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Analysis of WMN-HC Simulation System Data Using Friedman Test

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***Abstract*—With the fast development of wireless technologies, Wireless Mesh Networks (WMNs) are becoming an important networking infrastructure due to their low cost and increased high speed wireless Internet connectivity. In this paper, we used our proposed and implemented system based on Hill Climbing algorithm, called WMN-HC for mesh router node placement in WMNs. We analyze WMN-HC simulation system data for different number of nodes using Friedman test. We took into consideration 8, 16, 32, 64, 128 mesh routers and 24, 48, 96, 192, 384 mesh clients. We use Size of Giant Component (SGC) and Number of Covered Mesh Clients (NCMC) as metrics. From the analysis, for all cases, the p-value of SGC is more than 0.05. Thus, we adopt H_0. On the other hand, for NCMC, we adopt H_1 because the p-value is less than 0.05. Friedman test results show that there is not difference for SGC parameter. However, there is difference for NCMC parameter.**

***Keywords*-Wireless Mesh Networks, Hill Climbing, Node Placement, Connectivity, Coverage, Friedman Test.**

I. INTRODUCTION

The wireless networks and devises are becoming increasingly popular and they provide users access to information and communication anytime and anywhere [1]–[12]. Wireless Mesh Networks (WMNs) are gaining a lot of attention because of their low cost nature that makes them attractive for providing wireless Internet connectivity. A WMN is dynamically self-organized and self-configured, with the nodes in the network automatically establishing and maintaining mesh connectivity among them-selves (creating, in effect, an ad hoc network). This feature brings many advantages to WMNs such as low up-front cost, easy network maintenance, robustness, and reliable service coverage [13]. Moreover, such infrastructure can be used to deploy community networks, metropolitan area networks, municipal and corporative networks, and to support applications for urban areas, medical, transport and surveillance systems.

Mesh node placement in WMN can be seen as a family of problems. It belongs to the family of placement problems, which are shown (through graph theoretic approaches or placement problems, e.g. [14], [15]) to be computationally hard to solve for most of the formulations [16]. In fact, the node placement problem considered here is even more challenging due to two additional characteristics: (a) locations of mesh router nodes are not pre-determined (any available position in the considered area can be used for deploying the mesh routers), and (b) routers are assumed to have their own radio coverage area. Here, we consider the version of the mesh router nodes placement problem in which we are given a grid area where to deploy 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.

Node placement problems are known to be computationally hard to solve [17]–[19]. In some previous works, intelligent algorithms have been recently investigated [20]–[26].

In this paper, we deal with connectivity and coverage in WMNs. Because this problem is known to be NP-Hard, we propose and implement a system based on Hill Climbing algorithm, called WMN-HC (WMN-Hill Climbing). We analyze the WMN-HC simulation system data by using Friedman test. We consider Size of Giant Component (SGC) and Number of Covered Mesh Clients (NCMC) as metrics and different number of router nodes and mesh client nodes.

The rest of the paper is organized as follows. The mesh router nodes placement problem is defined in Section II. We present our proposed and implemented WMN-HC simulation system in Section III. The simulation results are given in Section V. Finally, we give conclusions and future work in Section VI.

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 SGC 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.

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 giant component) and then, the maximization of the number of the covered mesh clients.

III. Proposed WMN-HC System

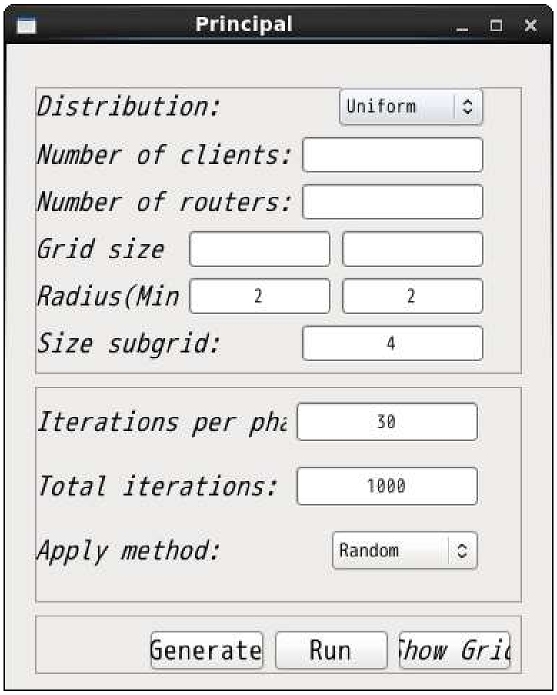
A. HC Algorithm

HC is local search algorithm and is based on incremental improvements of solutions as follows: it starts with a solution (which may be randomly generated or ad hoc computed) considered as the current solution in the search space. The algorithm examines its neighboring solutions and if a neighbor is better than current solution then it can become the current solution; the algorithm keeps moving from one solution to another one in the search space until no further improvements are possible. There are several variants of the algorithm depending on whether a simple climbing, steepest ascent climbing or stochastic climbing is done:

Simple climbing: the next neighbor solution is the first that improves current solution.

Steepest ascent climbing: all neighbor solutions are examined and the best one is chosen as next solution.

Stochastic climbing: a neighbor is selected at random, and according to yielded improvement of that neighbor is decided whether to choose it as next solution or to examine another neighbor. This kind of climbing has more general forms known as Metropolis and Simulated Annealing algorithms.



Distribution: Uniform
Number of clients:
Number of routers:
Grid size
Radius(Min 2 2
Size subgrid: 4
Iterations per ph 30
Total iterations: 1000
Apply method: Random

Fig. 1: GUI tool for WMN-HC system.

There are several versions of the algorithm are possible depending on the way a neighbor solution is selected.

It should be noted that HC usually ends up in local optima, which can be overcome in some cases by adopting additional techniques such as:

(a) getting back to a previous state and exploring another direction;
(b) jumping to a new solution, possibly “far away” from current solution;
(c) considering several search direction in solution space at the same time.

B. WMN-HC system for Mesh Router Node Placement

We propose and implement a new simulator that uses HC algorithm to solve the problem of node placement in WMNs. We call this simulator WMN-HC. Our system can generate instances of the problem using different iterations per phase of client and mesh routers. The GUI interface of WMN-HC is shown in Fig. 1.

We present here the particularization of the HC algorithm (see Algorithm 1) for the mesh router node placement problem in WMNs.

a) Initial solution: The algorithms starts by generating an initial solution either random or by *ad hoc* methods [21].

b) Evaluation of fitness function: An important aspect is the determination of an appropriate objective function and its encoding. In our case, the fitness function follows a hierarchical approach in which the main objective is to maximize the SGC in WMN.

Algorithm 1 Hill Climbing algorithm for maximization of f (fitness function).

```
Start: Generate an initial solution $s_0$;
$s = s_0$; $s^* = s_0$; $f^* = f(s_0)$;
repeat
    Movement Selection: Choose a movement $m = select\_movement(s)$;
    Evaluate & Apply Movement:
    if $\delta(s, m) \geq 0$ then
        $s' = appply(m, s)$;
        $s = s'$;
    end if
    Update Best Solution:
    if $f(s') > f(s^*)$ then
        $f^* = f(s')$;
        $s^* = s'$;
    end if
    Return $s^*$, $f^*$;
until (stopping condition is met)
```

c) Neighbor selection and movement types: The neighborhood $N(s)$ of a solution s consists of all solutions that are accessible by a local move from s. In the implementation of HC, we defined three different types of movements, namely, Random, Radius and Swap. We also considered a fourth movement type which is a combination of Random, Radius and Swap movements.

Random: This movement chooses a router at random and places it to a new position selected at random in the grid area.

Radius: This movement selects the router of largest radio coverage and places it in the most dense area in terms of number of client mesh nodes of the grid area. This movement could yield better performance but has the drawback of concentrating mesh routers in the most dense area of clients.

Swap: This movement consists in exchanging the placement of two routers. More precisely, the worst router (that of smallest radio coverage) in the most dense area (in terms of number of client mesh nodes) is exchanged with the best router (that of largest radio coverage) of the sparsest area. The idea is to promote the placement of best routers in most dense areas of the grid area.

Combination: In this movement, we consider a composition of previous movements in blocks yielding to a larger sequence:

$$< Rand_1, \ldots, Rand_k; Radius_1, \ldots, Radius_k; \\ Swap_1, \ldots, Swap_k >,$$

where k is a user specified parameter.

d) Acceptability criteria: The acceptability criteria for newly generated solution can be done in different ways (simple ascent, steepest ascent, or stochastic). In our case, we have adopted the simple ascent, that is, if s is current solution and m is a movement, the resulting solution s' obtained by applying m to s will be accepted, and hence become current solution, if the fitness of s' is at least as good as fitness of solution s. In terms of δ function, s' is accepted and becomes current solution if $\delta(s, m) \geq 0$. It should be noted that in this definition we are also accepting solutions that have the same fitness as previous solution. The aim is to give chances to the search to move towards better solutions in solution space. A more strict version would be to accept only solutions that strictly improve the fitness function ($\delta(s, m) > 0$).

TABLE I: Simulation parameters.

Parameters	Values
Clients distribution	Uniform distribution
Grid size	25 × 25
Number of mesh routers	8, 16, 32, 64, 128, 256
Number of mesh clients	48, 96, 192, 384
Total number of iterations	13000
Iteration per phase	64
Radius of a mesh router	2 × 2
Movement methods	Combination

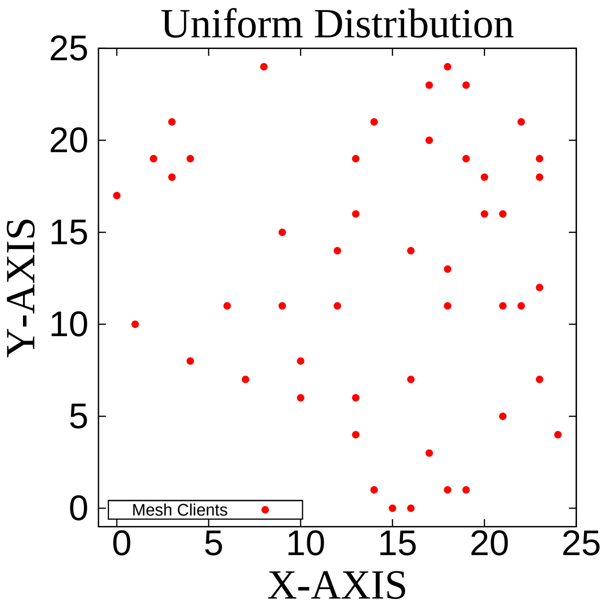


Fig. 2: Example of 48 mesh clients by Uniform distribution.

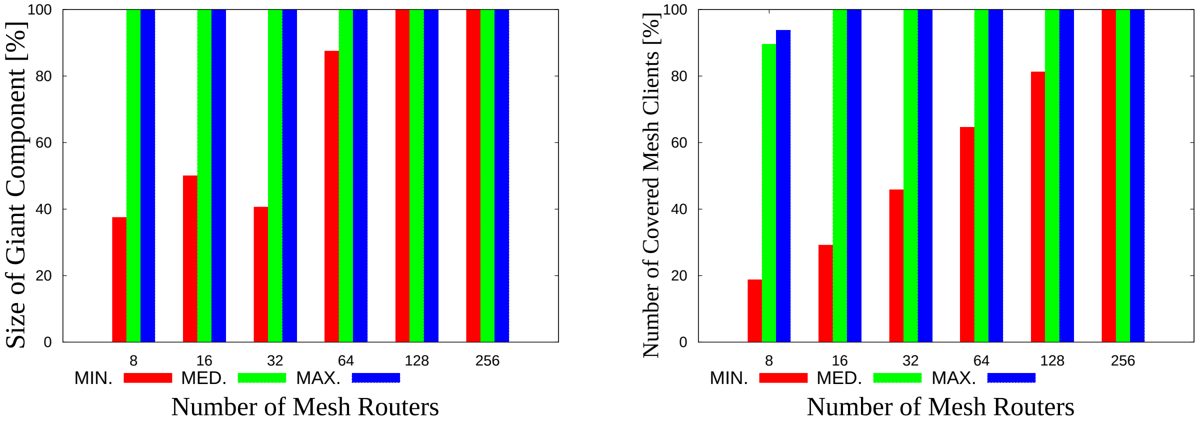
IV. FRIEDMAN TEST

The Friedman test [27] is a nonparametric statistical test of multiple group measures. It can be used to approve the null hypothesis that the multiple group measures have the same variance to a certain required level of significance. On the other hand, failing to approve the null hypothesis shows that they have different variance values.

We analyze the difference in performance among the number of located mesh routers using Friedman test. We considered as null hypothesis H_0 that there is not difference in the performance among the number of located mesh routers. And as alternative hypothesis we considered H_1 that there is difference in the performance among the number of located mesh routers. As value of the hypothesis testing we took the maximum value of NCMC and SGC. The significance level in this testing hypothesis is $\alpha = 0.05$. We reject H_0 for $p < \alpha$,

TABLE II: Result of Friedman test

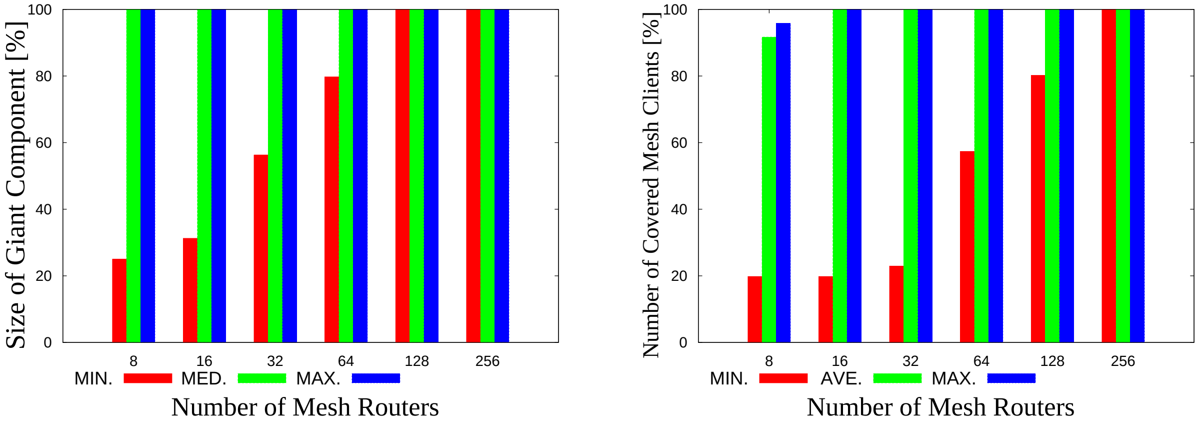
Number of mesh clients	p-value of SGC	p-value of NCMC
48	0.14	0.0136
96	0.14	0.0427
192	0.0934	0.0086
384	0.1325	0.03



(a) SGC vs. number of routers for 48 mesh cients

(b) NCMC vs. number of routers for 48 mesh clients

Fig. 3: Simulation results when the number of mesh clients is 48.



(a) SGC vs. number of routers for 96 mesh cients

(b) NCMC vs. number of routers for 96 mesh clients

Fig. 4: Simulation results when the number of mesh clients is 96.

where, p-value is given by

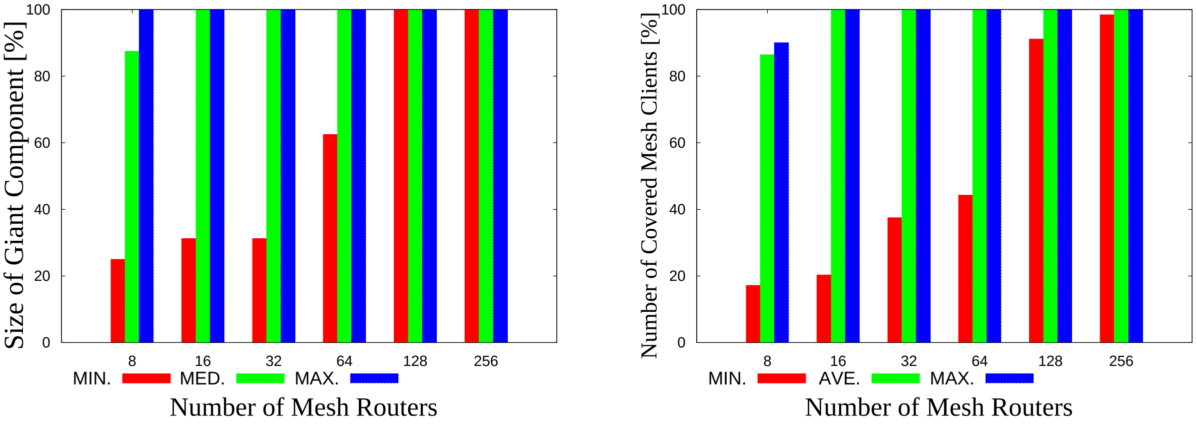
$$p = \frac{12}{rc(c+1)} \sum_{j=1}^{c} R_j^2 - 3r(c+1).$$

Here, r is a number of row, c means a number of column, R_j is the j^{th} colunm's ranked numbers, respectively.

p-value is the probability of obtaining a test statistic at least as extreme as the one that was actually observed, assuming that the null hypothesis is true

V. SIMULATION RESULTS

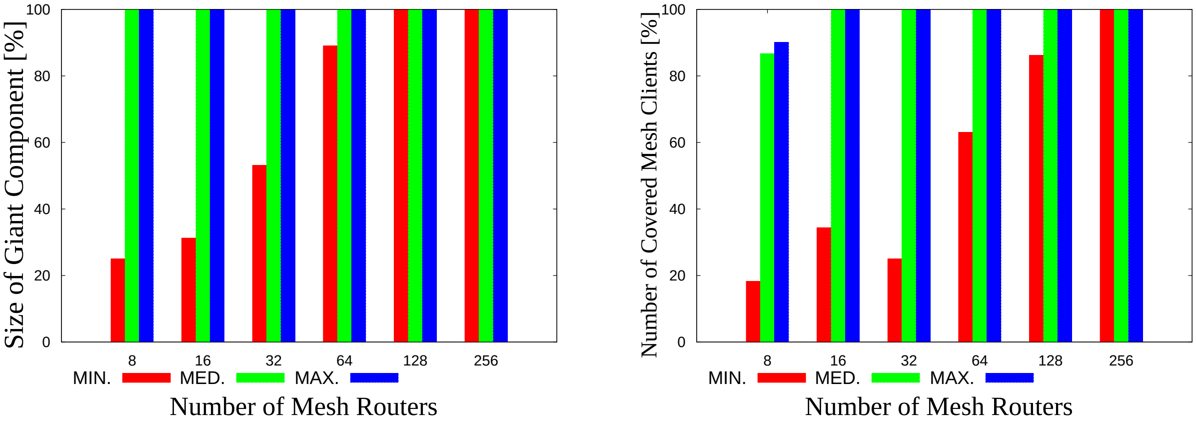
In this section, we show simulation results using WMN-HC system. In this work, the grid size is considered (25×25). The number of mesh routers is considered 8, 16, 32, 64, 128, 256 and the number of mesh clients 48, 96, 192, 384. We used Uniform distribution of mesh clients. In Fig. 2, we show an example for Uniform distribution of mesh clients. For the simulations, we used Combination replacement method. The total number of iterations is considered 13000 and the iterations per phase is considered 64. The simulation parameters and their values are shown in Table I. We carried out



(a) SGC vs. number of routers for 192 mesh cients

(b) NCMC vs. number of routers for 192 mesh clients

Fig. 5: Simulation results when the number of mesh clients is 192.



(a) SGC vs. number of routers for 384 mesh cients

(b) NCMC vs. number of routers for 384 mesh clients

Fig. 6: Simulation results when the number of mesh clients is 384.

many simulations to evaluate the performance of WMNs using WMN-HC system. In Table II, we show results of Friedman test.

From the Friedman test, we show results when the number of mesh clients is 48 in Fig. 3. The results of Friedman test show that p-value of SGC is 0.14. Then we adopt H_0 because $p > 0.05$. For NCMC, p-value is 0.0136. Thus $p < 0.05$ and H_1 is adopted.

In Fig. 4, we increase the number of mesh clients to 96. The results also show that p-value of SGC is 0.14. So we adopted H_0. The p-value of NCMC is 0.0427. Thus we adopt H_1 since $p < 0.05$.

In Fig. 5, we show results when the number of mesh clients is 192. The p-value of SGC is 0.0934, thus H_0 is adopted. While, p-value of NCMC is 0.0086, so we choose H_1. We show results when the number of mesh clients is 384 in Fig. 6. The p-value of SGC is 0.1325. Thus H_0 is adopted. For NCMC p-value is 0.03. Therefore, we adopt H_1.

These results show that there is not difference for SGC parameter. However, there is difference for NCMC parameter.

VI. CONCLUSIONS

In this work, we analyze the simulation data of WMN-HC system using Friedman test in order to solve the problem of mesh router placement problem in WMNs. For analysis, we have used the proposed and implemented simulation system called WMN-HC and consider different numer of mesh routers. We considered Uniform distribution of mesh clients.

From the simulation results analysis, for all cases of SGC, the p-value is more than 0.05. Thus, we adopt H_0. On the other hand, for all cases of NCMC, we adopt H_1 because the p-value is less than 0.05. These results show that there is not difference for SGC parameter. However, there is difference for NCMC parameter.

In our future work, we would like to evaluate the performance of the proposed system for different parameters and different scenarios. Moreover, we would like to implement a system based on other algorithms and compare with WMN-HC system.

REFERENCES

[1] O. Boyinbode, H. Le, and M. Takizawa, “A Survey on Clustering Algorithms for Wireless Sensor Networks,” *International Journal of Space-Based and Situated Computing*, vol. 1, no. 2, pp. 130–136, 2011.

[2] M. Puzar and T. Plagemann, “Data Sharing in Mobile Ad-hoc Networks – A Study of Replication and Performance in the MIDAS Data Space,” *International Journal of Space-Based and Situated Computing*, vol. 1, no. 2, pp. 137–150, 2011.

[3] D. Martins and H. Guyennet, “Security in Wireless Sensor Networks: A Survey of Attacks and Countermeasures,” *International Journal of Space-Based and Situated Computing*, vol. 1, no. 2, pp. 151–162, 2011.

[4] A. Koyama, Y. Sato, and L. Barolli, “IEZRP: An Improved Enhanced Zone-based Routing Protocol for MANETs and its Performance Evaluation,” *International Journal of Space-Based and Situated Computing*, vol. 1, no. 4, pp. 213–221, 2011.

[5] M. Hiyama, E. Kulla, M. Ikeda, and L. Barolli, “Evaluation of MANET Protocols for Different Indoor Environments: Results from a Real MANET Testbed,” *International Journal of Space-Based and Situated Computing*, vol. 2, no. 2, pp. 71–82, 2012.

[6] M. Ikeda, “Analysis of Mobile Ad-hoc Network Routing Protocols using Shadowing Propagation Model,” *International Journal of Space-Based and Situated Computing*, vol. 2, no. 3, pp. 139–148, 2012.

[7] M. Hiyama, S. Sakamoto, E. Kulla, M. Ikeda, and L. Barolli, “Experimental Results of a MANET Testbed for Different Settings of HELLO Packets of OLSR Protocol,” *Journal of Mobile Multimedia*, vol. 9, no. 1-2, pp. 27–38, 2013.

[8] E. Spaho, G. Mino, L. Barolli, and F. Xhafa, “Goodput and PDR Analysis of AODV, OLSR and DYMO Protocols for Vehicular Networks using CAVENET,” *International Journal of Grid and Utility Computing*, vol. 2, no. 2, pp. 130–138, 2011.

[9] K. Goto, Y. Sasaki, T. Hara, and S. Nishio, “Data Gathering using Mobile Agents for Reducing Traffic in Dense Mobile Wireless Sensor Networks,” *Mobile Information Systems*, vol. 9, no. 4, pp. 295–314, 2013.

[10] F. Xhafa, J. Sun, A. Barolli, A. Biberaj, and L. Barolli, “Genetic Algorithms for Satellite Scheduling Problems,” *Mobile Information Systems*, vol. 8, no. 4, pp. 351–377, 2012.

[11] F. Xhafa, J. Kolodziej, L. Barolli, V. Kolici, R. Miho, and M. Takizawa, “Hybrid Algorithms for Independent Batch Scheduling in Grids,” *International Journal of Web and Grid Services*, vol. 8, no. 2, pp. 134–152, 2012.

[12] A. Aikebaier, T. Enokido, and M. Takizawa, “TMPR-scheme for Reliably Broadcast Messages Among Peer Processes,” *International Journal of Grid and Utility Computing*, vol. 2, no. 3, pp. 175–182, 2011.

[13] I. F. Akyildiz, X. Wang, and W. Wang, “Wireless Mesh Networks: A Survey,” *Computer Networks*, vol. 47, no. 4, pp. 445–487, 2005.

[14] S. N. Muthaiah and C. P. Rosenberg, “Single Gateway Placement in Wireless Mesh Networks,” in *Proc. of 8th International IEEE Symposium on Computer Networks*, 2008, pp. 4754–4759.

[15] A. A. Franklin and C. S. R. Murthy, “Node Placement Algorithm for Deployment of Two-tier Wireless Mesh Networks,” in *Proc. of Global Telecommunications Conference*. IEEE, 2007, pp. 4823–4827.

[16] T. Vanhatupa, M. Hannikainen, and T. Hamalainen, “Genetic Algorithm to Optimize Node Placement and Configuration for WLAN Planning,” in *Proc. of 4th IEEE International Symposium on Wireless Communication Systems*, Oct 2007, pp. 612–616.

[17] A. Lim, B. Rodrigues, F. Wang, and Z. Xu, “k-Center Problems with Minimum Coverage,” pp. 349–359, 2004.

[18] T. Maolin *et al.*, “Gateways Placement in Backbone Wireless Mesh Networks,” *Int’l J. of Communications, Network and System Sciences*, vol. 2, no. 01, p. 44, 2009.

[19] J. Wang, B. Xie, K. Cai, and D. P. Agrawal, “Efficient Mesh Router Placement in Wireless Mesh Networks,” in *Proc. of IEEE Internatonal Conference on Mobile Adhoc and Sensor Systems (MASS-2007)*. IEEE, 2007, pp. 1–9.

[20] F. Xhafa, L. Barolli, and A. Durresi, “An Experimental Study on Genetic Algorithms for Resource Allocation on Grid Systems,” *Journal of Interconnection Networks*, vol. 8, no. 04, pp. 427–443, 2007.

[21] F. Xhafa, C. Sanchez, and L. Barolli, “Ad hoc and Neighborhood Search Methods for Placement of Mesh Routers in Wireless Mesh Networks,” in *Proc. of 29th IEEE International Conference on Distributed Computing Systems Workshops (ICDCS-2009)*. IEEE, 2009, pp. 400–405.

[22] S. Sakamoto, E. Kulla, T. Oda, M. Ikeda, L. Barolli, and F. Xhafa, “Performance Evaluation Considering Iterations per Phase and SA Temperature in WMN-SA System,” *Mobile Information Systems*, vol. 10, no. 3, pp. 321–330, 2014.

[23] T. Oda, A. Barolli, F. Xhafa, L. Barolli, M. Ikeda, and M. Takizawa, “Performance Evaluation of WMN-GA for Different Mutation and Crossover Rates Considering Number of Covered Users Parameter,” *Mobile Information Systems*, vol. 8, no. 1, pp. 1–16, 2012.

[24] S. Sakamoto, E. Kulla, T. Oda, M. Ikeda, L. Barolli, and F. Xhafa, “A Comparison Study of Simulated Annealing and Genetic Algorithm for Node Placement Problem in Wireless Mesh Networks,” *Journal of Mobile Multimedia*, vol. 9, no. 1-2, pp. 101–110, 2013.

[25] T. Oda, A. Barolli, E. Spaho, F. Xhafa, L. Barolli, and M. Takizawa, “Evaluation of WMN-GA for Different Mutation Operators,” *International Journal of Space-Based and Situated Computing*, vol. 2, no. 3, pp. 149–157, 2012.

[26] E. Amaldi, A. Capone, M. Cesana, I. Filippini, and F. Malucelli, “Optimization Models and Methods for Planning Wireless Mesh Networks,” *Computer Networks*, vol. 52, no. 11, pp. 2159–2171, 2008.

[27] M. Friedman, “The Use of Ranks to Avoid the Assumption of Normality Implicit in the Analysis of Variance,” *Journal of the American Statistical Association*, vol. 32, no. 200, pp. 675–701, 1937.