Connectivity Analysis of WSN Nodes using Neighborhood Search Technique (WSN^{NST})

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Abstract— A new approach to wireless sensor network (WSN) communication through multi-hop routing is investigated in this work. The proposed approach utilizes search radius expansion in order to find highest energy nodes within a WSN network and preserves the energy of the lowest energy nodes. This approach which is built on trust in terms of providing good quality communication channels between a source node and a destination node considers energy as one parameter of trust that will enable strong, reliable communication channels and shorter routes to be used in a WSN. This approach enables efficient energy consumption during data communication, but with higher level energy consumption due to expanded search radius, which can be minimized using search time limit. The work also relates through mathematical equations, number of discovered routes, maximum hops, and search time to the considered search radius. The overall objective of this work is to enable faster and efficient channel communication between WSN nodes, through gradual cost effective search in neighborhoods. This is achieved by uncovering shorter and less number of routes within an acceptable time limits. The proposed and simulated approach presented in this work differ in terms of the gradual expansion of search and the equal increments in search radius compared to other used techniques. The presented work also adds a unique feature of allowing re-charging of low energy nodes using the already established routes connecting high energy nodes through the registration of weak nodes locations. A final general expression relates search radius to other WSN variables is also presented.

Keywords— WSN, Routing, Search Radius, Hops, Transmission, Packets, Random Uniform

I. Introduction

Wireless sensor networks (WSNs) consists of interconnected sensing devices used to detect changes and wirelessly communicate data within the created network topology. WSNs can be formed through deployment of number of sensing nodes over a specified area with sink node receiving the results and processing to enable action and control. WSNs conventionally comprises a large number of sensor nodes distributed either randomly (especially in areas hard to reach) or as a function of predefined topology over a geographical area of interest covering many application areas, such as environmental, health, security, and military among others [1], [2], [3], [4].

Communication range coverage is critical to achieve efficiency and effectiveness in WSNs. The area under consideration should be sufficiently covered to enable proper data exchange with certainty. WSNs can suffer in addition to energy shortage as function data communication levels, to operational failure and environmental effects [5], [6].

WSNs is affected by the topology and density of the network, which affects selection of active nodes and links within a region of interest or trusted radius or zone. This affects the overall energy consumption of the whole WSN as it affects nodes level of participation in data communication. Thus, changing sensing and communication range can result in finding an optimum energy level where a balanced consumption is achieved with enough nodes coverage over the area of the deployed sensors.

Researchers also worked on most efficient routes and the optimum routing process using and combining various techniques and algorithms in order to achieve energy-efficient routing, which will greatly improve WSN life time. The work is mainly based on hierarchical and multi-hop methods. Such work is also supported by other approaches regarding selection of nodes that results in a more efficient energy usage, under the principle of clustering. Research also covering heterogeneous WSNs looked at three types of nodes (normal, advanced, super). The normal node has the lowest energy, with the advanced node having the highest energy, and used probability functions based on energy levels to select nodes and in some other works to select cluster heads [7], [8], [9], [10].

In WSNs, the overall nodes lifetime can be increased by determining a minimum set of neighborhood nodes that can achieve optimum coverage within a search radius (SR). This is equivalent to having adjustable communication ranges among nodes by selecting a SR that includes optimum number of nodes and links [11], [12], [13], [14], [15].

Fundamental issues when deploying WSNs, are sensing and communication coverage range, and connectivity. The sensing and coverage range is a function of each WSN node capability of processing, memory, and its wireless communication capabilities), which has effect on node energy and functionality, and necessitate an optimizing approach to deployment [16], [17], [18], [19], [20].

The issue of connectivity and links requires an optimized routing algorithm with establishment of trusted zones or radius that holds the necessary nodes with enough linkage, which will use multi-hops and distance vector bases algorithms. The issue of connectivity is critical in terms of assuring that enough links are present that interconnects all selected nodes and covers the required areas encircled by SR [21], [22], [23], [24], [25], [26]. .

To carry out routing, a system can utilize either multi-hop routing or cluster based routing technique. Cluster based routing is more efficient as it has lower transmission rates to the base station (BS), but such efficiency is compromised if the BS is located far in a static WSN environment with good chance of collision. Multi-hop routing has the advantage of being able to control energy consumption as it uses nodes with most energy to enable more efficient communication. This makes such algorithms able to handle large WSNs with indirect paths to BS [27], [28], [29], [30].

Cluster-based routing allocates areas or regions with cluster head (CH) responsible to communicate accumulated data to the BS. Thus, ensuring small number of transmissions and reduces energy consumption and extends network life time.

In a multi-hop zone-based routing, different size zones are allocated over different topological regions, with usage of nodes with highest energy in routing communication data and control information. This leads to lower network life time, due to the carried overhead [31], [32], [33].

In some cases, WSN could underperform due selection of nodes that are not energy sufficient (weak node). This will affect the overall network performance, reliability, and stability.

In this work an investigation through MATLAB simulation is carried out to study the efficiency and effectiveness of Search Radius as a process to establish routes and communication channel between any two WSN nodes over a random uniform topology. The objective is to try and show effectiveness of such proposed technique, which is different from other Distance vector based approaches as it uses weight elimination approach based on weak nodes with low energy from the paths between any two nodes and initiates a route discovery process to replace the weak routes. This is done in order to guarantee communication channel strength and reliability and bidirectional symmetry.

The contributions of this paper is as follows:

1. Simulation of a new energy based trusted routing technique for WSNs.
2. The use of equal increments of search radius based on selecting highest nodes for routing routes with mapping and registration of lowest energy.
3. Correlation between search radii to the following:
   I. Discovered routes
   II. Hop-count
   III. Routes discovery time
   IV. Number of weak nodes

II. METHODOLOGY

Figures 1 to 4 show the simulated WSN with 70 nodes distributed in a randomly uniform topology, with four different search radiuses with equal increment in radius {150 m, 200 m, 250 m, 300 m}. This is to enable gradual approach to routing, such that minimum search radius is used first, then if high energy nodes are exhausted and there is a need to further communicate between the two specified nodes, then larger radius is used. This is based on trust principle, such that the algorithm trusts nodes with highest energy to pass information in multi-hop arrangement. Further, it allows preservation of low energy nodes power until being re-charged again.

Equal radius increments makes this approach different from other cluster based or zone based techniques. The increments in search radius means increments of links between source node and neighbors in order to expand search efforts for shortest path routes with high energy nodes. Along the search path, the algorithm examines energy levels of encountered nodes and eliminates low energy ones from the route, and switches to other routes, while recording the nodes that have low energy for the purpose of re-charging [34], [35], [36].

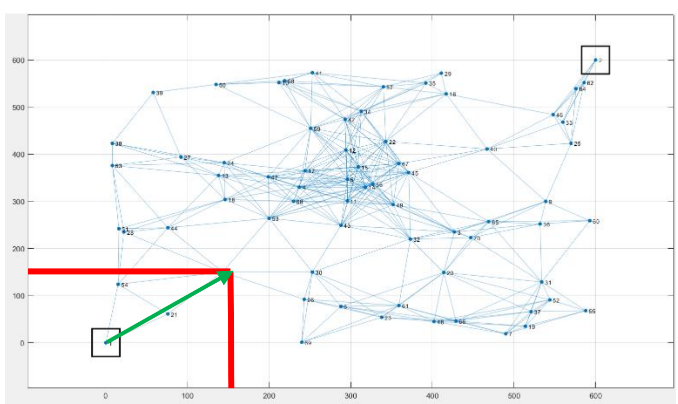

Figure 1. WSN with 150 meters search radius.

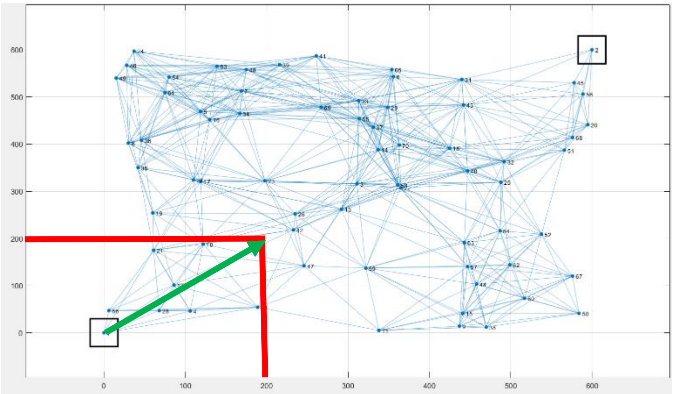

Figure 2. WSN with 200 meters search radius.

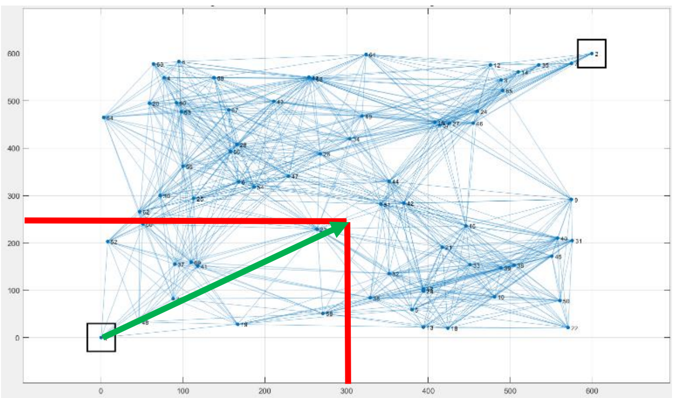

Figure 3. WSN with 250 meters search radius.

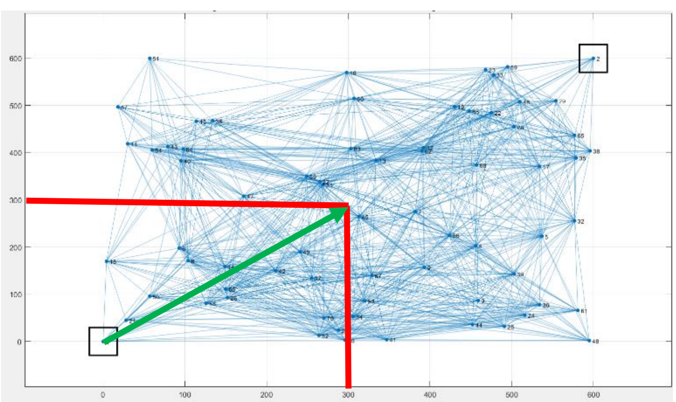

Figure 4. WSN with 300 meters search radius.

In this paper, the simulation model considered for WSN communication is based on the following criteria:

1. All the nodes in the network are static.
2. Nodes Energy levels are responsible for defining communication routes.
3. The search area is incremented in equal steps if optimum routes are not discovered.
4. Nodes are distributed in a random uniform manner with limited power.
5. Communication is based on multi-hop routing.
6. Nodes of lowest energy are recorded and mapped in order to enable re-charging.

III. Results and Discussion

Figures 5 to 8 show results of simulation. Figure 5 clearly indicates that as the search radius is expanded, more routes will become available and more paths will be provided for data communication with reliable channels as such routes cover nodes with highest energy. Figure 6 shows that as the search radius is incremented, shorter routes are found, which means that over all energy consumption during the communication process will be reduced. In addition, the simulated technique maps all the lowest energy nodes per search radius (weak nodes) and tabulate them in order to avoid route searching through them again and to preserve their minimum energy, and enable locating them in case of re-charging. This technique also uses trust approach to guarantee reliable communication channels and paths between nodes by using energy level as a parameter for trust in a stable communication channel.

However, increasing the search radius, with associated reduction in hops count has a negative initial effect which is the energy consumed during the path discovery process. This needs to be considered with the objective of making the overall consumed energy is not significantly increased as the radius is expanded and this can be achieved by limiting the number of maximum routes to be discovered such that a time limit is applied. This is supported by Figures 7 and 8 in terms of total transmitted packets and total routes discovery time.

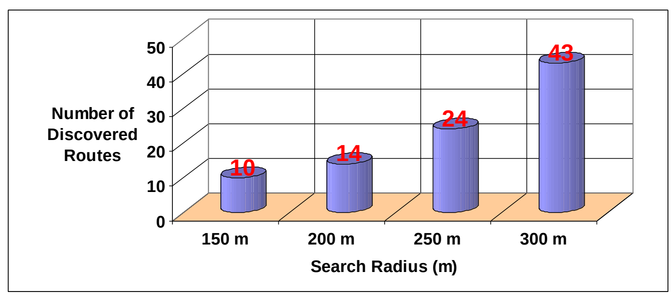

Figure 5. Relationship between search radius and discovered routes.

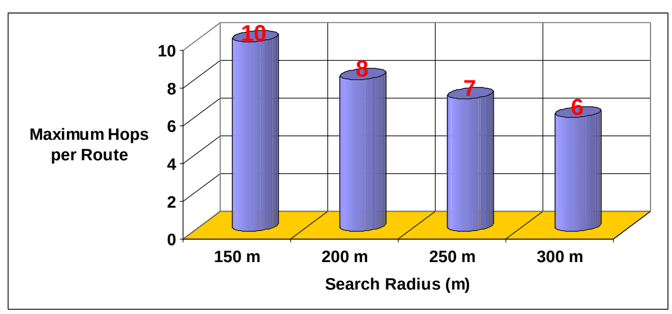

Figure 6. Relationship between search radius and number of hops.

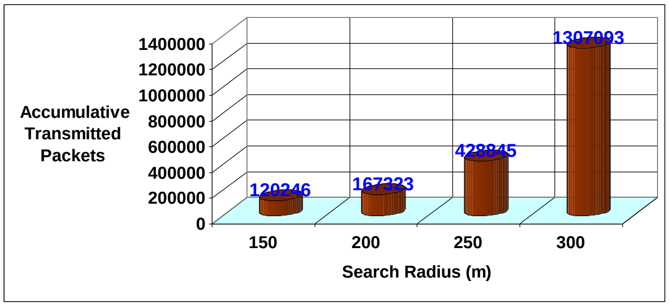

Figure 7. Relationship between search radius and number of hops.

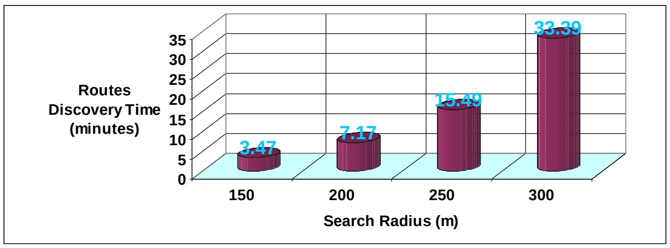

Figure 8. Relationship between search radius and routes discovery time.

Equations 1 to 4 mathematically describe three important characterizing relationships as a function of search radius:

1. Discovered routes.
2. Maximum Hops
3. Routes Search time

$$Routes_{Discovered} = \theta * e^{(\phi * Radius_{Search})} \quad \dots (1)$$

Where: $\theta \geq 2, \phi \geq 0.01$

$$Hops_{Maximum} = \omega * e^{(-\lambda * Radius_{Search})} \quad \dots (2)$$

Where: $\omega \geq 2^{\alpha}, \alpha \geq 4, \lambda \leq 0.003$

$$Time_{Routes\ Discovered} = \delta * e^{(\kappa * Radius_{Search})} \quad \dots (3)$$

Where: $\delta \geq 0.35, \kappa \geq 0.015$

$$Packets_{\ acuumulated\ transmitted} = \chi * e^{(\varphi * Radius_{Search})} \quad \dots (4)$$

Where: $\chi \geq 2^{\varepsilon},\ \varepsilon \geq 13,\ \varphi \geq 0.016$

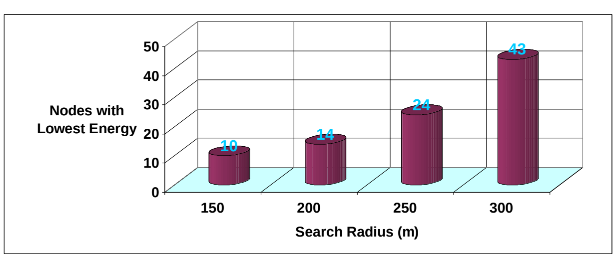

Figure 9. Relationship between search radius and number of nodes with lowest energy

Figure 9 shows a relationship between search radius and number of nodes with almost depleted energy. These nodes are left out of routes and as a matter of fact, such nodes are driving the formation of new routes with nodes having high energy levels. Thus, the number of discovered routes and subsequent hop count is affected by the number and location of the low energy nodes, which are abandoned in terms of path selection and mapped to enable re-charging.

The relationship between search radius and nodes with lowest energy (weak nodes) is shown in equation (5).

$$Nodes_{Lowest\ Energy} = \gamma * e^{(\sigma * Radius_{Search})} \quad \dots (5)$$

Where: $\delta \geq 2, \kappa \geq 0.01$

From equations (1) to (5), a general expression can be developed that relates search radius to other WSN variables, as presented in equation (6)

$$Variable_j = \Omega_j * e^{(\Gamma_j * Radius_{Search})} \quad \dots (6)$$

Where: Ω_j and Γ_j are specific parameters to the variable to be measured.

IV. Conclusions

In this work, investigation is carried out through simulation on the efficiency of using search radius increase and expansion in order to discover viable, high energy nodes to enable continuous and good quality communication between two WSN nodes. The proposed approach demonstrated that shorter routes can be found using this approach, which means lower energy consumption per route. However, longer times are needed to uncover routes as search radius is expanded, which uncovers more routes with lower hops and higher energy.

The work also found that this technique can be very effective if search time limit is applied to limit number of transmitted control packets trying to uncover routes with highest nodes energy in order to increase efficiency of energy consumption and effective search time. In addition, the algorithm registers nodes with low energy to enable future re-charging, thus preserving WSN network usability.

This work introduces a new parameter into the technique of trust, which is usually used for security in WSNs. The new approach of trusting nodes with highest energy contributes to a great deal to the process of Quality of Service (QoS) and the reliability of communication channels between nodes in a WSN. In addition, this approach of radius search enables better overall energy conservation and allows for more time to enable re-charging of weak nodes using already established routes for high energy nodes as weak nodes are mapped and registered in terms of energy and location.

Acknowledgment

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