Metaheuristic Approaches for Gateway Placement Optimization in Wireless Mesh Networks: A survey

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Summary
Recently Wireless Mesh Networks (WMNs) have gained significant roles in communication technologies and have been used in many applications with high sensitivity to packet loss, delay and transmission time. Therefore, many researchers paid their attention for solving WMNs related issues. The WMN consists of Mesh Routers (MRs) and Mesh Clients (MCs), some of MRs have external interfaces and additional functionalities to act as internet gateways so that most of the network traffics move toward these gateways. Thus, Gateways placement is critical in WMN design and there are many conflicting requirements that make the problem difficult to be solved such as construction cost, interference, transmission delay, congestion. Hence, the gateway placement is considered NP-Hard so that it's difficult to find the optimal solution and methods to find approximate or near optimal solution are required. In this paper, we will present some issues related to gateway placement problem, some research efforts that have done in this area especially the research works that based on metaheuristic methods finally discussion and recommendations about the existence solutions will be presented to help the readers how to choose among these solutions.

Keywords:
Wireless Mesh Network, Gateway Placement, Metaheuristic, Methods, optimization

1. Introduction

Wireless Mesh Network (WMN) is a communication technology used in many important applications such as recue, surveillance, emergency systems and also as an internet access to solve the last-mile problems [1]. WMN is made of Mesh Routers (MRs) and Mesh Clients (MCs). To connect the internal network to internet some MRs must be supported by additional functionalities to facilitate packets forwarding between the networks [3] called gateways, so that most the network traffic move towards the gateways and this may result in bottleneck points in the gateways [3]. Therefore, gateway positioning is critical to enhance the network performance, and there are many issues related to gateways placement, such as construction cost due to the high cost of the physical links that used to connect the gateways, interference, path length which represented by the number of hops that the packet traverse and transmission delay. Some of the requirements are conflict with others. Thus, the gateway placement is an optimization problem which, had proven as NP-Hard [2], and can be formulated as combinatorial problem [4]. Hence, finding the optimal solution is very difficult or required long time sometimes requires polynomial time so, that some metaheuristic methods to find the near optimal solution are required. There are many methods and algorithms that can be used such as Genetic Algorithm (GA), Evolutionary Algorithm (EA), Simulated Annealing (SA), Ant Colony Optimization (ACO) and Particle Swarm Optimization (PSO), besides the other optimization methods such as Linear Programming (LP) and Integer LP (ILP). Furthermore, there are many methods developed for the specific problem such as In [14], a Multihop Traffic-flow Weight (MTW), Random Gateway Placement (RDP), Regular Placement (RGP) and Busiest Router Placement (BRP) algorithms, all these algorithms were developed specially for only solving MRs and gateway placement.

In this paper, we will discuss some research works that were proposed to solve this problem.

The next sections of this paper are organized as follows: section 2 presents the previous research works that have proposed based on metaheuristic methods to address the gateway placement problem in WMN, section 3 presents discussion and recommendations that can help the readers to determine which of the proposed solutions is suitable for each specific network requirements and also which metaheuristic methods as well. Finally, section 4 presents the conclusion and the future works.

2. Metaheuristic Approaches for Gateway Placement

Many research works have been proposed for solving gateway placement problem using different methods and techniques. In this section we will present the approaches that based on the metaheuristic such as GA, SA, EA, ACO and PSO in comparison with some other optimization methods such as LP, ILP, as well as discussing in brief what inside each approach and finally

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we will conclude this section with our recommendations and the benefits that we have gained.

In [5], a GA based approach to find the near optimal solution for MRs and nodes placement problem has been proposed. The proposed approach aimed to maximize the size of giant network's component as a primary objective and the number of users to be converged as second objective. The approach has been evaluated based on a number of generated instances using different statistical distribution methods that were used in estimating the users' locations. The results show the usefulness of the GA on solving the placement problem of nodes and MRs on different network sizes but the user coverage mainly depends on how the users were distributed on the specific area. In [8], further discussion about the approach proposed in [5] and also the analysis results shows the efficiency of GA on solving this problem.

In [6], two algorithms for load balancing among the clusters as well as satisfying the quality of service constraints have been proposed. The network here has been divided to a number of disjoint clusters and each algorithm aimed to minimize the load difference between these clusters in term of aggregated traffic in the cluster head which were determined by the gateways. The first algorithm is greedy one named GA-LBC and the second is combination of greedy and GA formed new algorithm named HA-LBC. The results showed that the Hybrid algorithm outperformed the greedy algorithm due to the ability of GA to solve multiple objectives problems.

In [7], a mixed approach of GA and LP methods has been proposed to optimize the WMN planning at the earlier stages. The approach considers two issues related to the WMN that affect the network performance, the approach used to solve the Channel Assignment (CA) using GA and Multi-Channel Routing problems (MCR) using LP methods. The main idea is to find the optimal CA configuration with corresponding MCR schedule in the network in order to increase the overall network capacity. However, the genetic algorithm based approach achieved better result on solving this problem.

In [9], a GA based solution has been proposed to solve the placement of gateway problem. The approach aimed to integrate the locations of the existing gateways that based on physical links (wired cable) as well as minimizing the number of extra gateways that are required to satisfy the users' demands to enhance the network capacity. The extra gateways based on Hybrid-FSO/RF that may use either Free Space Optical (FSO) or RF to form new clusters. The GA based solution is used to find the near optimal solution. However, the evaluation result has shown that the proposed solution achieved the optimum solution in small network made of up to 50 APs, which compared to result which generated by the ILP formulation. Furthermore, the result has shown the feasibility of the approach in relatively large network.

In [10], the design of network topology and the gateway placement issues had been studied in order to minimize the network construction cost. Two algorithms have been proposed to address this problem; the first algorithm is the Predefined Gateway Set Algorithm (PGSA); the second algorithm is the Self-Constituted Gateway Algorithm (SCGA), also enhanced Dijkstra's algorithm has been proposed that is used with GA in the main two algorithms to find network configuration with low-cost constraints such as delay and link capacity. However, the evaluation results show that PGSA has less computation time in comparison with SCGA, but the SCGA can achieved better result with we are concerning with the network construction cost but it requires more time.

In [12], a new scheme for planning and optimizing the gateway locations in WMN has been proposed. The authors proposed two algorithms to optimize the location of the gateways, algorithm based on the simple GA and the other based on proposed improved GA. However, the experimental results show that both of the two algorithms achieved better than the developed greedy algorithm and improved GA achieved better than the simple one.

In [14], a new approach based on EA has been to address the gateway placement problem. The proposed approach aimed to maximize the network throughput. In this approach, the gateways randomly distributed then the fitness calculated to find the near optimal solution. However, the numerical results had shown that the proposed approach achieved better than the "Multihop Traffic-flow Weight (MTW)" algorithm proposed in [11]. The remarkable point here MTW algorithm have been evaluated in [11] and achieved better than "Random Gateway Placement (RDP)", "Regular Placement (RGP)" and "Busiest Router Placement (BRP)" algorithms. This shows us the superiority of the evolutionary approaches over the random and the other conventional approaches in solving the problem gateways placement.

In [13], the efficiency of the PSO, ACO and GA in solving the problem of gateway placement has been studied and a comparative study between these algorithms has been presented. The evaluation results show that all of these algorithms outperformed the MTW. Moreover the results show that the algorithms based on PSO and ACO showed better proprieties than the one that based on the GA in small network.

In [18], the gateway placement problem has been studied and new hybrid algorithm based on GA and SA has been proposed. The SA used to enhance the conventional mutation operator to avoid the local optima solution in GA. The proposed algorithm aimed to minimize the number of gateways and satisfy the Quality of service (QoS) constraints. However, the evaluation results had shown the efficiency of the proposed algorithm.

In [15], the WMN planning for load balancing has been studied and a new model to optimize the load balancing in multicast network called "Path-MeshRouter-Gateway load balancing (PMRGLB)". The model developed based on the PSO to minimize the all following four factors: (1) network's cost; (2) the length of the path; (3) interference in the path; (4) load variation among the gateways. However, the proposed model achieved better on minimizing the path length and better load balancing as well.

In [16], a model based on SA for solving the problem of MRs and gateways placement has been proposed. The model aimed to maximize the connectivity via maximizing the size of giant network's components as well as maximizing the users' coverage by satisfying the QoS requirements. The model evaluated by a number of generated instances where the users and MRs were distributed in square area. However, the evaluation results that the model can achieve better performance in different network sizes.

In [17], a PSO based model has been proposed to solve MRs placement in dynamic network. The model considered the mobility of both MRs and MCs, and MCs can change the network access to on or off. Thus, the MRs dynamically allocated in the specific area. The model aimed to maximize the network connectivity and users' coverage based on mathematical formulation. However, the performance of the PSO based algorithm has been evaluated by discussing the influences of the different parameters on the network design to present the convergence in the PSO toward the solution.

3. Discussion and Recommendations

From the previous section, the metaheuristic approaches achieved better than the conventional approaches on solving the optimization problem that related the WMN design. The solution that based on LP and ILP can achieved good result in the small network with limited number gateways but it may take a long time to find the optimal solution (exact solution) or polynomial time. PSO and ACO based solution have better properties than GA due to the ease of implementation but both of PSO and ACO can stuck easily in the local optima solution. The solutions Based on SA have the minimum execution time in compression with other methods. Hence, SA is suitable for large network and when the execution time is an important. In contract GA shown its superiority over all other metaheuristic method due to many reasons such as the GA is a population based method and this may lead to better convergence rate from the initial solution to the best solution and the genetic operators (crossover and mutation) can prevent the algorithm from the local optima solution if they implemented well. The following table summarizes of the previous works we were mentioned.

Table 1: Brief description of the proposed solutions

Serial No	Methods	Objective(s)
1	GA based approach	Nodes placement to achieve: - Maximize the connectivity by Maximizing the giant componets. - Maximize the users' coverge
2	Based on SA	Nodes placement to achieve: - Maximize the connectivity by maximizing the giant components. - Maximize the users' coverage
3	Two algorithms: Greedy Algorithm Hybrid	Keep Load balancing among clusters (netowrk devided to a number of clusters)
4	Mixed approach of GA and LP	WMN planning optimization: - Channel Assignment. - And corresponding Multi-Channel routing configuration.
5	GA based approach	- Integrate existing gateways that using physical links. - Minimizing extra gateways using wireless links.
6	Two algorithms namely : PGSA and SCGA comined with Dijkstra algorithm	Gateway placement to minimize the network cost.
7	Two algoritms based on simple GA and improved GA.	Network planning to : - maximize the minimum throughput - optimize channels allocation
8	Based on EA	Gateway placement to maximize the network throughput
10	Comparison of three algorithms based on PSO, ACO and GA.	All of the algorithm aimed to maximize the network throughput via optimizing the gateways locations.
11	Hybrid algorithm based on GA and SA	- minimize the number of gateways. - and satisfy the QoS Constraints
12	Based on PSO	To optimize the load balancing in multicast network by minimizing: - Network's cost. - The length of the path. - Interference in the path. - Load variation among the
13	Based on PSO and mathmatical formulation	Gateway placement considering the mobility of MCs and MRs.

From the previous works it's clear the gateway placement is an optimization problem, and there are many requirements for this problem. Therefore, the best solution is the solution that satisfies the requirements for the specific network with specific purposes. Hence, in the following subsection we will present some recommendations about some of the previous solutions which were mentioned in this paper.

Is such situations if the cost is not important and high connectivity is required, because high connectivity requires more resources which leads to high cost, the planning time is not critical issue and high performance is required we can used the model proposed in [5], in contrast the model that proposed in [16] uses the same criteria to solve this problem but the main difference is the former based on GA which needs more time to find the best solution in comparison with the later that based on SA which return the best solution in reasonable time but with less quality if compared with GA and this due the nature of the GA and SA.

The models proposed in [7 and 12] can reduce the interference by optimize the channels allocation but the model proposed in [7] can maintain multichannel routing where the model in [12] is not where the model proposed in [12] considers the throughput as a measure in the deployment. The model proposed has a limited network size because of using LP to formulate the constraints where the model proposed in [12] depends mainly on GA which has ability to deal perfectly with large network.

The model proposed in [9] is very effective when network expansion is expected in the future, but low performance may occur due to wireless links used to connect the additional gateways.

The model proposed in [10] is suitable if the minimum cost is required, where the model that proposed in [18] aimed to minimize the network cost besides maintaining the QoS constraints, moreover, the model that proposed in [15] added more criterions to deploy the networks such as path length, interference and load balancing, but the model based on PSO which can stuck easily in the local optimum solution.

The model that proposed in [17] has distinguish feature because of considering the mobility of MRs and MCs, but also the model may suffer from low performance issues because of wireless links for new MRs that will be configured dynamically as gateways.

4. Conclusion

In this paper, some issues related to the gateway placement problem in WMNs have been presented and some research efforts solving these issues as well. There are many research works have been done to address these issues from different aspects using different methods. In this paper we presented and discussed the works that dealt with the gateway as an optimization problem, hence, we discussed the works that were developed based on metaheuristic methods such as GA, SA, EA, PSO and ACO in comparison with other comparing the metaheuristic among themselves. Finally we presented some recommendations and suggestions to help the readers to determine the suitable method(s) to be used according to their requirements and considerations in the network design. In future, we will propose our own model to solve the gateway placement optimization problem.

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