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Application of WMN-SA Simulation System for WMN Node Placement in a Realistic Scenario

Shinji Sakamoto*, Tetsuya Oda*, Leonard Barolli†, Makoto Ikeda†, Fatos Xhafa‡, Kazunori Uchida†

**Graduate School of Engineering*
Fukuoka Institute of Technology (FIT)
3-30-1 Wajiro-Higashi, Higashi-Ku, Fukuoka 811-0295, Japan
E-mail: shinji.t.sakamoto@gmail.com, oda.tetsuya.fit@gmail.com

†Department of Information and Communication Engineering
Fukuoka Institute of Technology (FIT)
3-30-1 Wajiro-Higashi, Higashi-Ku, Fukuoka 811-0295, Japan
E-mail: barolli@fit.ac.jp, m-ikedad@fit.ac.jp, k-uchida@fit.ac.jp

‡Technical University of Catalonia
Department of Languages and Informatics Systems
C/Jordi Girona 1-3, 08034 Barcelona, Spain
E-mail: fatos@lsi.upc.edu

***Abstract*—One of the key advantages of Wireless Mesh Networks (WMNs) is their importance for providing cost-efficient broadband connectivity. In WMNs, there are issues for achieving the network connectivity and user coverage, which are related with the node placement problem. In this work, we consider the router node placement problem in WMNs. We want to find the optimal distribution of router nodes in order to provide the best network connectivity (the maximal number of connected routers) and coverage (maximal number of covered clients). We apply our proposed WMN-SA simulation system in a realistic scenario of the distribution of mesh clients considering Itoshima City, Fukuoka Prefecture, Japan. From simulation results, we found many insights that can be very important for real deployment of WMNs.**

***Keywords*-WMNs, Simulated Annealing, Connectivity, Coverage, Intelligent Algorithms.**

I. Introduction

Wireless Mesh Networks (WMNs) [1]–[3] are important network infrastructure for providing cost-efficient broadband wireless connectivity. They are showing their applicability in deployment of medical, transport and surveillance applications in urban areas, metropolitan, neighbouring communities and municipal area networks. At the heart of WMNs are the issues of achieving network connectivity and stability as well as QoS in terms of user coverage. These issues are very closely related to the family of node placement problems in WMNs, such as mesh router nodes placement.

Node placement problems have been long investigated in the optimization field due to numerous applications in location science (facility location, logistics, services, etc.) and classification (clustering). Facility location problems are thus showing their usefulness to communication networks, and more especially from WMNs field. WMNs are currently attracting a lot of attention from wireless research and technology community for providing cost-efficient broadband wireless connectivity.

WMNs are based on mesh topology, in which every node (representing a server) is connected to one or more nodes, enabling thus the information transmission in more than one path [4]. The path redundancy is a robust feature of this kind of topology. Compared to other topologies, mesh topology needs not a central node, allowing networks based on such topology to be self-healing. These characteristics of networks with mesh topology make them very reliable and robust networks [5] to potential server node failures. In WMNs mesh routers provide network connectivity services to mesh client nodes. The good performance and operability of WMNs largely depends on placement of mesh routers nodes in the geographical deployment area to achieve network connectivity, stability and user coverage. The objective is to find an optimal and robust topology of the mesh router nodes to support connectivity services to clients.

For most formulations, node placement problems are shown to be computationally hard to solve to optimality [6]–[9], and therefore heuristic and meta-heuristic approaches are useful approaches to solve the problem for practical purposes. Several heuristic approaches are found in the literature for node placement problems in WMNs [10]–[14].

In our previous work [15], [16], we implemented a simulation system using Simulated Annealing (SA) for WMNs. We call this simulation system WMN-SA.

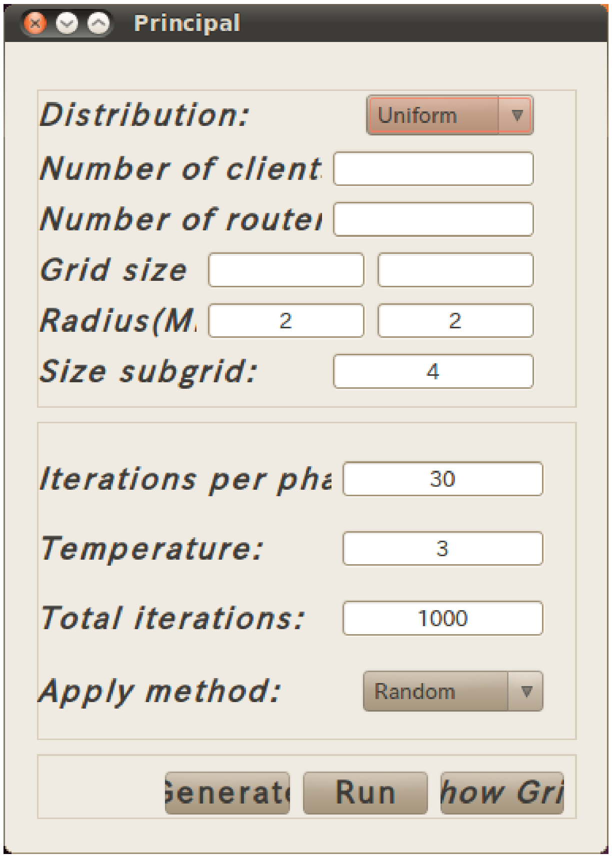


Figure 1. GUI tool for WMN-SA system.

In this work, we applied our implemented WMN-SA system in a realistic scenario considering the distribution of mesh clients in Itoshima City, Fukuoka Prefecture, Japan. For simulations, we consider a realistic distributions of 108 mesh clients in Itoshima city. Then, we deployed 36 mesh routers and run WMN-SA simulation system to maximize the size of Giant Component (GC) and Number of Covered Mesh Clients (NCMC).

The rest of the paper is organized as follows. The definition of node placement problem is presented in Section II. The proposed and implemented WMN-SA simulation system is presented in Section III. The simulation results are given in Section IV. Finally, concluding remarks and future work are given in Section V.

II. Node Placement Problem in WMNs

In this problem, we are given a grid area arranged in cells where to distribute a number of mesh router nodes and a number of mesh client nodes of fixed positions (of an arbitrary distribution) in the grid area. The objective is to find a location assignment for the mesh routers to the cells of the grid area that maximizes the network connectivity and client coverage. Network connectivity is measured by the size of the GC of the resulting WMN graph, while the user coverage is simply the number of mesh client nodes that fall within the radio coverage of at least one mesh router node.

Algorithm 1 : Pseudo-code of SA.

t := 0
Initialize T
$s0$:= Initial_Solution()
$v0$:= Evaluate($s0$)
while (stopping condition not met) **do**
  while t mod MarkovChainLen = 0 **do**
    t := t+1
    $s1$:= Generate($s0$,T) *//Move*
    $v1$:= Evaluate($s1$)
    if Accept($v0$,$v1$,T) **then**
      $s0$:= $s1$
      $v0$:= $v1$
    end if
  end while
  T := Update(T)
end while
return $s0$

An instance of the problem consists as follows.

- N mesh router nodes, each having its own radio coverage, defining thus a vector of routers.
- An area $W \times H$ where to distribute N mesh routers. Positions of mesh routers are not pre-determined, and are to be computed.
- M client mesh nodes located in arbitrary points of the considered area, defining a matrix of clients.

It should be noted that network connectivity and user coverage are among most important metrics in WMNs and directly affect the network performance.

In this work, we have considered a bi-objective optimization in which we first maximize the network connectivity of the WMN (through the maximization of the size of the GC) and then, the maximization of the number of covered mesh clients.

III. Proposed and Implemented WMN-SA System

In this section, we present WMN-SA simulation system. Our system can generate instances of the problem using different distributions of clients and mesh routers.

The web interface of WMN-SA system is shown in Figure 1. We set the network configuration parameters, such as distribution, number of clients, number of mesh routers, grid size, radius of transmission distance and the size of subgrid.

A. Simulated Annealing

1) Description of Simulated Annealing: SA algorithm [17] is a generalization of the metropolis heuristic. Indeed, SA consists of a sequence of executions of metropolis with a progressive decrement of the temperature starting from a rather high temperature, where almost any move is accepted, to a low temperature, where the search resembles Hill Climbing. In fact, it can be seen as a hill-climber with an internal mechanism to escape local optima (see pseudo-code in Algorithm 1). In SA, the solution s' is accepted as the new current solution if $\delta \leq 0$ holds, where $\delta = f(s') - f(s)$. To allow escaping from a local optimum, the movements that increase the energy function are accepted with a decreasing probability $\exp(-\delta/T)$ if $\delta > 0$, where T is a parameter called the "temperature". The decreasing values of T are controlled by a *cooling schedule*, which specifies the temperature values at each stage of the algorithm, what represents an important decision for its application (a typical option is to use a proportional method, like $T_k = \alpha \cdot T_{k-1}$). SA usually gives better results in practice, but uses to be very slow. The most striking difficulty in applying SA is to choose and tune its parameters such as initial and final temperature, decrements of the temperature (cooling schedule), equilibrium and detection.

For further details on initial solution, fitness evaluation and movement types refer to [15][1]. However, the acceptability criteria of neighbouring solutions is different, as explained next.

2) Acceptability Criteria: The acceptability criteria for newly generated solution is based on the definition of a threshold value (accepting threshold) as follows. We consider a succession t_k such that $t_k > t_{k+1}$, $t_k > 0$ and t_k tends to 0 as k tends to infinity. Then, for any two solutions s_i and s_j, if $fitness(s_j) - fitness(s_i) < t_k$, then accept solution s_j.

For the SA, t_k values are taken as accepting threshold but the criterion for acceptance is probabilistic:

- If $fitness(s_j) - fitness(s_i) \leq 0$ then s_j is accepted.
- If $fitness(s_j) - fitness(s_i) > 0$ then s_j is accepted with probability $\exp[(fitness(s_j) - fitness(s_i))/t_k]$ (at iteration k the algorithm generates a random number $R \in (0,1)$ and s_j is accepted if $R < \exp[(fitness(s_j) - fitness(s_i))/t_k]$).

In this case, each neighbour of a solution has a positive probability of replacing the current solution. The t_k values are chosen in way that solutions with large increase in the cost of the solutions are less likely to be accepted (but there is still a positive probability of accepting them).

B. Clients Distribution

As the distribution of mesh clients, we considered a realistic scenario in Itoshima City, Fukuoka Prefecture, Japan and applied our WMN-SA simulation system.

Itoshima City is located in the west of Fukuoka Prefecture. The mesh clients distribution of Itoshima City is shown in Fig. 2. We deployed 108 mesh clients in the city area.

[1] Initial solution, fitness evaluation and movement types are the same for Hill Climbing and Simulated Annealing.

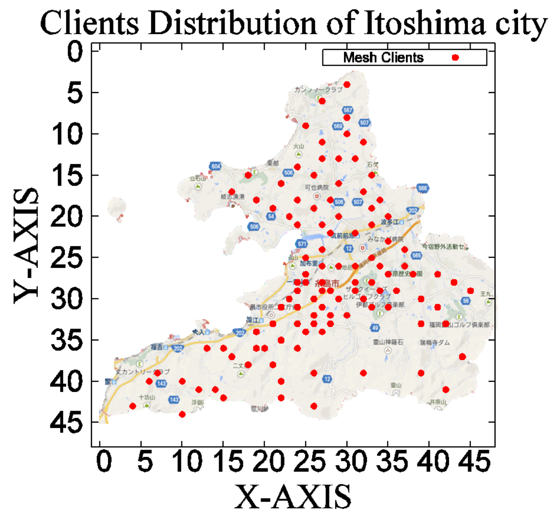


Figure 2. Clients distribution of Itoshima city.

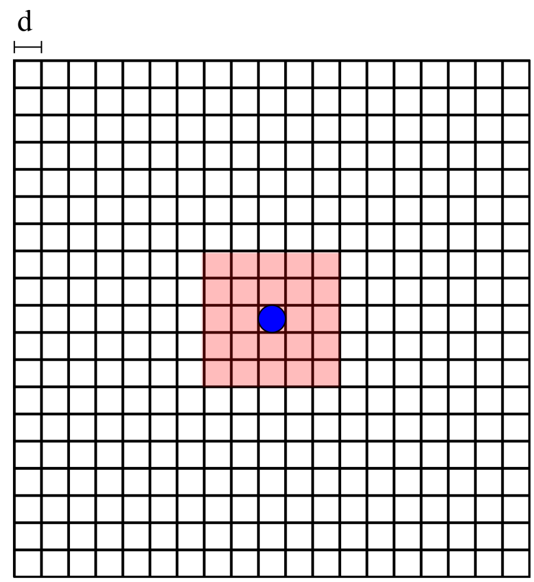


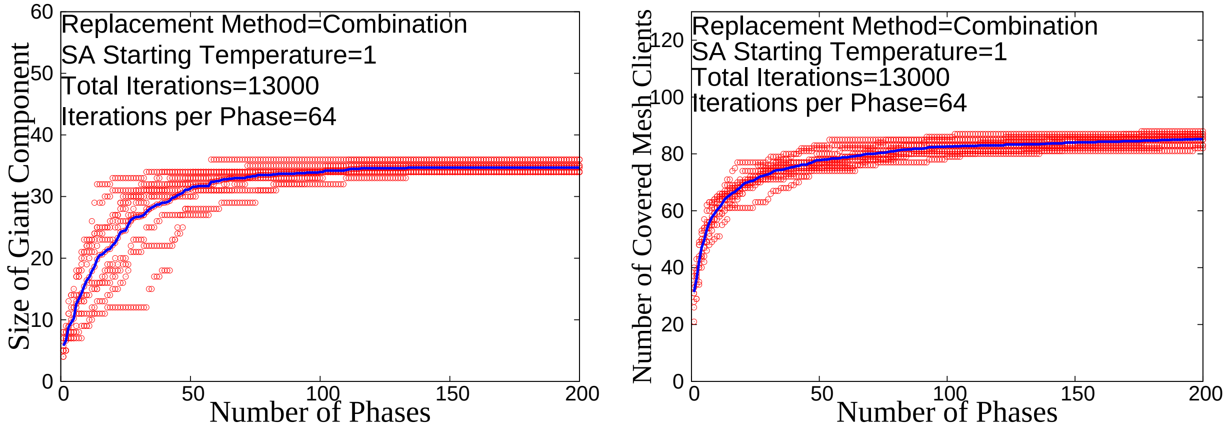
Figure 3. Radius of a mesh router.

Table I
SIMULATION SETTINGS.

Parameters	Values
Area size	48×48
Number of mesh routers	36
Number of mesh clients area	108
Client distribution	Itoshima city model
Communication distance	2
SA temperature	1
Iteration per phase	64
Total Iteration	13000
Apply method	Combination

IV. SIMULATION RESULTS

In this section, we present the simulation results by applying the implemented WMN-SA simulation system in



(a) Giant component

(b) Covered mesh clients

Figure 4. Evaluation of WMNs for 36 mesh routers.

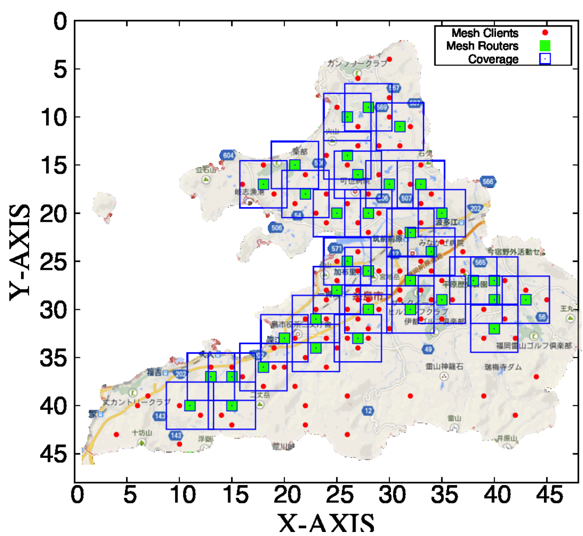


Figure 5. Visualization of simulation result.

a realistic scenario in Itoshima City.

For simulations, we considered a grid size is 48×48, 108 mesh clients and 36 mesh routers. We show the simulation parameters in Table I.

The replacement method of mesh routers is Combination. The radius of mesh router nodes in WMN-SA system is set to 2 as shown in Figure 3. One grid unit is considered 400m $\times$ 400m (d=400m). We keep both the number of iterations per phase and SA temperature fixed to 64 and 1, respectively.

For each phase, the WMN-SA runs 64 iterations. Because of the presence of random processes in our simulation system, we conduct the simulations 10 times, in order to avoid the effect randomness and create a general view of results.

Simulation results are shown in Fig. 4 and the visualization of simulation results is shown in Fig. 5. From the simulation results, we see that the size of GC is maximum for 138 phases (see Fig. 4(a)). While, the NCMC is 88 (See Fig. 4(b)). In order to cover all mesh clients, we need to deploy more mesh routers. However, the cost of the implementation of WMNs will be increased. Also, some of mesh clients are scattered in remote areas and they have low density, so it is difficult to cover all of them. For this reason, we will carry out other simulation results to improve the coverage of mesh clients.

V. Conclusions

In this paper, we apply our proposed WMN-SA simulation system in a realistic scenario of the distribution of mesh clients considering Itoshima City, Fukuoka Prefecture, Japan. From the simulation results, we conclude as follows:

- The size of GC is maximal for 138 phases, so the convergence of WMN-SA system is very good.
- Only 88 mesh clients were covered by 36 routers, so we need to add more mesh routers to improve the coverage.
- However, by increasing the number of mesh routes the cost of the deployment for WMNs will be increased.

From simulation results, we found many insights that can be very important for real deployment of WMNs.

In our future work, we would like to make evaluations for different cases and patterns. We will also investigate the optimized number of routers needed for certain realistic scenarios and patterns. Moreover, we would like to implement other search optimization algorithms in our simulation system.

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