Optimization Model for Relays Placement in Mutli-Radio Multi-Channel Wireless Mesh Networks

Tarik Mountassir[1], Bouchaib Nassereddine[1], Abdelkrim Haqiq[1,2] Samir Bennani[3]
[1]LIR2M Laboratory, FST
Hassan 1st University, Settat, Morocco
[2]e-NGN Research Group-Africa and Middle East
[3]RIME Laboratory
Mohammedia Engineering Schoo, Agdal
Rabat, Morocco
{t.mountassir, ahaqiq}@gmail.com, bouchaib.nassereddine@fsts.ac.ma, sbennani@emi.ac.ma

ABSTRACT: *Wireless mesh networks have seen a real progress because of their implementation at a low cost. Thus, the planning of such networks presents many challenges for network operators. Our aim in this paper is to provide a new solution for relays placement problem using a multi-objective optimization approach.*

Keywords: Wireless Mesh Networks, Planning, Improvement, Multi-Objective Optimization, Topology

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1. Introduction

Wireless Mesh Networks (WMNs) are a class of Next- Generation Networks (NGN) that provides one of the most promising solutions to improve network coverage, deliver community broadband Internet access services and reduce deployment cost. In such networks, communications between two nodes can be supported by intermediate nodes called Mesh Relays (MRs). Figure 1 illustrates a relatively static infrastructure of a WMN composed by three types of wireless routers. Therouters which connect the clients to the requesting service are called Access Points (APs). The relays route the traffic to other relays via a point-to-point connection until a router with an Internet connection is found. Such a wireless router is called a Mesh Gateway (MG) [1].

To further allow simultaneous communications and improve the capacity of mesh networking, a mesh router is usually equipped with multiple wireless interfaces built on either on the same or different wireless access technologies.

WMNs have been deployed in diverse environments such as home networks, companies and universities. Such networks can also serve the purpose of temporary infrastructure in disaster and emergency situations or in various control system such as public area surveillance. However, these applications continue to confront the problems of connectivity and performance caused by poor planning of wireless networks.

In the last six years, considerable interest has been given by researchers to WMNs design problems. Most of these studies have focused on routing [2], interference and capacity analysis [3], power control [4], topology control [5], link scheduling [6] and

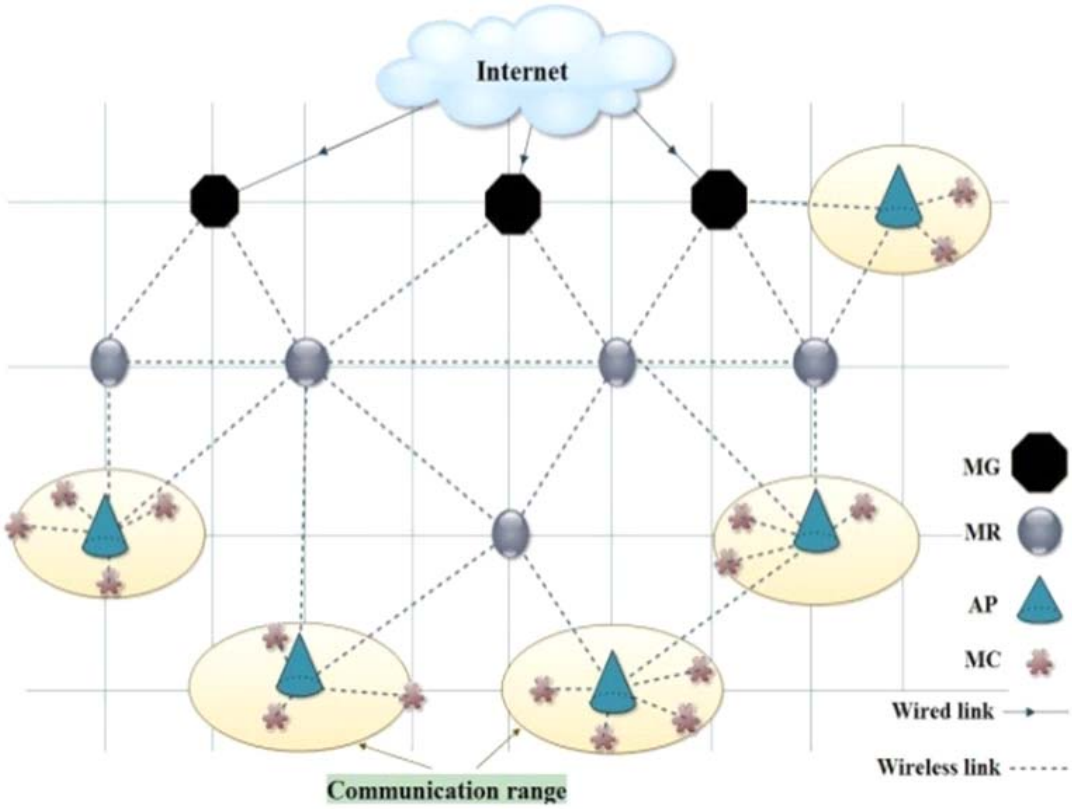

Figure 1. Infrastructure of a WMN

channel/radio assignment [7]. However, few studies have addressed the placement of nodes in the network.

In this paper, we consider the planning of Multi-Radio Multi-Channel WMNs and we focus on the relays placement.

Thus, our contribution can be summarized as follow:

• We considered all parameters that influence the result of the design including: Deployment cost, channels assignment, network capacity, interference, robustness and load-balancing.

• We proposed a new model for the problem of WMNs planning where the two conflicting objectives are optimized simultaneously; minimizing the cost (namely Relays number) and the throughput improvement (by balancing the load on the links).

• To resolve this problem, we used a meta-heuristic in order to obtain optimal results and allowing the planner to choose the one that satisfies his budget.

The rest of the paper is organized as follow: Related works are presented in Section II. We present the formulation of our model in Section III. In Section IV, we propose a multiobjective optimization of the proposed model. Section V presents experimental results. We conclude our work and give directions for future research in Section VI.

2. Related Works

Many formulations and algorithms have been proposed for WMNs planning. The authors of [8], [9], [10] optimized the placement of MRs (i.e. the backbone WMNs) to provide large coverage to clients at a minimum cost while guarantying good performances and a minimum level of interference. Other contributions (eg [11], [12], [13]) have introduced different methods to select a minimum number of MRs to become gateways while satisfying the throughput, interference and congestion constraints. In [14],

the authors define a generalized form of a linear program that takes into account interference and transmission power to minimize the cost function. The study of [15] present an optimization model for WMNs planning that aims to minimize the network deployment cost while providing complete clients coverage. Most studies propose models with one objective which is to minimize the cost. However, the planning problem invokes multiple performance measurements or objectives (which are often conflicting) to be simultaneously optimized. In this context, a multi-objective formulation of this problem has been proposed in [16] where the authors simultaneously optimize the cost and the level of interference on all network links. These authors have added a third objective function (minimizing congestion in the neighborhood of gateways) to their model in [17]. Their approach seems to be more realistic. Thus, we exploit their works and we introduce more constraints and objective functions to improve the planning solution.

3. Network Model and Formulation

In this section, we propose the network model by presenting a new multi-objective formulation of Relays placement problem. Our model contains two objective functions and exploits the tradeoff between the deployment cost, client coverage, throughput and robustness. Indeed, maximizing the coverage will influence the throughput, and increase the number of MRs. However, minimizing nodes number will decrease client's coverage and influence on the throughout. Our model differs from others in that we consider all the parameters that have an impact on the planning solution and that we use a multi-objective formulation which represents a more realistic approach.

We consider a Multi-Channel Multi-Radio WMN represented by a graph $G = (V, E)$ where V is the set of wireless routers and E describes the set of links between each pair of MRs. We assume the MRs have the same number of radio interfaces R. Each one is equipped with K channels ($K > R$). A link can be established between two MRs when one of their interfaces use the same channel and the distance between them is less than the transmission range of each MR. To consider interference between the links of WMNs, we adopt the Protocol Interference Model [3] where a transmission on the channel k is successful when all interferes in the neighborhood of the transmitter and receiver are silents on channel k during the transmission time. Let $N = \{1, ..., n\}$ be the set of relays to be placed (MR) and $S = \{1, ..., s\}$ be the set of Candidate Sites to host a node (including AP already placed) . Table 1 shows the notations used to describe the model.

$\boldsymbol{n}$	Number of Relays
$\boldsymbol{s}$	Number of Candidate Sites (CS)
$\boldsymbol{C_{jl}^k}$	Capacity of link (j, l) using channel k
$\boldsymbol{R}$	Number of radio interfaces per node
$\boldsymbol{K}$	Number of channels per radio interface
$\boldsymbol{r_j}$	Installation of a router at CS j
$\boldsymbol{w_j^k}$	Installation of a router at CS j using the channel k
$\boldsymbol{L_{jl}^k}$	Establishing radio communication between CSs j and l using the channel k
$\boldsymbol{f_{jl}^k}$	Flow on channel k between CSs j and l
$\boldsymbol{Q}$	All frequency channels $Q = \{1, ..., K\}$

Table 1. List of Parameters and Variables

The objectives of our planning problem are to:

1. Select the set of candidate sites where mesh relays can be installed so that the graph $G = (V, E)$ become connected.

2. Maintain the number of relays as small as possible to satisfy the financial requirement while improving the throughput.

Furthermore, our model minimizes the deployment cost (Relays number) and minimizes links congestion. Therefore, our model is formulated as follows:

$$\boldsymbol{Min} \sum_{j \in S} r_j \tag{1}$$

$$\boldsymbol{Max}(\boldsymbol{Min}_{\substack{j,\, l \in S \\ k \in Q}}(L_{jl}^k C_{jl}^k - f_{jl}^k)) \tag{2}$$

Subject to :

$$\sum_{j \in S} \sum_{k \in Q} L_{jl}^k \leq R \qquad \forall\, l \in S \tag{3}$$

$$\sum_{k \in Q} L_{jl}^k \leq K \qquad \forall\, j, l \in S \tag{4}$$

$$\sum_{l \in S} L_{jl}^k \leq 1 \qquad \forall\, j \in S, \forall\, k \in Q \tag{5}$$

$$\sum_{y,\, h \in I_{jl}} L_{jl}^k \leq 1 \qquad \forall\, j, l \in S, \forall\, k \in Q \tag{6}$$

$$\sum_{l \in S} L_{jl}^k + \sum_{l \in S} L_{jl}^k \leq 1 \qquad \forall k \in Q \tag{7}$$

$$\sum_{j \in S} \sum_{k \in Q} L_{jl}^k \leq 2 \qquad \forall l \in S \tag{8}$$

$$f_{jl}^k \leq L_{jl}^k C_{jl}^k)) \qquad \forall\, j, l \in S, \forall k \in Q \tag{9}$$

$$2\, L_{jl}^k \leq b_{jl}(w_j^k + w_l^k)) \qquad \forall\, j, l \in S, \forall k \in Q \tag{10}$$

$$\sum_{k \in Q} w_j^k \leq R\, r_j \qquad \forall\, j \in S \tag{11}$$

$$r_j, L_{jl}^k, w_j^k \in \{0,\ 1\} \qquad \forall\, i \in N, \forall\, j \in S \tag{12}$$

$$f_{jl}^k \in R^+ \qquad \forall\, j, l \in S \tag{13}$$

The objective function (1) minimizes the total number of relays in the network while the function (2) balances the loads between links. A node can use at most R radio interfaces; this is expressed by constraint (3). The constraint (4) indicates that the maximum number of channels that can be active on the link (j, l) does not exceed K. The constraint (5), (6) and (7) limit the interference between links while inequality (8) expresses the robustness constraint: once a router is deployed on a CS, it is necessary that there are at least two nodes on disjoint paths that connect it to the network; this ensures that a single failure does not disconnect the network. Inequality (9) explains that the flow on a link cannot exceed the capacity of this link. For the constraint (10), it allows the existence of a link between two routers in CSs j and l using channel k only when both routers are installed, and use the same channel k. The constraint (11) states that the number of links from a mesh node is limited by the number of radio interfaces.

4. Model Resolution

In this section, we propose an algorithm for relays placement in a WMN. The problem as it was formulated in the previous section has two objective functions with a large number of constraints, making it difficult to solve with standard simple methods because it does not have a single solution but a set of solutions located in the front of Pareto, unlike the single-objective methods which ignore this compromise solution. The advantage of multi-objective method is that it allows decision makers to choose the best solution according to the encountered situation. Thus, we use the evolutionary technique called Multi-Objective Particle Swarm Optimization (MOPSO) proposed in [18] where authors introduced the mechanism of Crowding Distance to maintain diversity in the Pareto frontier. This method is based on the PSO of Kennedy and Eberhart [19] which is built on the social behavior of flocks of birds that tend to imitate successful actions they see around them, while there bringing their personal variations. A swarm (population) consists of several particles (individuals).

```
Input: mut: mutation factor, gmax, A: Set of APs
Output: Archive
Begin
        Initialize swarm //Construct initial feasible solutions
        Evaluate all particles in swarm // Compute Objectives
        Store all non-dominated solutions into the Archive
Repeat (g < gmax)
  For each particle in the archive
        Compute Crowding Distance (CD) value,
        Sort the Archive in a descending order of CD values
        Mutation (mut)
           Relays Placement // invoke algorithm 2
        EndFor
           Check for constraints satisfaction
           Evaluation // Compute Objective functions
          Update Archive
          g++
Until ( g >= gmax )
End
```

Algorithm 1. Planning Main Algorithm

```
Input: A: Set of APs
Output N: Set of Mesh Relays
Begin
        Initialize n //MRs number n = 0
Repeat
   For each AP j in A
        If (AP j is placed on a corner)
             Add 2 nodes in the neighborhood // n = n + 2
        End if
        If (AP j is placed on an edge)
            Add 3 nodes in the neighborhood // n = n + 3
        End if
        If (AP j is placed on an internal)
            Add 4 nodes in the neighborhood // n = n + 4
        End if
  End For
Until ( all APs are visited )
End
```

Algorithm 2. Relays Placement

In this method, the building of an initial solution that meets the constraints is a sensitive task that should be done carefully. This leads us to propose the algorithm 1 where we first construct the initial feasible solutions, representing the placement of Mesh Relays, which will be stored in the archive. A particle represents the binary variable representing the solution of the problem namely, *rj*

We considered the planning of a network with a grid topology to increase the number of neighbors of a CS ([20]) and we proceeded to the placement of mesh relays by requiring all nodes to have at least two neighbors. The proposed solution makes the graph G (V, E) connected.

These steps are accompanied by a constraints checking and objective functions evaluation. Mutation and Crowding Distance techniques are applied to different generations of the swarm to provide different non-dominated solutions.

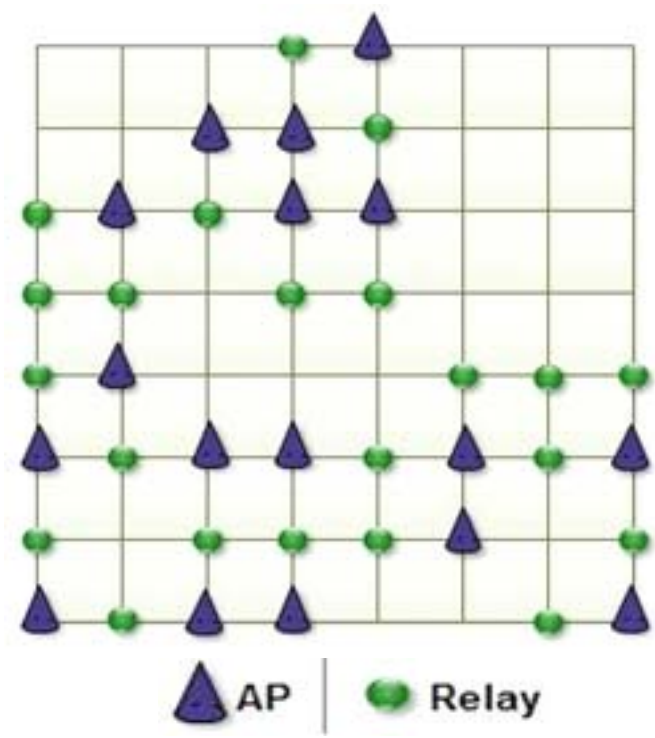

Figure 2. A Planning solution for R = 3 and S = 64

Cost (Number of relays)	Load Balancing
10	54
18	54
21	30
28	46

Table 2. Non- Dominated Planning Solution

S	Cost (Number of relays)	LoadBalancing
36	0	28
49	6	32
64	10	45
100	17	54

Table 3. Cheapest Solutions When S Varies

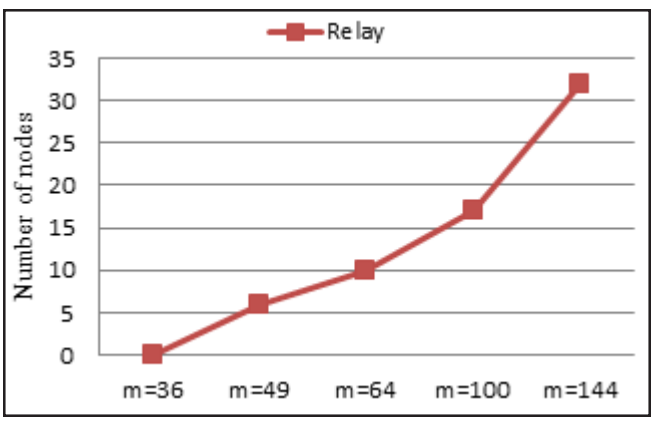

Figure 3. Number of nodes when S varies

5. Results and Analysis

To show the quality of the proposed solution, we study the performance of our algorithm by investigating the effect of varying several parameters that influence the deployment of WMN on a grid topology. We first define standard settings by considering 8×8 grid topology for the candidates sites, C_{jl}^{k} = 54Mb/s, R = 3 and k = 11. We suppose that the APs (input of our algorithm) are deployed on the grid considered topology). All experiments were carried out on a Core i3 machine. Table 2 shows the first 4 non-dominated solutions.

Then we represent the output solution in Figure 2 which shows that for 17 access points, we have 22 relays to be deployed. This is a well optimized solution because only 46,8% of candidate sites will be occupied. We observe that our solution provides good performances with a low cost. In the following, we present the effects of changing key parameters namely: The number of candidate sites (S) and the number of radio interfaces (R).

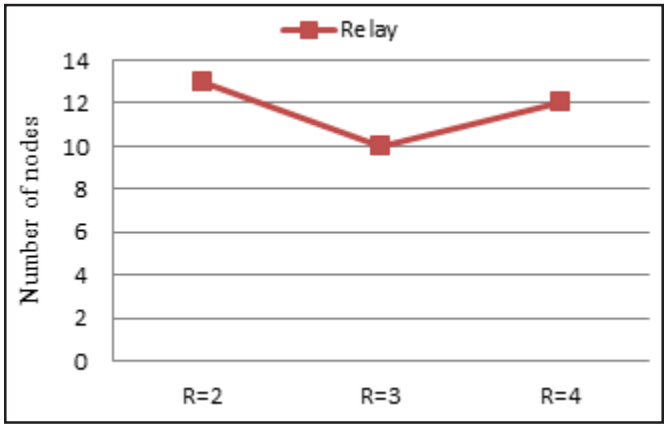

Figure 4. Number of nodes when *R* varies

R	Cost (Number of relays)	LoadBalancing
2	13	54
3	10	32
4	12	45

Table 3. Cheapest Solutions When S Varies

By varying the number of CSs, we observe in Figure 3 and TABLE III that the number of relays increases when the number of CSs increases. This is caused by the need of connecting the graph G = (V, E).

Finally, an optimal number of radio interfaces permits the maximization of throughput with minimum number of nodes. Figure 4 and Tables 4 show that when $R = 2$, the throughput (Load Balancing function) are maximized while the cost is minimized when $R = 3$.

6. Conclusion

In this paper, we proposed a new model and algorithm for relays placement in wireless mesh networks by optimizing new objective functions subject to additional constraints to take into account interference, robustness and load balancing. The use of the MOPSO method provides very interesting results and lets the network planner decide which solution responds to his requirements. Additionally, we studied the effect of varying the key parameters on the cost and the performance of the WMN.

As further research topic, we intend to propose new algorithm to provide a complete solution for WMNs planning. Thus, our goal is to simultaneously optimize the access points, mesh relays, and mesh gateways deployment.

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