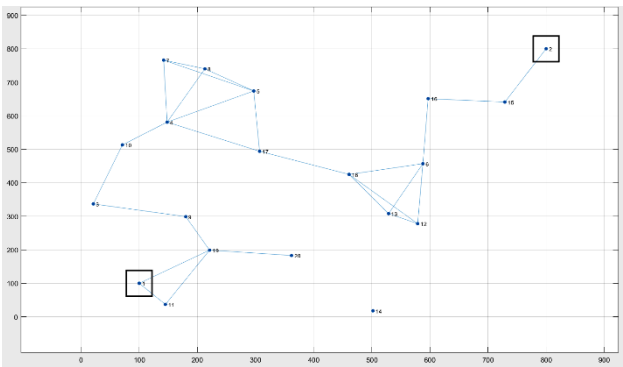

Fig. 1. 20 Nodes WSN random uniform topology-Initial State

The simulated topologies for objectives (1) and (2) are shown in Figures 1 to 10, while objective (3) is presented in Figures 11 to 20 where the figures show the initial state and the final state for each topology, with data sent from node 1 to node 2.

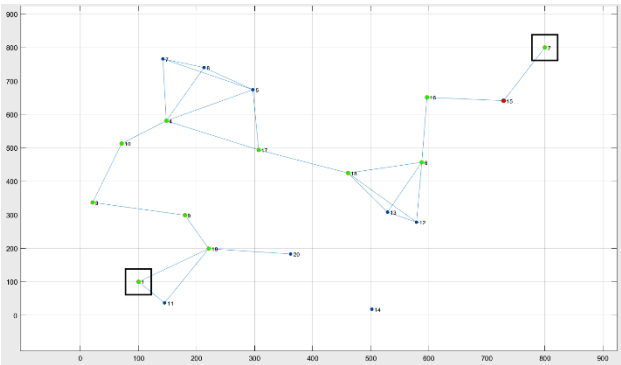

Fig. 2. 20 Nodes WSN random uniform topology-Final State with Red node indicates that this path is no longer available

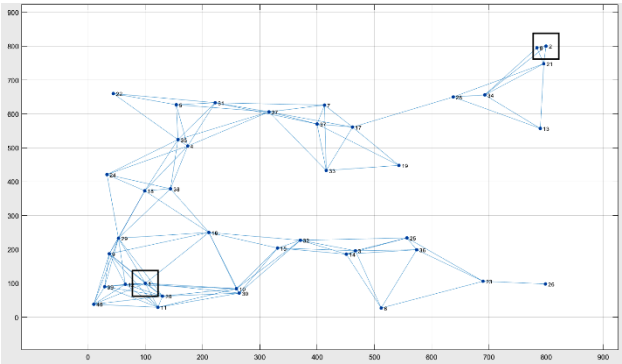

Fig. 3. 40 Nodes WSN random uniform topology-Initial State

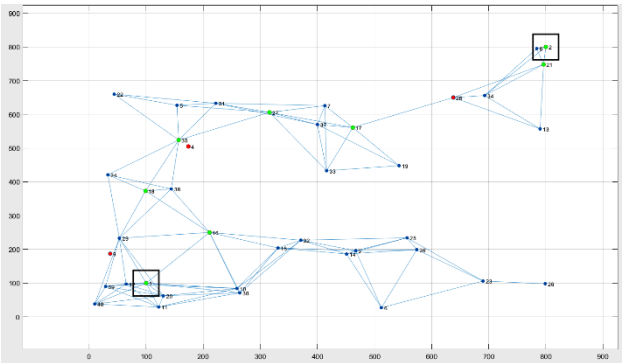

Fig. 4. 40 Nodes WSN random uniform topology-Final State with Red node indicates that this path is no longer available

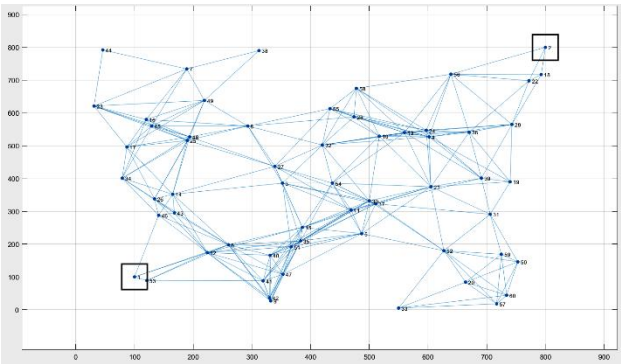

Fig. 5. 60 Nodes WSN random uniform topology-Initial State

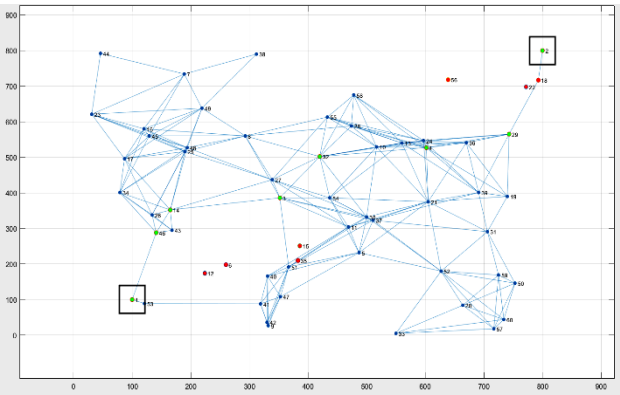

Fig. 6. 60 Nodes WSN random uniform topology-Final State with Red node indicates that this path is no longer available.

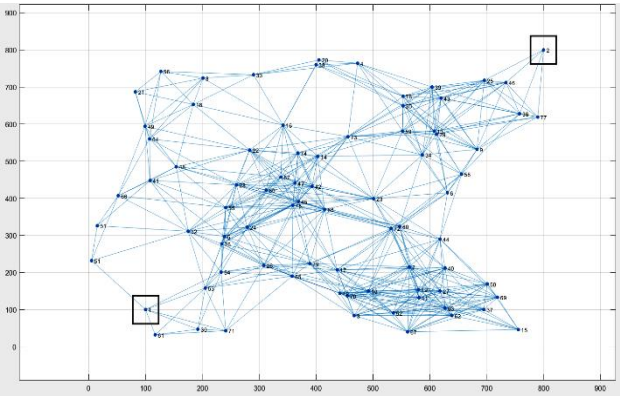

Fig. 7. 80 Nodes WSN random uniform topology-Initial State

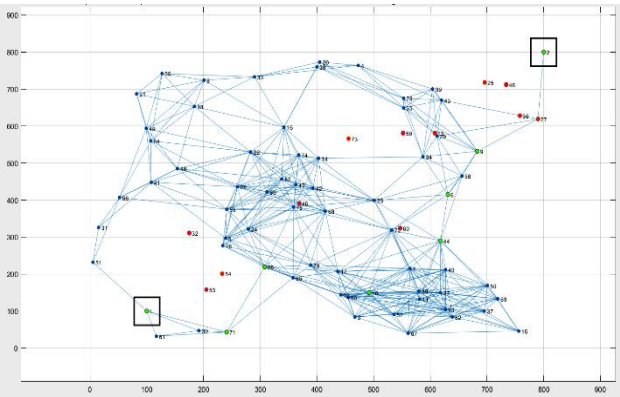

Fig. 8. 80 Nodes WSN random uniform topology-Final State with Red node indicates that this path is no longer available

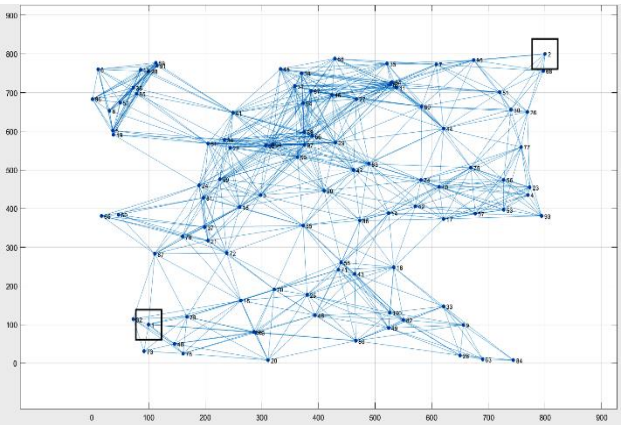

Fig. 9. 100 Nodes WSN random uniform topology-Initial State

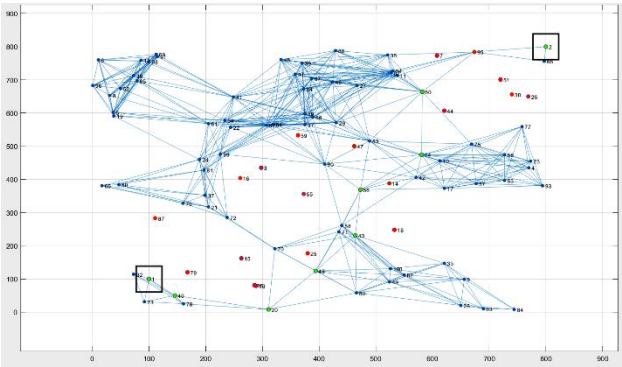

Fig. 10. 100 Nodes WSN random uniform topology-Final State with Red node indicates that this path is no longer available

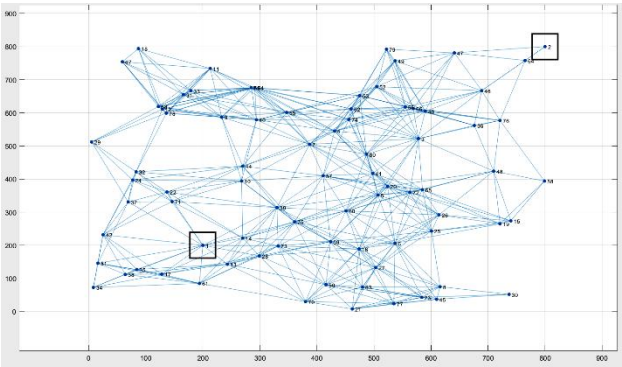

Fig. 11. 80 Nodes WSN random uniform topology-Initial State with source node located at (200m, 200m)

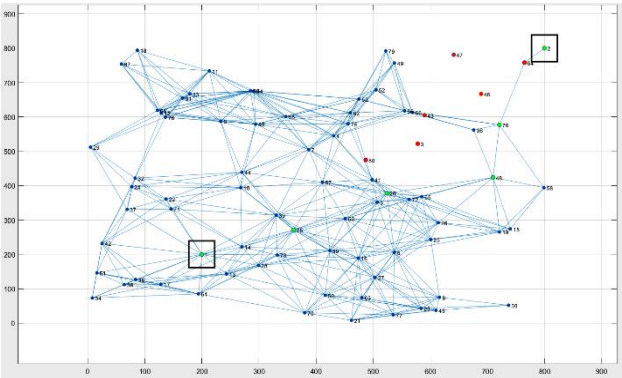

Fig. 12. 80 Nodes WSN random uniform topology-Final State with source node located at (200m, 200m) and Red node indicates that this path is no longer available

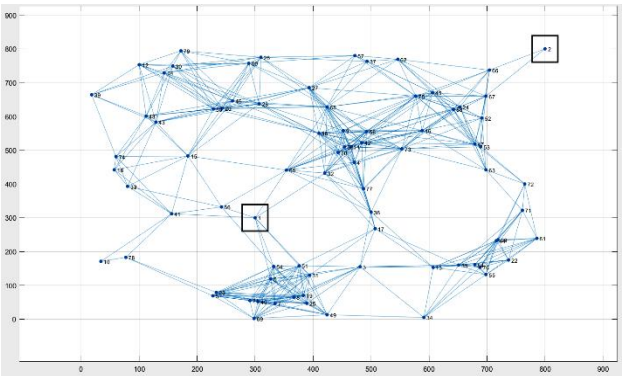

Fig. 13. 80 Nodes WSN random uniform topology-Initial State with source node located at (300m, 300m)

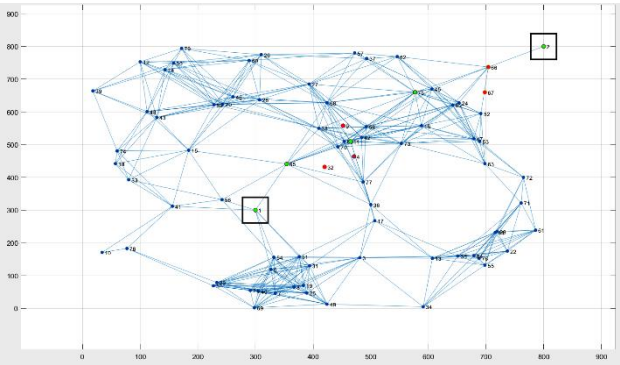

Fig. 14. 80 Nodes WSN random uniform topology-Final State with source node located at (300m, 300m) and Red node indicates that this path is no longer available

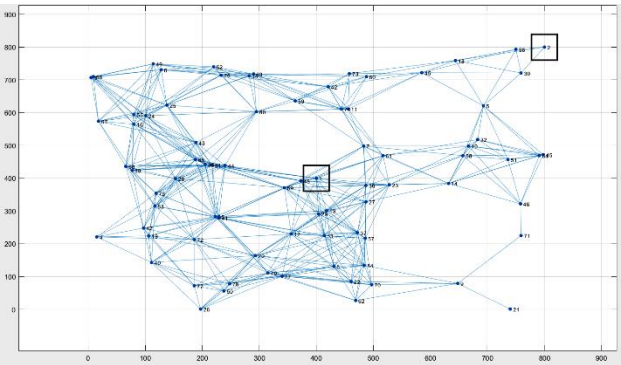

Fig. 15. 80 Nodes WSN random uniform topology-Initial State with source node located at (400m, 400m)

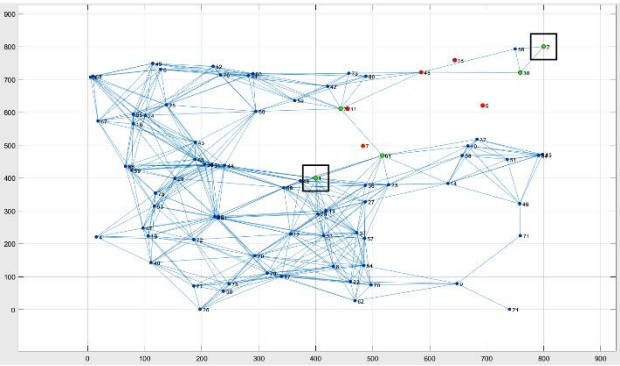

Fig. 16. 80 Nodes WSN random uniform topology-Final State with source node located at (400m, 400m) and Red node indicates that this path is no longer available

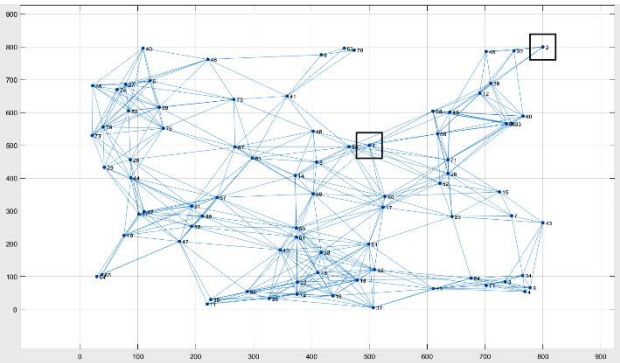

Fig. 17. 80 Nodes WSN random uniform topology-Initial State with source node located at (500m, 500m)

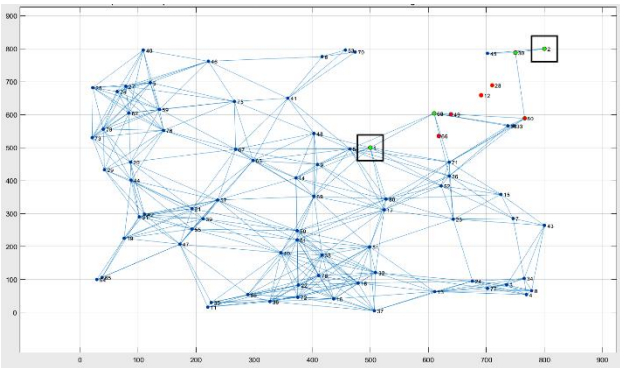

Fig. 18. 80 Nodes WSN random uniform topology-Final State with source node located at (500m, 500m) and Red node indicates that this path is no longer available

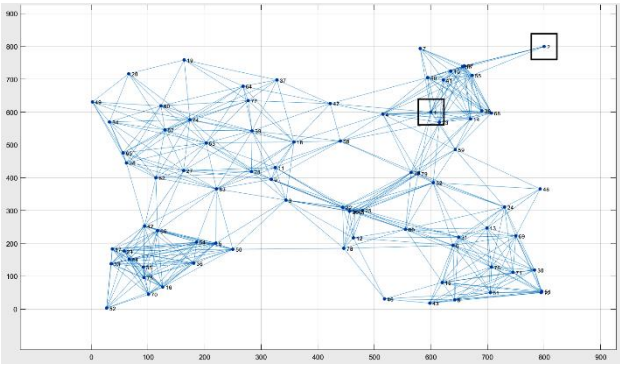

Fig. 19. 80 Nodes WSN random uniform topology-Initial State with source node located at (600m, 600m)

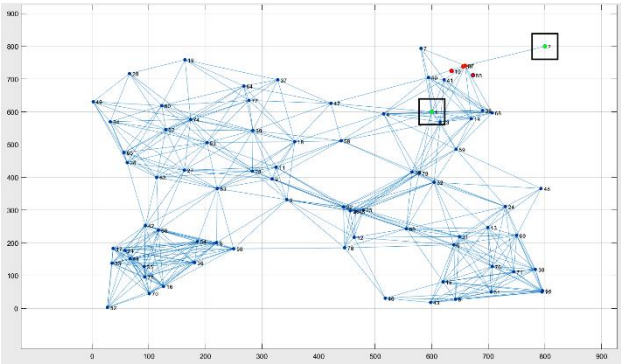

Fig. 20. 80 Nodes WSN random uniform topology-Final State with source node located at (600m, 600m) and Red node indicates that this path is no longer available

III. Results and Discussion

Fig. 21 shows the algorithm used to carry out simulation. The algorithm is based on distance and energy computation to choose the shortest path with consideration of communication medium and attenuation factor as factors contributing to path loss. The algorithm also considers alternative routes as a function of energy drained nodes that cannot be part of the route any loner as they cannot forward transmitted data any longer.

Fig. 22 shows as predicted and especially for the Random Uniform WSN nodes distribution that it takes longer times to find routes as the number of Nodes in the in the WSN increases.

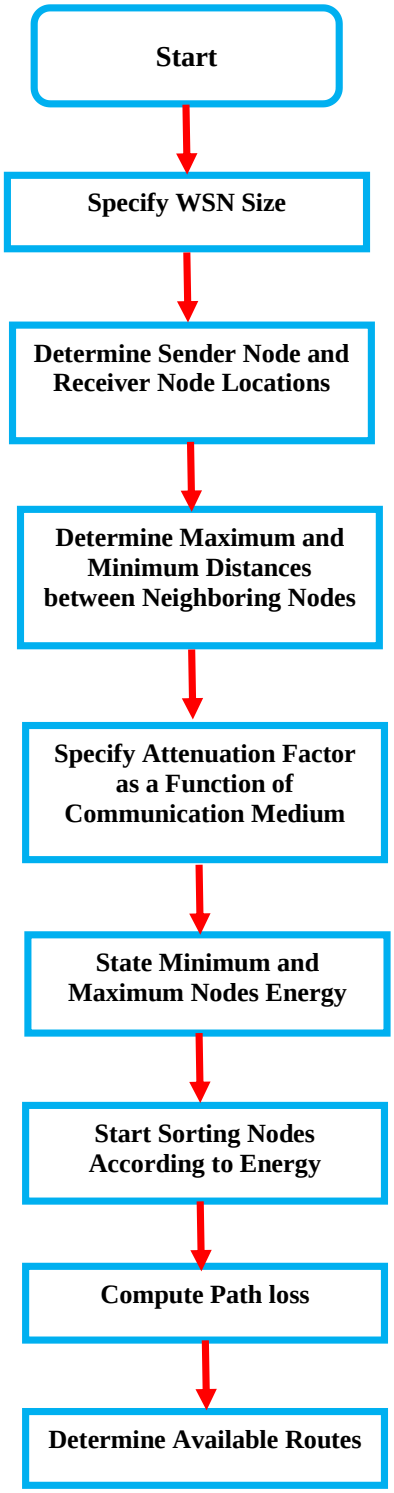

Fig. 21. Simulation algorithm

The relationship between routes discovery elapsed time and WSN number of Nodes can be approximated as in equation (1)

$$Time_{Discovered\ Routes} = \phi * Nodes^{\theta} \qquad (1)$$

where:

ϕ: Multiplication coefficient ≤ 0.1

θ: Power coefficient ≤ 3

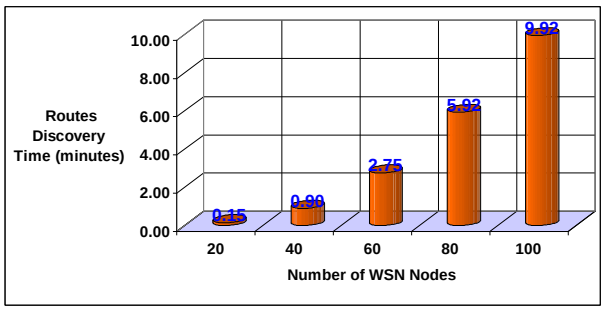

Fig. 22. Effect of WSN nodes on routes discovery time.

Fig. 23 presents effect of increasing number of nodes per same covered WSN area (800 m by 800 m). From the presented data, it is evident that the number of available routes to be uncovered increases in proportion to the increase in the available WSN nodes, which provides alternative paths. This agrees with Fig. 22, as more time is required to discover and map higher number of nodes and routes.

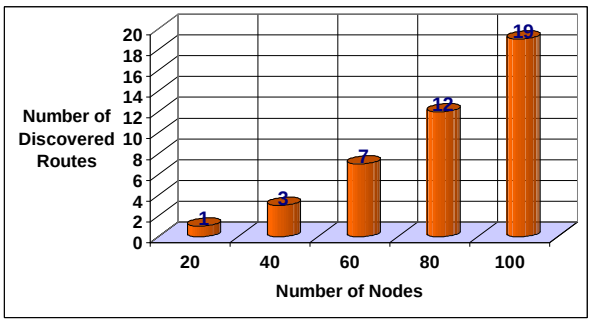

Fig. 23. Effect of WSN nodes on discovered routes.

Equation (2) describes the relationship between discovered routes and number of WSN nodes.

$$\boldsymbol{Discovered\ Routes = \psi * Nodes^{\kappa}} \quad (2)$$

where:

ψ: Multiplication coefficient ≤ 0.1

κ: Power coefficient ≤ 2

Dividing equation (1) by equation (2), yields equation (3)

$$\frac{\boldsymbol{Discovered\ Routes}}{\boldsymbol{Time_{(Discovered\ Routes)}}} = \left(\frac{\boldsymbol{\psi}}{\boldsymbol{\phi}}\right) * \left(\frac{\boldsymbol{Nodes^{\kappa}}}{\boldsymbol{Nodes^{\theta}}}\right) \quad (3)$$

Equation (3) can be further simplified, resulting in equation (4) with effect of WSN size on minimum number of hops per route presented in Fig. 24.

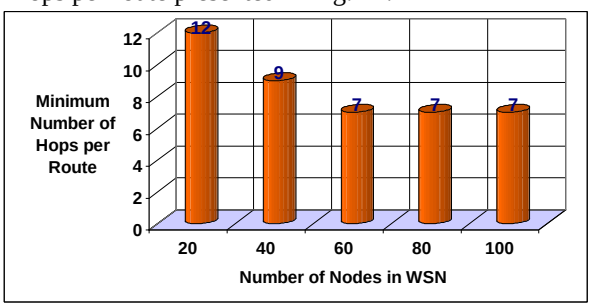

Fig. 24. Effect of number of nodes hops count per route.

$$\boldsymbol{Hops\ (per\ route)_{(min)} = \beta * (Nodes^{-\alpha})} \quad (4)$$

where:

β: Multiplication coefficient ≤ 40

α: Power coefficient ≤ 0.4

From equations (2) and (4), equation (5) is obtained.

$$\boldsymbol{Hops\ (total)_{(min)} = Hops(per\ route)_{min} * Discovered\ Routes} \quad (5)$$

From equation (5), equation (6) is obtained.

$$\boldsymbol{Hops\ (total)_{(min)} = (\beta * \psi) * Nodes^{(\kappa-\alpha)}} \quad (6)$$

From equations (6) and (1), path rate expression can be obtained:

$$\frac{\boldsymbol{Hops(total)_{min}}}{\boldsymbol{Time_{Discovered\ Routes}}} = \left(\frac{\boldsymbol{\beta * \psi}}{\boldsymbol{\phi}}\right) * \boldsymbol{Nodes^{(\kappa-\alpha-\theta)}} \quad (7)$$

Equation (7) can be represented in terms of path search efficiency as a function of WSN density as in equation (8)

$$\boldsymbol{Paths_{(Rate)} = \Upsilon * Nodes^{\Gamma}} \quad (8)$$

Path loss which reflects energy consumption and affects nodes lifetime is proportional to WSN size in terms of nodes number and can be related to each path through multiplication of the average path loss per selected shortest path, using equation (4), resulting in equation (9)

$$\boldsymbol{Pathloss_{Shortest\ path} = \vartheta * \beta * (Nodes^{-\alpha})} \quad (9)$$

where:

ϑ: Average path loss value per hop and 30dBm ≤ ϑ ≤ 40dBm.

The overall path loss associated with searching for all routes in order to find shortest path among available routes can be approximated using equation (2), resulting in equation (10).

$$\boldsymbol{Discovered\ Routes = \vartheta * \psi * Nodes^{\kappa}} \quad (10)$$

Figures 11 to 20 show a source WSN node with changing distance to the destination node with Figures 25 to 27 presenting effect of distance variation on routes discovery time, number of discovered routes, and minimum number of hops per route.

From the plots, it is evident that there is a correlation between increasing the number of nodes and reducing distance between the source and destination nodes, such that the elapsed routes discovery time increases with increasing number of nodes and with increasing distance between the source and destination nodes. Also, the number of discovered routes between the source node and destination node increases as the number of WSN nodes increases and the distance decreases between the source node and destination nodes increases. In addition, the

minimum number of hops is reduced as the nodes count per WSN increases and decreases as a function of reduced separation between the source node and destination node.

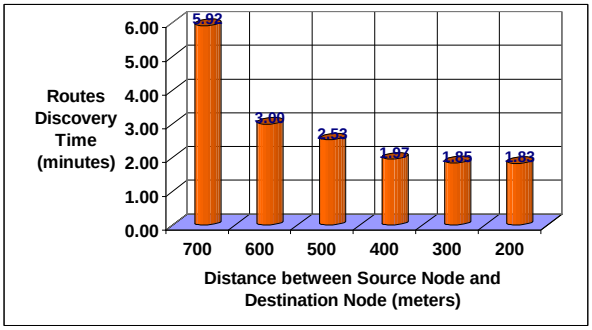

Fig. 25. Effect of distance between source node and destination node on routes discovery time.

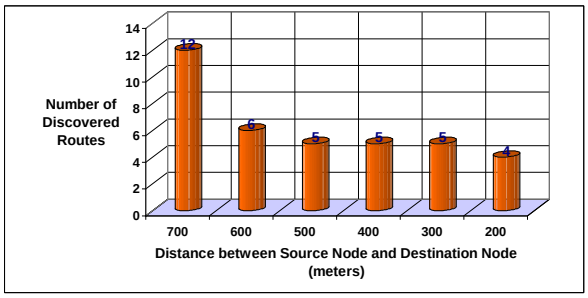

Fig. 26. Effect of distance between source node and destination node on number of discovered routes.

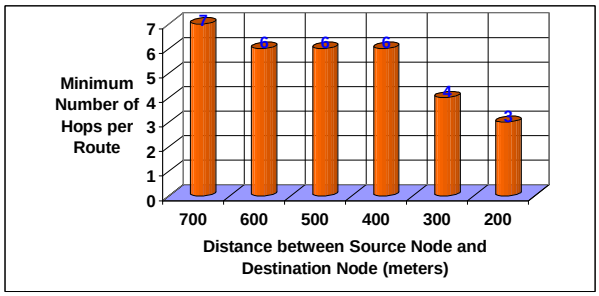

Fig. 27 Effect of distance between source node and destination node on minimum number of hops per route.

From simulation data, we obtain equation (11).

$$\boldsymbol{Time_{Discovered\ Routes} = \Theta * exp(v * Distance)} \quad (11)$$

where:

v: Multiplication coefficient ≥ 0.7

Θ: Power coefficient ≥ 0.003

The relationship between discovered routes and distance between the source and s=destination nodes can be approximated by equation (12).

$$\boldsymbol{Discovered\ Routes = \xi * exp(\varepsilon * Distance)} \quad (12)$$

where:

ξ: Multiplication coefficient ≥ 0.5

ε: Power coefficient ≥ 0.004

The minimum hops count as a function of distance between the source and destination nodes is given by equation (13).

$$\boldsymbol{Hops(Route)_{min} = \rho * exp(\varphi * Distance)} \quad (13)$$

where:

ρ: Multiplication coefficient ≤ 2.5

φ: Power coefficient ≥ 0.001

Path loss can be approximated in the case of distance variation by using equation (13), resulting in equation (14).

$$\boldsymbol{Pathloss_{Shortest\ path} = \vartheta * \rho * exp(\varphi * Distance)} \quad (14)$$

ϑ: Average path loss value per hop and 30dBm ≤ ϑ ≤ 40dBm.

As path loss increases, so does the consumed energy. Thus, nodes would lose more energy due to an increase in path loss, which is mainly a function, distance between communicating nodes and, and medium. Thus the used routing algorithm search for shortest path in order to avoid high energy consumption and dissipation due to route length and path loss factor. In addition, having more nodes will definitely results in more available routes, which in turn affects search space and energy consumption as more nodes result in more consumed energy as number of hops increases as well.

At WSN (nodes =80), equations (9) and (13) can be equated resulting in equation (15).

$$\boldsymbol{\vartheta * \beta * Nodes^{-\alpha} = \vartheta * \rho * exp(\varphi * Distance)} \quad (15)$$

From equation (15), equation (16) is obtained.

$$\boldsymbol{Nodes^{-\alpha} = \left(\frac{\rho}{\beta}\right) * exp(\varphi * Distance)} \quad (16)$$

From equation (16), distance-nodes relationship can be obtained as in equation (17).

$$\boldsymbol{Distance = \left(\ln\left(\left(\frac{\beta}{\rho}\right) * Nodes^{-\alpha}\right) * \varphi^{-1}\right)} \quad (17)$$

Equation (17) correlates WSN nodes size with distance between source node and destination node. This correlation is implicitly affecting the number of available routes, consumed energy, lifetime, and connection reliability. In addition, path loss is also affected indirectly with increasing or decreasing the number of WSN nodes as travelled routes would increase.

Now substituting equation (17) into equation (14), results in equation (18).

$$\boldsymbol{Pathloss_{Shortest\ path} = \left(\frac{\vartheta * \beta^2}{\rho}\right) * Nodes^{-2\alpha}} \quad (18)$$

Equation (18) relates path loss to number of WSN nodes, which in effect relates energy consumption to communicating nodes within a route, which in the utilized algorithm is chosen to be the shortest path available within the specified sender-receiver distance. The optimum

distance is regarded as the distance at which path loss is minimum, which indicates shorter paths and minimum number of hopes with fewer nodes. Thus, node energy consumption should be minimal. This is also related to communication time, as when time increases with the node is still transmitting, it means more energy consumption, assuming same packet size. If different packet sizes are transmitted, it is a fact that more energy will be consumed as the packet size increases.

IV. Conclusion

This work investigated effect of WSN node size and distance between source node and destination node on routes discovery and hopes per route through MATLAB simulation. Such investigation is important as it maps and helps in determining optimum distance and number of nodes in order to help saving energy for WSN nodes. It also assist in efficiency determination through path loss computation and correlation with distance and number of nodes used in a WSN or in a cluster. The work reached relationships between nodes number and the following:

1. Routes discovery time as a function of nodes and distance
2. Number of discovered routes per WSN nodes size
3. Number of discovered routes as a function of distance
4. Minimum number of hops per route as a function of WSN nodes
5. Minimum number of hops per route as a function of distance between source and destination nodes.
6. Path loss relationship
7. Nodes relationship with distance
8. Path loss and WSN nodes

Two important expressions (equations (17) and (18)) are developed which accounts for effect of distance between source and destination nodes on the number of nodes, and a relationship between path loss and number of nodes. This will affect routing and route selection, which in turn affects total WSN energy consumed.

The findings of this work agrees with many published literature in terms of distance, energy and number of routes available. The presented mathematical equations contributes to a great extent in optimizing WSN design using simulation and before actual implementation by providing quantitative way of optimizing proposed WSN topologies and feeding back into the simulation to optimize routes selection and number of nodes before deployment.

Conflict of Interest

The author declares no conflict of interest.

Author Contributions

The author carried out all the required work and approved the final version.

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The original code is developed by: cesar silva (2020). MATLAB wsn code (https://github.com/cesarfgs/matlab-wsn-code), GitHub. Retrieved December 3, 2020.

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