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QOS BASED PATH SELECTION FOR MODIFIED SMART OPTIMIZATION METHODS

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ABSTRACT

The routing technology is a major challenge in determining the performance of the Ad Hoc Wireless Sensor Network (AHWSN). In this paper, we propose a routing methods to reinforce network performance and overcome network problems such as path destroying within a specified time. The proposed method considers the all possible paths between source node and destination node are discovered. Each path has three metrics of Quality of Service (QoS): bit rate, packet loss rate and delay to be considered in path selection methods instead of single metric. Therefore, this problem is considered as an NP-complete problem. The proposed methods aims to finding the robust path between source and destination node in the face of conflicting design objectives. This is done by minimize packet loss rate, maximize the bit rate and minimize delay using three methods in path selection decision: Weighted Sum optimization method, Weighted Sum Based Genetic Algorithm optimization method and the Non-dominated Sorting based Genetic Algorithm-II (NSGA-II) with two types of Crossover. The obtained results of the three methods are compared with Bellman-ford algorithm based Ad Hoc on Demand Distance Vector (AODV) protocol and compared with NSGA-II priority based encoding. Simulation results, performed in Matlab (2017a), prove that the effectiveness of the proposed methods in terms of finding best path to solve routing problem and QoS requirements in static and dynamic environment. There is important decrease in packet loss rate, delay and increase in bit rate by the proposed method under the varying sensor nodes. In addition, the proposed methods save energy because they do not need to reroute again when route failure occurs.

Keywords: *AHWSN, Weighted Sum, Genetic Algorithms, NSGA-II, AODV.*

1. INTRODUCTION

Wireless sensor networks (WSN) involves a wide number of tiny sensor nodes. These sensors are composed of sensing, processing, power, and transceiver units. They are connected in ad hoc style and defined as a self-configured, decentralized and without infrastructure and has the characteristic of being dynamic or static. WSN are used to monitor material or environmental events, such as humidity, vibration, temperature, pressure, motion or pollutants. Additionally, they are employed to cooperatively pass their data over the network to base stations or sink nodes through the gateway, for example the internet, through multi hop environment [1]. Due to the limited feature of the AHWSN, such as hardware failure, sensor node mobility, environmental factors and path destroying, etc., efficient routing techniques in this network is much more challenging. In addition, efficient routing techniques in AHWSN must be able to meet the quality of service (QoS) requirements. Therefore, it is very essential of finding the robust path between source and destination node for data transmission within a specified time.

In the literature, there are a large number of WSN routing algorithms. Bellman-Ford based Ad hoc On Demand Distance Vector (AODV) protocol and NSGA-II with priority based encoding are adopted to be compared with proposed methods. Traditional AODV that uses Bellman-Ford algorithm to find the shortest path with single metric which is hop count. They discover and maintain routes only when needed [2]. The main disadvantage of traditional AODV is the lack of the QoS conditions. Another drawback of traditional AODV protocol and NSGA-II with priority based encoding algorithm, when a link failure is discovered, a route error message will be created

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and must be sent to a source node. As a result, the route discovery process must be initiated again.

In QoS routing strategy, the path must be creating by requirements of the data flows, such as bandwidth, hop count, delay, packet loss rate, cost, etc. Since all requirements must be treated simultaneously, a set of optimal solutions or near-optimal solutions will be produced, also known as the Pareto solutions or non-dominated solutions [3] of the multi-objective problem. In another meaning, there is no a single solution that can optimize all objective functions together. While, in single-objective problems, it determines the best solution over other solutions through comparing their objective values according to a set of constraints.

In [4] the author proposed approach for selecting the best path between source and destination node for data transmission based on distance only and he did not take care with the other metrics. In [5] the author proposed approach for finding a feasible path between source and destination node which uses adjacency-constraint matrix based on a genetic algorithm with a maximum of two metric using genetic algorithm. Camelo et al. [6] proposed a multi objective optimization method for selecting the paths by considering some QoS in Wireless Mesh Networks (WMNs). Anjum and Gihan of [7] proposed approach for selecting optimal path between source and destination node depending on one metric (number of hops) using genetic algorithm. In [8] the authors proposed a new routing method in wireless multimedia sensor networks to optimize only delay and the expected transmission count. In [9] a non-control sorting method was proposed to get the Pareto optimal routing path set, but it was not clear how they implemented his approach.

In this paper, we use three methods to improve the QoS conditions and to overcome the network problems as the proposed methods reduces transmission delays and path loss as well as increasing the bit rate. They also can save node energy consumed during re-discovery process when route failure occurs. The simulation results of the proposed methods show the optimized way of finding the best routing path in the case of static and dynamic (mobile) network. To analyze the quality of solution produced by the proposed methods, the same problem is solved in Bellman-Ford based AODV and NSGA-II with priority based encoding.

2. PROBLEM FORMULATION

AHWSN can be modeled as an undirected graph, G = (V, E, Q), with N nodes (terminals), where V denotes the set of vertices that represent the nodes, E denotes the set of edges that represent the links between nodes, and Q is the QoS vector for each link which specified by the QoS matrices. The distance of a link $l(s_i, s_j) \in E$ between the adjacent nodes s_i and s_j is $d_{s_i s_j}$. A path *P* is a series of links between the source node and the destination node without repeating nodes in that path. Each link has the link connection pointer denoted by X_{ij}, providing information about the link status. The problem is to find a path between the source and destination nodes having minimum packet loss rate and end to end delay as well as maximum bit rate.

2.1 Decision Variables

The purpose of routing problems is to find a path p, which the data is being sent through it. Thus the decision variable on the network links can be defined as below:

$X_{ij} =$ 1, if the link from node i to node j is used.

$X_{ij} =$ 0, otherwise

2.2 Objective Functions

The goal is to minimize packet loss rate and Delay and maximize Bit rate.

2.2.1 Packet Loss Rate:

The packet loss rate is an important QoS metric, which mirror the rate of packet loss for link. In other words, it is used to measure the probability of transmission failures and can be expressed in terms of data delivery ratio. This value is stochastic and depends on many factors (quality of link, traffic on the link, etc.). It may be obtained using historical values for each link.

If the packet loss rate of the link i, j, denoted as $PLR_{link_{ij}}$, then the end-to-end packet loss rate [10], for the path p can be calculated as follows:

$$PLR_{e2e_{path_p}} = \prod_{(i,j) \in E} X_{ij} * PLR_{link_{ij}} \quad (1)$$

2.2.2 Bit Rate:

In telecommunication and computing, bit rate is the number of bits that are conveyed or processed per unit of time. We assume the value of bit rate for each link as $BR_{link_{ij}}$, then the end-to-end bit rate for path p [10]:

$$BR_{e2e_{path_p}} = \min(BR_{link_{ij}}) \mid link_{ij} \in path_p \quad (2)$$

2.2.3 Delay:

Delay is the time elapsed for the transfer of a data packet from the source to the destination node. The delay metric between two nodes represented as $D_{link_{ij}}$ is the summation of processing, queuing, transmission, and propagation delay. Many of the WSNs applications are sensitive to real-time delay constraints. Therefore, WSN must use an efficient routing technique that reduces delay in packet delivery. The end-to-end delay of a path p, $D_{e2e_{path_p}}$, is the summation of the delays between all of the intermediate nodes along the path p [10]:

$$D_{e2e_{path_p}} = \sum_{(i,j)\in E} X_{ij} * D_{link_{ij}} \quad (3)$$

2.3 Constraints

Generally, a multi-objective optimization problems treat one or more constraints. In this problem, we take into account the flow-conservation constraints.

$$\sum_{(i,j)\in E} X_{ij} - \sum_{(i,j)\in E} X_{ji} = 1, \ i = S \quad (4)$$

$$\sum_{(i,j)\in E} X_{ij} - \sum_{(i,j)\in E} X_{ji} = -1, \ i = D \quad (5)$$

$$\sum_{(i,j)\in E} X_{ij} - \sum_{(i,j)\in E} X_{ji} = 0, \ i \neq S, i \neq D \quad (6)$$

$$X_{ij} = 0 \quad or \quad 1 \quad (7)$$

Constraint of equation (4) ensures that, for every data single path exits from the origin node. Constraint of equation (5) ensures that, for every data single path will reach the destination node. Constraint of equation (6) ensures that every data which reaches an intermediate node (other than source S or destination D). The variable X_{ij} in equation (7) show whether the link (i, j) is used or not to transmit information to the destination node D.

3. THE PROPOSED METHOD

The proposed method is introduced to improve the network performance by selecting the path with the best QoS parameters. In addition, it finds several backup routes to avoid another route discovery process when the link failure occurs as shown in Fig. 1. When source node wants to send data to destination node, first it checks the routing table. If the path is existed, then the node uses such path. Otherwise, it initiates a route discovery process by broadcasting a RREQ packet to neighbor nodes in order to find the path using Bellman-ford algorithm [11]. It finds the path with minimum hop counts. After the source node finds the first path to destination, then the source node uses Yen's algorithm [12] for finding other possible paths between the same source and destination nodes. For all paths between source and destination node, we calculate the QoS parameters as shown in section II.

After that, the source node contains all the route reply messages (each message contains a particular path information in terms of QoS parameters), and must build the source decision table, from the information, collected in each message. Then, the source node selects the robust path from the source to decision table that satisfies the following objective functions:

$$f : \min(f_{PLR_{e2e_{path_p}}}), \min(-f_{BR_{e2e_{path_p}}}), \min(f_{D_{e2e_{path_p}}}) \quad (8)$$

Where, p (number of paths) = {1, 2, . . . ,n}

The first expression ($f_{PLR_{e2e_{path_p}}}$), in the objective function of equation (8) specifies the packet loss rate, the second expression ($-f_{BR_{e2e_{path_p}}}$) specifies the bit rate, while the third expression ($f_{D_{e2e_{path_p}}}$) is the delay. Hence, the objective function is to minimizing the packet loss rate, maximizing the data transferring rate while minimizing the delay.

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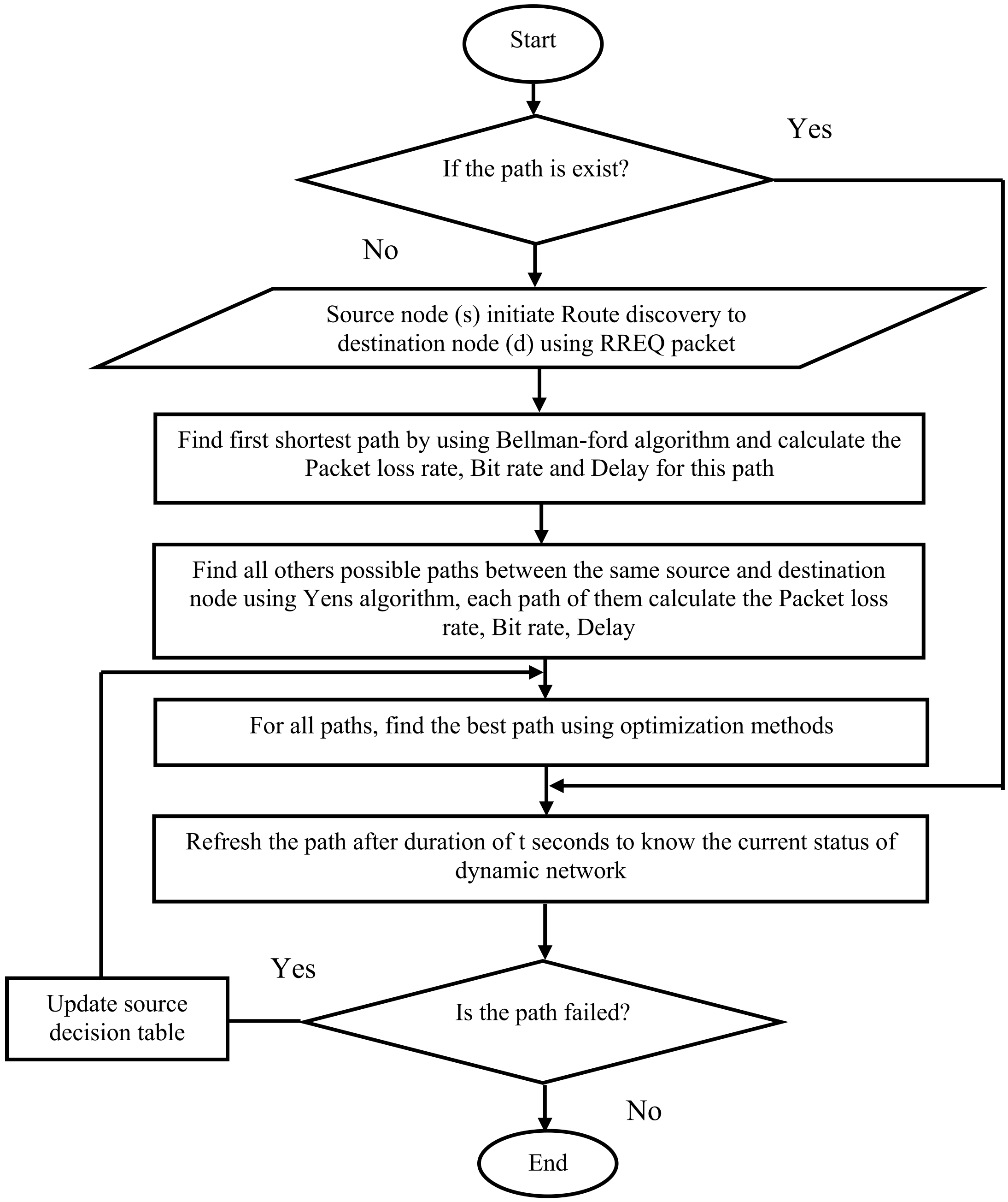

Figure 1: Flow Chart Of The Proposed Methods.

3.1 Weighted Sum Optimization Method for Routing Problem

This method consists of combination of the three functions in equation (8) to become a single-objective function model as expressed in equation (9). The n objective functions is assigned with a weight to each of the functions [10].

$$F = \min \sum_{k=1}^{n} f_k \times w_k \quad (9)$$

Where f_p is the normalized QoS metrics for each path.

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$$\sum_{k=1}^{m} w_k = 1$$

Finally, equation (9) can be rewritten as follows:

$$F_i = \min\left(w_1 \times PLR_{e2e_{path_i}} - w_2 \times BR_{e2e_{path_i}} + w_3 \times D_{e2e_{path_i}}\right) \quad (10)$$

To maximize bit rate, we put a negative signal in order to obtain minimum value to the combined function. Subsequently, we can find the best path using this method as shown in Fig. 2.

3.2 Weighted Sum Based GA Optimization Method for Routing Problem

In this section, we apply the Weighted Sum Based GA on the source decision table to get the best path and as illustrated in Fig.3

3.2.1 Representation of Chromosome (or chromosome encoding)

The process of mapping a decision variable space is called encoding and is one of the most important stages in solving optimization problems. Each chromosome or individual corresponds to the candidate solution and representing a path between a source node S and a destination node D. The chromosome consists of a series of positive integers which representing the nodes IDs through which the routing path passes. Each gene in the chromosome has locus and allele, where the locus represents the position of the gene in the structure of the chromosomes and the allele represents the value that the gene takes. Chromosomal lengths are different, and the length of each chromosome must not exceed the maximum number of nodes in the network, as follows:

The example bellow represents encoding two chromosomes in the routing problem.

1	2	8	3	10	
1	6	2	9	3	10

Each node in this example is represented by a numeric value. Number 1 is the source node, and number 10 is the destination node and the rest of the numeric values are the intermediate nodes of the routing path.

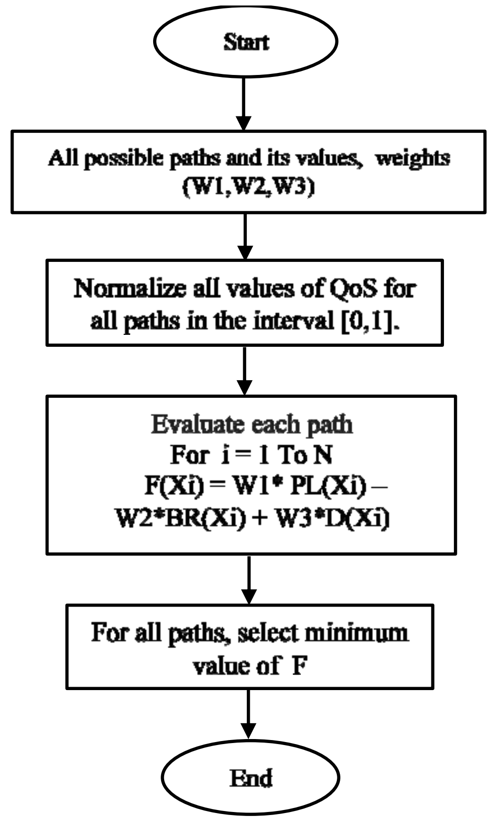

Figure. 2. Weighted Sum Optimization Method

3.2.2 Population Initialization

The initial population in the proposed approach is created by selecting N paths randomly from all possible paths that found in source decision table which we obtained them previously (as described in this section). The rest of the chromosomes (generated by genetic operators) can also be obtained by fetching them from the source decision table.

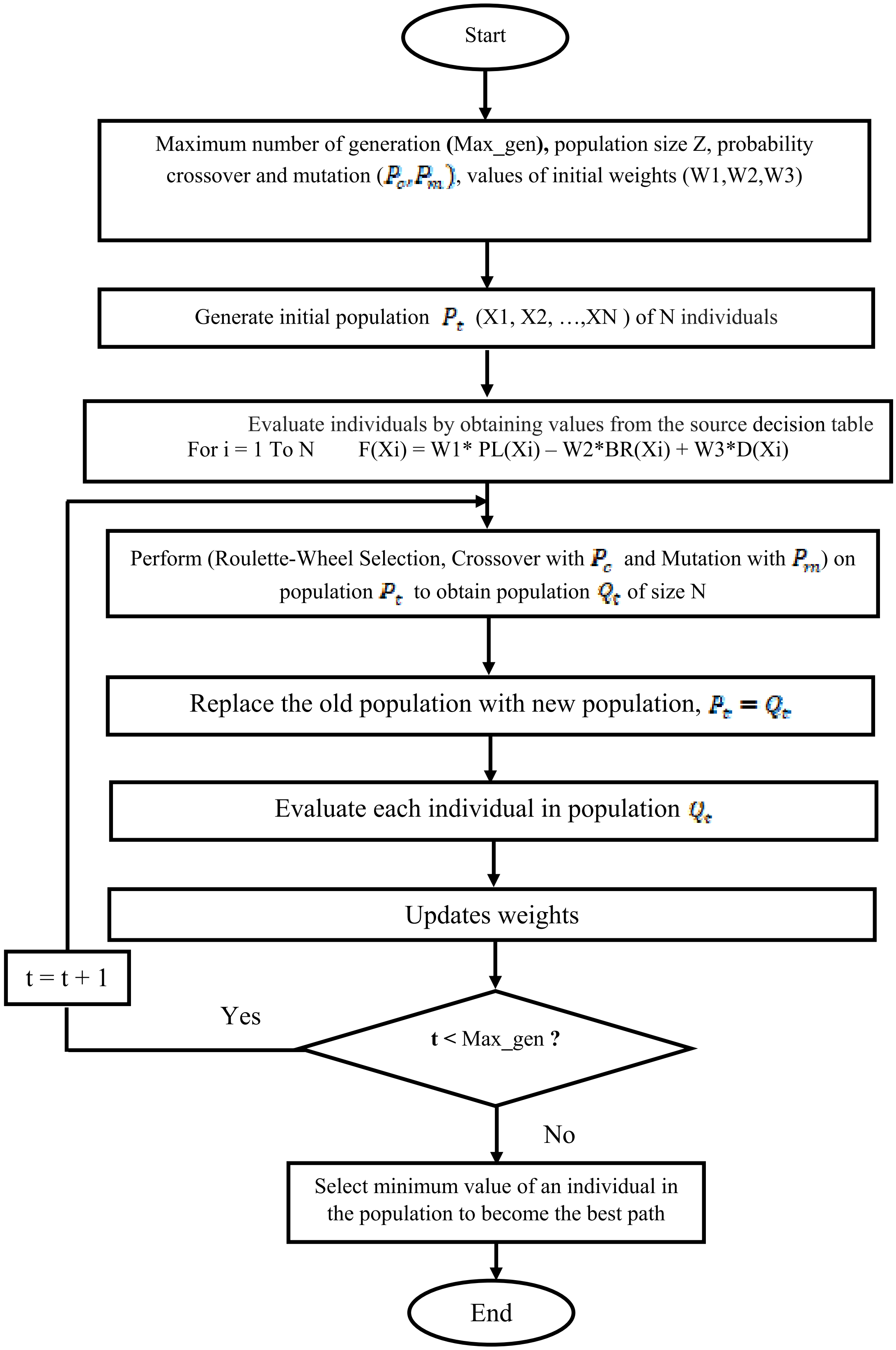

Figure 3. Weighted Sum Based GA Optimization Method

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3.2.3 Fitness assignment

Fitness values are assigned to each chromosome in the population using equation (10), where a suitable initial weights values are given at the beginning of the algorithm and then these weights are updated based on previous experiments [13].

$$w_c = \frac{w_p + |f_c - f_p|}{1 + e^{-f_p}} \qquad (11)$$

Where f_c and f_p are the fitness parameters values of the current and previous best chromosomes respectively, w_c and w_p are the current and previous weights.

3.2.4 Selection

The selection plays a key role in genetic algorithm as it focuses on good solutions in the population and passing it to the next generation, while trying to ignore bad solutions, and also maintain population size. There are several technique of selection in GA such as tournament selection, Roulette wheel selection, rank selection, elitist selection, scaling selection, etc. Roulette wheel selection is adopted in this work. In Roulette wheel selection, individuals are selected based on their fitness values. Where the chromosomes that are fittest have higher chance to be selected.

3.2.5 Crossover

The crossover or recombination is the primary genetic operation done on the chromosomes in the mating pool in order to create an information exchanged between Parent chromosomes to generate new Off-springs. Several crossover types are proposed in the literature. We apply two types of crossover: the node based crossover (NBX) method [14], and the partial mapped crossover (PMX) method [15]. The algorithm first checks the crossover probability Pc to decide if the parents are crossed or not. In our optimization methods, when occurs crossover between two parents, the resulted offspring must be checked with all possible paths, obtained previously. If the offspring is found in all possible paths, then these offspring are evaluated. If the offspring is not found in all possible paths, then it is rejected and replaced with parents.

3.2.6 Mutation

The Mutation operator is used to generate the offspring (solution) and it has the capability to search of global optimal (or near optimal) solutions. Several Mutation types are proposed in the literature. We apply the type of Mutation in [14]. The algorithm first checks the Mutation probability Pm to decide if the mutation operator will take place or not. After finishing from mutation, the offspring must be checked with the same procedure in crossover validation.

3.2.7 Stopping Criteria

When the number of iteration exceeds the maximum generations, the algorithm is stopped.

3.3 Non-Dominating Sorting Genetic Algorithm (NSGA-II) for routing problem

Multi-objective optimization problems can be solved using several approaches. NSGA-II has been chosen to solve our problem because it can find multiple solutions in single run. NSGA-II is one of the most efficient and common multi-objective optimization algorithms, proposed by Deb et al [16]. It is based on three mechanisms: 1) it is uses fast non-dominating sorting procedure for fitness assignment, 2) it is uses crowding distance mechanism for improving the diversity in the population and 3) it is uses elitism mechanism, which keeps the best individuals from the parent and child population. Therefore, the use of elitist mechanism is prominent to decrease the delay and packet loss as well as to increase bit rate by the optimization process in WSN. The Main Steps of NSGA-II is shown in Fig. 4.

The steps of NSGA-II are applied on source decision table to get Optimal Pareto Routing Paths (OPRP) and as illustrated in Figure 5. Then, weighted sum Optimization method is applied on OPRP to choose the best path as illustrated in this section (paragraph A). The *Chromosome encoding, Population Initialization, Crossover, Mutation* and *stopping criteria* are evaluated following the same steps explained in this section (paragraph B), in addition to need clarification of the *Fitness assignment* and *Selection operator.*

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3.3.1 Fitness assignment

Fitness values are assigned to each chromosome in the population using the packet loss rate, bit rate and delay values, obtained previously in the source decision table. The set of non-dominated solutions are selected taking into account the individual's fitness values.

3.3.2 Selection

The binary tournament selection is adopted in this work. In this method, if there are two solutions A and B, then Solution A wins a tournament with solution B if one of the following conditions is met:

- If solution A has a lower (better) rank, that is A < B, when A and B with the different fronts.
- If both with the same level (rank), but the solution A has a high crowding distance than solution B, that is A = B and dA > dB.

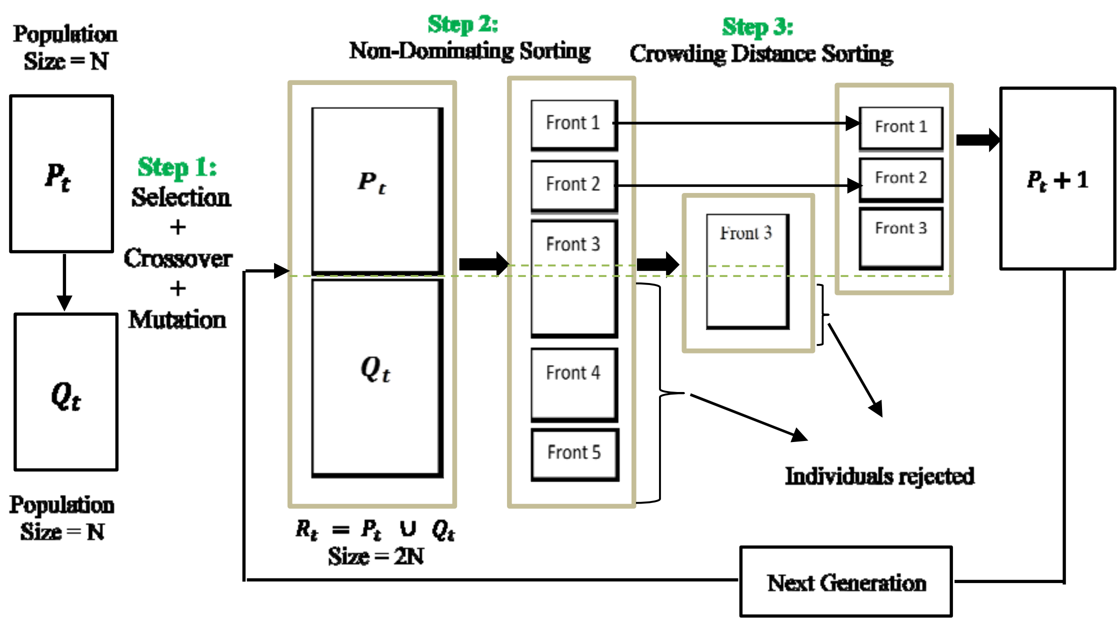

Figure. 4. Standard Representation of NSGA-II

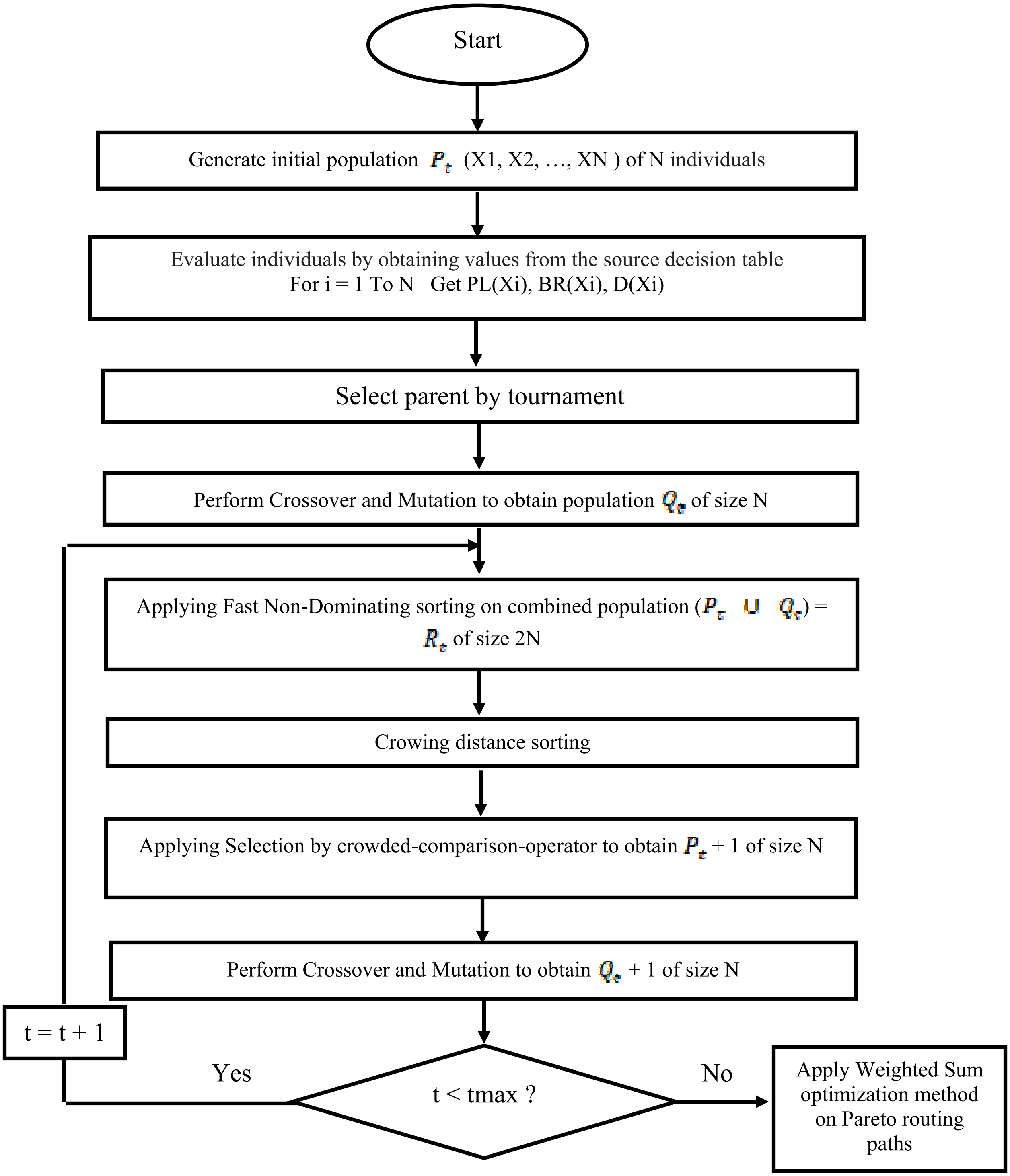

Figure 5. NSGA-II Optimization Method

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4. SIMULATION TOOLS USED AND RESULTS

In order to evaluate the proposed methods for the best path in routing problems, simulation environment are built using an HP PC with Core i5 processor using Matlab (2017 a). An undirected network with 10 nodes, deployed randomly as shown in Fig. 6 in an area of 100m x 100m and with 46m transmission range for each node, following the type of network is Ad Hoc Network. Every link between two nodes in the network are assigned according to the Euclidean distance between them and the value of the transmission range. Each link is associated with three weights for the mentioned QoS parameters of packet loss rate, bit rate and delay. The range of generated packet loss rate varies from (0.1 to 1), (1 to 100) (Mbs) range for bit rate and the range of delay varies from (1 to 120) (ms). Over all the runs, the node number one as the source node and the node number ten as a target node are selected in hoping to get a larger number of possible paths in the network as shown in Fig. 6.

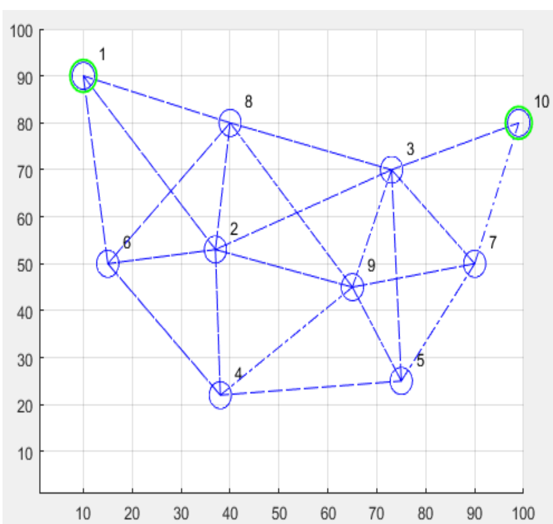

Figure. 6: Simulation Environment

The parameters of QoS between nodes are described in the Table 1, generated randomly. The algorithms, used to find the best path between two nodes according to the QoS parameters, assume that there is a system that collects these information about the link state (packet loss rate, bit rate and delay.

For covering the most of the network conditions, two case studies have been considered. These case studies are explained as follows:

4.1 Case Study One:

Case study one considers the finding of the best path between two nodes when the network is fixed (no mobility), and Table 2 shows a set of parameters related to the path-finding algorithms.

Table 1: The parameters between nodes

Link	Packet loss rate	Bit rate	Delay
(1,2) = (2,1)	0.538817	42	83
(1,6) = (6,1)	0.586555	91	17
(1,8) = (8,1)	0.57839	41	29
(2,3) = (3,2)	0.039055	17	106
(2,4) = (4,2)	0.447894	91	36
(2,6) = (6,2)	0.139276	81	48
(2,8) = (8,2)	0.90338	58	1
(2,9) = (9,2)	0.690897	100	21
(3,5) = (5,3)	0.146729	59	84
(3,7) = (7,3)	0.623672	76	42
(3,8) = (8,3)	0.617145	33	64
(3,9) = (9,3)	0.137136	94	84
(3,10) = (10,3)	0.552822	85	15
(4,5) = (5,4)	0.102334	42	84
(4,6) = (6,4)	0.165354	93	42
(4,9) = (9,4)	0.066	76	91
(5,7) = (7,5)	0.269928	90	52
(5,9) = (9,5)	0.923025	72	15
(6,8) = (8,6)	0.885942	36	110
(7,9) = (9,7)	0.01988	3	4
(7,10) = (10,7)	0.279184	59	117
(8,9) = (9,8)	0.246211	87	65

Table 2: Control parameters selected for path-finding algorithms.

Parameter	Set value
Population size, Z	20
Number of generations, Max_gen	100
Crossover probability, P_c	0.85
Mutation probability, P_m	0.1
Weights (W1=W2=W3)	0.333333333333333

In Weighted Sum (WS) optimization method, the weight values, assigned to packet loss rate, delay and bit rate, are equal, as shown in Table 2, according to the assumption of the three QoS metric are with the same importance. We have applied the WS method with the Pareto optimal routing path discovered by: NSGA-II with priority based encoding initialization and proposed NSGA-II with all possible paths based initialization. Table 3 shows the best routes with the related QoS parameters for the considered methods for the comparison. In terms of packet loss, the proposed weighted sum method obtains the best results, while the same method achieves the best bit rate value. In consideration to delay, the proposed weighted sum based GA obtains the best value.

4.2 Case Study Two:

This case study considers the finding of the best path between two nodes when the network is dynamic (mobile nodes). The parameters of Table 2 are adopted in this case study as well to apply the proposed path-finding algorithms. Thus, the proposed methods used the same values of QoS parameters, listed in Table 1, but when we applying Bellman-Ford and NSGA-II with priority based encoding initialization algorithms, the values of QoS are different. This is due to the taking the path--after several movements of nodes in the network. Finally, the paths that we obtained after applying path-finding algorithms in this case study are shown in Table 4. In terms of packet loss, the proposed Weighted Sum Based GA method obtains the best value amongst the other method. NSGA_II with priority-based encoding and (NBX) crossover method achieve the best bit rate with a little difference over the proposed NSGA_II Based all possible paths initialization with PMX crossover. The Bellman-Ford Based AODV method obtains the less delay over the other methods as it depends on the shortest path regardless the other QoS parameters.

Table 3: Best Routes And Its Qos In Fixed Network

Method no.	Routing Algorithm	Path	Packet loss rate	Bit rate (b/s)	Delay (Ms/s)
1	Bellman-Ford Based AODV	1-2-3-10	0.0116	17	204
2	NSGA_II with priority-based encoding and(NBX)crossover	1-6-2-9-3-10	0.0042	81	185
3	Proposed Weighted Sum	1-6-4-2-9-3-10	0.0022	85	215
4	Proposed Weighted Sum Based GA	1-2-8-3-10	0.1660	33	163
5	Proposed NSGA_II Based all possible paths initialization with NBX crossover	1-6-2-9-3-10	0.0042	81	185
6	Proposed NSGA_II Based all possible paths initialization with PMX crossover	1-6-2-9-3-10	0.0042	81	185

Table 4: Best Routes And Its Qos In Dynamic Network

Method no.	Routing Algorithm	Path	Packet loss rate	Bit rate (b/s)	Delay (Ms/s)
1	Bellman-Ford Based AODV	1-8-3-10	0.1973	33	108
2	NSGA_II with priority-based encoding and(NBX)crossover	1-8-9-3-10	0.0107	85	155
3	Proposed Weighted Sum	1-8-9-3-10	0.0108	41	193
4	Proposed Weighted Sum Based GA	1-2-6-4-9-3-10	6.2089e-05	42	363
5	Proposed NSGA_II Based all possible paths initialization with NBX crossover	1-8-2-9-3-10	0.0273	41	150
6	Proposed NSGA_II Based all possible paths initialization with PMX crossover	1-6-2-9-3-10	0.0042	81	185

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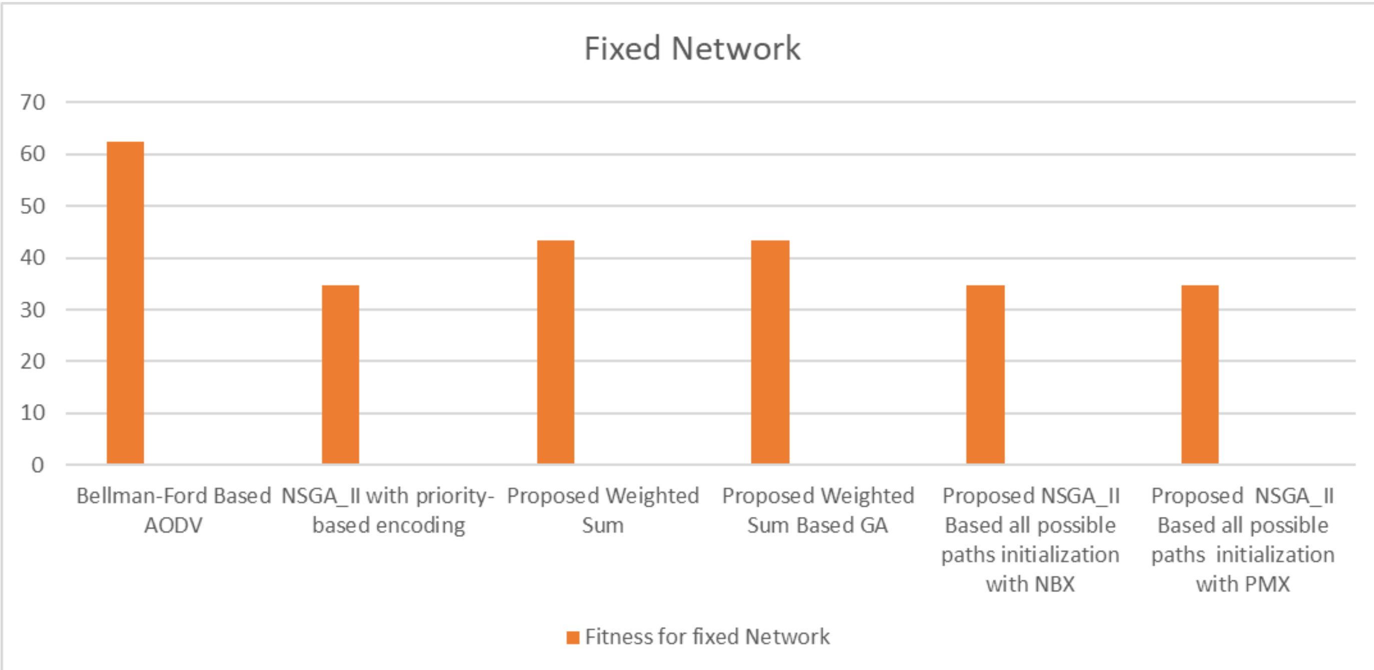

Figure 7: The Fitness Function For Path Finding

Fig. 7 shows the fitness function of the considered path finding methods for fixed case study. The fixed is selected as the dynamic one is not changing the fitness function, and therefore this figure is adopted for both case studies. From Figure 7, we can conclude that the proposed NSGA-II are obtained the same value of NSGA-II with priority based-encoding and better than Bellman-Ford Based AODV. While, the other proposed methods are close to NSGA-II with priority based-encoding, but also better than Bellman-Ford Based AODV.

In Fig. 7 the name of methods (method no.) the same order in Table 3 or Table 4, i.e. method no. 1 represent Bellman-Ford based AODV, etc.

5. CONCLUSIONS

The proposed optimized path finding methods aimed to select the route with the high bit rate, low packet loss rate and low delay from source to destination nodes simultaneously. In proposed methods, three QoS parameters (packet loss rate, bit rate, and delay) were considered in routing decision. In fixed network, the proposed (Weighted NSGA-II with priority based encoding. But the delay of the proposed methods was increased in the case of increasing the number of node in some scenario compared to Bellman-Ford based AODV. Proposed NSGA-II with all possible paths initialization and NSGA-II with priority based encoding found serval alternative paths, by applying Weighted Sum Optimization method with equal weights for three QoS, and the best path was found. Another advantage of proposed methods was when route failure occurs, it did not need to reroute discovery, while, in Bellman-Ford based AODV and NSGA-II with priority based encoding, the reroute discovery should be initiated again. Therefore, avoiding route discovery process saved the battery power consumed and increase the network lifetime.

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