Effective combination for router placement optimization problem and improve performance in wireless mesh networks

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Abstract

Wireless Mesh Networks (WMNs) as an important technology and communication infrastructure in order to access different networks, particularly the Internet, because of the convenient features for next-generation wireless networks are considered. Mesh router nodes placement is a central problem in problems of WMNs. The main design WMNs are Router/Gateway placement, connectivity and coverage area, which are critical issues to improve network performance and directly related to network reliability. In this paper we try to consider all effective parameters such as network connectivity, end-to-end transmission delay, node placement/ location to optimize WMN designing. A hybrid binary genetic algorithm (BGA) and particle swarm optimization (PSO) is used to solve the multi objective optimization problem. BGA/PSOH help us to design a WMN with optimum deployment cost, packet transmission delay and router placement/ location. The experimental results confirm the effectiveness of the proposed method and illustrate the relationship between network connectivity, total delay and number of required routers.

Key words: Genetic algorithm, particle swarm optimizer, placement, wireless mesh network.

1. Introduction.

As various wireless networks evolve into the next generation to provide better services, a key technology, WMNs, has emerged recently. The functionalities of mesh routers enable users to integrate WMNs with various existing wireless networks such as Wi-Fi, WSN, Wi-MAX and etc. In WMNs, two types of nodes are used, mesh routers and mesh clients. In the multi hop mesh technology each node (mesh client or mesh router) should forward packets to reach their destination. Therefore, the WMNs could be used in Infrastructure/ Backbone manner. The architecture of such networks is shown in Fig. 1.

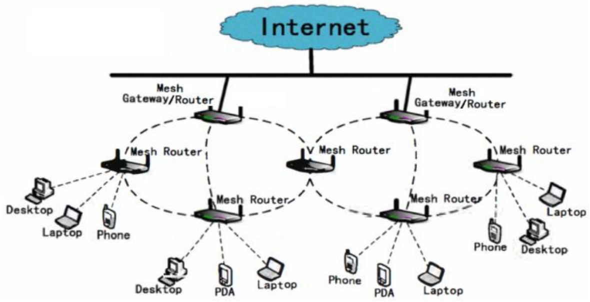


Fig 1: Sample architecture of a wireless mesh network.

The mesh routers which are connected with dash lines form the infrastructure, and communication between clients could be established via the backbone. Because of the mentioned specifications the WMNs are used in wide range of applications such as home network, community and neighborhood networks, enterprise networking, building automation, etc. Mesh routers could be placed on the roof of houses in a neighborhood which serve as access points for users inside the homes and along the roads. Considering the connectivity of mesh clients and mesh routers leads to some advantages such as network maintenance, robustness and reliable service coverage. The end-to-end packet transmission delay, network throughput and network reliability are main objects in network planning which are affected by router placement/location. In addition the number of routers is other important factor affecting the objects of network planning. The number of routers directly related to end-to end delay and deployment cost. More recent research works focus on optimizing the WMNs design and network planning via genetic algorithm and other optimization heuristic techniques. In the works done by [12] the load balancing of gateway placement is considered. In this work the network area is divided to clusters which all intra cluster traffic is routed to a gateway that is assign to cluster. They propose a greedy algorithm for load balancing clustering in a WMN. The authors in [13] have used genetic algorithm for channel assignment in wireless mesh networks. They proposed a solution for an unfixed topology WMNs. In similar researches, some techniques to place and minimize the number of gateways while supporting a specific amount of traffic to and from the internet are proposed in [9, 15]. However, most of these studies don't take into account the end-to-end delay, number and placement of routers involved in the design of WMNs. Authors in [2] proposed a genetic algorithm solution to optimize the router placement in wireless mesh network. The two fold optimization has been proposed in which the size of giant component which is used as connectivity criteria is maximized and also the work tries to optimize the user coverage. The presented works in [2] has some drawbacks such as:

- The networks area is considered as a grid area and the placement of router is restricted to the grid location. This is very important especially when the clients are distributed in a network area randomly.
- Some important issues such as packet transmission delay and number of routers are not considered in optimization problem.

In the latest research, conducted from the Hybrid GA algorithm (BGA and RGA(GA)) with minimum number and find the optimal position of the routers at the same time, reduce the average delay was also associated in the evaluation grid [16]. In this paper, we try to solve and improve these draw backs **using a BGA/PSOH based solution**. Our proposed optimization structure considers the average end to end delay for packet transmission. It means that the packet transmission delay is divided into two parts: inter domain delay and intra domain delay. The inter domain delay is defined as packet transmission delay from source node to the nearest router node. And the intra domain delay is defined as the delay from the source router to the destination router.

The rest of the paper is organized as follows: the network parameters are calculated in section 2. Section 3 describes the optimization-solution and simulation results are discussed in section 4. Finally the paper is concluded in section 5.

2. Network Specification and Parameter Calculation.

In this section, we show the parameters which have to evaluate in order to optimize WMNs designing. The considered WMN is worked in IEEE 802.11 via DCF configuration. In the DCF communication any station with a packet to transmit is required to perform the physical carrier sensing to determine the current state of the channel. If the channel is sensed as busy, the station defers its transmission. If the channel is sensed as idle for a period of time greater than a distributed inter-frame space (DIFS), the station would attempt transmission once after the back-off counter reaches to zero. The back-off counter, uniformly chosen from contention window (0, Wi– 1) for the attempt on the i^{th} retransmission, is decremented as long as the channel is sensed as idle and frozen when the channel is sensed as busy (we regard this frozen time as a part of back-off process). The decrementing of the back-off counter is resumed only when the channel is sensed as idle again for more than a DIFS. The IEEE 802.11 characteristics with considering the queuing theory help us to formulate the end-to-end delay as a main important parameter of WMN planning [16].

2.1 End-to-End Delay.

The following assumption is used to calculate the end-to end delay:
1- Each packet experiences multi-hop forwarding transmission till to reach the nearest router and pass truogh multi-Hop router forwarding to reach the end router and finally sends to destination clients with single hop transmitting.
2- The packet generation in each node followed Poisson process with rate.
3- It is assumed that all packets should be transmitted via router backbone.
4- Each client node is modeled as M/G/1 queue and a new mathematical model for multi-hop packet transmission is considered.
5- Also the input rate of each router is modeled as general distribution, so a G/G/1 queue is proposed for mathematical modeling of router nodes.
6- The total available bandwidth for clients and routers are 11Mbps but in different frequency bands.
The total delay of packet transmission is divided into two distinct parts:
a) Between client delay. b) Between Mesh-router delay.
According to [11] the channel at any moment is in one of the following state:
1- Idle state (S_i). 2- Collision (S_c). 3- Successful transmission (S_s).
So in a multi-hop network in which nodes have n -1neighbors, the probability of each state is defined as.

$$p_i = (1-\tau)^n \tag{1}$$

$$p_s = \binom{n}{1} * \tau * (1-\tau)^{n-1} \tag{2}$$

$$p_c = 1 - p_i - p_s \tag{3}$$

If α be the average length of slot time, then we have:

$$\alpha = p_i * \sigma + p_c * T_c + p_s * T_s \tag{4}$$

where σ is an empty slot time defined in the standard. For the time intervals T_c and T_s we follow the definition given by [11].
For the back-off process, the binary exponential back-off is used in which W_{min} and W_{max} denote the minimum and maximum contention window respectively. Finally the total delay could be given by:

$$D = D_1 + D_2$$

$$D_1 = h * \{(\alpha * W_{av}) + \frac{\text{packet length}}{\text{Bandwidth}}\} \tag{5}$$

$$D_2 = H * \{(\alpha * W_{av}) + \frac{\text{packet length}}{\text{Bandwidth}}\} \tag{6}$$

Where h is the average hop count between client to nearest router and H is the average hop count between routers to destination. Also W_{av} is the average back-off window size. Additionally the connectivity of each client or server is as the number of neighbor nodes. Table 1 contains some important parameters that are used to end to end delay computation.

2.2 Node Connectivity (Reliability requirement).

Our method is very simple, but useful for network performance, followed by network design with acceptable reliability and is resistant wrong. Also, depending on the amount of network application, the value of the standard deviation (variance) is compared to the neighboring network, which should be higher. Connectivity (Connectivity) in wireless mesh networks, each node the number of neighbors that are located within its release, will be equal.

Parameter	Value	Description
Bandwidth	11 M bits/s	Channel bit rate
L.PHY	192 bits	PHY header
L.MAC	272 bits	Mac header + FCS
L.RTS	352 bits	RTS frame
L.CTS	304 bits	CTS frame
L.ACK	304 bits	ACK frame
σ	20 µs	Slot time
T.SIFS	10 µs	SIFS time
T.DIFS	50 µs	DIFS time
δ	1 µs	Air propagation time
C. W min	32	Min. contention window
C. W max	1024	Max. contention window

Table 1. The MAC layer parameters which are used in proposed model [11].

3. Optimization and Solution.

In this section, objective function, genetic algorithm and particle swarm optimization algorithm we introduce useful and combine them to design infrastructure wireless mesh networks offer. The results of the algorithm combined compare by BGA/RGAH (GA). Due to the continuous nature of the particle swarm optimizer algorithm is expected to have better results in BGA/PSOH.

3.1 *Objectives function.*

Optimized to obtain optimal values for the parameters so as to obtain the highest value for the merit function, the optimization problem is:
a) - the minimum number of routers. b) - The average end to end delay in the network is minimized. c) - average connectivity (to ensure network reliability) to maximize. d) - surface area to maximize coverage.
optimum parameters simultaneously with Eq. 7 indicates that the merit function is obtained. According to the degree of importance of each factor λ (weight) that its value interval [0, 1] is selected, it will multiply. Sum of the coefficients according to Eq. 8 must be greater than one.

$$F = \lambda_1 f_1 + \lambda_2 f_2 + \cdots + \lambda_n f_n \ - \text{Penalty} \tag{7}$$

$$\lambda_1 + \lambda_2 + \cdots + \lambda_n = 1 \tag{8}$$

in Eq. 7 to get answers efficient and practical than the beam (the feasible and optimal solutions) from the search space, in the absence of established reliability requirement (optimal connectivity) and a reduction in the surface condition of the premises are term of a fine (penalty) the distance between the parameter values obtained with the situation is assumed to reduce the adverse responses have merit.

3.2 *Genetic Algorithm.*

Genetic Algorithms are a family of computational models inspired by evolution. These algorithms encode a potential solution to a specific problem on a simple chromosome-like data structure and apply recombination and mutation operators to these structures so as to preserve critical information. An implementation of a genetic algorithm begins with a population of (usually random) chromosomes. One then evaluates these structures and allocates reproductive opportunities in such a way that those chromosomes which represent a better solution to the target problem are given more chances to reproduce than those chromosomes which are poorer solutions. The goodness of a solution is typically defined with respect to the current population. The genetic algorithm can be viewed as two stage process. It starts with the current population. Selection is applied to the current population to create an intermediate population. Then recombination and mutation are applied to the intermediate population to create the next population. Refers to this basic implementation as a Genetic Algorithm in the first generation the current population is also the initial population. There are a number of ways to do selection. After selection has been carried out the construction of the intermediate population is complete and recombination can occur. Crossover is applied to randomly paired strings with a probability denoted Pc. A pair of strings is picked with probability Pc for recombination. These strings form two new strings that are inserted into the next population. After recombination, mutation operator is applied. For each bit in the population, is mutated with some low probability Pm. Typically the mutation rate is applied with less than 1% probability. In some cases mutation is interpreted as randomly generating a new bit in which case, only 50% of the time will the mutation actually change the bit value. After the process of selection, recombination and mutation, the next population can be evaluated. The process of evaluation, selection, recombination and mutation forms one generation in the execution of a genetic algorithm [14].

3.3 *Particle Swarm Optimization Algorithm.*

Particle Swarm Optimization (PSO) incorporates swarming behaviors observed in flocks of birds, schools of fish, or swarms of bees, and even human social behavior, from which the idea is emerged. PSO is a population-based optimization tool, which could be implemented and applied easily to solve various function optimization problems. The original PSO formulae define each particle as potential solution to a problem in D-dimensional space. The position of particle i is represented as: $X_i = (x_{i1}, x_{i2}, \dots, x_{iD})$. Each particle also maintains a memory of its previous best position, represented as: $P_i = (p_{i1}, p_{i2}, \dots, p_{iD})$. A particle in a swarm is moving; hence, it has a velocity, which can be represented as: $V_i = (v_{i1}, v_{i2}, \dots, v_{iD})$. Each particle knows its best value so far (p-best) and its position. Moreover, each particle knows the best value so far in the group (g-best) among p-bests. This information is analogy of knowledge of how the other particles around them have performed. Each particle tries to modify its position using the following information:

- the distance between the current position and p-best.
- the distance between the current position and g-best.

This modification can be represented by the concept of velocity. Velocity of each agent can be modified by the following Eq. 9 in inertia weight approach (IWA):

$$v_{id} = w * v_{id} + c_1 * r_1 * (P_{id} - X_{id}) + c_2 * r_2 * (p_{gd} - X_{id}) \quad (9)$$

where v_{id} - velocity of particle, X_{id} - current position of particle, w - inertia factor, c_1, c_2 - determine the relative influence of the cognitive component, and the social component in the interval [1.5,2]. P_{id} (p-best) of particle i, P_{gd} (g-best) of the group, r_1, r_2 - random numbers and are uniformly distributed in the interval [0,1]. The following inertia factor is usually utilized in Eq. 10 :

$$w = w_{max} - \frac{w_{max} - w_{min}}{iter_{max}} * iter \quad (10)$$

where w_{max}, w_{min} – initial and final inertia factor, $iter_{max}$, iter – maximum and current iteration number. The current position (searching point in the solution space) can be modified by means of the Eq. 11 :

$$X_{id}(t) = X_{id}(t) + V_{id}(t) \tag{11}$$

All swarm particles tend to move towards better positions; hence, the best position (optimum solution) can eventually be obtained through the combined effort of the whole population [17, 18].

3.4 *BGA/PSO Hybrid*

The considered problem in this paper is multi-objective optimization problem in which the BGA/PSOH (Fig. 3) is used as a solution. So the encoding of the chromosome/solution is combined of two different types:

a) Binary encoding used as a BGA. b) Real encoding used as a PSO

The length of binary part is L, which is the maximum number of routers. Each bit in this part introduces existence or not existence of the router. If the bit presents 1, the corresponding router is assigned to the position given by corresponding real part of individual, else it is removed. In the real part the location of the routers is encoded which is contained X and Y. In other words the real part of each chromosome is an answer of the problem and the length of this part is 2L. The Fig. 4 shows a sample of a chromosome/solution. As shown in Fig. 4 the one number in the first part determines the existence of router and the parts of (x, y) shows the location of the router.

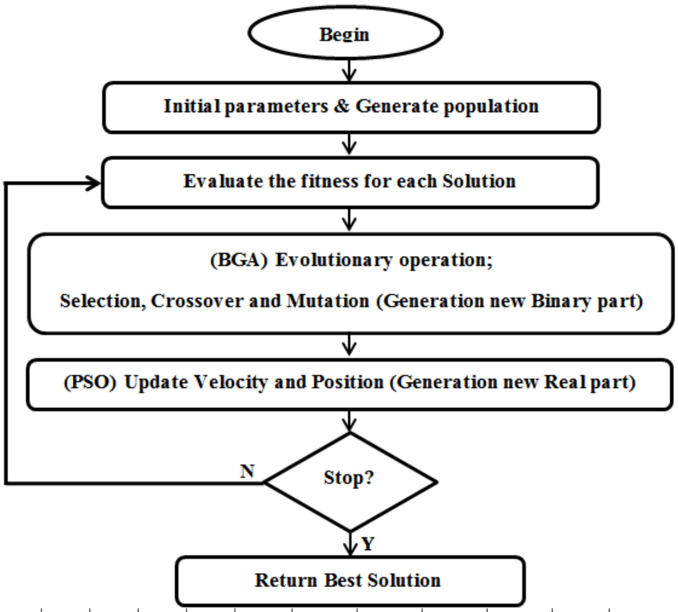
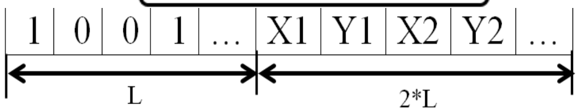


Fig. 3: BGA/PSO



Flowchart of Hybrid.

Fig. 4: A sample solution [16].

The binary part has one-point crossover and Uniform mutation. Finally the Rolette wheel is considered as selection operator in BGA.

4. Simulation Results.

We conduct extensive experiments to evaluate the performance of network. The network area contains two different types of nodes, mesh clients and mesh routers. The network topology used in our experiments is uniform randomly distributed clients. All mesh clients are Wi-Fi nodes with multi-hop communication scenario. A send packet is forwarded between clients to reach the nearest mesh router and then is forwarded between mesh routers to reach the end router. The end router is a mesh router which the destination client is in that area. The destination node is uniformly selected from all other clients. The considered network area is 1000m*1000m. The comparative metrics are the number of routers and the networks connectivity. The simulation results help us to find minimum number of routers for minimum end to-end delay. Also our proposed BGA/PSOH is applicable if the designer wants a WMN based on fixed connectivity and minimum number of routers and minimum end-to-end delay. Fig. 5 shows the minimum number of router versus some fixed connectivity. As we expected when the network connectivity is increased the number of deployed router is also increased. For the optimum number of routers the end to end delay is shown in Fig. 6. The connectivity of routers determines the number of neighbors. In other words the high connectivity equals with the large number of neighbors and also high collision rate. As shown in Fig. 6 increasing the connectivity would be increased the end-to-end delay. For all optimum experimental results the routers positions are obtained.

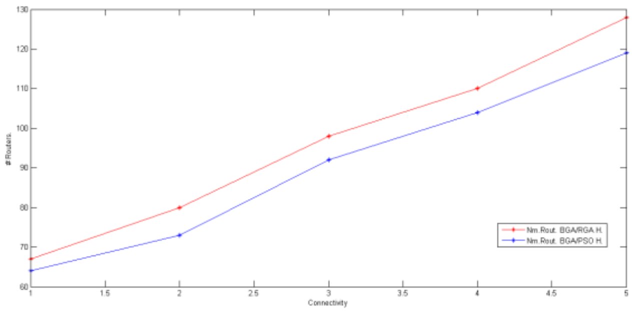


Fig. 5: The number of routers to satisfy the required connectivity.

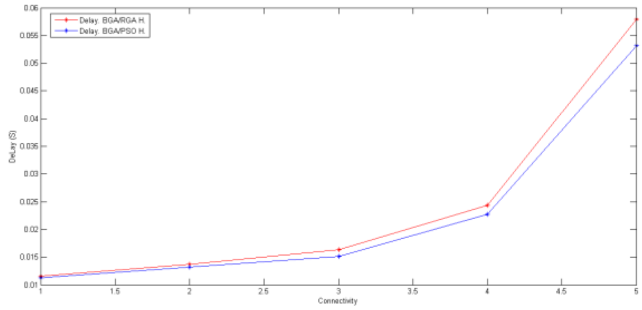


Fig. 6: Increasing the End-to-End delay versus connectivity.

5. Conclusions

About designing wireless mesh networks we find few proposals in the literature and most of them don't take into account all effective parameters involved in the design of WMNs. Main contribution of our work is minimizing the number of routers for desired connectivity. As shown in the experimental results the node location for the proposed scenario leads to two tier WMN in which there is no orphan router. So the connectivity of all distributed routers is equal or greater than one. Also in the proposed BGA/PSOH, if the desirable connectivity is changed the optimum number of required router could be calculated. This is main advantage of proposed method to fault tolerant WMN designing.
Additionally the proposed BGA/PSOH, minimizes the end-to-end delay of packet transmission and also finds the best location for router to increase the connectivity and network coverage area.

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