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Performance Analysis of WMN-GA Simulation System for Different WMN Architectures Considering OLSR

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***Abstract*—Wireless Mesh Networks (WMNs) are attracting a lot of attention from wireless network researchers. Node placement problems have been investigated for a long time in the optimization field due to numerous applications in location science. In our previous work, we evaluated WMN-GA system which is based on Genetic Algorithms (GAs) to find an optimal location assignment for mesh routers. In this paper, we evaluate the performance of two different distributions of mesh clients for two WMN architectures considering throughput, delay and energy metrics. For simulations, we used ns-3 and Optimized Link State Routing (OLSR). We compare the performance for normal and uniform distributions of mesh clients by sending multiple Constant Bit Rate (CBR) flows in the network. The simulation results show that for both distributions, the throughput of Hybrid WMN is higher than I/B WMN architecture. The delay of Hybrid WMN is a lower compared with I/B WMN. The delay for Hybrid WMN is almost the same for both distributions. However for I/B WMN, the delay is lower for Uniform distribution. For Normal distribution, the energy decreases sharply, because of the high density of nodes. For Uniform distribution, the remaining energy is higher compared with Normal distribution.**

***Keywords*-Wireless Mesh Networks, mesh router node placement, OLSR, GA.**

I. Introduction

Wireless Mesh Networks (WMNs) can be seen as a special type of wireless ad-hoc networks. WMNs are based on mesh topology, in which every node (representing a server) is connected through wireless links to one or more nodes, enabling thus the information transmission in more than one path. The path redundancy is a robust feature of mesh topology. Compared to other topologies, mesh topology does not need a central node, allowing networks based on it to be self-healing. These characteristics of networks with mesh topology make them very reliable and robust networks to potential server node failures.

There are a number of application scenarios for which the use of WMNs is a very good alternative to offer connectivity at a low cost. It should also mentioned that there are applications of WMNs which are not supported directly by other types of wireless networks such as cellular networks, ad hoc networks, wireless sensor networks and standard IEEE 802.11 networks. There are many applications of WMNs in Neighboring Community Networks, Corporative Networks, Metropolitan Area Networks, Transportation Systems, Automatic Control Buildings, Medical and Health Systems, Surveillance and so on.

In WMNs, the 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 client coverage.

In our previous work [1]–[3], we considered 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. We used mesh router nodes placement system that is based on Genetic Algorithms (GAs) to find an optimal location assignment for mesh routers in the grid area in order to maximize the network connectivity.

In this work, we use the topology generated by WMN-GA system and evaluate by simulations the performance of two different distributions of mesh clients considering two architectures of WMNs by sending multiple Constant Bit Rate (CBR) flows in the network. For simulations, we use ns-3 and Optimized Link State Routing (OLSR). As evaluation metrics we considered throughput, delay and energy.

The structure of the paper is as follows. In Section II, we discuss the related work. In Section III, we explain architectures of WMNs. In Section IV, we present an overview of OLSR routing protocol. In Section V, we give a short description of NS3. In Section VI, we show the description and design of the implemented WMN=GA simulation system. In Section VII, we discuss the simulation results. Finally, conclusions and future work are given in Section VIII.

II. Related Work

Until now, many researchers performed valuable research in the area of multi-hop wireless networks by computer simulations and experiments [4]. Most of them are focused on throughput improvement and they do not consider mobility [5].

WMNs are attracting a lot of attention from wireless research. Node placement problems have been investigated for a long time in the optimization field due to numerous applications in location science (facility location, logistics, services, etc.).

The main issue of WMNs is to achieve network connectivity and stability as well as QoS in terms of user coverage. Several heuristic approaches are found in the literature for node placement problems in WMNs [6]–[9]. As node placement problems are known to be computationally hard to solve for most of the formulations [10], [11], GAs have been recently investigated as effective resolution methods. However, GAs require the user to provide values for a number of parameters and a set of genetic operators to achieve the best GA performance for the problem [12]–[17].

III. Architectures of WMNs

In this section, we describe the architectures of WMN. The architecture of the nodes in WMNs [18] can be classified according to the functionalities they offer as follows:

Infrastructure/Backbone WMNs: This type of architecture (also known as infrastructure meshing) is the most used and consists of a grid of mesh routers which are connected to different clients. Moreover, routers have gateway functionality thus allowing Internet access for clients. This architecture enables integration with other existing wireless networks and is widely used in neighboring communities.

Client WMNs: Client meshing architecture provides a communications network based on peer-to-peer over client devices (there is no the role of mesh router). In this case we have a network of mesh nodes which provide routing functionality and configuration as well as end-user applications, so that when a packet is sent from one node to another, the packet will jump from node to node in the mesh of nodes to reach the destination.

Hybrid WMNs: This architecture combines the two previous ones, so that mesh clients are able to access the network through mesh routers as well as through direct connection with other mesh clients. Benefiting from the advantages of the two architectures, Hybrid WMNs can connect to other networks (Internet, Wi-Fi, and sensor networks) and enhance the connectivity and coverage due to the fact that mesh clients can act as mesh routers.

IV. Overview of OLSR Routing Protocol

The OLSR protocol [19] is a pro-active routing protocol, which builds up a route for data transmission by maintaining a routing table inside every node of the network. The routing table is computed upon the knowledge of topology information, which is exchanged by means of Topology Control (TC) packets.

OLSR makes use of HELLO messages to find its one hop neighbours and its two hop neighbours through their responses. The sender can then select its Multi Point Relays (MPR) based on the one hop node which offer the best routes to the two hop nodes. By this way, the amount of control traffic can be reduced. Each node has also an MPR selector set which enumerates nodes that have selected it as an MPR node. OLSR uses TC messages along with MPR forwarding to disseminate neighbour information throughout the network. Host Network Address (HNA) messages are used by OLSR to disseminate network route advertisements in the same way TC messages advertise host routes.

V. NS-3

The ns-3 simulator is developed and distributed completely in the C++ programming language, because it better facilitated the inclusion of C-based implementation code. The ns-3 architecture is similar to Linux computers, with internal interface and application interfaces such as network interfaces, device drivers and sockets. The goals of ns-3 are set very high: to create a new network simulator aligned with modern research needs and develop it in an open source community. Users of ns-3 are free to write their simulation scripts as either *C++ main()* programs or *Python* programs. The ns-3's low-level API is oriented towards the power-user but more accessible "helper" APIs are overlaid on top of the low-level API.

In order to achieve scalability of a very large number of simulated network elements, the ns-3 simulation tools also support distributed simulation. The ns-3 support standardized output formats for trace data, such as the pcap format used by network packet analyzing tools such as tcpdump, and a standardized input format such as importing mobility trace files from ns-2.

The ns-3 simulator is equipped with *Pyviz* visualizer, which has been integrated into mainline ns-3, starting with version 3.10. It can be most useful for debugging purposes, i.e. to figure out if mobility models are what you expect, where packets are being dropped. It is mostly written in Python and it works both with Python and pure C++ simulations. The function of ns-3 visualizer is more powerful than network animator (*nam*) of ns-2 simulator.

The ns-3 simulator has models for all network elements that comprise a computer network. For example, network devices represent the physical device that connects a node to the communication channel. This might be a simple Ethernet network interface card or a more complex wireless IEEE 802.11 device.

The ns-3 is intended as an eventual replacement for popular ns-2 simulator. The ns-3's wifi models a wireless network interface controller based on the IEEE 802.11 standard [20]. The ns-3 provides models for these aspects of 802.11:

1) Basic 802.11 DCF with infrastructure and ad hoc modes.
2) 802.11a, 802.11b, 802.11g and 802.11s physical layers.
3) QoS-based EDCA and queueing extensions of 802.11e.
4) Various propagation loss models including Nakagami, Rayleigh, Friis, LogDistance, FixedRss, and so on.
5) Two propagation delay models, a distance-based and random model.
6) Various rate control algorithms including Aarf, Arf, Cara, Onoe, Rraa, ConstantRate, and Minstrel.

VI. Implemented WMN-GA System Description and Design

In this section, we present the implemented WMN-GA System. First, we introduce the GA and then present the GUI of the WMN-GA System.

A. Genetic Algorithms

GAs have shown their usefulness for the resolution of many computationally combinatorial optimization problems. For the purpose of this work we have used the *template* given in Algorithm 1.

We present next the particularization of GAs for the mesh router nodes placement in WMNs.

Algorithm 1 Genetic Algorithm Template

Generate the initial population P^0 of size μ;
Evaluate P^0;
while not termination-condition **do**
  Select the parental pool T^t of size λ; $T^t := Select(P^t)$;
  Perform crossover procedure on pairs of individuals in T^t with probability p_c; $P^t_c := Cross(T^t)$;
  Perform mutation procedure on individuals in P^t_c with probability p_m; $P^t_m := Mutate(P^t_c)$;
  Evaluate P^t_m ;
  Create a new population P^{t+1} of size μ from individuals in P^t and/or P^t_m ;
  $P^{t+1} := Replace(P^t; P^t_m)$
  $t := t + 1$;
end while
return Best found individual as solution;

1) Encoding: The encoding of individuals (also known as chromosome encoding) is fundamental to the implementation of GAs in order to efficiently transmit the genetic information from parents to offsprings.

In the case of the mesh router nodes placement problem, a solution (individual of the population) contains the information on the current location of routers in the grid area as well as information on links to other mesh router nodes and mesh client nodes. This information is kept in data structures, namely, `pos_routers` for positions of mesh router nodes, `routers_links` for link information among routers and `client_router_link` for link information among routers and clients (matrices of the same size as the grid area are used). Based on these data structures, the size of the giant component and the number of users covered are computed for the solution.

It should be also noted that routers are assumed to have different radio coverage, therefore to any router could be linked to a number of clients and other routers. Obviously, whenever a router is moved to another cell of the grid area, the information on links to both other routers and clients must be computed again and links are re-established.

2) Selection Operators: In the evolutionary computing literature we can find a variety of selection operators, which are in charge of selecting individuals for the pool mate. The operators considered in this work are those based on *Implicit Fitness Re-mapping* technique. It should be noted that selection operators are generic ones and do not depend on the encoding of individuals.

- *Random Selection*: This operator chooses the individuals uniformly at random. The problem is that a simple strategy does not consider even the fitness value of individuals and this may lead to a slow convergence of the algorithm.
- *Best Selection*: This operator selects the individuals in the population having higher fitness value. The main drawback of this operator is that by always choosing the best fitted individuals of the population, the GA

converges prematurely.

- *Linear Ranking Selection*: This operator follows the strategy of selecting the individuals in the population with a probability directly proportional to its fitness value. This operator clearly benefits the selection of best endowed individuals, which have larger chances of being selected.
- *Exponential Ranking Selection*: This operator is similar to Linear Ranking but the probabilities of ranked individuals are weighted according to an exponential distribution.
- *Tournament Selection*: This operator selects the individuals based on the result of a tournament among individuals. Usually winning solutions are the ones of better fitness value but individuals of worse fitness value could be chosen as well, contributing thus to avoiding premature convergence. Particular cases of this operator are the *Binary Tournament* and $N-$*Tournament Selection*, for different values of N.

3) Crossover Operators: The crossover operator selects individuals from the parental generation and interchanging their *genes*, thus new individuals (descendants) are obtained. The aim is to obtain descendants of better quality that will feed the next generation and enable the search to explore new regions of solution space not explored yet.

There exist many types of crossover operators explored in the evolutionary computing literature. It is very important to stress that crossover operators depend on the chromosome representation. This observation is especially important for the mesh router nodes problem, since in our case, instead of having strings we have a grid of nodes located in a certain positions. The crossover operator should thus take into account the specifics of mesh router nodes encoding. We have considered the following crossover operator, called *intersection operator* (denoted `CrossRegion`, hereafter), which take in input two individuals and produce in output two new individuals.

4) Mutation Operators: Mutation operator is one of the GA ingredients. Unlike crossover operators, which achieve to transmit genetic information from parents to offsprings, mutation operators usually make some small local perturbation of the individuals, having thus less impact on newly generated individuals.

Crossover is “a must” operator in GA and is usually applied with high probability, while mutation operators when implemented are applied with small probability. The rationale is that a large mutation rate would make the GA search to resemble a random search. Due to this, mutation operator is usually considered as a secondary operator.

In the case of mesh routers node placement, the matrix representation is chosen for the individuals of the population, in order to keep the information on mesh router nodes positions, mesh client positions, links among routers and links among routers and clients. The definition of the mutation

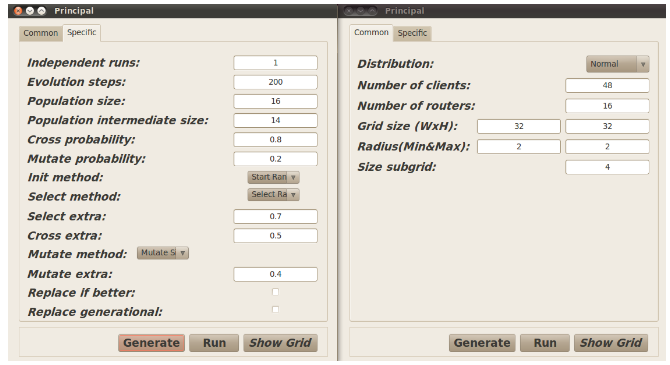


Figure 1. GUI tool for WMN-GA system.

operators is therefore specific to matrix-based encoding of the individuals of the population. Several specific mutation operators were considered in this study, which are move-based and swap-based operators.

- *SingleMutate*: This is a move-based operator. It selects a mesh router node in the grid area and moves it to another cell of the grid area.
- *RectangleMutate*: This is a swap-based operator. In this version, the operator selects two “small” rectangles at random in the grid area, and swaps the mesh routers nodes in them.
- *SmallMutate*: This is a move-based operator. In this case, the operator chooses randomly a router and moves it a small (*a priori* fixed) number of cells in one of the four directions: up, down, left or right in the grid This operator could be used a number of times to achieve the effect of SingleMutate operator.
- *SmallRectangleMutate*: This is a move-based operator. The operator selects first at random a rectangle and then all routers inside the rectangle are moved with a small (*a priori* fixed) numbers of cells in one of the four directions: up, down, left or right in the grid.

B. GUI of WMN-GA System

The WMN-GA system can generate instances of the problem using different distributions of client and mesh routers.

The GUI interface of WMN-GA is shown in Fig. 1. The left site of the interface shows the GA parameters configuration and on the right side are shown the network configuration parameters.

For the network configuration, we use: distribution, number of clients, number of mesh routers, grid size, radius of transmission distance and the size of subgrid.

For the GA parameter configuration, we use: number of independent runs, GA evolution steps, population size, population intermediate size, crossover probability, mutation probability, initial methods, select method.

Table I
INPUT PARAMETERS OF WMN-GA SYSTEM.

Parameters	Values
Number of clients	48
Number of routers	16, 20, 24, 28, 32
Grid width	32 units
Grid height	32 units
Independent runs	10
Number of generations (NG)	200
Population size	64
Selection method	Linear Ranking
Crossover rate	80 %
Mutate method	Single
Mutate rate	20 %
Distribution of clients	Normal, Uniform

Table II
EVALUATION OF WMN-GA SYSTEM.

Number of mesh routers	Normal Distribution		Uniform Distribution	
	SGM	NCN	SGC	NCM
16	16	44	16	21
20	20	46	20	22
24	24	47	24	27
28	28	48	28	33
32	32	48	32	35

Table III
SIMULATION PARAMETERS FOR NS-3.

Parameters	Values
Area Size	640m×640m
Number of mesh routers	24, 32
Distributions of mesh clients	Normal, Uniform
Number of mesh clients	48
MAC	IEEE 802.11b
Propagation loss model	Log-distance Path Loss Model
Propagation delay model	Constant Speed Model
Routing protocol	OLSR
Transport protocol	UDP
Application type	CBR
Packet size	1024 bytes
Number of source nodes	10
Number of destination node	1
Transmission energy	17.4 mA
Receiving energy	19.7 mA
Simulation time	60 sec

VII. SIMULATION RESULTS

A. Positioning of mesh routers by WMN-GA system

We use WMN-GA system for node placement problem in WMNs. A bi-objective optimization is used to solve this problem by first maximizing the number of connected routers in the network and then the client coverage. The input parameters of WMN-GA system are shown in Table I. In Fig. 2 and Fig. 3, we show the location of mesh routers and clients for first generations and the optimized topologies generated by WMN-GA system for Normal and Uniform distributions, respectively.

In Fig. 4 and Fig. 5 are shown the simulation results of Size of Giant Component (SGC) vs. number of generations. After few generations, all routers are connected with each other.

Then, we optimize the position of routers in order to cover as many mesh clients as possible. We consider normal and uniform distributions of mesh clients, which are similar with nodes concentrated in event-site environment. The simulation results of SGC and Number of Covered Mesh clients (NCM) are shown in Table. II.

B. Simulation Description

We conduct simulations using ns-3 simulator. The simulations in ns-3 are done for number of generations 1 and 200. The area size is considered 640m×640m (or 32 units×32 units) and the number of mesh routers is from 16 to 32. We used OLSR routing protocol and sent multiple CBR flows over UDP. The pairs source-destination are the same for all simulation scenarios. Log-distance path loss model and constant speed delay model are used for the simulation and other parameters are shown in Table III.

C. Discussion of Simulation Results

We used the throughput, delay and energy metrics to evaluate the performance of WMNs for Normal and Uniform distributions for I/B WMN and Hybrid WMN architectures.

In Fig. 6(a) and Fig. 6(b), we show the simulation results of throughput for Normal and Uniform distributions, respectively. For both distributions, the throughput of Hybrid WMN is higher than I/B WMN architecture.

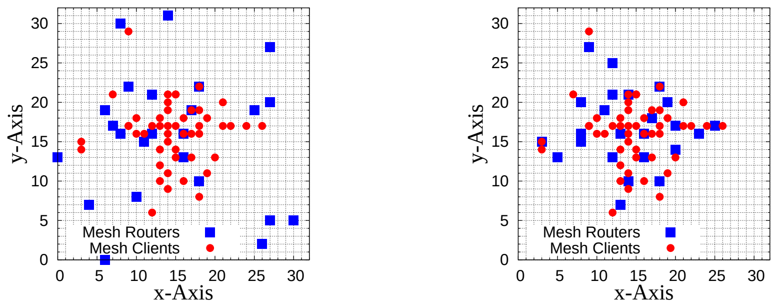
In Fig. 7(a) and Fig. 7(b), the delay of Hybrid WMN is a lower compared with I/B WMN. The delay for Hybrid WMN is almost the same for both distributions. However for I/B WMN, the delay is lower for Uniform distribution.

In Fig. 8(a) and Fig. 8(b), we show the remaining energy for both WMN architectures for Normal and Uniform distributions, respectively. For Normal distribution, the energy decreases sharply, because of the high density of nodes. For Uniform distribution, the remaining energy is higher compared with Normal distribution.

VIII. CONCLUSIONS

In this paper, we evaluated by simulations the performance of WMNs considering throughput, delay and energy metrics. We used two architectures of WMNs. The topologies of WMNs are generated using WMN-GA system with area size 640m×640m. The clients are distributed in the grid using Normal and Uniform distributions.

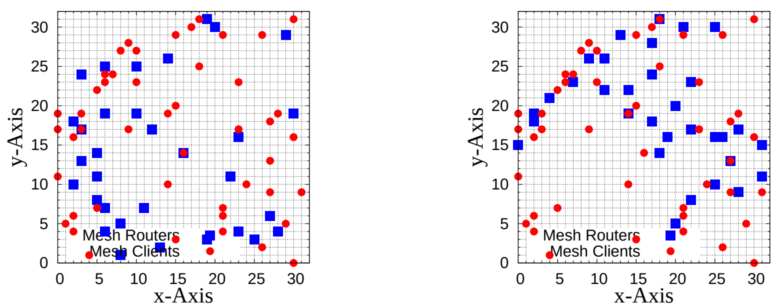
We carried out the simulations using ns-3 simulator. We transmitted multiple CBR flows over UDP. For simulations, we considered OLSR protocol, log-distance path loss model and constant speed delay model. From simulations, we found the following results.



(a) Number of generations: 1 (8, 12)

(b) Number of generations: 200 (24, 47)

Figure 2. Location of mesh routers by WMN-GA system, (m, n): m is number of connected mesh routers, n is number of covered mesh clients of normal distribution.



(a) Number of generations: 1 (15, 18)

(b) Number of generations: 200 (32, 35)

Figure 3. Location of mesh routers by WMN-GA system, (m, n): m is number of connected mesh routers n is number of covered mesh clients of uniform distribution.

1) For both distributions, the throughput of Hybrid WMN is higher than I/B WMN architecture.
2) The delay of Hybrid WMN is a lower compared with I/B WMN. The delay for Hybrid WMN is almost the same for both distributions. However for I/B WMN, the delay is lower for Uniform distribution.
3) For Normal distribution, the energy decreases sharply, because of the high density of nodes. For Uniform distribution, the remaining energy is higher compared with Normal distribution.

In the future, we would like to make extensive simulations for different density of mesh clients, distribution of mesh clients and grid sizes.

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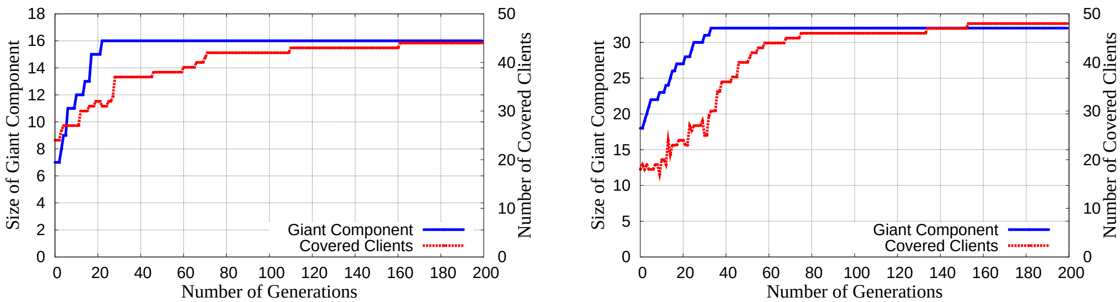
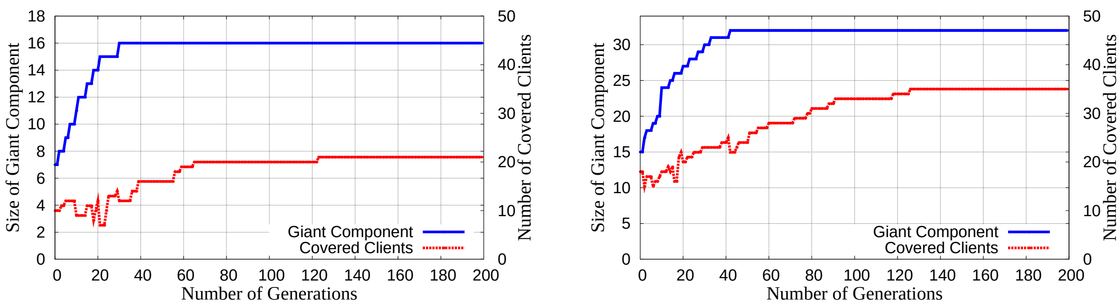


(a) Number of mesh routers: 16

(b) Number of mesh routers: 32

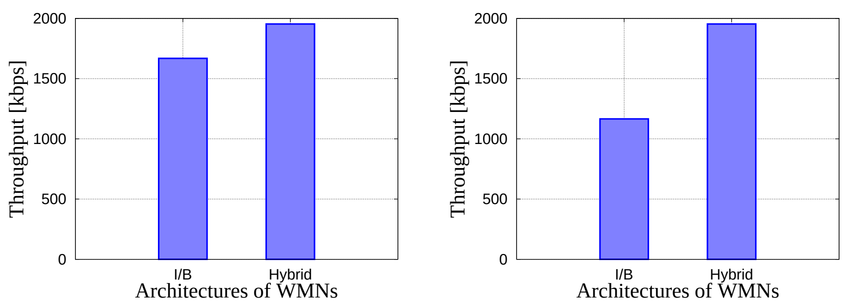
Figure 4. SGC and NCM vs. number of generations for Normal Distribution.



(a) Number of mesh routers: 16

(b) Number of mesh routers: 32

Figure 5. SGC and NCM vs. number of generations for Uniform Distribution.



(a) Normal distribution

(b) Uniform distribution

Figure 6. Results of average throughput for WMNs of different distributions.

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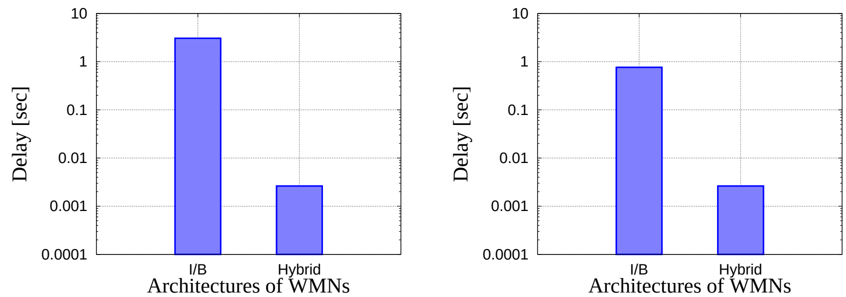
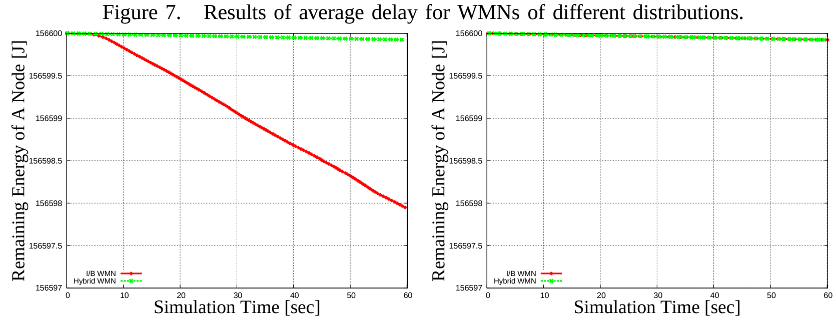


(a) Normal distribution

(b) Uniform distribution

Figure 7. Results of average delay for WMNs of different distributions.



(a) Normal distribution

(b) Uniform distribution

Figure 8. Results of remaining energies for WMNs of different distributions.

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