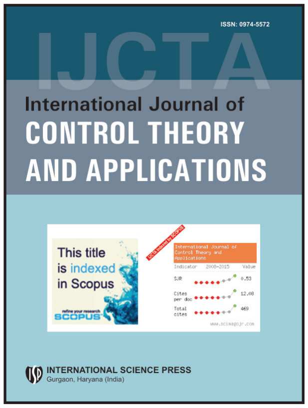

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Adaptive Algorithm for Optimal Route Configuration in Multi-Hop Wireless Sensor Network

Hikma Shabani[a], Ahmed M.A. Haidar[b], Norhuzaimin Julai[c], Musse M. Ahmed[d], P.R.P. Hoole[e] and Majdi Marai[f]

[a]Corresponding author, Deparment of Electrical and Electronic Engineering, Universiti Malaysia Sarawak, Sarawak, Malaysia. Email: shikma@unimas.my
[b-e]Deparment of Electrical and Electronic Engineering, Universiti Malaysia Sarawak, Sarawak, Malaysia
[f]Department of Electronic and Communications Engineering, Hadhramout University of Yemen, Yemen

Abstract: Wireless Sensor Networks (WSNs) are best solutions for numerous aspects of engineering applications such as monitoring, control and surveillance of electrical plant amongst others. Autonomously, sensors will communicate with each other, collaborate, share and forward information in a multi-hop fashion without any centralized controller. To gather relevant data, the route optimization mechanism is used to solve the long routing problem and provide the shortest path amongst communicating nodes. Thus, this shortest path criterion is not suitable for WSN as it may lead to power drainage of several nodes and may cause high signaling and processing costs due to the network reconstruction. This paper proposes an optimal route configuration technique based on an adaptive genetic algorithm in which the architecture of multi-hop wireless sensor network is considered as a distributed computing infrastructure. The obtained results show that the proposed algorithm provides an optimal route configuration with the best performance in terms of evaluating the covered distance, packet loss and time delay.

***Keywords*:** Adaptive Genetic Algorithm; Optimal Route Configuration; Multi-Hop Wireless Sensor Network; Distributed Computing Infrastructure.

1. INTRODUCTION

Nowadays, the remote monitoring and control of electrical plants has emerged as the best approach to maximize the electricity production and mitigate power station failure rates [1]. Conventional current and voltage monitoring methods are expensive and difficult to implement in complex systems [2]. Being one of the options, fiber-optic require optoelectronic transmitters in remote areas [3]. Thus, wireless sensor networks (WSNs) offer an attractive alternative to wired systems due to their easy access to remote sites, no leasing cost and adaptability to changing network [4]. In fact, to ensure a long lifetime network system, just like any battery operated wireless device, the energy resource management is one of the vital concerns in WSNs. Though, the traditional routing optimization protocols such as ad-hoc on-demand distance vector (AODV), dynamic source routing (DSR) and temporarily ordered routing algorithm (TORA) use the shortest path criterion which is not suitable for wireless sensor networks (WSNs) as several nodes may experience power drainage as portrayed in Figure 1 [5]. Overusing node 3 as the intermediate node for node 1, node 2 and the gateway will cause an early failure for this node [5].

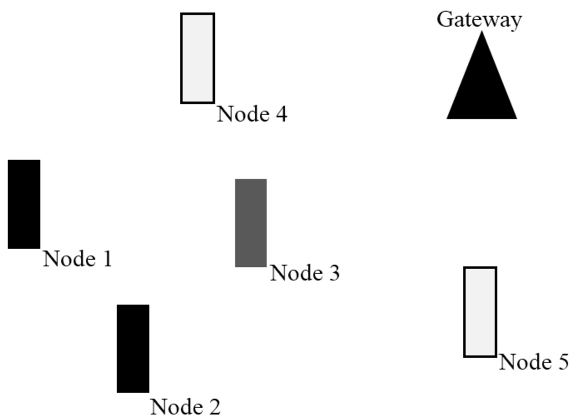

Figure 1: Configuration of connected nodes with the gateway

In the network of Figure 1, assume that the shortest paths from node 1 and node 2 to the gateway are $1 \rightarrow 3 \rightarrow$ gateway and $2 \rightarrow 3 \rightarrow$ gateway. Hence, the permanent use of these routes will accelerate the power drainage of node3 and may cause the delay in data delivery due to the network reconstruction [5]. Therefore, an effective routing algorithm is needed in order to extend the node lifetime and mitigate the risk of connectivity loss in the network which might be caused by power drainage of some nodes with data transmission delay as imminent consequence.

Different networks would have different network topology and the data routing technique used in the networks are not the same. Wireless sensor networks (WSN) is formed dynamically and temporarily without centralized management. The transmission range of wireless interface and multi hop networks may need one or more nodes to transmit date with other nodes and mobile node in the network dynamically establish routing between them to form a dynamic network. Therefore, it is possible for wireless mobile users to exchange information through WSN [6]. Route construction should be done with a minimum of overhead and bandwidth consumption. The on-demand routing protocols create route only when desired by the source node. Hence, the optimal route configuration has to consider more about energy efficiency, connectivity, coverage, topology control, redundant control and reliability in order to maximize the effectiveness of available nodes and extend the network lifetime [7]. Most of the existing multi-hop wireless network protocols optimize hop count as building a route selection. However, the selected routes based on hop count alone may be of bad quality since the routing protocols do not ignore the links and the quality of signals which are typically used to connect to remote nodes [8].

The current sensor array optimization methods use feature selection methods to search the feature sets and to find the features combination with the best performance such as the highest correct recognition rate. Nevertheless, the functions of different sensors in the optimized array are out of the consideration. It becomes a problem when the sensor array optimization is combined with sensing materials preparation and materials searching by combinatorial techniques [9]. Usually, a WSN for monitoring consists of hundreds of low cost nodes with both a fixed or mobile location called base stations and a number of wireless sensors. Flows of data are gathered at the base stations by which the WSNs can be connected to other networks such as internet. Base stations have higher capabilities over simple sensor nodes since they can do complex data processing [10]. Various researches deal with the WSNs and the placement of nodes in network design. These range from dynamic programming [11] to genetic algorithms (GA) [12, 13]. A combination of intelligent optimization was proposed for WSN consisting of stable nodes to maintain network life time at a maximum, while discovering the shortest paths from the source nodes to the base node using swarm intelligence based Ant Colony Optimization [14]. Multi objective and GA for the sensor placement was implemented in [15, 16].

In this research work, an adaptive genetic algorithm (AGA) for optimal route configuration is applied. A simple objective function considering both data transfer rate and economy efficiency was established. On the other hand, in order to extend the network lifetime, this new algorithm takes into account various network parameters such as energy efficiency, connectivity, coverage, topology control, redundant control and reliability.

2. MULTI-HOP WIRELESS SENSOR NETWORK

Multi-hop wireless sensor Network consists of distributed autonomous mobile nodes capable of collecting data from remote areas and communicating with each other without a centralized infrastructure [17]. The collected data is delivered to one or more sinks, generally via multi-hop fashion [18].

2.1. Wireless Sensor Network Formation

Wireless Sensor Networks (WSNs) are formed dynamically and temporarily without centralized management as shown in Figure 2. Generally, route construction should be done with a minimum of overhead and bandwidth utilization. Most of the existing wireless multi-hop network protocols optimize hop count as building a route selection. However, the one hop mechanism does not guarantee an optimal route since the routing protocols do include weak quality links as well. In fact, the poor signal-to-noise ratio (SNR) from these weak quality links mitigates the network throughput [19].

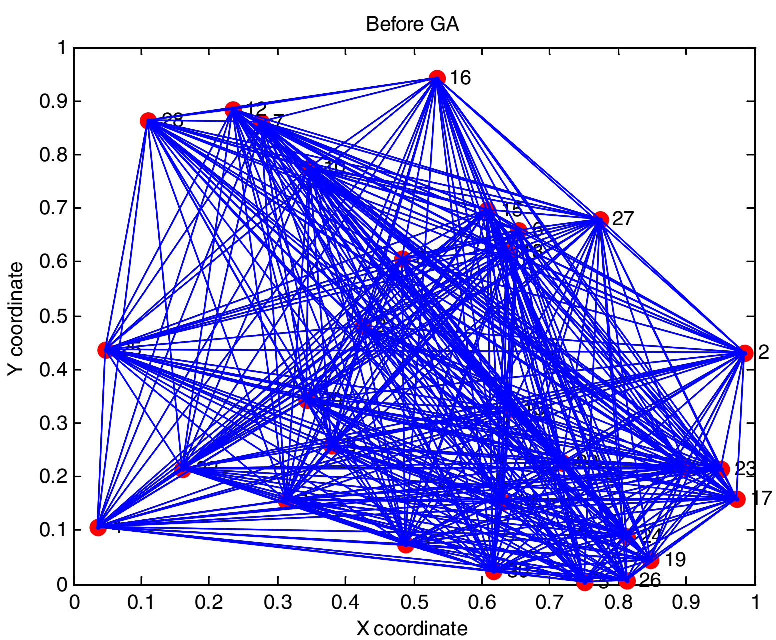

Figure 2: Random route in WSN with 30 Nodes

2.2. Packet Delivery Ratio (PDR)

Packet Delivery Ratio (PDR) as per Equation (1) is the ratio of successfully delivered packets over the transmitted packets [20].

$$PDR = \frac{1}{N_C} \sum_{i=1}^{N_C} \frac{R_i}{T_i} \quad (1)$$

where, N_C = Total number of node connections

R_i = Number of packets successfully received on i^{th} connection

T_i = Number of transmitted packets on i^{th} connection

2.3. End-to-End Delay (E2ED)

End-to-end delay (E2ED) is the delay encountered by all transmitted packets till their reception [20] and can be obtained from Equation (2).

$$E2ED = \frac{1}{N} \sum_{i=1}^{N} D_i \quad (2)$$

where, N = Number of packets successfully received

D_i = Delay encountered by the i^{th} received packet

3. ADAPTIVE GENETIC ALGORITHM FOR OPTIMAL ROUTE

Genetic Algorithms (GAs) are part of innovative computing which is a rapidly growing area of artificial intelligence [18]. On a given population, these genetic algorithms (GAs) search potential solutions based on some specifications or criteria. Afterward, feasible solutions are modeled as individuals described by genomes. A genome is an arrangement of several chromosomes, which symbolize characteristics of the individual [21]. Population is the total number of individuals, from which, some individuals can survive and others will die in the next generation due to their own fitness and/or based on given selection rules. The GA will generally include the following three fundamental criteria: genetic operations of selection, crossover and mutation [22].

The basic structure of GA is illustrated in Figure 3, in this structure, the GA operators are used to modify the chosen solutions and select the most appropriate offspring to pass on to the succeeding generations. The crossover operator defines the procedure generating a child from parent's genomes. The mutation is carried out chromosome by chromosome, its exploration and exploitation helps the algorithm to avoid local optimum. If current population accepts the given termination condition, new generation is not produced any more. Otherwise, dominant individuals are selected and genetic operators reproduce new individuals from them. The best individual of each generation is transferred over to the next generation if elitism is adopted [23, 24].

This work assumes a hypothetical application which involves deployment of random node sensors on a two-dimensional field for data monitoring. The distance ($d_{i,j}$) from node i to node j is specified by the Equation (3) [25].

$$d_{i,j} = x_{i,j} + y_{i,j} \quad (3)$$

where, $x_{i,j}$ = Distance in X axis between nodes i and j

$y_{i,j}$ = Distance in Y axis between nodes i and j

Therefore, the transmission time ($t_{i,j}$) of the sensor signal from node i to j node is obtained from Equation (4).

$$t_{i,j} = max\left(\frac{d_{i,j}}{v_{i,j}}\right) \quad (4)$$

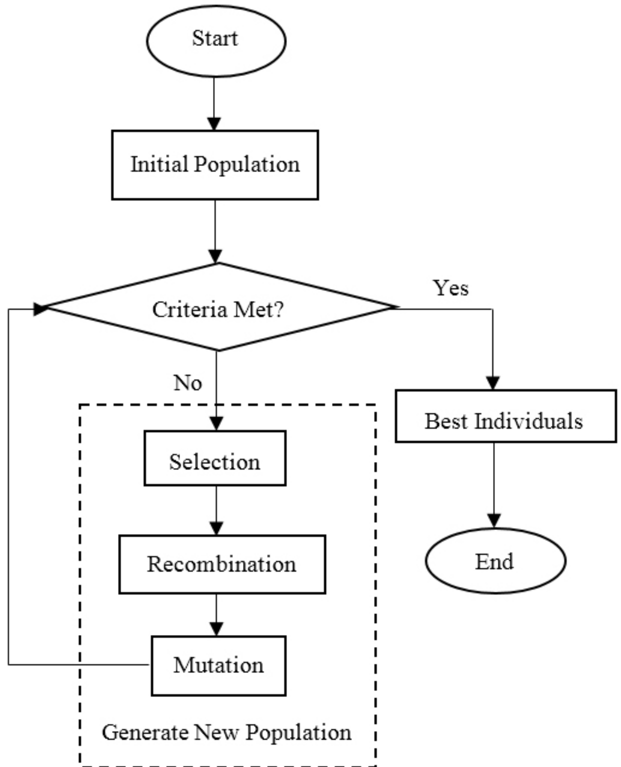

Figure 3: The basic structure of GA

where, $v_{i,j}$ = Travel speed of signal from node *i* to *j* node.

In this adaptive algorithm, it is assumed that, a single signal travels to each node and completes the path by returning to the starting point. If the nearest node is assessed three times busy, the signal moves to the second nearest node and so on. Genes in a chromosome represent the number of node sensors, thus, to find the minimum sum of distances, the fitness function given in Equation (5) is implemented.

$$\text{Min}\left(\sum_{ij=1}^{m} d_{ij}\right) \tag{5}$$

where, m = Total number of nodes.

4. SIMULATION RESULTS AND DISCUSSION

The adaptive genetic algorithm has been evaluated on a large area of *X* and *Y* coordinates in which 30 nodes were distributed randomly. The route optimization results are graphically summarized in Figure 4 and 5. Several investigations were conducted to determine appropriate generated population size ranging from 100 to 300 individuals. The best performance was achieved with a population size of 200 individuals as shown in Figure 5.

Referring to Figure 4 and 5, it can be clearly seen that in the initial population, there are overcrossings between the nodes while in the last generation there is an improvement in routes between nodes.

Consider The evolution progress of the best route found by the adaptive genetic algorithm is depicted in Figure 6, where both the fitness progress of the best individual and the average fitness of the entire population at each generation are plotted. For the performance optimization, the best probability of crossover and mutation in genetic algorithm are $P_C = 0.7$ and $P_m = 0.01$, respectively for a population size of 30 [26].

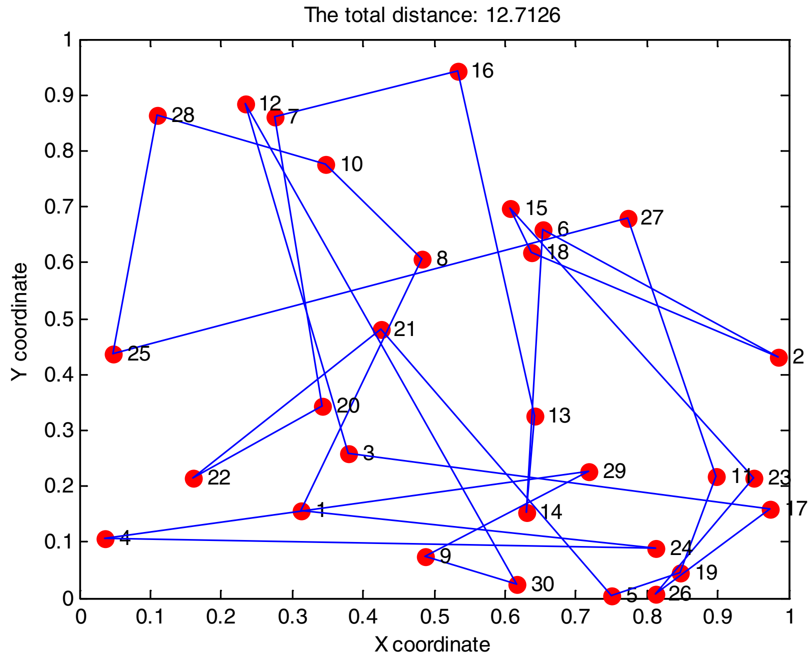

Figure 4: The best route in the initial optimization

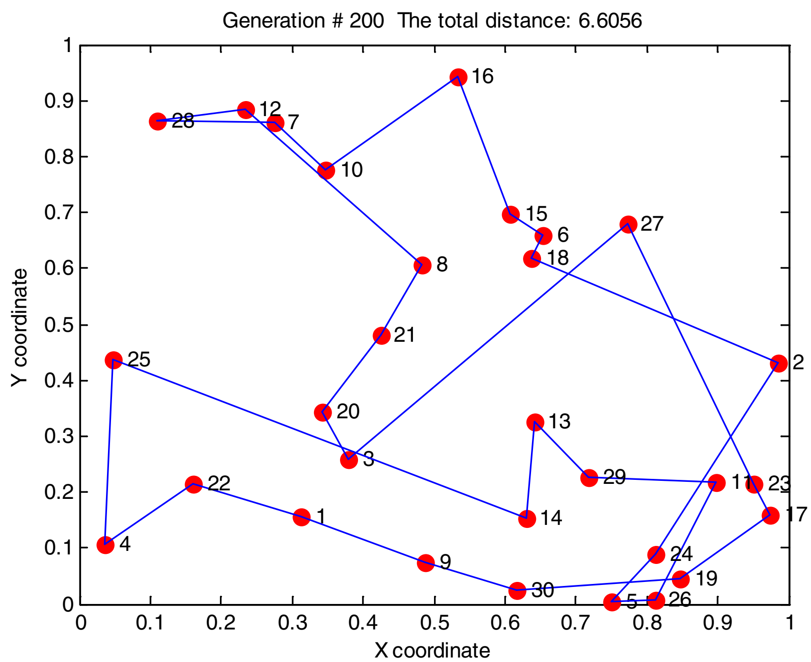

Figure 5: The best route in the final optimization

The multi-hop wireless sensor network performance comparison for packet delivery ratio (PDR) is depicted in Figure 7, while, the performance comparison for end-to-end delay is depicted in Figure 8. From the obtained results, it is evident that finding the optimal route will reduce the total distance (see Figure 4 and 5), packet loss (see Figure 7) and time consumption (see Figure 8).

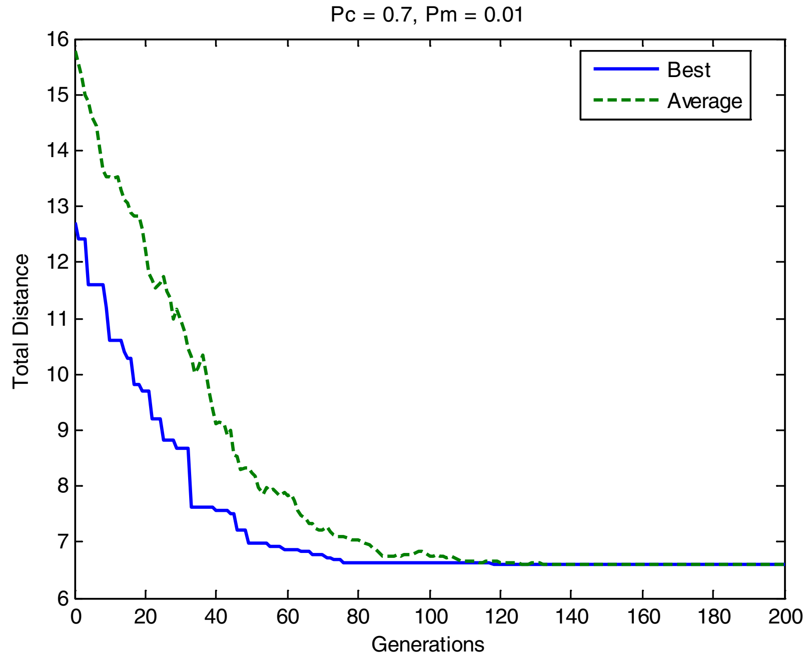

Figure 6: Performance Analysis

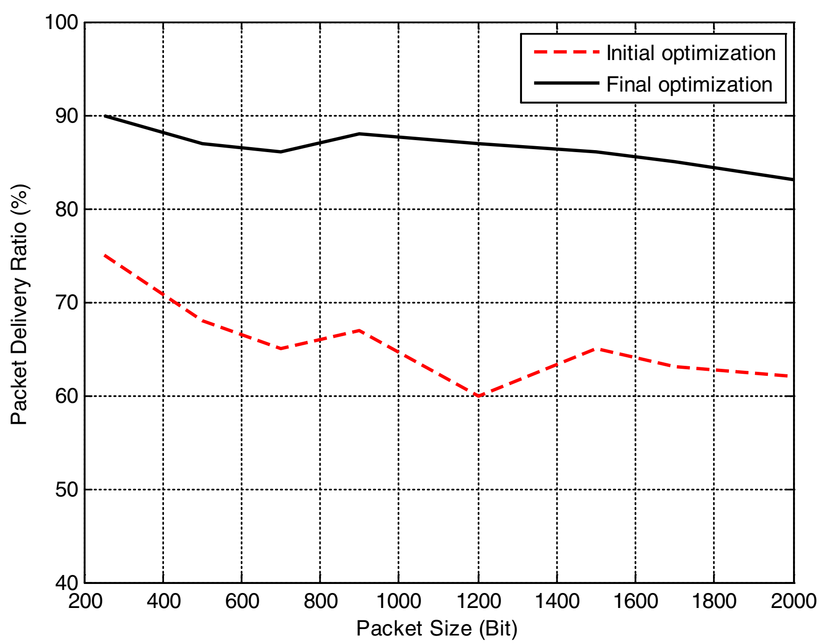

Figure 7: PDR for initial and final optimizations

5. CONCLUSION

This paper presents an adaptive genetic algorithm for optimal route configuration in ad hoc wireless sensor network. The optimization assists the generation of short distance that limits the necessity for route floods. The efficient scheme found by the route optimization will reduce the signaling cost caused by the long route distance. The algorithm can be used for nodes with greater mobility which is capable to initiate the route maintenance process in a preventative manner so that the active node finds a candidate before a route is disconnected. Finally, it is worth to note that the proposed algorithm can be used to locate the base stations with more coverage and less base stations. Optimization results prove that near optimal solution can be found by the proposed intelligent optimization.

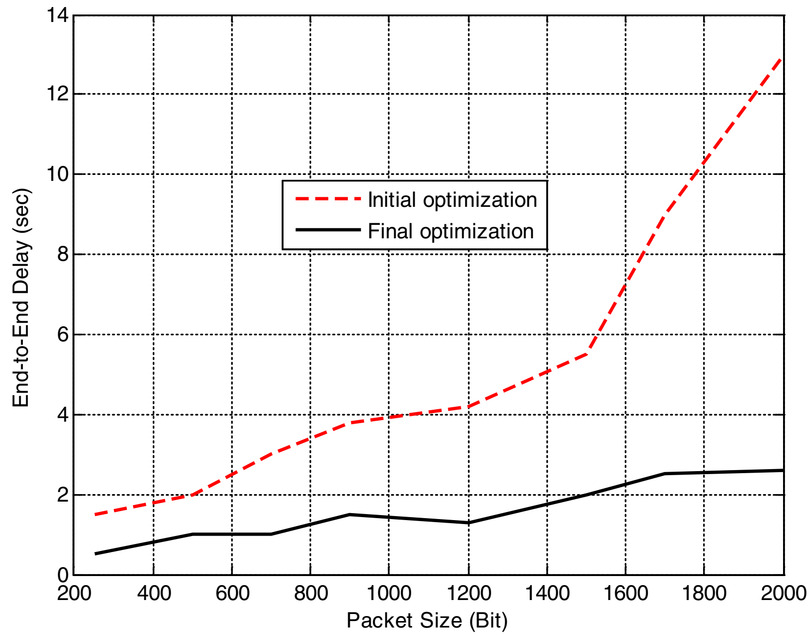

Figure 8: E2ED for initial and final optimizations

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