A GA-Based Simulation System for WMNs: Performance Analysis for Different WMN Architectures Considering Weibull Distribution, HWMP and TCP Protocols

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Abstract. In our previous work, we implemented WMN-GA system which is based on Genetic Algorithms (GAs) and used it for node placement problem in WMNs. In this paper, we evaluate the performance of Weibull distribution of mesh clients for two WMN architectures considering PDR, throughput, delay, fairness index and energy metrics. For simulations, we used ns-3, Hybrid Wireless Mesh Protocol (HWMP) and TCP. We compare the performance of both architectures. The simulation results show that the PDR for both WMN architectures is almost the same. The throughput of I/B WMN is a little bit higher than Hybrid WMN. The delay of Hybrid WMN is lower than I/B WMN. The fairness index and the remaining energy for both WMN architectures are almost the same.

1 Introduction

Wireless Mesh Networks (WMNs) [1] 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

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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.

The main issue of WMNs is to achieve network connectivity and stability as well as QoS in terms of user coverage. This problem is very closely related to the family of node placement problems in WMNs [2–5], among them, the mesh router mesh nodes placement. 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.

As node placement problems are known to be computationally hard to solve for most of the formulations [6,7], Genetic Algorithms (GAs) has been recently investigated as an effective resolution method.

In our previous work [8,9], 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 WMN-GA system to optimize the location of mesh routers the network connectivity.

In this work, we use the topology generated by WMN-GA system and evaluate by simulations the performance of Weibull distribution of mesh clients considering two architectures of WMNs by sending multiple Constant Bit Rate (CBR) flow in the network. For simulations, we use ns-3, Hybrid Wireless Mesh Protocol (HWMP) and TCP. As evaluation metrics we considered PDR, throughput, delay, fairness index and energy.

The structure of the paper is as follows. In Sect. 2, we make an explanation of architectures of WMNs. In Sect. 3, we make an overview of HWMP routing protocol. In Sect. 4, we show the description and design of the simulation system. In Sect. 5, we show the simulation results. Finally, conclusions and future work are given in Sect. 6.

2 Architectures of WMNs

In this section, we describe the architectures of WMN. The architecture of the nodes in WMNs [10–16] 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.

3 Overview of HWMP Routing Protocol

Hybrid Wireless Mesh Protocol (HWMP) defined in IEEE 802.11s, is a basic routing protocol for a wireless mesh network. It is based on AODV [17] and tree-based routing. It relies on peer link management protocol by which each mesh point discovers and tracks neighboring nodes. If any of these are connected to a wired backhaul, there is no need for HWMP, which selects paths from those assembled by compiling all mesh point peers into one composite map.

HWMP protocol is hybrid, because it supports two kinds of path selection protocols. Although these protocols are very similar to routing protocols, but bear in mind, that in case of IEEE 802.11s these use MAC addresses for "routing", instead of IP addresses. Therefore, we use the term "path" instead of "route" and thus "path selection" instead of "routing".

HWMP is intended to displace proprietary protocols used by vendors like Meraki for the same purpose, permitting peer participation by open source router firmware.

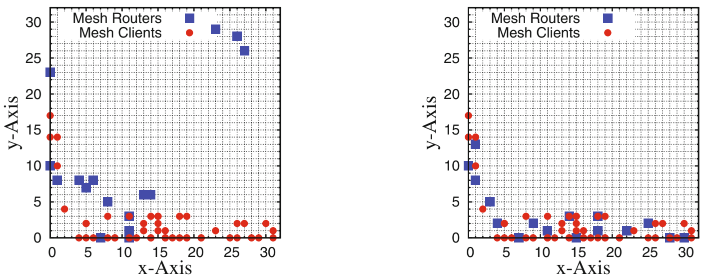
4 Simulation System Description and Design

4.1 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 1. In Fig. 1, we show the location of mesh

Table 1. 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	200
Population size	64
Selection method	Linear ranking
Crossover rate	80%
Mutate method	Single
Mutate rate	20%
Distribution of clients	Weibull



(a) Number of generations: 1 (12, 17) (b) Number of generations: 200 (16, 47)

Fig. 1. Location of mesh routers and clients for exponential distribution; (m, n): m is SGC, n is NCMC.

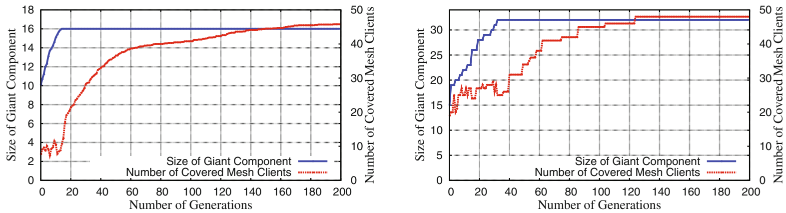
routers and clients for first generations and the optimized topologies generated by WMN-GA system for Weibull distribution.

In Fig. 2 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. The simulation results of SGC and Number of Covered Mesh Clients (NCMC) are shown in Table 2.

4.2 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 640 [m] $\times$ 640 [m]



(a) Number of mesh routers: 16 (b) Number of mesh routers: 32

Fig. 2. SGC and NCMC vs. number of generations for exponential distribution.

Table 2. Evaluation of WMN-GA system.

Number of mesh routers	Weibull distribution	
	SGC	NCMC
16	16	47
20	20	48
24	24	48
28	28	48
32	32	48

(or 32 units × 32 units) and the number of mesh routers is from 16 to 32. We used HWMP routing protocol and sent multiple CBR flows over TCP. 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 3.

4.3 NS-3

The ns-3 simulator [18] 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 [19].

Table 3. Simulation parameters for ns-3.

Parameters	Values
Area size	640 [m] × 640 [m]
Number of mesh routers	24
Distributions of mesh clients	Weibull
Number of mesh clients	48
MAC	IEEE 802.11s
Propagation loss model	Log-distance path loss model
Propagation delay model	Constant speed model
Routing protocol	HWMP
Transport protocol	TCP
Application type	CBR
Packet size	1024 [Bytes]
Number of source nodes	10
Number of destination nodes	1
Transmission energy	17.4 [mA]
Receiving energy	19.7 [mA]
Simulation time	600 [s]

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.

5 Simulation Results

In this section, we present the simulation results. For evaluation, we used the PDR, throughput, delay, fairness index and energy metrics. We analyze and compare the simulation results of I/B WMN and Hybrid WMN architectures considering Weibull distribution.

In Fig. 3, we show the simulation results for PDR metric. The simulation results show that the PDR for both WMN architectures is almost the same. In Fig. 4, we show the simulation results of throughput metric. The throughput of I/B WMN is a little bit higher than Hybrid WMN.

In Fig. 5, the delay of Hybrid WMN is lower than I/B WMN. In Fig. 6, we show the fairness index. The fairness index for both WMN architectures is almost the same. In Fig. 7, we show the remaining energy for both WMN architectures. We can see that the remaining energy for both architectures is almost the same.

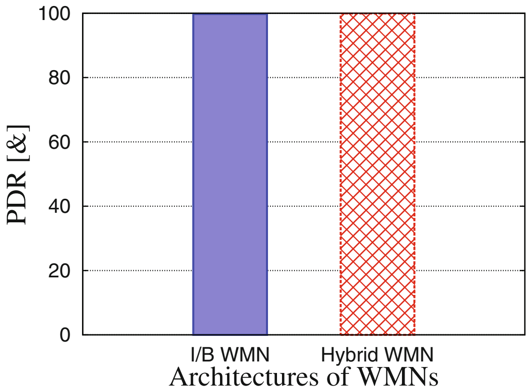


Fig. 3. Results of average PDR.

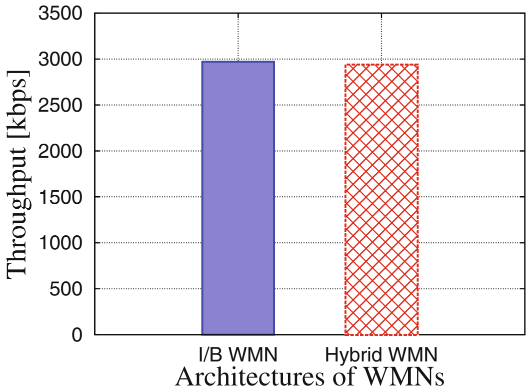


Fig. 4. Results of average throughput.

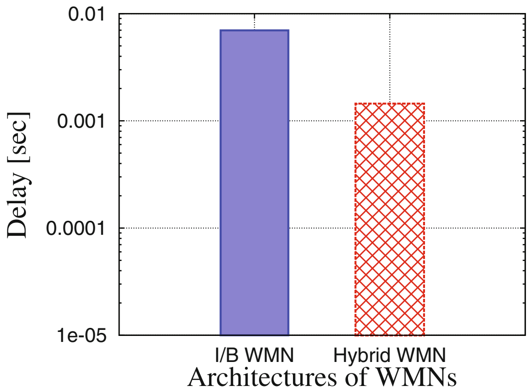


Fig. 5. Results of average delay.

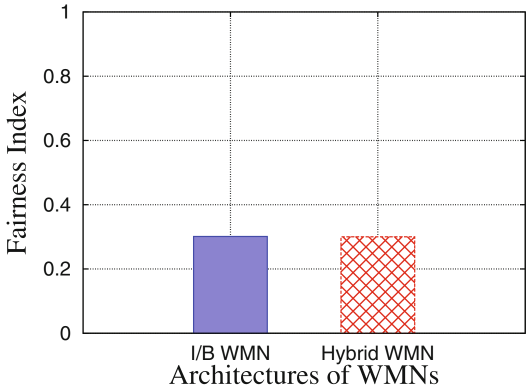


Fig. 6. Results of fairness index.

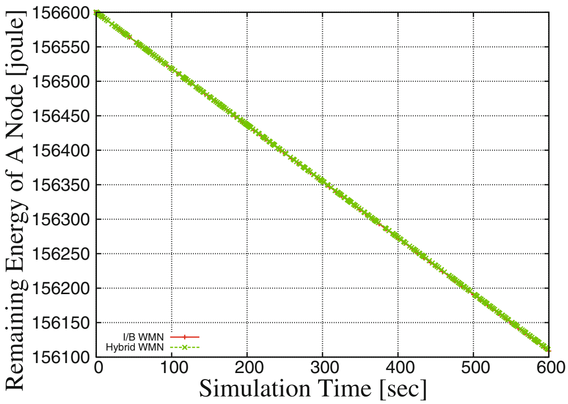


Fig. 7. Results of remaining energies.

6 Conclusions

In this paper, we evaluated by simulations the performance of the WMN architectures considering PDR, throughput, delay, fairness index and energy metrics. The topologies of WMNs are generated using WMN-GA system. The clients are distributed in the grid area using Weibull distribution.

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

- The PDR for both WMN architectures are almost the same.
- The throughput of I/B WMN is a little bit higher than Hybrid WMN.
- The delay of Hybrid WMN is lower than I/B WMN.
- The fairness index and remaining energy for both WMN architectures are almost the same.

In this work, we consider HWMP and TCP protocols. In the future work, we would like to make extensive simulations for different density of mesh clients and grid sizes.

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