Comparison Analysis by WMN-GA Simulation System for Different WMN Architectures, Normal and Uniform Distributions, DCF and EDCA Functions

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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 this paper, we evaluate the performance of two WMN architectures considering throughput, delay, jitter and fairness index metrics. For simulations, we used ns-3 and Optimized Link State Routing (OLSR). We compare the performance of Distributed Coordination Function (DCF) and Enhanced Distributed Channel Access (EDCA) 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 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

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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 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.

1 Introduction

Wireless Mesh Networks (WMNs) [1] are important networking infrastructures. These networks are made up of wireless nodes, organized in a mesh topology, where mesh routers are interconnected by wireless links and provide Internet connectivity to mesh clients.

WMNs distinguish for their low cost nature that makes them attractive for providing wireless Internet connectivity. 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.

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 [3, 4, 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 effective resolution method.

In our previous work [8, 9, 10], 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 and client coverage.

In this work, we use the topology generated by WMN-GA system and evaluate by simulations the performance of uniform distribution of mesh clients considering two architectures and two MAC protocols 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, one-way delay, jitter and fairness.

The rest of the paper is organized as follows. Architectures of WMNs are presented in Section 2. In Section 3, we show the description and design of the simulation system. In Section 4, we discuss the simulation results. Finally, conclusions and future work are given in Section 5.

2 Architectures of WMNs

In this section, we describe the architectures of WMN. The architecture of the nodes in WMNs [11, 12, 13, 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 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 Simulation Description and Design

3.1 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.

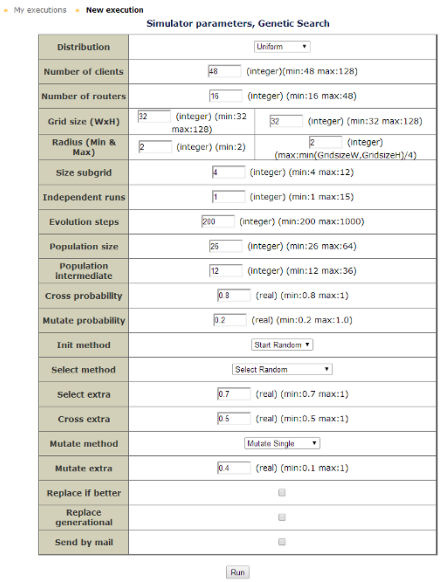


Fig. 1 GUI tool for WMN-GA system.

3.2 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. 2, 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 distribution.

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

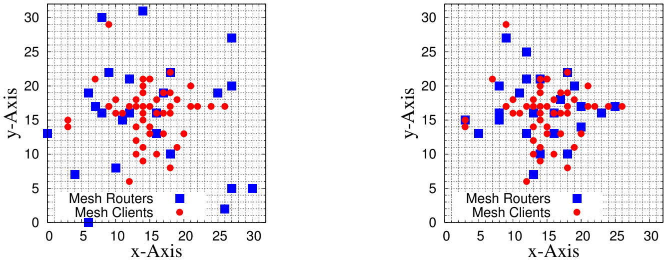
Then, we optimize the position of routers in order to cover as many mesh clients as possible. The simulation results of SGC and NCMC are shown in Table 2.

3.3 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$\times$640m (or 32 units$\times$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

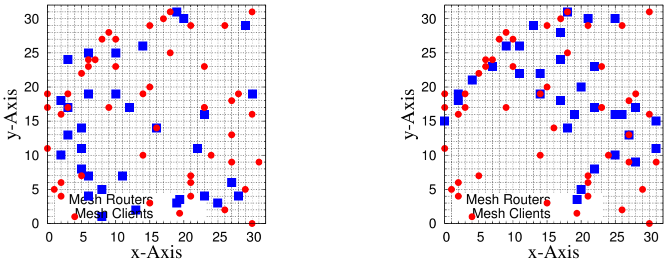
Table 1 Input parameters of WMN-GA system.

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



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

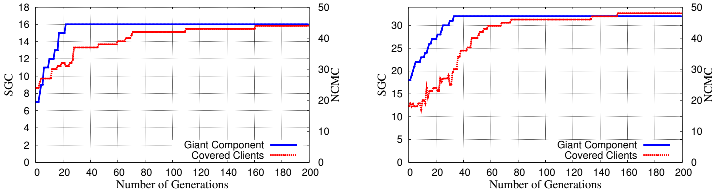
Fig. 2 Location of mesh routers by WMN-GA system for normal distribution; (*m*, *n*): *m* is number of connected mesh routers, *n* is number of covered mesh clients.



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

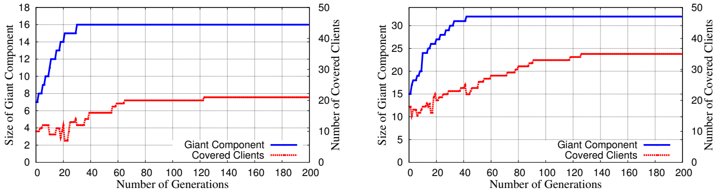
Fig. 3 Location of mesh routers by WMN-GA system for uniform distribution; (*m*, *n*): *m* is number of connected mesh routers, *n* is number of covered mesh clients.

loss model and constant speed delay model are used for the simulation and other parameters are shown in Table 3.



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

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



(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 2 Evaluation of WMN-GA system.

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

3.4 NS-3

The ns-3 simulator [15] 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

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]

network packet analyzing tools such as tcpdump, and a standardized input format such as importing mobility trace files from ns-2 [16].

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 [17]. 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.

3.5 Overview of DCF and EDCA Protocols

In our study we concentrate on two distributed access methods: DCF from legacy 802.11 [18] and EDCA from 802.11e [19]. The centralised access methods, Point Coordination Function (PCF) [18] and Hybrid Controlled Channel Access (HCCA) [19] are not considered as they are rarely implemented in hardware devices [20].

3.5.1 DCF

DCF is a random access scheme based on the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) scheme. A legacy DCF station with a packet to send will first sense the medium for activity. 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.

$$CW_{min} \leq CW \leq CW_{max} \qquad (1)$$

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 [18]. 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. On reaching 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. The retry limit is manufacturer dependent and can vary considerably.

3.5.2 Enhanced Distributed Channel Access (EDCA)

The enhanced access method EDCA builds on the legacy DCF process and introduces 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.

3.6 Overview of OLSR Routing Protocol

The OLSR protocol [21] 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.

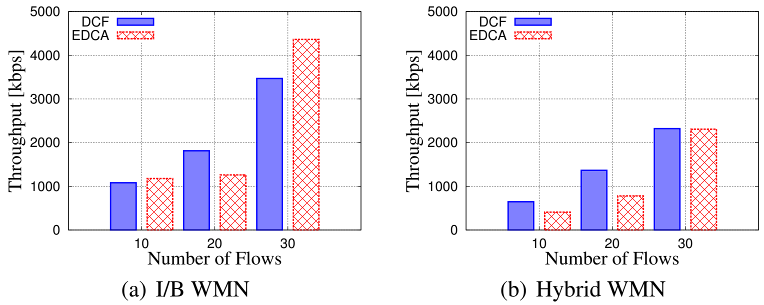


Fig. 6 Results of average throughput considering normal distribution.

4 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, and normal and uniform distributions.

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 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.

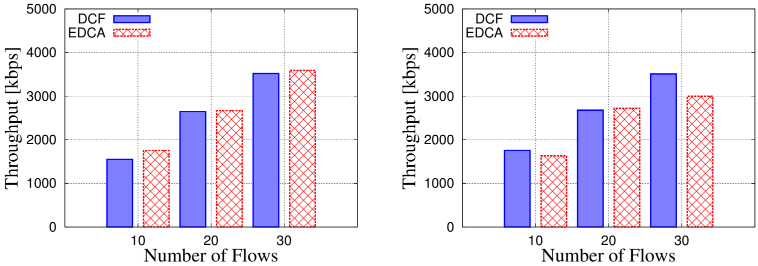
In Fig. 8, Fig. 9, Fig. 10 and Fig. 11, for normal distribution, the delay and jitter of Hybrid WMN is lower compared with I/B WMN. In uniform distribution case, the delay and jitter of both architectures are almost the same. However, in the case of DCF for 20 flows, the delay and jitter of I/B WMN is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

5 Conclusions

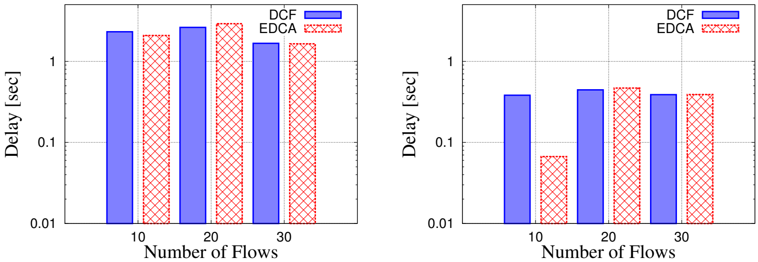
In this work, we presented WMN-GA system and applied it for node placement problem in WMNs. We evaluated the performance of WMN-GA system for normal and uniform distributions of mesh clients considering DCF, EDCA and OLSR protocols.

From the simulations we conclude as follows.



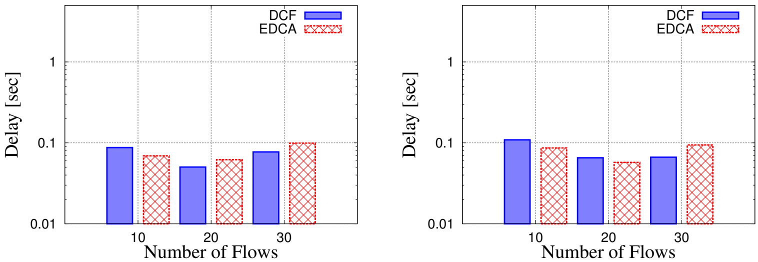
(a) I/B WMN (b) Hybrid WMN

Fig. 7 Results of average throughput considering uniform distribution.



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

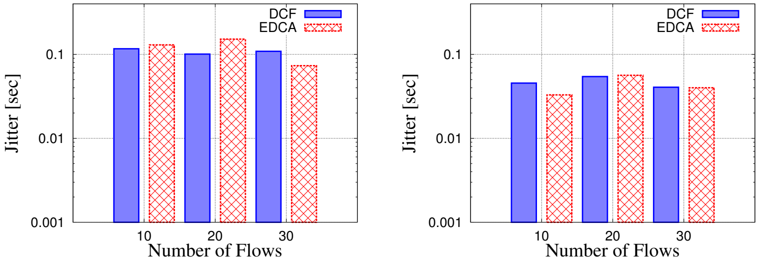
Fig. 8 Results of average delay considering normal distribution.



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

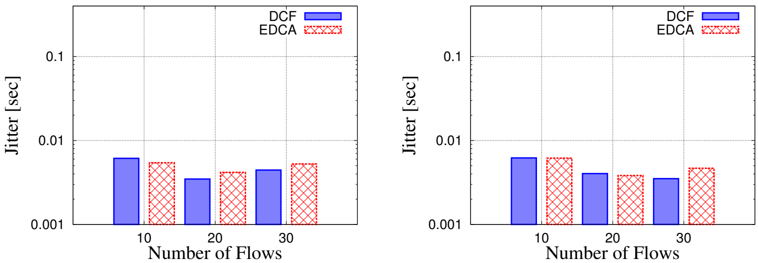
Fig. 9 Results of average delay considering uniform distribution.

- 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



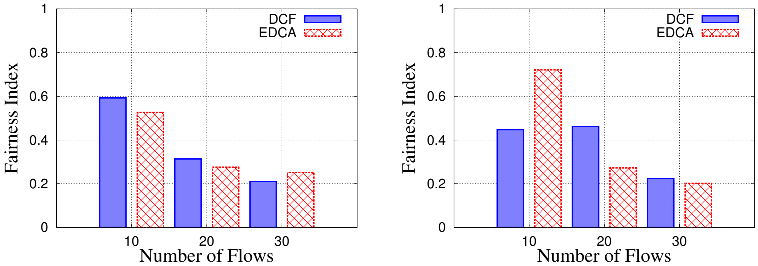
(a) I/B WMN (b) Hybrid WMN

Fig. 10 Results of average jitter considering normal distribution.



(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.

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.

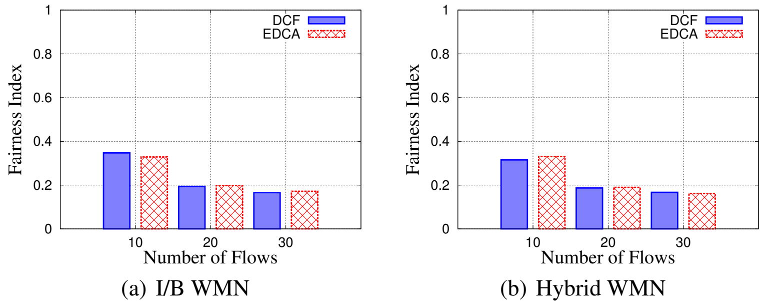


Fig. 13 Results of fairness index considering uniform distribution.

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