# Fault Tolerance and Interference Aware Topology Control in Wireless Sensor Networks using NSGA-II

Nahid Sarbandi Farahani[1*], Asad Vakili[2]
1- Department of Computer Engineering, Saveh Branch, Iran Islamic Azad University, Saveh, Iran.
Email: Farahani.1990@yahoo.com (Corresponding author)
2 Department of Computer Engineering, Saveh Branch, Iran Islamic Azad University, Saveh, Iran.
Email: Asad.vakili@gmail.com

Received: May 2020 Revised: July 2020 Accepted: August 2020

**ABSTRACT:**
Research on topology control protocols in wireless sensor networks has often been designed with the goal of creating a dynamic topology and extensibility. The present study focuses on finding high quality paths, instead of minimizing the number of hops that can cause reduction of the received signal strength and maximizing the rate of loss. The purpose of this research is to create a topology control that focuses on reducing the fault and minimizing interference simultaneously. For this purpose, the fault rate and the degree of interference minimizing functions are modeled by using a two-objective genetic algorithm. Since the genetic algorithm is a revelation algorithm, the proposed method is compared in terms of convergence with similar algorithms. The obtained graphs show that the proposed algorithm has a good degree of convergence compared to similar models. The "runtime", "memory consumption" and "energy required to transmit the statement" are the variables used to compare with similar algorithms. By observing the obtained graphs, the proposed algorithm compared to similar methods, reduces the time needed for topology control and also it lowers the energy consumption, but is not able to reduce memory consumption for more packages. The main reason for conducting the test is the comparison of the quality of the routes created, which were executed in 20 different requests with the number of routes 5, 10 and 20. The quality of the routes produced by the proposed method has a 1% improvement over the SMG method and a 3% compared to the PSO method according to the route quality criteria.

**KEYWORDS:** Topology Control, Fault Tolerance, Interference, Wireless Sensor Networks, NSGA-II Algorithm, Throughput.

## 1. INTRODUCTION

In wireless sensor networks[1], the high demand for real-time services has created many challenging issues for service quality. Designing routing protocols that can meet multi-objective goals is computationally difficult and confusing. K-connection based topology control of the connection can withstand the performance of multi-cast wireless networks. The existing algorithms are generally focused on maintaining a k- Connection between the two nodes. However, in the implementation of network operations, k-connection algorithms reduce network performance, and on the other hand, topology requires fault tolerance and interference [1].

Topology control in WSN is the art of coordinating nodes by deciding on the range of their radio transmissions in order to create a network with the desired characteristics such as connection, coverage, interference, etc. [2]. Energy consumption is one of the main challenges in WSN. Every method and mechanism presented in the field of WSN should be energy-oriented, in other words, consider the limitation of energy consumption. In addition, the ability of each method to reduce energy consumption can be very effective in evaluating its efficiency and acceptability. Topological control in WSN provides an optimal infrastructure for meeting the needs of applications such as network connection and network coverage [3].

Nowadays, most wireless networks are expanding at a significant rate. In these networks, the sensor may break down and fail due to factors such as energy depletion, hardware malfunctions, environmental conditions, etc. Therefore, the failure of the sensors affects the performance of the network, so one of the important requirements in WSN is fault tolerance, which should be increased as much as possible [4].

Interference in a WSN is a key issue that affects performance. The middle node should be placed in a way that maximizes the passage and minimizes interference

[1] WSN

between the middle nodes [5,6]. The location of the middle node has a great impact on the efficiency of the network. If the distance between the middle nodes is too large, the signal strength decreases. Therefore, the distance between the middle nodes should be optimal [7].

Multi-objective optimization topics have objective functions that contradict each other, causing a set of answers to be generated instead of producing one answer. One of the main goals of optimization is to get a set of optimally distributed responses. Multi-objective algorithms are used to solve these problems; The goal of these algorithms is to provide a set of optimal solutions. Then, the final solution is found by choosing the best solution from the available solutions [8]. Genetic algorithm is one of the applied algorithms in multi-objective optimization.

Genetic algorithm is an optimized method inspired by living nature that can be classified as a numerical method, direct and random search. This algorithm is based on repetition, and its basic principles are adapted from the science of genetics and by imitating a number of processes observed in the evolution of invented nature and effectively uses the old knowledge of a population to create new and improved solutions [9].

In many of the methods presented so far, the issue of topology control has been accompanied by the issue of awareness, fault tolerance. For example, in the research of Bao et al. [10] and Zhao et al. [11] using fault tolerance, first a method is presented to control the topology and then a method is proposed to delay the transmission over time. This paper focuses on minimizing fault as well as simultaneously minimizing interference using the two-objective genetic algorithm, so that by meeting the two main objectives of the problem, the convergence of the two-objective genetic algorithm with similar algorithms such as PSO [12], SMG [13], and DDSE [14] algorithms are compared. PSO or particle algorithm known as swarm algorithm is one of the basic optimization methods and two other algorithms called SMG greedy algorithm and DDSE evolutionary algorithm which are new algorithms are used for experiments. Finally, based on the quality of the paths created, the numerical values are concluded.

PSO or Particle Collision Algorithm in 1995, Eberhard and Kennedy first introduced PSO as an uncertain search method for optimizing a function. This algorithm is inspired by the mass movement of birds looking for food. PSO is a universal minimization method that can be used to deal with problems whose answer is a point or level in the next n-space. This method has shown great success in solving continuous optimization problems. It has a relatively good convergence rate [12].

In the first part of the article, the introduction of the article was stated. The second part describes the related works. In the third section, the proposed method is described step by step. In the fourth section, the simulation and comparison results are displayed graphically and numerically, and at the end, a conclusion is made.

## 2. LITERATURE REVIEW

In their paper, Heydari and Asadpour use a fast-scalable (SMG) greedy algorithm to maximize network impact. Influence maximization is the problem of finding k most influential nodes in a social network. Many works have been done in two different categories, greedy approaches and heuristic approaches. The greedy approaches have better influence spread, but lower scalability on large networks. The heuristic approaches are scalable and fast but not for all type of networks. The fast greedy algorithm called State Machine Greedy that improves the existing algorithms by reducing calculations in two parts: (1) counting the traversing nodes in estimate propagation procedure, (2) Monte-Carlo graph construction in simulation of diffusion. The results show that our method makes a huge improvement in the speed over the existing greedy approaches [13].

Laizhong et al. Analyzed the reasons for the low efficiency of greedy approaches and proposed a new evolutionary algorithm called DDSE Search Engine Optimization for maximum impact on social network. The basic idea is to eliminate repeated simulations and replace it with rough estimation. The existing solutions to influence maximization perform badly in either efficiency or accuracy. In this study, it analyzes the causes for the low efficiency of the greedy approaches and propose a more efficient algorithm called degree-descending search evolution (DDSE). Firstly, they propose a degree-descending search strategy (DDS). DDS is capable of generating a node set whose influence spread is comparable to the degree centrality. Based on DDS, it develops an evolutionary algorithm that is capable of improving the efficiency significantly by eliminating the time-consuming simulations of the greedy algorithms. The proposed algorithm has two notable features: it is very efficient and very accurate, and it performs much better than existing heuristics [14].

Wilder et al. Introduced a new fault-tolerance routing protocol that ensures service quality, which ensures delay, vibration, and reliability in wireless multimedia sensor networks. The simulation results prove the effectiveness of this protocol in ensuring delay, vibration and reliability, efficiently in terms of energy consumption, in wireless multimedia sensor networks, but it cannot always reduce the interference by improving these parameters [1].

In their paper, Zhang and Jiao discussed the problem of broadcast timing in wireless networks that focus on packet delay limit. This was done with the aim of minimizing the number of packets. The simulation results show that algorithm significantly reduces the computational time but does not cover the fault tolerance [15].

## 3. MATERIAL AND METHODS

The WSN can be defined as the graph G = (V.E) in which V contains a set of nodes and E represents the set of edges between these nodes. A path from the Vi node to the Vj node is a sequence of V nodes. The problem of topology control is defined in such a way that there is a path between the source node and the destination nodes with minimal transmission fault and minimal interference.

### 3.1. Decision Variable

The decision variable of the binary Xij is shown to indicate whether the path containing the edge (i, j) belongs to E and is shown as relation (1).

$$X_{ij} = \begin{cases} 1 & if the\ link\ (i.j) is\ included\ in\ the\ path \\ 0 & if\ the\ link\ (i.j) is\ not\ included\ in\ the\ path \end{cases} \quad (1)$$

### 3.2. Target Functions of Topology Control Problem

This section describes the target functions, the following is how to calculate them on the WSN.

#### 3.2.1. Fault function

This function is intended to minimize the fault of transferring packets from the source node to the destination node. Transmission fault are always assigned to a node. For example, for node A in a wireless network, the relation (2) is calculated:

$$STD_n.A = \sum \alpha(1-\alpha)^{n-i} D_{i.A} \quad (2)$$

In this case, n represents the number of detected routes, α is the transmission fault coefficient, and D is the measured error value for node A. Therefore, the objective function, Minimum fault rate will be calculated as (3):

$$f_1 = min \sum_{(i.j)\in E} D_{i.j} X_{i.j} \quad (3)$$

#### 3.2.2. Interference Function

The goal is to select routes with minimal interference. Interference parameter for a path p that contains the links (edges) $v_1$, $v_2$, …, $v_n$ and with the transfer rate $fd_{vi}$ and the waiting rate $rd_{vi}$ for the edge $v_i$ is calculated as the relation (4):

$$t_{v_i} = \frac{1}{(fd_{v_i} \times rd_{v_i})} \quad (4)$$

The probability that a packet of data will successfully reach the recipient is the probability of a forward-to-forward delivery ratio and a reverse delivery ratio that the packet receives successfully. The objective function for minimizing the interference with relation (5) is obtained.

In other words, the function of the second objective in this study is considered $f_2$.

$$f_2 = min \sum_{(i.j)\in E} T_{i.j} X_{i.j} \quad (5)$$

When it sends the requested node, it not only attaches its address, but also adds the link criterion that received the request. These criteria are also in response to the path that is returned to the sender. When it receives the requested node, which it has already sent, it will be re-sent if the path criterion is better than the criteria previously sent with this request ID. This increases the likelihood that the exporter will find the best metrics. The entries in the link's temporary memory are weighted by the criteria in the path answers.

### 3.3. Two- objective Genetic Algorithm

The multi-objective genetic algorithm, by non-dominate sorting the second version, is such that by adding two essential operators to the conventional single-objective genetic algorithm, it becomes a multi-objective algorithm that, instead of finding the best answer, gives the best answers. It is known as Pareto-Front. These two operators are:

1) An operator who assigns a criterion of superiority (rank) to members of the population based on non-dominate sorting.

2) An operator that maintains a variety of answers among Answers with equal rank.

Figure 1 shows flowchart of the proposed method.

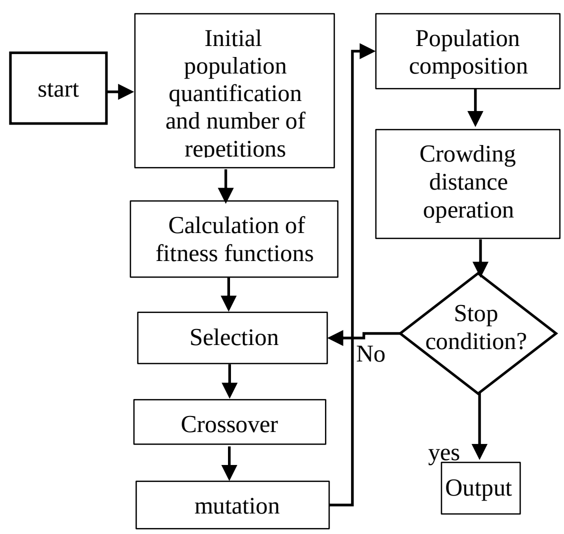


**Fig. 1.** Flowchart of the proposed method.

The steps in Fig. 1 are interpreted as follows:

- Primary population: The routes identified are from the source node to the destination node. In fact, routes are a collection of our edges between the source node and the destination that can be used to send packets. As a result of the search space here, these paths are identified between the two nodes of source and destination.

- Objective function: The objective function is an indicator of how people function in the problem space. For example, if our goal in solving a problem is to find the minimum answer, the most suitable person is the one whose function has the least amount of purpose. The aim of this study is to minimize the fault of transmission and minimize interference, which are calculated based on the functions presented in the previous section.

- Selection: At this stage, the routes are reviewed and evaluated based on the fault and interference functions and are sorted according to their value. The routes that have the highest value, i.e. the lowest fault value and interference, are selected.

- Crossover: In this operator, paths are randomly selected and parts of these paths, which are actually edges, are selected and replaced, and the resulting paths are added to the new paths and join the population of this algorithm. The crossover rate here is 85%. In fact, one random number between 1 and 100 is produced for each path. If the number produced is between 1 and 85, the crossovering and edge replacement operation is performed and a new path is generated.

- Mutation: In this process, a number of routes are randomly selected and a 10% jump rate is used. This means that for each selected path, a random number is generated between 1and one 100. If this number is between 1and 10, a mutation occurs and one edge changes in the selected path, and the new path is added to the population. Otherwise, it goes to the next step. The low value of the mutation rate is due to the fact that the mutation must occur very little so that there is not much change in the paths. On the other hand, mutations are used so that if the optimal global point is somewhere outside the current search range, it allows the algorithm to be able to examine those paths as well. If the path obtained from the mutation procedure is better than the current search paths, the algorithm will move towards it, otherwise it will continue to search in the same range. The most important task of mutation is to prevent convergence in the local optimal. Mutations occur on the basis of probability, If the steps of the mutation are large, the search for the genetic algorithm is completely random.

- Population composition: In this section, the population has reached its final state after going through the crossover and mutation stages, and new paths are added to the previous population.

- Crowding distance: When the number of solutions in the proposed method exceeds the size of the initial population, to eliminate additional chromosomes, the NSGAII method uses the crowding distance (CD) criterion according to Equation (6). Chromosomes that have lower values than CD are preferred to those that have higher values than CD in the removal process.

$$CD_i = \frac{1}{r}\sum_{k+1}^{r} |f_{i+1}^{r} - f_{i-1}^{r}| \quad (6)$$

In relation (6) r is the number of nodes, $f_{i+1}^{r}$ is the $k_{th}$ target of (i + 1)th chromosome, and $f_{i-1}^{r}$ is also the $k_{th}$ target of (i-1)th chromosome after sorting the population by CD.

A Crowding distance operator is an operator that maintains a variety of answers among answers with equal rank. This means that if the number of paths created exceeds the number of initial paths, it removes paths that are duplicate or of lower value.

- Stop condition: At this stage, the routes are evaluated using the objective functions. The path that has the fitness criterion means the least amount of interference and fault, as the path that has the most reliability, sends to the output for the path to fit. Otherwise, these paths are re-selected as the initial population, and the algorithm process is repeated to achieve evolution and optimal output.

## 4. RESULTS AND DISCUSSION

In this paper, simulation and evaluation for the proposed method using the two-objective genetic optimization algorithm are presented. Here's how to simulate the proposed method on WSN. The simulation conditions for the proposed method and similar methods for comparison are the same. A Dell computer with a Core i7 2.0 (GHz) processor and 4 GB of main memory is used for all experiments. MATLAB software has been used to simulate and evaluate the proposed algorithm. Table 1 shows the parameters related to the two-objective genetic algorithm.

**Table 1.** Parameters of the two-handed genetic algorithm.

| Parameter | amount |
|---|---|
| Number of primary particles | 20 |
| The number of repetitions | 100 |
| crossover rate | 0/85 |
| Mutation rate | 0/1 |
| Select operator | Tournament |

Table 2 is presented in Table 2 to evaluate the proposed method with the two-objective genetic method environmental and the evaluation conditions of WSN. The number of nodes is 20, 40, 60, 80 and 100.

**Table 2.** Simulation parameters.

| Parameter | VALUE |
|---|---|
| Network size | 1000 × 1000 (M) |
| Maximum number of packets | 60 |
| Number of nodes | 20-40-60-80-100 |
| IEEE ST | 802.11(bit) |
| Traffic type | CBR |
| Transmission range | 250 (M) |
| Maximum mesh client speed | 20 (M/S) |
| Smoothing factor | 0.4% |
| Simulation duration | 500 (s) |

### 4.1. Convergence

The convergence parameter is used to evaluate the genetic algorithm. The convergence parameter, that is, the candidate's answers, often resemble a single answer. When maximum responses indicate a common answer, the probability of that answer being more likely to be true is chosen as the final answer. In fact, convergence means the end of the algorithm and the choice of the answer. However, if the algorithm obtained similar results in consecutive execution, Has more stability.

For convergence testing, the proposed method as well as SMG, DDSE and PSO algorithms have been implemented. And Figures 2, 3, 4, and 5 show how the final answer converges, respectively. These algorithms have been chosen because they are all used to solve optimization and minimization problems, and the PSO algorithm or particle optimization method is a basic and old method, And the DDSE algorithm, or the evolutionary algorithm for degree descending search and SMG or Fast scalable greedy algorithm are among the new algorithms.

In the diagrams mentioned, the horizontal axis of the algorithm repetition order and the vertical axis also show the best competence of each iteration. In the convergence diagram, when the line is horizontal and straight, it means that it is convergent to the optimal answer and the output is obtained. In all diagrams, Nseed_set represents the set of nodes considered for correlation. In Figures 2, 3, 4, and 5, the number of nodes is considered to be 10, 5, 15, and 20, respectively.

The test is that because the initial population is randomly selected, the output will naturally be different each time it is executed, if the output is close to each other at each run and has a lower standard deviation. That is, the algorithm is stable and vice versa.

Checking the results of this experiment, it is clear that the proposed method for topology control has a good degree of convergence and finds near-optimal penetration. Examination of the results also shows that the DDSE algorithm has premature convergence. In this case, the optimal local answer is given as the final answer, so in subsequent experiments it is removed from the comparisons.

### 4.2. Execution Time Metric

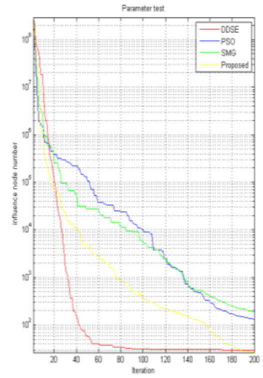


**Fig. 3**.Comparison of convergence of methods for Nseed_set = 5

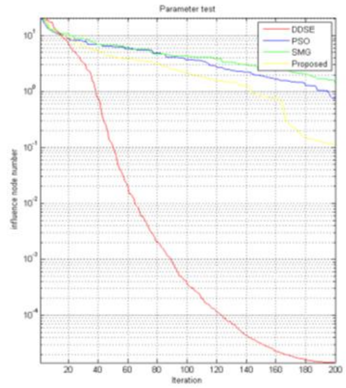


**Fig. 2.** Comparison of convergence of methods for Nseed_set = 10

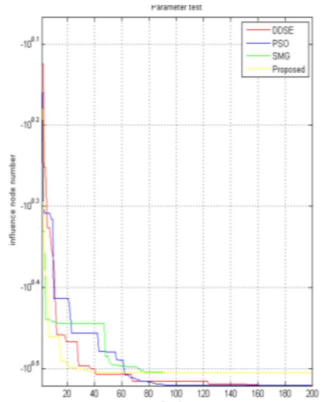


**Fig. 5.**Comparison of convergence of methods for Nseed_set = 20

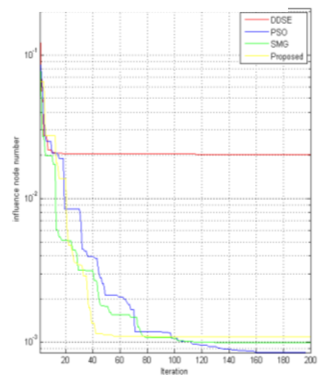


**Fig. 4.**Comparison of convergence of methods for Nseed_set = 15

In this criterion, the time it took for the topology control requests to be completed is fully compared. At

Each step, the packet size is increased in WSN, as shown in Figure 6.

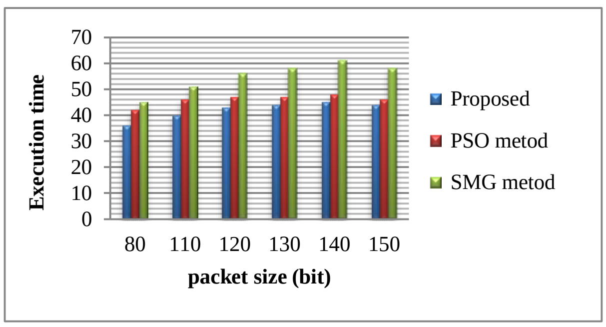


**Fig. 6.** Performance time metric

### 4.3. Consumption Memory Metric

As can be seen in Figure 7, this measurement measures the amount of memory consumed (Mb) to fully comply with topology control requests. Based on the number of packets sent, the results show that method three has the lowest amount of memory consumption for more packets, and the proposed method has not been able to reduce memory consumption for more packets.

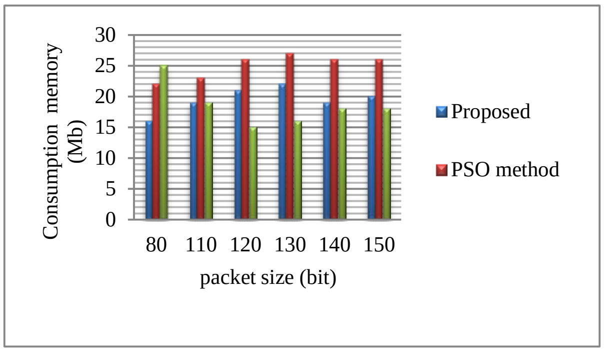


**Fig. 7.** Consumer memory.

### 4.4. Consumption Energy Metric

In this criterion, the amount of energy consumed to transfer information from source to destination in WSN has been compared to complete topology control requests, with the number of data packets increasing at each step. As can be seen in Figure 8, the proposed method has a lower energy consumption than similar methods.

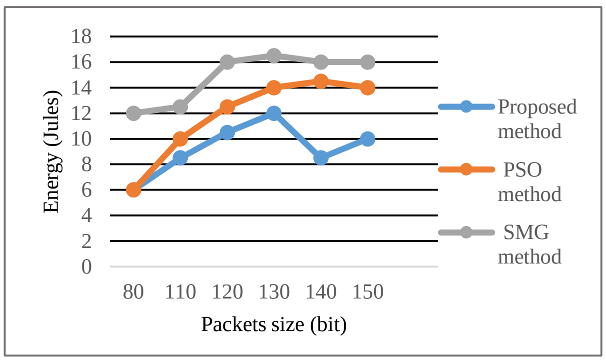


**Fig. 8.** Energy required to transfer the request.

### 4.5. Quality Testing

The main reason for this experiment is to evaluate and compare the quality of the paths created in WSN by the proposed method and similar algorithms. To perform this test for 20 different requests with the number of routes 5, 10 and 20, the above methods have been implemented and the average Throughput or average successful delivery rate of the message obtained from their implementation is given in Table 3. According to the results of Table 3, it can be said that the quality of the routes produced by the proposed method is better than the PSO and SMG algorithms according to the quality criteria of the route. The proposed method has improvement in terms of Throughput by 1% compared to SMG and 3% compared to PSO.

**Table 3.** Comparison of the quality of WSN paths produced based on the average Throughput per bit per second.

| Method | n=5 | n=10 | n=20 |
|---|---|---|---|
| PSO Method | 10.98562 | 1.6752 | 0.28952 |
| SMG Method | 13.2234 | 3.5968 | 0.36961 |
| Proposed Method | 15.68594 | 4.89854 | 0.42658 |

Considering the characteristics of evolutionary algorithms, what seems obvious is the high advantage of multi-purpose systems. That is, due to the inherently random nature of evolutionary algorithms, it is possible to achieve the desired results by using different goals and designing a multi-objective, by covering a more complete space of the problem.

## 5. CONCLUSION

The study provided a new fault tolerance and interference aware framework for topology control in wireless sensor networks. The effort was to find an optimal topology that minimizes interference and fault and has good Competence. In order to demonstrate the performance of each algorithm, it is necessary to compare it with other algorithms. Therefore, the results of the work were compared with similar algorithms. Comparing the algorithms, it was observed according to the convergence graphs that the two-objective genetic algorithm has good convergence. It can be concluded that the response time of the two-objective genetic algorithm is shorter and that the two-objective genetic algorithm is well-established. The proposed algorithm was implemented with different parameters and related diagrams were discussed. Two-objective genetic algorithm will reduce the time required for topology control requests to some extent and provide a near-optimal answer. The proposed method has less energy consumption than similar methods but, has not been able to consume less memory for more packets. The obtained Throughput shows an improvement of 1% compared to SMG method and 3% compared to PSO method.

For future work one may work on a method or making changes to the structure of this algorithm, to improve memory usage of the algorithm.

Other open issue is to use this proposed algorithm in wireless sensor networks which include mobile nodes, and evaluate the efficiency of the algorithm for topology control.

## 6. ACKNOWLEDGMENT

The author states that this article was the result of her academic dissertation research at the Islamic Azad

University, Saveh Branch, in order to obtain a master's degree in software technology engineering.

## REFERENCES


[1] E. Wilder, D. Castellanos, D. Juan, G. Pau, **"A QoS-aware routing protocol with adaptive feedback scheme for video streaming for mobile networks"**, *Computer Communications*, Vol. 77, pp 10-25, March. 2016.

[2] S. Palaniappan, P. Periasamy, **"Quality of Service and Topology Control Protocol in Wireless Sensor Network: A Survey"**, *Journal of Signal Processing and Wireless Networks*, Vol. 2, No.1, pp. 1-12, 2016.

[3] K. Guleria., A. K. Verma, **"Comprehensive review for energy efficient hierarchical routing protocols on wireless sensor networks"**, *Wireless Netw 25*, pp.1159-1183, April. 2019.

[4] M. Shyama, A. S. Pillai, **"Fault-Tolerant Techniques for Wireless Sensor Network-A Comprehensive Survey"**, *Innovations in Electronics and Communication Engineering*, Vol. 65, pp. 261-269, February. 2019.

[5] M. Li, Z. Li and A. V. Vasilakos, **"A Survey on Topology Control in Wireless Sensor Networks: Taxonomy, Comparative Study, and Open Issues"**, *in Proceedings of the IEEE*, Vol. 101, pp. 2538-2557, Dec. 2013

[6] J. Jia, X. Wang, J. Chen, J.yu, **"Joint topology control and routing for multi-radio multi-channel WMNs under SINR model using bio-inspired techniques"**, *Applied Soft Computing*, vol.32, pp. 49-58, July. 2015.

[7] Md. E. Haque, A. Rahman, **"Fault Tolerant Interference-Aware Topology Control for Ad Wireless Networks"**, *international conference on Ad-hoc, mobile, and wireless networks*, Vol. 6811, pp. 100-116, 2011.

[8] M. Camelo, C. Omana, H. Castro, **"QoS routing algorithms based on multi-objective optimization for mesh networks"**, *in IEEE Latin America Transactions*, Vol. 9, pp. 875-881, Sept. 2011.

[9] D. Chakraborti, P. Biswas, B. B. Pal, **"FGP approach for solving fractional Multiobjective Decision making problems using GA with Tournament Selection and arithmetic crossover"**, *Procedia Technology*, Vol.10: pp. 505-514, Dec.2013.

[10] X. Bao, C. Deng, **"FICTC: fault-tolerance-and-interference aware topology control for wireless multi-hop networks"**, *EURASIP Journal on Wireless Communications and Networking*, pp.175-190, Aug.2016.

[11] J. Zhao, G. Cao, **"Robust topology control in multi-hop cognitive radio networks"**, *IEEE Transactions on Mobile Computing*, vol.13, pp. 2634-2647, Nov. 2014.

[12] I.C. Trelea, **"The particle swarm optimization algorithm: convergence analysis and parameter selection"**, *Information Processing Letters*, Vol. 85, pp. 317-325, March.2003.

[13] M. Haidari, M. Asadpour, H. Faili, **"SMG: Fast scalable greedy algorithm for influence maximization in social networks"**, *Physica A: Statistical Mechanics and its Applications*, Vol.420, pp. 124-133, Feb.2015.

[14] L. Cui, H. Hu, Sh. Yu, **"DDSE: A novel evolutionary algorithm based on degree-descending search strategy for influence maximization in social networks"**, *Journal of Network and Computer Applications*, Vol.103, pp.119-130, Feb.2018.

[15] B. Zhang, Z. Jiao, C. Li, Z. Yao, and A. V. Vasilakos, **"Efficient location-based topology control algorithms for wireless ad hoc and sensor networks"**, *Wireless Communications and Mobile Computing*, Vol. 16, pp. 1943–1955, Feb.2016.