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A GA-Based Simulation System for WMNs: Comparison Analysis for Different Number of Flows, Client Distributions, DCF and EDCA Functions

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Abstract In this paper, we compare the performance of Distributed Coordination Function (DCF) and Enhanced Distributed Channel Access (EDCA) for normal and uniform distributions of mesh clients considering two Wireless Mesh Network (WMN) architectures. As evaluation metrics, we consider throughput, delay, jitter and fairness index metrics. For simulations, we used WMN-GA simulation system, ns-3 and Optimized Link State Routing (OLSR). The simulation results show that for normal distribution, the throughput of I/B WMN is higher than Hybrid WMN architecture. For uniform distribution, in case of I/B WMN, the throughput of EDCA is a little bit higher than Hybrid WMN. However, for Hybrid WMN, the throughput of DCF is higher than EDCA. For normal distribution, the delay and jitter of Hybrid WMN is lower compared with I/B WMN. For uniform distribution, the delay and jitter of both architectures are almost the same. However, in the case of DCF for 20 flows, the delay and jitter of I/B WMN are lower compared with Hybrid WMN. For I/B architecture, in case of normal distribution the fairness index of DCF is higher than EDCA. However, for Hybrid WMN, the fairness index of EDCA is higher than DCF. For uniform distribution, the fairness index of few flows is higher than others for both WMN architectures.

1 Introduction

The Wireless Mesh Networks (WMNs) [4] are important networking infrastructures, which are constructed by wireless nodes, and organized in a mesh topology. The mesh routers are interconnected by wireless links and provide Internet connectivity to mesh clients.

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In general, the WMNs have low cost, which makes them attractive for providing wireless Internet connectivity. Such infrastructure can be used for different networks such as: community networks, metropolitan area networks, municipal and, corporative networks, and they can support applications for urban areas, medical, transport and surveillance systems.

The goal of WMNs is to achieve network connectivity and QoS in terms of user coverage. This optimization problem considering two parameter is related to the family of node placement problems in WMNs [12,10,1,19]. In our work, we consider the mesh router nodes placement problem. We consider a grid area and want tofind 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.

The node placement problems are known to be computationally hard to solve for most of the formulations [2], [8] and Genetic Algorithms (GAs) have been investigated as an effective method.

In our previous work [15,9,18], we used WMN simulation system that is based on GAs (called WMN-GA) to find an optimal location assignment for mesh routers in the grid area.

In this paper, the motivation of our work is to present a comparison study between Distributed Coordination Function (DCF) and Enhanced Distributed Channel Access (EDCA) MAC protocols for normal and uniform distributions of mesh clients considering two Wireless Mesh Network (WMN) architectures. We use the topology generated by WMN-GA system and evaluate by simulations the performance for these two distributions of mesh clients 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, jitter and fairness.

The rest of the paper is organized as follows. Architectures of WMNs are presented in Section 2. In Section 4, we show the description and design of the simulation system. In Section 5, we discuss the simulation results. Finally, conclusions and future work are given in Section 6.

2 Architectures of WMNs

In this section, we describe the architectures of WMN. The architecture of the nodes in WMNs [3,16,17,14] 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 architecture for WMN. It consists of a grid of mesh routers connected to different clients.The routersare equipped with gateway functionality allowing Internet access for clients. This architecture also enables integration with other existing wireless networks and is widely used in neighboring communities.

Client WMNs: This architecture provides a communications network based on Peer-to-Peer (P2P) over client devices (there is no the role of mesh router). The mesh nodes provide routing functionality and configuration as well as end-user applications. When a packet is sent from one node to another, the packetis transmitted through mesh nodes to reach the destination.

Hybrid WMNs: This architecture combines two previous ones. The mesh clients are able to access the network through mesh routers as well as through direct connection with other mesh clients. The Hybrid WMNs also can connect to other networks (Internet, Wi-Fi, and sensor networks) and enhance the connectivity and coverage because that mesh clients can act as mesh routers.

3 Mesh Router Node Placement Problem

For the mesh router node placement problem, we consider a grid area arranged in cells. 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. The network connectivity is measured by the Size of Giant Component (SGC), which is the number of connected routers). While the user coverage is simply the Number of Covered Mmesh Clients (NCMC) that fall within the radio coverage of at least one mesh router node.

We formulate the problem 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.

The network connectivity and user coverage are the most important metrics in WMNs and directly affect the network performance. But, the network connectivity is usually considered as more important than user coverage, because if the mesh routers are not connected then we will have separated networks not connected together.

For evaluation purpose it is interesting to consider concrete distributions of mesh client nodes such as: Uniform, Normal, Exponential and Weibull distributions.

We can formalize an instance of the problem by constructing an adjacency matrix of the WMN graph, considering router nodes, client nodes and whose the links between nodes in a WMN. Each mesh node in the graph is a triple $v =< x, y, r >$ representing the 2D location point and r is the radius of the transmission range. There is an arc between two nodes u and v, if v is within the transmission circular area of u. It should be noted that the deployment grid area is partitioned by cells, representing graph nodes, where we can locate mesh router nodes. We assume that in a cell, both a mesh router node and a mesh client node can be placed.

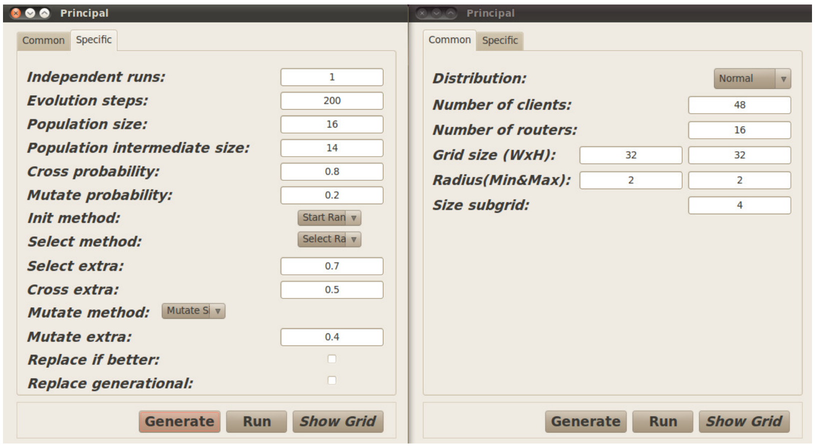


Fig. 1 GUI tool for WMN-GA system.

For optimization problems having two or more objective functions, two settings are usually considered: the hierarchical and simultaneous optimization. In the hierarchical optimization, the objectives are classified according to their priority. Thus, for the bi-objective case, one of the objectives (f_1), is considered as a primary objective and the other (f_2), as secondary one. The meaning is that the f_1 is optimized first and then when no further improvements are possible the f_2 is optimized without worsening the best value of f_2. In the case of WMNs is used the hierarchical approach because the network connectivity is considered more important than user coverage. However, due to this optimization priority, some client nodes may not be covered because the user coverage is less optimized.

4 Simulation Description and Design

4.1 GUI of WMN-GA System

The implemented WMN-GA simulation 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. On left site of the interface are shown GA configuration parameters and on the right side 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 1 Input parameters of WMN-GA system.

Parameters	Values
Number of clients	48
Number of routers	16, 24, 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 2 Evaluation of WMN-GA system.

Number of	Normal Distribution		Uniform Distribution	
mesh routers	SGC	NCMC	SGC	NCMC
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

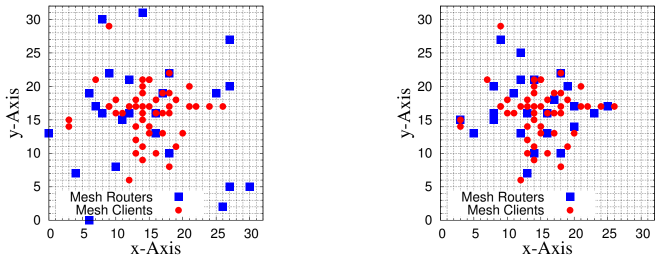
4.2 Positioning of mesh routers by WMN-GA system

We use WMN-GA simulation system for node placement problem in WMNs. A bi-objective optimization is used to solve this problem by first maximizing the SGC and then the NCMC. The input parameters of WMN-GA system are shown in Table 1. In Fig. 2, we show the location of mesh routers and clients for first generations and the optimized topologies generated by WMN-GA simulation system for Weibull distribution.

In Fig. 4 are shown the simulation results of SGC and NCMC 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 NCMC are shown in Table 2.

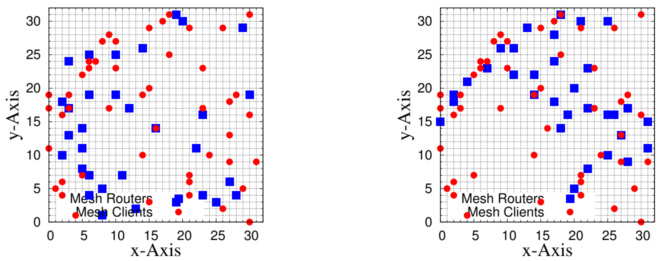
4.3 Simulation Description

The simulations are done by using ns-3 simulator. 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 DCF, EDCA and 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 3.



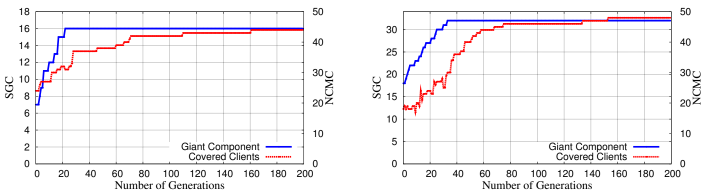
(a) Number of generations: 1 (8, 12) (b) Number of generations: 200 (32, 35)

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



(a) Number of generations: 1 (8, 12) (b) Number of generations: 200 (32, 35)

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

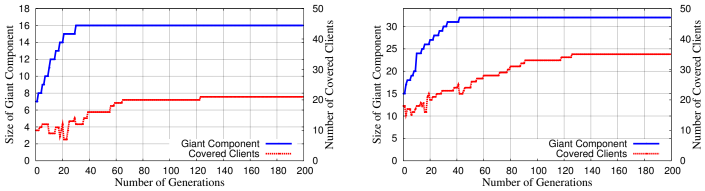


(a) Number of mesh routers: 16 (b) Number of mesh routers: 32

Fig. 4 SGC and NCMC vs. number of generations for normal distribution.

4.4 NS-3

The ns-3 simulator [20] is developed and distributed completely in the C++ programming language. The ns-3 architecture is similar to Linux. The users of ns-3 can write the simulation scripts by *C++ main()* or *Python* programs. The ns-3 simulation tools support distributed simulation and the 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 [21]. The ns-3 simulator is equipped



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

Fig. 5 SGC and NCMC vs. number of generations for uniform distribution.

Table 3 Simulation parameters for ns-3.

Parameters	Values
Area Size	640[m]×640[m]
Distributions of mesh clients	Normal, Uniform
Number of mesh routers	16
Number of mesh clients	48
PHY protocol	IEEE 802.11b
Propagation loss model	Log-distance Path Loss Model
Propagation delay model	Constant Speed Model
MAC protocols	DCF, EDCA
Routing protocol	OLSR
Transport protocol	UDP
Application type	CBR
Packet size	1024 [Bytes]
Number of source nodes	10, 20, 30
Number of destination node	1
Transmission current	17.4 [mA]
Receiving current	19.7 [mA]
Simulation time	600 [sec]

with *Pyviz* visualizer. The function of ns-3 visualizer is more powerful than network animator (*nam*) of ns-2 simulator.

The ns-3 is intended as an eventual replacement of ns-2 simulator. The ns-3 can model a wireless network interface controller based on the IEEE 802.11 standard [5].

The ns-3 provides models for these aspects of IEEE 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.

4.5 Overview of DCF and EDCA Protocols

In this paper, we consider two distributed access methods: DCF from IEEE 802.11 [6] and EDCA from IEEE 802.11e [7]. The centralised access methods, Point Coordination Function (PCF) [6] and Hybrid Controlled Channel Access (HCCA) [7] are not considered as they are rarely implemented in hardware devices [11].

4.5.1 DCF

DCF is a random access scheme based on the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) scheme. A DCF station with a packet to send will first sense the medium. Then, if the channel is idle for a Distributed Inter-Frame Space (DIFS), the station will attempt to transmit after a random back-off period. This period is referred as the Contention Window (CW). The value for the CW is chosen randomly from a range $[0, 2^n - 1]$, i.e.

$$CW_{min} \leq CW \leq CW_{max} \tag{1}$$

where n is PHY dependent. Initially, CW is set to the minimum number of slot times CW_{min}, which is defined per PHY in microseconds [6]. The randomly chosen CW value (referred as the back-off counter) is decreased each slot time if the medium remains idle. If during any period the medium becomes busy, the back-off counter is paused and resumed only when the medium becomes idle. When it reaches zero, the station transmits the packet in the physical channel and awaits an acknowledgment (ACK). The transmitting station then performs a post back-off, where the back-off procedure is repeated once more. This is to allow other stations to gain access to the medium during heavy contention.

If the ACK is not received within a Short Inter-Frame Space (SIFS), it assumes that the frame was lost due to collision or being damaged. The CW value is then increased exponentially and the back-off begins once again for retransmission. This is referred as the Automatic Repeat Request (ARQ) process. If the following retransmission attempt fails, the CW is again increased exponentially, up until the limit CW_{max}. The retransmission process will repeat for up to 4 or 7 times, depending on whether the short retry limit or long retry limit is used. Upon reaching the retry limit the packet is considered lost and discarded.

4.5.2 EDCA

The enhanced access method EDCA has four different Access Categories (ACs) or traffic classes for service differentiation at the MAC layer. This is achieved by varying the size of CW in the backoff mechanism on a per category basis. Service differentiation is provided by the following methods:

Arbitration Inter-Frame Space (AIFS) : This is similar to the DIFS used in DCF, except the AIFS can vary according the access category;

Variable Contention Window : By giving higher priority traffic smaller contention windows, less time is spent in the back-off state, resulting in more frequent access to the medium.

Transmission Opportunity (TxOP) : This allows a station that has access to the medium to transmit a number of data units without having to contend for access to the medium. In fact this is a form of frame bursting. The TxOP limit is defined per traffic class.

Multiple AC queues can exist on a single station, contending with each other for the physical medium. This is regarded as virtual contention.

4.6 Overview of OLSR Routing Protocol

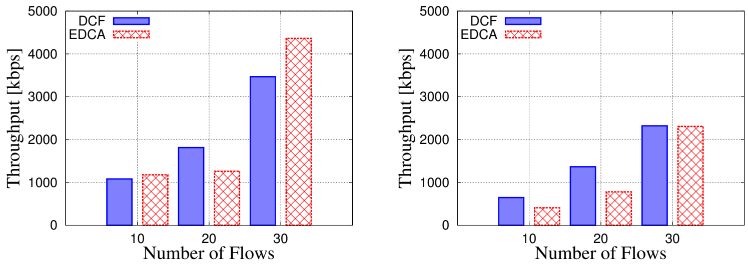
The OLSR protocol [13] is a pro-active routing protocol. It can build a route for data transmission by maintaining a routing table inside every node of the network. The routing table is computed upon the knowledge of topology information, which is exchanged by means of Topology Control (TC) packets.

The OLSR uses 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. The OLSR uses TC messages along with MPR forwarding to disseminate neighbour information throughout the network. The Host Network Address (HNA) messages are used by OLSR to disseminate network route advertisements in the same way TC messages advertise host routes.

5 Simulation Results

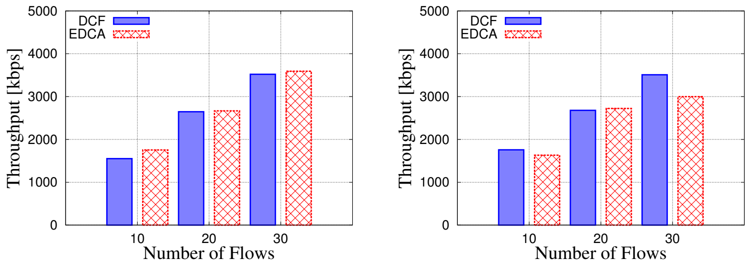
We used the throughput, delay, jitter and fairness index metrics to evaluate the performance of WMNs for two architectures considering DCF and EDCA functions, normal and uniform distributions, and different number of flows.

In Fig. 6 and Fig. 7, we show the simulation results of throughput. For normal distribution, the throughput of I/B WMN is higher than Hybrid WMN architecture. For 30 flows, the throughtput of EDCA in case of I/B WMN is about 2 times higher than Hybrid WMN. But the throughtput of DCF in case of Hybrid WMN is about 65 [%] of I/B WMN. For uniform distribution, in case of I/B WMN, the throughput of EDCA is a little bit higher than Hybrid WMN. For 10 flows, the throughtput of DCF in case of I/B WMN is about 88



(a) I/B WMN (b) Hybrid WMN

Fig. 6 Results of average throughput considering normal distribution.



(a) I/B WMN (b) Hybrid WMN

Fig. 7 Results of average throughput considering uniform distribution.

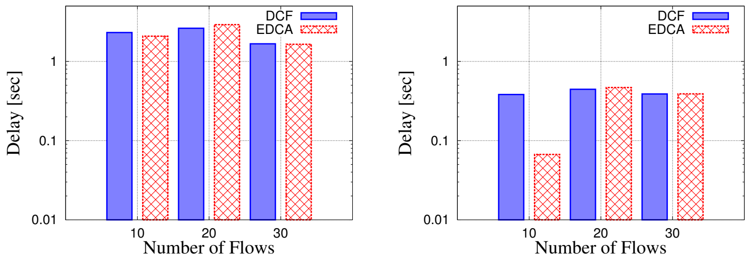
[%] of EDCA. However, for Hybrid WMN, the throughput of DCF is higher than EDCA.

In Fig. 8, Fig. 9, Fig. 10 and Fig. 11, for normal distribution, the delay and jitter of Hybrid WMN is lower compared with I/B WMN. The delay of Hybrid WMN is about 10 times lower than I/B WMN. In uniform distribution case, the delay and jitter of both architectures are almost the same. However, in the case of DCF for 20 flows, the delay and jitter of I/B WMN is lower compared with Hybrid WMN.

In Fig. 12 and Fig. 13, we show the fairness index. For normal distribution, the fairness index of 10 and 20 flows is higher than 30 flows for both WMN architectures. For I/B architecture the fairness index of EDCA for 10 flows is about 92 [%] of DCF. However, for Hybrid WMN, the fairness index of DCF is about 60 [%] of EDCA. In uniform distribution case, the fairness index of 10 flows is higher than other flows for both WMN architectures.

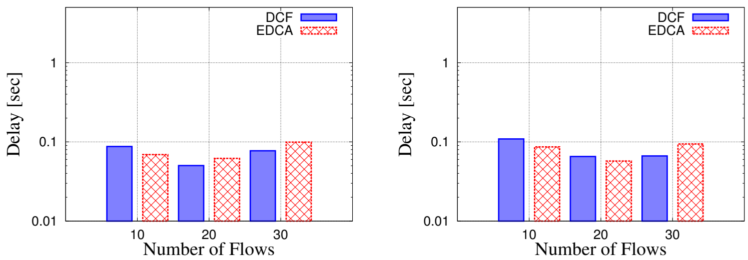
6 Conclusions

In this work, we presented WMN-GA system and applied it for node placement problem in WMNs. We evaluated the performance of WMN by WMN-GA sys-



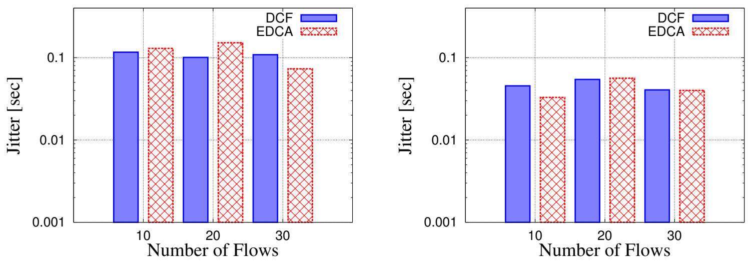
(a) I/B WMN (b) Hybrid WMN

Fig. 8 Results of average delay considering normal distribution.



(a) I/B WMN (b) Hybrid WMN

Fig. 9 Results of average delay considering uniform distribution.



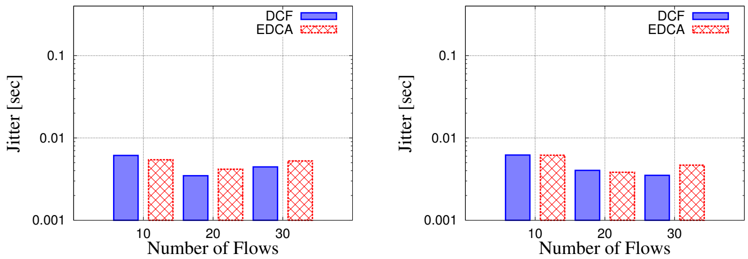
(a) I/B WMN (b) Hybrid WMN

Fig. 10 Results of average jitter considering normal distribution.

tem for normal and uniform distributions of mesh clients considering different number of flows, DCF, EDCA and OLSR protocol.

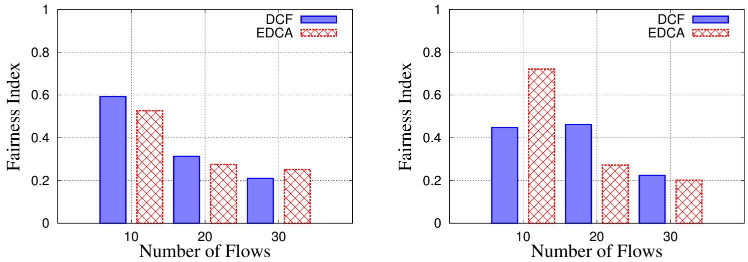
From the simulations we conclude as follows.

- For normal distribution, the throughput of I/B WMN is higher than Hybrid WMN architecture. For uniform distribution, in case of I/B WMN, the throughput of EDCA is a little bit higher than Hybrid WMN. However, for Hybrid WMN, the throughput of DCF is higher than EDCA.
- For normal distribution, the delay and jitter of Hybrid WMN is lower compared with I/B WMN. For uniform distribution, the delay and jitter



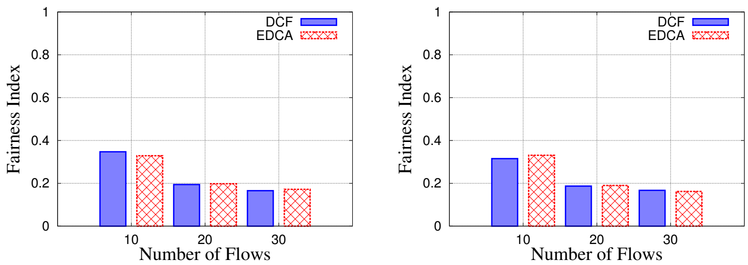
(a) I/B WMN (b) Hybrid WMN

Fig. 11 Results of average jitter considering uniform distribution.



(a) I/B WMN (b) Hybrid WMN

Fig. 12 Results of fairness index considering normal distribution.



(a) I/B WMN (b) Hybrid WMN

Fig. 13 Results of fairness index considering uniform distribution.

of both architectures are almost the same. However, in the case of DCF for 20 flows, the delay and jitter of I/B WMN is a lower compared with Hybrid WMN.

– In normal distribution case, the fairness index of 10 and 20 flows is higher than 30 flows for both WMN architectures. For I/B architecture the fairness index of DCF is higher than EDCA. However, for Hybrid WMN, the fairness index of EDCA is higher than DCF. For uniform distribution, the fairness index of 10 flows is higher than other flows for both WMN architectures.

In the future work, we would like to implement other intelligent systems based on tabu search, particle swarm optimization, hill climbing, simulated annealing and compare the performance with the proposed system.

7 Compliance with Ethical Standards

– **Funding**: This study was not funded by any grant.
– **Conflict of Interest**: All authors declares that they have no conflict of interest.
– **Ethical Approval**: This article does not contain any studies with human participants performed by any of the authors.

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