**Bulletin of Electrical Engineering and Informatics**
Vol. 11, No. 4, August 2022, pp. 2196~2203
ISSN: 2302-9285, DOI: 10.11591/eei.v11i4.3804


# Simulation and performance evaluation of IEEE802.11 WLAN under different operating conditions

**Sara Khalaf, Hamid M. Hasan**
Department of Control and Systems Engineering, University of Technology, Baghdad, Iraq

**Article Info**

***Article history:***

Received Mar 13, 2022
Revised May 15, 2022
Accepted Jun 9, 2022

***Keywords:***

Access point
DCF
IEEE 802.11
OPNET
WLAN

**ABSTRACT**

A wireless local area network (WLAN) based on IEEE802.11 protocol is the essential part for connection to the internet .and it is widely used in our life today and tomorrow. The growth in the number of nodes per small area likes home, office, and so on. This increase in density led to the degradation in performance in terms of throughput and delay experienced by the end-users. So many amendments proposed in order to improve the performance. Then the performance evaluation of WLAN is an important research topic. In this paper, the performance of WLAN working at 2.4 GHz and 5 GHz assessed in a home-like area under the widely used applications the assessment is in terms of throughput and delay. The evaluation conducted by using the optimum networks (OPNET) 14.5 modeler simulator. In this work, we concluded that: using a single AP showed degradation in performance due to congestion. Because all nodes use the same transmission channel which showed clearly in the case of the data rate of 6 Mbps in both (a and g) standards. The effectiveness is about (1.1%, 1.3%) respectively. While using two APs improves the performance for the same case to about (28% and 65%) since it mitigates the congestion because each AP uses a different communication channel.



***Corresponding Author:***

Sara Khalaf
Department of Control and Systems Engineering, University of Technology
Baghdad, Iraq
Email: cse.20.29@grad.uotechnology.edu.iq

## 1. INTRODUCTION

A wireless local area network (WLAN) is an adaptable data communication system used as an extension of the wired local area network (LAN) in buildings and campuses. A WLAN sends and collects data wirelessly, reducing the need for wired connections. Therefore, WLAN integrates data connectivity with user mobility [1], [2]. The 802.11 research group was established as part of the IEEE802 project to create an international standard for WLANs [3], [4]. WLAN allows devices to make a connection wirelessly to the LAN using a radio transmission to share applications, data, and other resources. It can also move from one location to another via the network [5]. The standard for WLAN communication is wireless fidelity (Wi-Fi). The IEEE 802.11 standard is one of the most widely utilized wireless data transfer methods today. Because of the demand for data rates at high speeds, several standards established to satisfy customers' requirements. As in [6], [7] Table 1 shows the most commonly used protocols [8], [9].

The industrial, scientific, and medical (ISM) band's 2.400–802.11b, 802.11g, and the low-frequency section of 802.11n use a 2.500 GHz spectrum. The 802.11n, 802.11a, and 802.11ac protocols employ the 4.915–5.825 GHz spectrum, which is more regulated. They are called also “2.4 GHz and 5 GHz frequency bands” and are commonly referred to as such. Each of these spectrums is divided into channels with a center frequency and bandwidth, similar to how the commercial spectrum is divided. Beginning with channel 1, which is centered on 2.412 GHz, the 2.4 GHz band is divided into 14 channels, each spaced 5 MHz apart in Figure 1. Because of differences in regulations between nations, the number of channels in the 5.725–5.875 GHz spectrum is less intuitive [9].

Table 1. IEEE 802.11 PHY standards

| Release date | Standard | Frequency band (GHz) | Bandwidth (MHz) | Modulation | Advanced antenna technologies | Maximum data rate |
|---|---|---|---|---|---|---|
| 1997 | 802.11 | 2.4 | 20 | DSSS, FHSS | N/A | 2 Mbits/s |
| 1999 | 802.11 b | 2.4 | 20 | DSSS | N/A | 11 Mbits/s |
| 1999 | 802.11 a | 5 | 20 | OFDM | N/A | 54 Mbits/s |
| 2003 | 802.11 g | 2.4 | 20 | OFDM, DSSS | N/A | 54 Mbits/s |
| 2009 | 802.11 n | 2.4, 5 | 20, 40 | OFDM | MIMO, up to 4 spatial streams | 600 Mbits/s |
| 2013 | 802.11 ac | 5 | 40, 80, 160 | OFDM | MIMO, MU-MIMO, up to 8 spatial streams | 6.93 Gbits/s |

IEEE 802.11 is a significant WLAN standard that uses the logical link control (LLC) protocol, which is separated into sub-layers, the medium access control (MAC) layer, and the physical layer (PHY). This arrangement offers optimized functionality to wireless communication. First 802.11 consists of two physical layers, a direct sequence spread spectrum (DSSS) and a frequency hopping spread spectrum (FHSS), then the physical layer is classified into three types with different frequency spectrums and physical characteristics. The physical characteristic of the 802.11a and the 802.11g are the same. They are both orthogonal frequency division multiplexing-based (OFDM-based) and have a data throughput of 54 Mbps. While they operate on different frequency bands, 802.11a uses the 5 GHz band while 802.11g uses the 2.4 GHz band.802.11a has a lot of advantages due to its huge range spectrum of 5 GHz, which has a greater number of free channels.The development of WLANs offers the support to a huge range of applications, maybe a simple application like file transferring (FTP), web browsing hypertext transfer protocol (HTTP), the email, or other applications, like the applications of the real-time multimedia (e.g., the video conferencing and the video streaming) [10].

On the other hand, this growth in the usage of such types of networks increases their density. Moreover, this increase in density led to degradation in their performance. There is a lot of research that tackles this problem and studies the performance of WLAN. Alisa [10] intends toimprove the delay bytransmission rate increasing. In addition, improve the throughput, by tuning the generation of data. The authors concluded that on a virtual local area network (VLAN) wireless network, there is a degradation in performancewhen the number of workstations is increasing [11]. They study the impact of increasing wireless node density on IEEE 802.11 to result that with an increasing number of nodes, the MAC delay increases [12]. Amewuda *et al.* [13] evaluate the station density effect in a network per access point [14]. Try to understand the effect of inter-cell interference in such high-density WLANs as a systematic analysis. According to [15], the increasing demand for capacity and coverage has resulted in multiple generations of IEEE 802.11 WLAN standards and the deployment of even more access points (APs). With the help of OPNET modeler and the usage of important performance measures such as throughput, average delay, and load data, they examined and evaluated the effect of the amount of traffic on the wireless network [8], [16]. The authors concluded that the amount of traffic load related to its delay time.

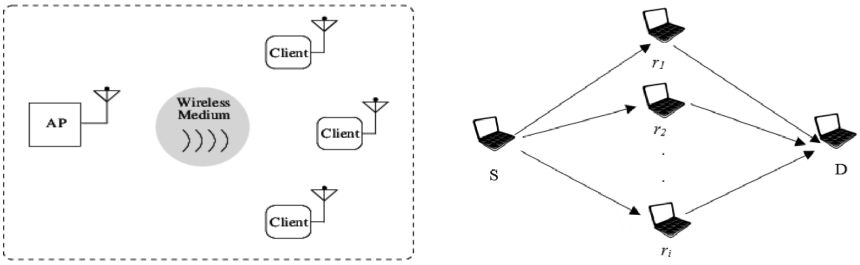
Our work is unique in that it proposes an examination of the disadvantages of using a single AP (the traditional WLAN configuration) by adding another AP and improving the WLAN from end to end. The development of new (and more complex) standards, as well as the densification of WLANs, both causes a slew of performance issues. WLAN performance evaluation will remain an important research topic for years to come, given the growing popularity of wireless communications.

In this paper, the evaluation of the performance of 802.11 a, g WLAN is the primary goal of the proposed work. It’s trying to study one protocol that works on 5GHz and another one that works on 2.4 GHz, in some use cases that exhibit dense nodes, which are represented in-home to match with the recent changes, we have experienced during the Corona pandemic period, have led to an urgent need for advanced technology. People to do their work at home without the need to go to their offices under most used applications like HTTP browsing, file transferring using FTP, video conferencing, and email. The performance was evaluated in terms of throughput, load, and end-to-end delay. The 802.11 WLAN is infrastructure-based using distributed coordination function (DCF) with single and multi-AP with different operating parameters for the purpose of comparison. OPNET 14.5 modeler was used to simulate the network setup. There are various scenarios in the simulation. Every scenario is distinct from the others, either in terms of physical layer technology, transmission rate, or data creation pace.

## 2. METHOD

### 2.1. Infrastructure based WLAN

A broadcast domain is a LAN in which all connected devices are in the same physical LAN without the use of a router [17]. Infrastructure mode and Ad-hoc mode are the two operating modes defined by the 802.11 communications standard [18]. Wireless hosts can connect with each other, as shown in Figure 1(a) in infrastructure mode, using access points, which is often the default mode [19]. Without an access point, in a peer-to-peer network, wireless hosts can connect directly with one another. As shown in Figure 1(b). The Adhoc network is a brief network connection that allows hosts to communicate data directly to other hosts rather than traveling through an access point.




(a) (b)

Figure 1. The WLAN 802.11 operating modes (a) infrastructure operating mode and (b) ad hoc operating mode

### 2.2. OPNET network simulator

The modeler OPNET is a trademark of OPNET Technologies. It offers a virtual environment for modeling, analyzing, and predicting the performance of most of the applications, networking technologies, and servers [16]. OPNET edition offered free software to all the students and university staff. However, the commercial version of OPNET (modeler) haswider capabilities designed for enterprise IT, documentation, environment, and professional support [20]. The OPNET provides the chance to design and study networks, protocols, devices, and applications with considerable flexibility [21]. It was intended in the basic package to simulate the network communication and to develop the protocols and devices [22].

### 2.3. Simulation model

On the OPNET 14.5 simulator, simulation creation and analysis were carried out, which provided a real-world network scenario, implementation, and outcomes utilizing multiple metrics. This paper examines the impact of using one and two routers to solve the problem of increasing the density of nodes in the use case and enhance wireless LAN throughput and delay under DCF channel occupancy shown in Figure 2. In Figure 3 the simulation model is shown, which consist the WLAN infrastructure that is made up of access points and stations of wireless and it can handle a large number depending on the access point's specifications, of a wireless station. Aunshielded twisted pair (UTP) cable can connect the wireless network to the Ethernet network for the distance between the AP and the switch or hub can be up to 100 meters [19]. Using service set identifier (SSID), the mobile station while communicating can move and search and connect automatically to the access point device, which is the wireless network's unique name that corresponds to the AP defined in the application. The SSID keeps packets in the right WLAN.

### 2.4. The performance metrics

This study considers the three important performance criteria listed below. For network evaluation:

a. Throughput: the packet delivery ratio is the average data packet rate that each node in the network sends and receives correctly, as shown in (1). Bits per second are the unit of measurement. When it comes to wireless networks, a greater throughput value equates to better performance [17], [19], [23].

$$\text{Throughput} = \frac{\text{noofsuccessfultransmitedpackets} * \text{packetlength(bit)}}{\text{Time (sec )}} \quad (1)$$

$$\text{Throughput DCF} = (MPDU\ size\ [MPDU\ size\ +\ MAC\ header\ size]) * (TMPDU, MAC/\ [TDIFS + TBACK\ OFF\ +\ TPOH + \ TMPDU, MAC +\ TSIFS +\ TACK]) \ *\ Data\ Rate \quad (2)$$

Figure 2 illustrates (2) by showing channel occupancy periods in DCF with DSSS PHY mode and 512-byte MPDU size. This equation would be (data rate=11 Mbps) and (MPDU size=512 bytes) if the values given in Figure 2 were replaced. When using (data rate=2Mbps) and (MPDU size=512 bytes) in (2), the DCF effectiveness is around 31%. With packet lengths, fewer than 1500 bytes, access to the DCF channel is nearly worthless.

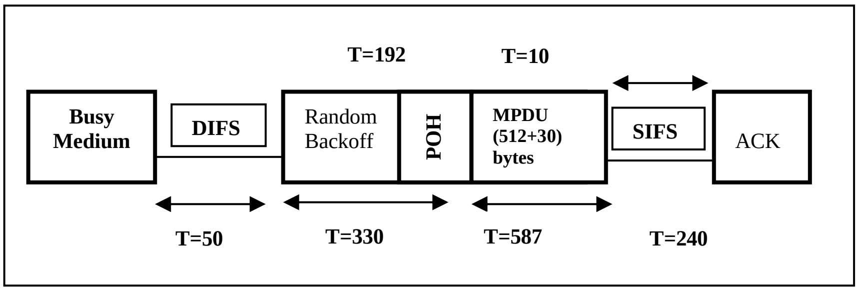



Figure 2. Under DCF channel occupancy times [23]

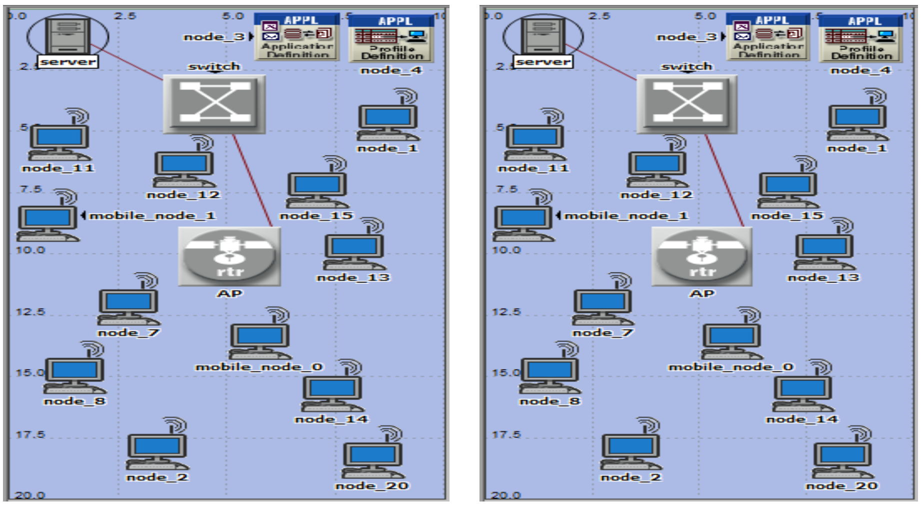
b. Load: is an important metric for analyzing network performance in large-scale wireless sensor networks, which are projected to serve pervasive applications such as personalized health care, smart cities, and smart homes, among others [24].
c. Delay: the amount of time it takes for a packet from a source node to arrive at its destination. It's measured in seconds, with a lower number suggesting better results [18], [23].

### 2.5. Simulation setup

We analyze the home applications shown in Table 2, by applying three heavy applications, which can be selected from the application definition attributes. Furthermore, we must identify apps and profiles before connecting the workstation to the profiles. We create two types of scenarios to analyze these applications, the first one with one access point as shown in Figure 3(a) and the second one with two access points shown in Figure 3(b),to compare their effectiveness ratio shown in Table 3, and to compaire results in different data rate (6, 36, and 54) for each types of standards (a,g) shown in Table 4 and Table 5.

Table 2. Applications used for load generation

| Application | Attribute | Value1 | Value2 |
|---|---|---|---|
| Http | Command mix (Get/total) | 50% | |
| | Inter-request time (seconds) | Exponential (3) | |
| | File size (bytes) | Constant (50000) | |
| FTP | Page interval time(seconds) | Exponential (5) | Page interval time(seconds) |
| | Page properties | Large image | Page properties |
| | Server selection | Page per server | Exponential (10) |
| Video conference | Frame interval time information (seconds) | 15 frames/sec | |
| | Frame size information(bytes) | 128*240pixels | |



(a) (b)

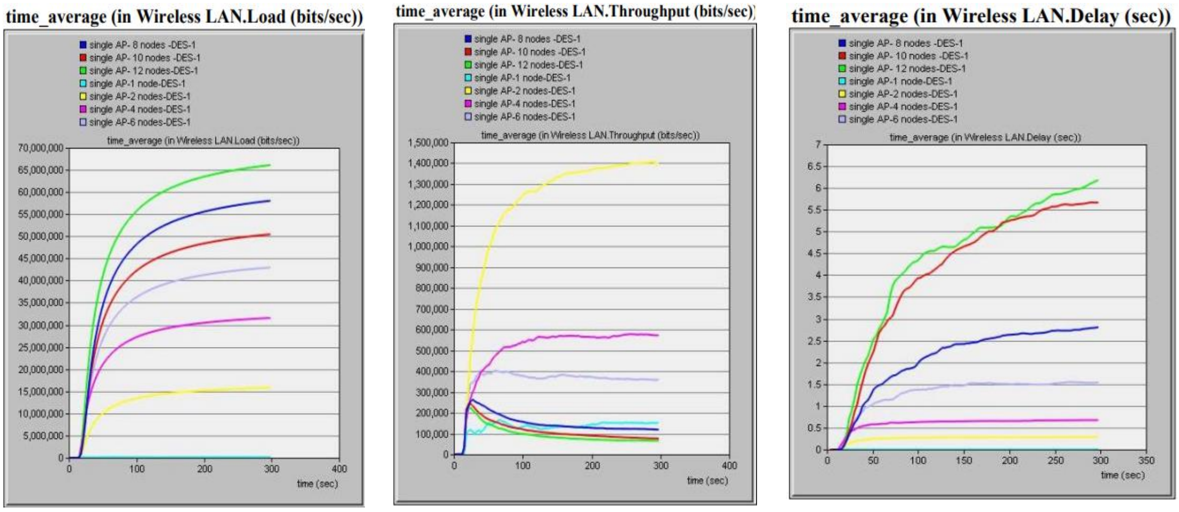
Figure 3. Simulation topologies (a) topology for first scenario and (b) topology for the second scenario

## 3. RESULTS AND DISCUSSION

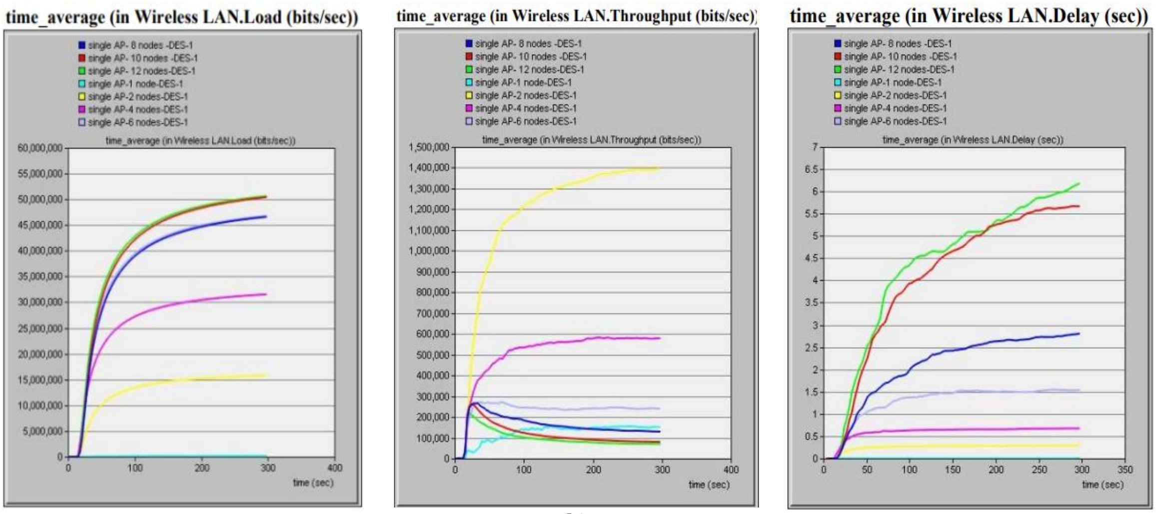
In order to conduct a simulation study, we used a square space of 10m x 10m. There were two situations created:

### 3.1. The first scenario (with a single access point)

As shown in Figure 3(a), the setup implies that one server and one switch are linking one sector with one access point. The simulation models use 12 nodes, each of which is wirelessly connected to the access point via a particular basic service set (BSS) and is randomly placed within a 200m square region. The IEEE 802.11 a and g MAC protocols, which allow wireless communication at up to 54Mbps [25], were originally utilized as the MAC protocol. Will use it in three steps (6, 36, 54) consecutively. The nodes were, connected to the access point wirelessly; the access points 1 and the server both were, connected to the switch by 100Base-T. Table 4 and Table 5 show the wireless LAN throughput, load, and delay for different numbers of nodes and different transmission rates. As we can see in Figure 4(a) the wireless LAN throughput, load, and delay for different numbers of nodes with 6 MHZ protocol g, and Figure 4(b) shows the wireless LAN throughput, load, and delay for different numbers of nodes with 6 MHZ protocol a. Moreover, according to the effectiveness ratio shown in Table 3 we found that the standard g ratio (1.3) is a little more than the standard a ratio (1.1) and that's because a is 2.4 MHz while g is a 5 MHz frequency band which means more free channels lads to less congestion.




(a)




(b)

Figure 4. A sample for the performance for single AP (a) performance of IEEE 802.11g protocol, 6 MHz and (b) performance of IEEE 802.11a protocol, 6 MHz

Table 3. Effectiveness ratio

| Standards | Transmission ratebits/s | 12 nodes | Effectiveness ratio (%) |
|---|---|---|---|
| IEEE 802.11 a | 6 M | Single AP | 1.1 |
| | | Double AP | 28 |
| IEEE 802.11 g | | Single AP | 1.3 |
| | | Double AP | 65 |

Table 4. IEEE 802.11a performance under different conditions

| standards | Transmission rate bits/s | No of nodes | Load bits/s | Throughput bits/s | Delay (s) |
|---|---|---|---|---|---|
| IEEE 802.11a | 6 M | 2 | 16 M | 1,4 M | 0.25 |
| | | 4 | 32 M | 585 K | 0.7 |
| | | 6 | 43 M | 360 K | 1 |
| | | 8 | 58 M | 120 K | 3 |
| | | 10 | 50M | 90 K | 5.25 |
| | | 12 | 66 M | 68 K | 6.1 |
| | 36 M | 2 | 15 M | 7.1 M | 0.025 |
| | | 4 | 31 M | 4.4 M | 0.9 |
| | | 6 | 44 M | 2.5 M | 0.16 |
| | | 8 | 50 M | 1.5 M | 0.25 |
| | | 10 | 78 M | 1 M | 0.37 |
| | | 12 | 70 M | 1.21 M | 0.31 |
| | 54 M | 2 | 15 M | 8.5 M | 0.02 |
| | | 4 | 32 M | 7.5 M | 0.05 |
| | | 6 | 44 M | 4.4 M | 0.09 |
| | | 8 | 50 M | 1.5 M | 0.25 |
| | | 10 | 74.5 M | 1.5 M | 0.24 |
| | | 12 | 74.8 M | 1.77 M | 0.22 |

Table 5. IEEE 802.11g performance under different conditions

| standards | Transmission rate bits/s | No of nodes | Load bits/s | Throughput bits/s | Delay (s) |
|---|---|---|---|---|---|
| IEEE 802.11 g | 6 M | 2 | 16 M | 1,4 M | 0.25 |
| | | 4 | 32 M | 590 K | 0.7 |
| | | 6 | 47 M | 250 K | 1.5 |
| | | 8 | 47 M | 130 K | 2.8 |
| | | 10 | 50M | 90 K | 5.6 |
| | | 12 | 50M | 80 K | 6.2 |
| | 36 M | 2 | 15 M | 8.1 M | 0.025 |
| | | 4 | 31 M | 4.4 M | 0.9 |
| | | 6 | 44 M | 2.1 M | 0.19 |
| | | 8 | 50 M | 2 M | 0.19 |
| | | 10 | 75 M | 1 M | 0.37 |
| | | 12 | 67 M | 1 M | 0.44 |
| | 54 M | 2 | 15 M | 8.5 M | 0.02 |
| | | 4 | 32 M | 7 M | 0.35 |
| | | 6 | 46 M | 3 M | 0.13 |
| | | 8 | 55 M | 2.5 M | 0.16 |
| | | 10 | 66 M | 1.4 M | 0.29 |
| | | 12 | 75 M | 1.6 M | 0.26 |

### 3.2. The second scenario with (multiple access points)

In this scenario, the setup assumes that there are one server and one switch, and two Access points shown in Figure 3(b). The simulation models use 12 nodes, each containing six nodes wirelessly connected to an AP using a unique BSS and in a random way placed within a 200m square region. The channel that APs use is chosen automatically. Table 6 and Table 7 shows throughput, load, and delay for 12 nodes under different transmission rates for both the single AP used in the first scenario and the two APs used in this scenario with protocol a and g sequentially. The nodes are, wirelessly connected to the access points. Access points 1 and 2 and the server are connected to the switch by 100 base-T. Here is the effectiveness ratio shown in Table 3 we found that the standard g ratio (65) is greater than the standard a ratio (28) for the same reason. In addition, we can see clearly the improvement in performance when using two access points, by comparing the ratios for a and g in the two scenarios.

Table 6. IEEE 802.11a performance comparison

| standards | Transmission rate bits/s | 12 nodes | Load bits/s | Throughput bits/s | Delay (s) |
|---|---|---|---|---|---|
| IEEE 802.11a | 6 M | single AP | 66 M | 68 K | 6.1 |
| | | double AP | 64 M | 1.68 M | 0.62 |
| | 36 M | single AP | 70 M | 1.21M | 0.32 |
| | | double AP | 89 M | 1.92 M | 0.63 |
| | 54 M | single AP | 74.8 M | 1.77 M | 0.22 |
| | | double AP | 100.4 M | 31 M | 0.38 |

Table 7. IEEE 802.11g performance comparison

| standards | Transmission ratebits/s | 12 nodes | Load bits/s | Throughput bits/s | Delay (s) |
|---|---|---|---|---|---|
| IEEE 802.11 g | 6 M | single AP | 50 M | 80 K | 6.2 |
| | | double AP | 77 M | 3,9 M | 0.49 |
| | 36 M | single AP | 67 M | 1 M | 0.44 |
| | | double AP | 95 M | 22.1 M | 0.064 |
| | 54 M | single AP | 75 M | 1.6 M | 0.26 |
| | | double AP | 86 M | 21.5 M | 0.042 |

## 4. CONCLUSION

From the simulation results for the single AP and bit rate of 6 Mbps, we noticed that the throughput is decreased as the number of nodes increases and the delay is increased. For2 nodes the throughput is 1.4Mbps and the delay is 0.25sec this performance can be accepted for the home-like applications. However, for the 12-node case, the throughput of 68kps and delay of 6.1 sec can be assigned as degradation in performance. This degradation is due to the congestion that occurs because all nodes use the same transmission channel. This is for both types a and g. for 36Mbps and 54 Mbps bitrates. When using two APs the performance is improved. This improvement is because each AP uses a different transmission channel selected from the non-overlapped channels for both the 2.4G and 5G spectrum.

## REFERENCES


[1] R. Jordan and C. T. Abdallah, “Wireless communications and networking: an overview,” *IEEE Antennas and Propagation Magazine*, vol. 44, no. 1, pp. 185-193, Feb. 2002, doi: 10.1109/74.997963.

[2] A. K. Salkintzis, “Interworking techniques and architectures for WLAN/3G integration toward 4G mobile data networks,” *IEEE Wireless Communications*, vol. 11, no. 3, pp. 50-61, June 2004, doi: 10.1109/MWC.2004.1308950.

[3] G. Bianchi, “Performance analysis of the IEEE 802.11 distributed coordination function,” *IEEE Journal on Selected Areas in Communications*, vol. 18, no. 3, pp. 535-547, March 2000, doi: 10.1109/49.840210.

[4] S. Banerji, “Upcoming Standards in Wireless Local Area Networks,” *Wireless & Mobile Technologies*, vol. 1, no. 1, pp. 6–11, 2013.

[5] I. Mittal and M. A. Anand, “WLan Architecture,” *Int. J. Comput. Trends Technol.*, vol. 8, no. 3, pp. 148-151, 2014.

[6] I. A. Alimi and A. O. Mufutau, "Enhancement of Network Performance of an Enterprises Network with VLAN," *American Journal of Mobile Systems, Applications and Services*, vol. 1, no. 2, pp. 82-93, 2015.

[7] O. E. Onyekachi, “Information and Knowledge Management Design and Simulation of Wireless Local Area Network for Administrative Office using OPNET Network Simulator: A Practical Approach,” *Information and Knowledge Management*, vol. 4, no. 10, pp. 27-33, 2014.

[8] B. Krupanek and R. Bogacz, “OPNET Modeler simulations of performance for multi nodes wireless systems,” *International Journal of Metrology and Quality Engineering*, vol. 7, p. 105, 2016, doi: 10.1051/ijmqe/2016006.

[9] Tektronix Inc., “Wi-Fi: Overview of the 802.11 Physical Layer and Transmitter Measurements,” 2013. [Online]. Available: http://www.cnrood.com/public/docs/WiFi_Physical_Layer_and_Transm_Meas.pdf

[10] Z. T. Alisa, “Evaluating the Performance of Wireless Network using OPNET Modeler,” *International Journal of Computer Applications*, vol. 62, no.13, pp. 22-28, 2013, doi: 10.5120/10140-4946.

[11] T. Al-Khraishi and M. Quwaider, “Performance Evaluation and Enhancement of VLAN via Wireless Networks using OPNET Modeler,” *Int. J. Wirel. Mob. Networks*, vol. 12, no. 3, pp. 15–30, Jun. 2020, doi: 10.5121/ijwmn.2020.12302.

[12] N. I. Sarkar, “Performance modeling of IEEE 802.11 WLAN using OPNET: A tutorial,” *Handbook of Research on Discrete Event Simulation Environments: Technologies and Applications*, 2010, pp. 398–417, doi: 10.4018/978-1-60566-774-4.ch018.

[13] A. B. Amewuda, F. A. Katsriku, and J. D. Abdulai, “Implementation and Evaluation of WLAN 802.11ac for Residential Networks in NS-3,” *J. Comput. Networks Commun.*, vol. 2018, p. 3518352, 2018, doi: 10.1155/2018/3518352.

[14] M. A. Ergin, K. Ramachandran, and M. Gruteser, “Understanding the effect of access point density on wireless LAN performance,” in *MobiCom '07: Proceedings of the 13th annual ACM international conference on Mobile computing and networking*, 2007, pp. 350–353, doi: 10.1145/1287853.1287902.

[15] M. Stojanova, “Performance Modeling of IEEE 802. 11 WLANs,” *l’Universite’ Clade Bernared Lyon 1*, 2019.

[16] A. H. Ali, A. N. Abbas, and M. H. Hassan, “Performance Evaluation ofIEEE802.11g WLANsUsing OPNET Modeler,” *American Journal of Engineering Research*, vol. 02, no. 12, pp. 9-15, 2013.

[17] S. A. Abdullah, “Simulation of Virtual LANs (VLANs) Using OPNET,” *IOSR Journal of Electronics and Communication Engineering*, vol. 11, no. 6, pp. 67–80, 2016, doi: 10.9790/2834-1106026780.

[18] D. A. J. Al-Khaffaf, “Improving LAN Performance Based on IEEE802. 1Q VLAN Switching Techniques,” *Journal of University of Babylon, Engineering Sciences*, vol. 26, no. 1, pp. 286–297, 2018.

[19] H. S. Mewara and K. S. Mukesh, "Performance Analysis of Access Point for IEEE802.11g Wireless LAN Using Opnet Simulator," *International Journal of Advanced Engineering Research and Science (IJAERS)*, vol. 1, no. 1, pp. 14–18, 2014.

[20] P. Jurčík and Z. Hanzálek, "Simulation study of energy efficient scheduling for IEEE 802.15.4/ZigBee cluster-tree Wireless Sensor Networks with time-bounded data flows,"*2010 IEEE 15th Conference on Emerging Technologies & Factory Automation (ETFA 2010)*, 2010, pp. 1-8, doi: 10.1109/ETFA.2010.5641262.

[21] Mu Wei and Z. Chen, "Study of LANs access technologies in wind power system," *IEEE PES General Meeting*, 2010, pp. 1-6, doi: 10.1109/PES.2010.5590088.

[22] Sapna and M. Sharma, "Performance evaluation of a wired network with & without Load Balancer and Firewall," *2010 International Conference on Electronics and Information Engineering*, 2010, pp. V2-515-V2-519, doi: 10.1109/ICEIE.2010.5559755.

[23] Z. M. A. Ameer, A. K. A. N. Alaloosy, and K. M. A. Alheeti, "Performance analysis and evaluation of ieee 802.11 distributed coordination function using opnet," *Bulletin of Electrical Engineering and Informatics*, vol. 9, no. 6, pp. 2595–2600, Dec 2020, doi: 10.11591/eei.v9i6.2477.

[24] A. Demertzis and K. Oikonomou, "Average Load Definition in Random Wireless Sensor Networks: The Traffic Load Case," *Technologies*, vol. 6, no. 4, p. 112, 2018, doi: 10.3390/technologies6040112.

[25] M. Quwaider, J. Rao and S. Biswas, "Neighborhood Route Diffusion for Packet Salvaging in Networks with High Mobility,"in *2008 IEEE International Performance, Computing and Communications Conference*, 2008, pp. 168-175, doi: 10.1109/PCCC.2008.4745134.


## BIOGRAPHIES OF AUTHORS

**Sara Khalaf** received a B.Sc. in control and systems engineering, in 2006 from the University of Technology, Iraq. Now she is studying M.Sc. in computer engineering at the university of technology, Iraq. She is interested in computer network studies and research. She can be contacted at email: cse.20.29@grad.uotechnology.edu.iq.

**Dr. Hamid M. Hasan** received a B.Sc. in control and systems engineering, and an M.Sc. in computer engineering from the university of technology, Iraq, in 1986 and 1990 respectively. He received Ph.D. in computer engineering, in 2012, from Basra University, Iraq. He is currently working as an Assistant professor at the faculty of control and systems engineering, university of technology, Iraq. He is interested in computer network studies and research, wireless sensor network realization, mobile robot navigation, IoT development and investigation, pattern recognition, face recognition, image processing, and stochastic DSP applications. He can be contacted at email: Hamid.M.Hasan@uotechnology.edu.iq.