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Evaluación del desempeño de la tecnología wifi en concordancia con los estándares IEEE 802.11 b/g/n en el interior de una cámara anecoica para la banda de 2.4 GHz

Performance evaluation of technology Wi-Fi in conformance with IEEE 802.11 b/g/n into an anechoic chamber for the 2.4GHz band

Avaliação de desempenho da tecnologia Wi-Fi de acordo com os padrões 802.11b/g/n para ao interior de uma câmera anecoica para a banda de 2.4GHz

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Resumen

El presente artículo realiza el análisis del desempeño de una red Wi-Fi en concordancia con los estándares IEEE 802.11 b/g/n en un escenario sin interferencia al interior de una cámara anecoica de 15 m^2, dentro de la cual se implementó una red inalámbrica punto a punto con una distancia de 2m entre el transmisor y el receptor. Las métricas de desempeño referentes al QoS fueron obtenidas utilizando una técnica intrusiva de inyección de tráfico mediante el *software* D-ITG, la cual proporciona información del *throughput* (η) para el cálculo de la eficiencia (Ef), *jitter* (j), retardo del canal (δ) y pérdida de paquetes (PL). Los resultados obtenidos mediante un análisis cuantitativo determinaron que el estándar IEEE 802.11n presenta el mejor desempeño en términos de Ef con 85.75%; posterior a esta, se encuentra el estándar IEEE 802.11g con una Ef de 73.73% y finalmente el estándar IEEE 802.11b es el que menor Ef presenta entre las evaluadas, con un 69.37%. Los resultados de este trabajo son contrastados con trabajos realizados en escenarios sometidos a interferencia por obstáculos e interferencia Co-Canal (ICC).

Palabras clave: cámara anecoica, *delay*, D-ITG, eficiencia, IEEE 802.11, *jitter*, paquetes perdidos, *throughput*.

Abstract

This paper presents the performance analysis of a Wi-Fi network in conformance with IEEE 802.11 b/g/n standards, in a non-interference scenario, which consists of an anechoic chamber with an area equal to $15m^2$, within was implemented a point-to-point wireless network with distance equal to 2m between transmitter and receiver. We used the intrusive traffic injection technique, in order to obtain the main metrics relating to *QoS*, by using the D-ITG software, which provides throughput information (η) for the calculation of efficiency (Ef), jitter (*j*), channel delay (δ) and Packets Loss (PL). Our quantitative analysis shows IEEE 802.11n standard presents the best performance in terms of efficiency with 85.75%, then, IEEE 802.11g standard with 73.73%, and finally IEEE 802.11b standard presented the lowest efficiency among those evaluated with 69.37%. In addition, we contrasted the results showed in this paper with works carried out in scenarios subject to co-channel interference and in presence of obstacles.

Keywords: anechoic chamber, delay, D-ITG, efficiency, IEEE 802.11, *jitter, packet loss, throughput.*

Resumo

O artigo faz uma análise do desempenho de uma rede Wi-Fi, de acordo com as normas IEEE 802.11 b/g / num palco sem interferência no interior de uma câmera anecoica $15m^2$, nesta frequência foi implementada uma rede sem fio ponto a ponto, com uma distância de 2 m entre o transmissor e o receptor. Sobre as métricas de desempenho de QoS, foram implantados usando uma técnica de injeção de tráfego intrusiva utilizando software D-ITG, que fornece informações sobre a taxa de transferência (η) para o cálculo da eficiência (Ef), o jitter (j), o atraso de canal (δ) e perda de pacotes (PL). Os resultados obtidos por meio de uma análise quantitativa determinaram que o padrão IEEE 802. 11n apresenta o melhor desempenho em termos de com 85.75%; depois o IEEE 802.11 g com uma Ef de 73.73% e, finalmente, o padrão IEEE 802. 11b é o mais baixo, apresenta-se entre os avaliados, com um 69.37%. Os resultados deste trabalho são contrastados com trabalho em cenários sujeita a interferências por obstáculos e interferência co canal (CCI).

Palavras-chave: câmera anecoica, delay, D-ITG, eficiência, IEEE 802.11, perda de pacotes, jitter, taxa de transferência.

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Introduction

Wireless communications are systems of technological networks that allow the exchange of information between terminals that are not linked by any physical means of connection (Tixi, 2016). An example of this is the Wi-Fi connection system, which works in accordance with the IEEE 802.11 standard, which has undergone several modifications in order to improve certain performance parameters related to the rates of transmission, coverage, modulation, among others.

For example, in 1999 the IEEE standard 802.11b was approved, which works in the 2.4GHz band and establishes a net transmission rate (raw bit rate or RBR for its acronym in English) of 11 Mbps (IEEE Standard for Information technology, 1999). Then, in 2003, the IEEE 802.11g standard was presented, which proposes a maximum RBR of 54 Mbps when using OFDM (orthogonal frequency division multiplexing), although in compatibility mode with the IEEE 802.11b standard it presents an RBR of 11 Mbps when using the DSSS transmission technique (from the English direct-sequence spread spectrum) (IEEE Standard for Information Technology, 2003). Subsequently, in 2009, the IEEE 802.11n standard appeared, which works in the 2.4 GHz and 5 GHz bands, and implements the MIMO (multiple input multiple output) and OFDM technology, which allows it to reach a maximum RBR of 300 Mbps. over a channel width of 20 MHz, and up to 600 Mbps with a channel width of 40 MHz (IEEE Standard for Information technology, 2009).

In other words, each new version of this standard has been aimed at improving certain performance factors of its predecessor. This can be verified, for example, with the IEEE 802.11n standard, which has twice the transmission speed than the IEEE 802.11g standard, and approximately 10 times more compared to the IEEE 802.11b standard (Puerto, Valdés and Mercado , 2008).

However, due to the omnipresence of Wi-Fi technology in multiple mobile devices, such as cell phones, tablets, laptops, among others (Cantillo, Roura and Sánchez, 2012), several investigations have arisen that have sought to analyze their performance. In this sense, we highlight the work of Mahajan and Shraddha (2017), who evaluated the performance of the IEEE 802.11b / n standards under different ad hoc routing protocols, such as AODV (of ad hoc on demand distance vector), DSR (from English dynamic source routing) and DSDV (from English destination-sequenced distance-vector). The conclusions of this work show that for the IEEE 802.11b standard, the DSR protocol works better than the AODV and DSDV protocols; whereas in the IEEE 802.11n standard, the AODV protocol works best in terms of packet delivery, and the DSR protocol is better in throughput (η). Also, and in relation to the delay (δ) for the IEEE 802.11b / n standards, the DSDV protocol works better than the AODV and DSR protocols; to perform this work, the performance metrics analyzed were the rate of packages delivered, η y δ.

A study similar to the previous one is carried out by Lara, Fernández and Morales (2016), who examined the performance of a downlink of networks based on the IEEE 802.11b / n and WDS (from the English wireless distribution system) standards. The results obtained by these authors show that the IEEE 802.11b standard and the WDS have a better performance in areas with obstacles, unlike the IEEE 802.11n standard, which has a better performance in environments without obstacles; the parameters evaluated were η, δ, jitter (j) and lost packets (PL, from English packet loss).

Another relevant work is that of Portillo, Villaseñor and Cabanillas (2008), who studied the performance of the MAC protocol for wireless local area networks according to the IEEE 802.11a / g standards. The findings of this inquiry allow us to conclude that the IEEE 802.11g standard performs better than the IEEE 802.11a standard in terms of η and PL.

Likewise, Sendra, Fernández, Turró and Lloret (2010), as well as Sendra, García, Turró and Lloret (2011) have compared the performance of the IEEE 802.11 a / b / g / n standards in indoor environments in terms of RSSI (from the English received signal strength indication), coverage area and measurement of co-channel interference (CCI). The data collected by these researchers indicate that the IEEE 802.11b / n standards have a better performance at short distances, while the IEEE 802.11g standard has better results over long distances.

Finally, Vallejo (2016) also investigated the performance of a Wi-Fi network according to the IEEE 802.11n standard in indoor scenarios with ICC and without ICC. The results of this work determine that the network reduces its throughput by 35% in scenarios with ICC.

From these studies it can be said that the performance of Wi-Fi technology is affected due to several factors, such as the characteristics of the communication channel, the ICC and the adjacent channel, the presence of obstacles, among others. However, up to now the functioning of the Wi-Fi technology has not been evaluated in an ideal environment without interference by means of an anechoic chamber.

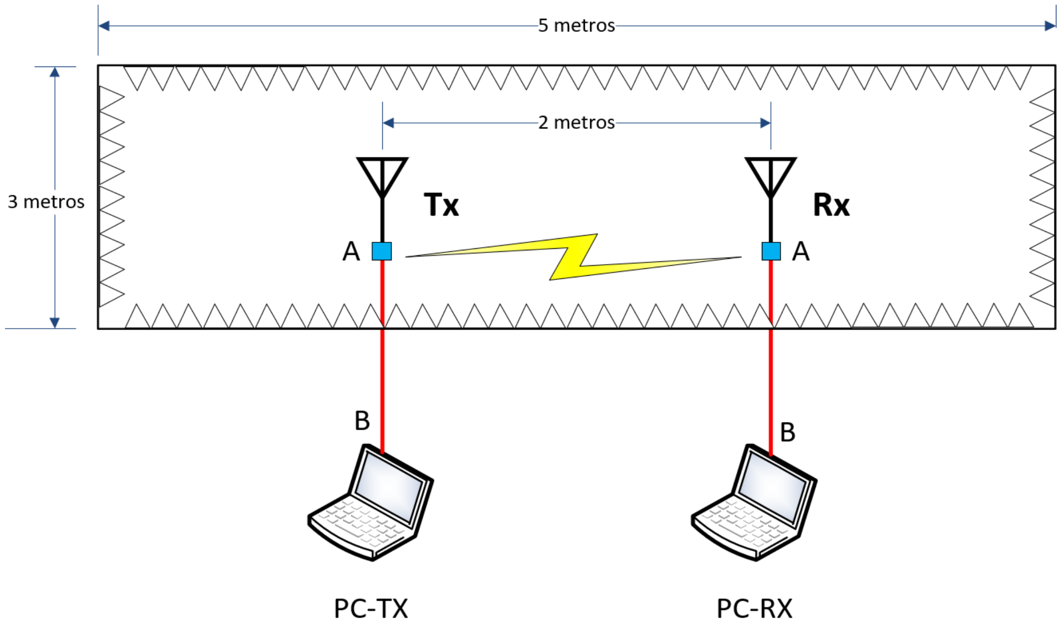
For this reason, the objective of this paper is to evaluate the performance of a point-to-point wireless network under the IEEE 802.11 b / g / n standards within an anechoic chamber to compare the results obtained with scenarios in the presence of obstacles and ICC. Specifically, this research focuses on identifying performance metrics that are related to the largest number of parameters related to QoS (English quality of service) such as Ef, δ, j and PL, metrics that were obtained using an intrusive injection technique traffic through the software D-ITG.

Method

Next, the elements used in the experimental tests are mentioned, for which software and hardware equipment was used. Subsequently, the proposed methodology for developing said tests is described and the performance metrics analyzed are defined.

Having explained the above, the test scenario consisted of a point-to-point network implemented inside an anechoic chamber, whose frequency range of operation was between 2 GHz and 3 GHz. This camera is located in the University of the Forces Armadas, ESPE (Ecuador), and has the following dimensions: 5 m long, 3 m wide and 3 m high. Its exterior is covered with metallic screen and its interior is made of absorbent material of pyramidal type made of solid foam (polystyrene) and impregnated with a mixture between latex paint and activated carbon; in its central part it has pedestals for support and positioning of antennas, where 2 directional antennas are placed 2 m apart, and two LMR-240 cables of 1 m long, which have SMA terminals (from the English subminiature version A) in both ends, as shown in Figure 1 (Brito y López, 2006).

Figura 1. Red inalámbrica implementada en una cámara anecoica



Nota: Las líneas rojas representan los cables LMR-240 y el pequeño cuadrado celeste representa la conexión entre el cable LMR-240 y la antena.

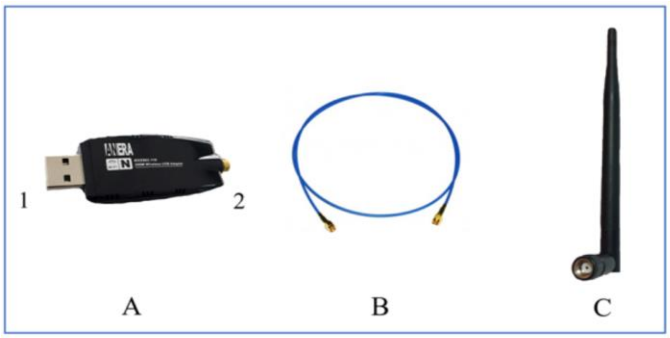
Fuente: Elaboración propia

As for the LM-240 cable, it has a loss of 0.42 dB / m and the deployment performed on the transmitter and receiver has a total length of 2 m, with a loss introduced by connectors of approximately 0.5 dB (Cordoví Rodríguez, 2016), which represents a loss of 1.84 dB in the connection due to the cable and the connectors. These losses should be minimal, because if they exceed 3dB, the power can be reduced by up to 50%, so it is usually advisable to use LMR or Heliax type cables and short transmission lines (Wireless networks in developing countries, 2007).

For the experimental tests, two portable computers were used: one for the transmission (PC-TX) and another for the reception of information (PC-RX). The transmitter had a seventh generation Intel Core i5 processor and 8 Gb SDRAM memory, while the receiver had a seventh generation Intel Core i3 processor and 4 Gb SDRAM memory. It is worth noting that both computers had the Linux operating system installed. (Ubuntu LTS 16.04) and its network cards supported the IEEE 802.11b / g / n / ac standards.

To complete the network within the anechoic chamber, two external wireless network cards connected to the computers were used (the characteristics of the cards are presented in Table 1). In this sense, it should be mentioned that both the computers and the network cards presented similar characteristics; due to this, it was determined that the uplink and downlink rates were the same, so a unidirectional communication was established between the PC-TX and PC-RX.

Figura 2. Tarjeta de red inalámbrica externa utilizada



Nota: La figura A representa el conector USB que se adaptó al computador; la figura B, el cable LMR-240, y la figura C, la antena que se conectó en el interior de la cámara anecoica.
Fuente: Elaboración propia

Now, if you look at Figure 1, it can be seen that the USB port of the computer was connected to the end 1 of the network card, which is represented in the letter A of Figure 2, whose end 2 is connected to the cable LM-240 of the anechoic chamber at end B. Finally, at end A the LM-240 cable is connected to the antenna represented by the letter C of figure 2. This procedure was performed for both the transmitter and the receiver.

Tabla 1. Características de las tarjetas de red inalámbricas externas utilizadas

Características	**Tarjeta de red**
Frecuencia de operación	2.4 GHz - 2.4835 GHz
Estándares soportados	IEEE 802.11 b/g/n
Ganancia de antenas	5 dB
Potencia de transmisión	100 mW
Velocidad máxima de transmisión	300 Mbps
Sistemas operativos soportados	Windows XP, 7, 8, 8.1, 10, MAC y Linux

Fuente: Elaboración propia

For the taking of measurements, an intrusive traffic injection technique was chosen through the D-ITG software, which provides in its entirety the metrics of interest for this work. For this reason, all the architecture and components of the D-ITG were installed in each computer, within which the configuration of its graphical user interface (GUI) allowed determining the maximum transmission capacity that each standard supported for the scenario. of tests raised.

Then, and with the purpose of determining said capacity, the communication channel was flooded until its throughput was determined. These transmission rates vary until obtaining a packet loss of less than 3%, which is advisable according to Vallejo (2016) to get a better response for real-time communications and guarantee the use of the full capacity of the communication channel. Table 2 shows the configurations made in the GUI of the D-ITG in the transmission part for each standard.

Tabla 2. Parámetros configurados en la GUI del D-ITG para el transmisor

Estándar	Parámetro	Valor
IEEE 802.11 b/g/n	Métrica	*One way delay*
	Duración (s)	30
	Inicio del retardo (s)	0
	Protocolo	UDP
	Tamaño del paquete (bytes)	512
IEEE 802.11 b	Tasa de transmisión (Mbps)	1/2/3/4/3.8
IEEE 802.11 g		1/2/4/6/7/6.5
IEEE 802.11 n		1/3/5/8/12/11

Fuente: Elaboración propia

In the present work we used the UDP protocol (from the English user data protocol), since not being oriented to the connection was the one indicated for real-time applications, which allowed observing PL values in the data transmission. As for the One way delay metric (recommended for working in laboratory environments), it was used to determine the time it took for a packet to travel from the transmitter to the receiver. Likewise, the packet size of 512 bytes, the start of the delay in 0 s and the duration of 30 s were established because they are advisable values for working in a laboratory environment that uses relatively small networks (Vallejo, 2016).

For each standard under the same scenario 10 measurements were made with the objective of reducing the mean square error; Likewise, Matlab mathematical tool was used to analyze the acquired data.

Tabla 3. Tasa de transmisión real para los estándares IEEE 802.11b/g/n en relación con la tasa de paquetes perdidos

Estándar	Tasa de transmisión (Mbps)	Tasa de recepción (Mbps)	Paquetes perdidos (%)	Paquetes transmitidos
802.11b	1.00	0.99	0	227
	2.00	1.99	0	453
	3.00	2.94	0.3	680
	4.00	3.89	8.4	906
	3.80	3.78	2.1	861
802.11g	1.00	0.99	0	227
	2.00	1.99	0	453
	4.00	3.99	0	906
	6.00	5.98	0.6	1359
	7.00	6.80	7.6	1586
	6.50	6.48	2.4	1472
802.11n	1.00	1.00	0	227
	3.00	2.99	0	680
	5.00	4.98	0	1133
	8.00	7.99	0	1812
	12.00	11.72	8.4	2718
	11.00	10.98	1.4	2491

Nota: Los valores con negrillas representan los resultados del *throughput* medio obtenido para las inyecciones de tráfico.

Fuente: Elaboración propia

Table 3 shows the traffic injections carried out to determine the total capacity of the channel and, subsequently, to establish the number of packets in the transmission of data for each of the standards. For this work, the RBRs for each standard have also been configured in the external wireless network cards, which are 5.5 Mbps for the IEEE 802.11b standard, 9 Mbps for the IEEE 802.11g standard and 13 Mbps for the IEEE 802.11n standard. Next, the performance metrics that are related to the QoS are defined in order to clarify the results presented in the later section.

Throughput

The *throughput* (η) of a data network is given by the number of bits that can be transmitted over the network in a given period. The Ef of a network is calculated by equation 1 (Lara-Cueva, Benítez, Caamaño, Zennaro y Rojo-Álvarez, 2014).

$$Ef = \frac{\eta}{RBR} \text{x } 100\ \% \qquad (1)$$

As η es the *throughput* received in the transmission and RBR is the net transmission rate.

Delay

The *delay* (δ) in a data transmission it is established as the time it takes for a data packet to arrive from a transmitting point to a receiving point (Cuesta and Romero, 2013); this value can not be negative, so the equipment must be configured to the same clock signal or as similar as possible in phase and frequency, since its synchronization serves to obtain correct values of the δ that will be delivered by the software D- ITG For this reason, an own server was installed - as detailed in Lara, Fernández and Morales (2016) - to synchronize computer clocks.

Jitter

The *jitter* (*j*) it is the variation that exists between the pulses of a digital transmission and can be manifested through variations in signal amplitude and intensity, which originate due to connection waiting times, congestion of data traffic and interference (Barrionuevo and Tamayo, 2011).

Lost packages

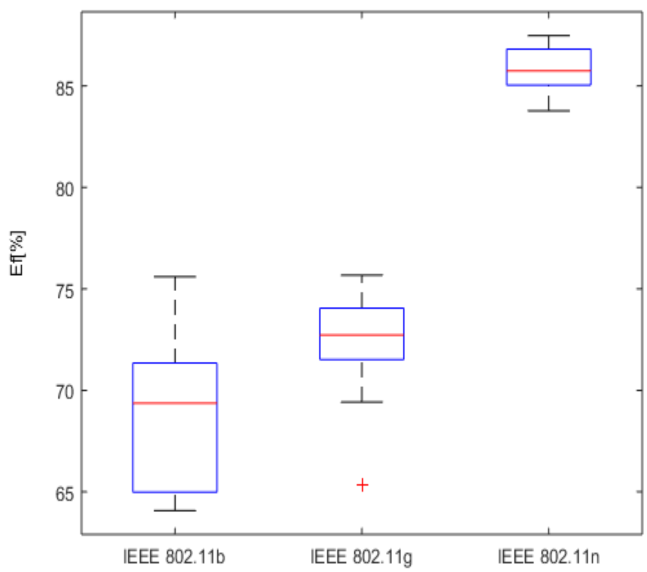
Lost packets (PL) for wireless data transmission occur due to the means by which they are transmitted, since a network can be interfered with by nearby equipment competing for access to the wireless channel or also by equipment that they are operating within the same frequency band. The percentage of PL can vary from a level less than 0.5% of package losses to more than 50% of losses (Barrionuevo y Tamayo, 2011).

Results

This section offers the results of the performance metrics analyzed for the scenario proposed according to each standard.

a. Efficiency

Figura 3. Ef de la red para los estándares IEEE 802.11b/g/n



Nota: Las medianas están representadas por la línea roja.

Fuente: Elaboración propia

Figure 3 shows the Ef values for the IEEE 802.11b / g / n standards under the same test scenario. In this figure it is observed that the standard with the highest Ef was the IEEE 802.11n with values that oscillated between 85.04% and 86.82% and with a median of 85.75%. For its part, the second best Ef was found in the IEEE 802.11g standard with 73.73% and with values that varied between 71.52% and 74.06%. It should be noted that for this standard an outlier was presented in 65.36% known as outlier, which is a discarded data because it is not within a range of valid records for an adequate analysis. Finally, the standard that the lowest Ef had was the IEEE 802.11b with values that ranged between 64.98% and 71.35% and with a median of 69.37%. In this regard, it is worth noting that the values of the median for all the scenarios and metrics evaluated were obtained with the graphical boxplot tool of Matlab.

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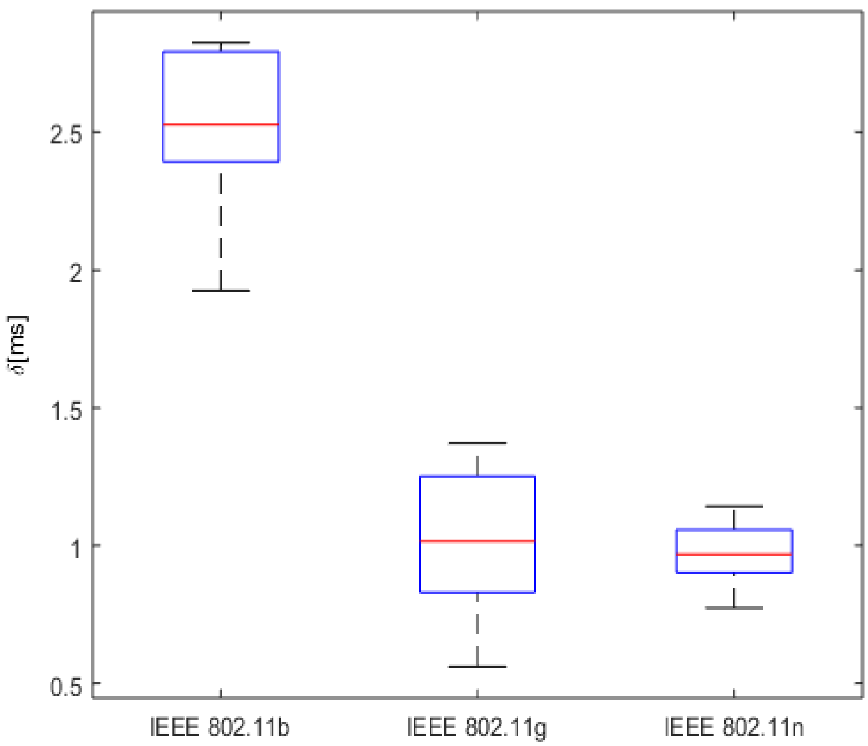
b. Delay

Figura 4. *Delay* de la red para los estándares IEEE 802.11b/g/n



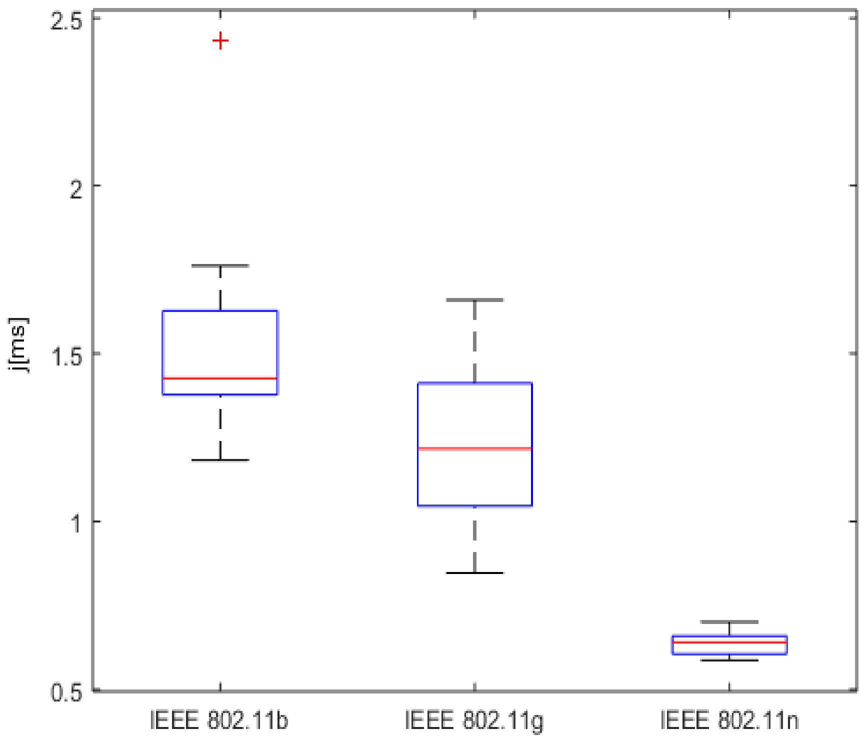
Nota: Las medianas están representadas por la línea roja.

Fuente: Elaboración propia

The results obtained around the δ for the IEEE 802.11b / g / n standards are presented in Figure 4, where it can be seen that the highest δ was obtained by the IEEE 802.11b standard, which achieved fluctuating values between 2.39 ms and 2.79. ms with a median of 2.53 ms, followed by the IEEE 802.11g standard, which reported values that varied between 0.83 ms and 1.25 ms with a median of 1.01 ms; finally, the IEEE 802.11n standard reached the lowest values of δ, since they oscillated between 0.90 ms and 1.06 ms with a median of 0.97 ms.

c. Jitter

Figura 5. *Jitter* de la red para los estándares IEEE 802.11b/g/n



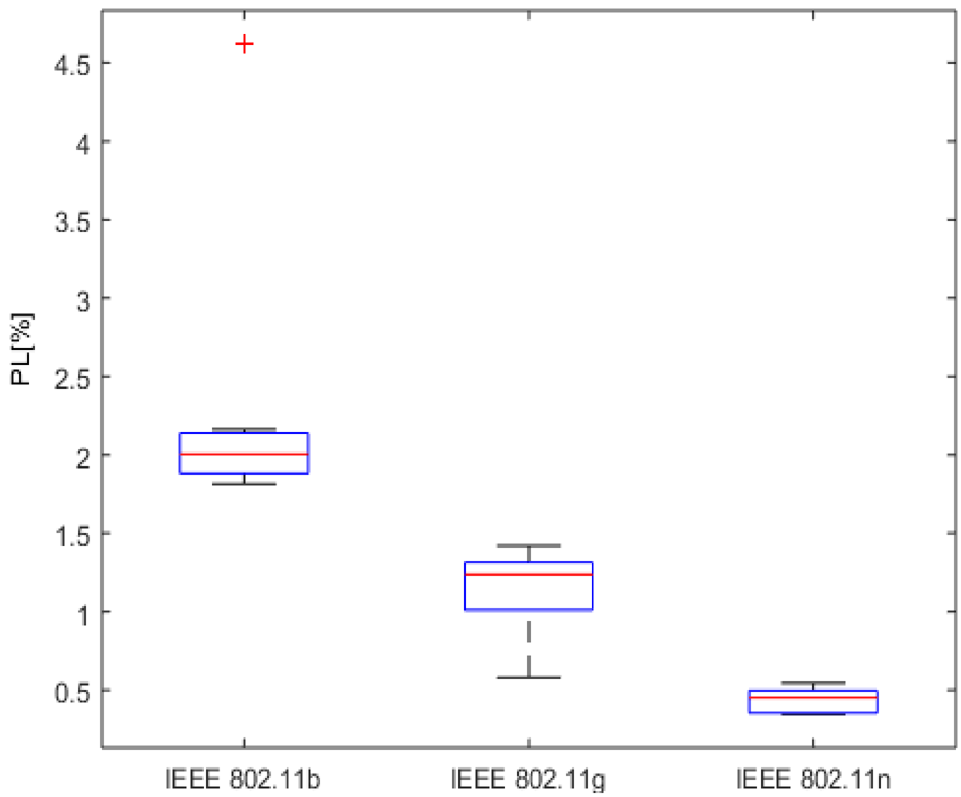
Nota: Las medianas están representadas por la línea roja.

Fuente: Elaboración propia

Figure 5 shows the values of j obtained for the IEEE 802.11b / g / n standards; in this figure it is observed that the standard with the lowest j presented was the IEEE 802.11n with 0.63 ms, followed by the IEEE 802.11g standard with values that oscillated between 1.04 ms and 1.41 ms and with a median of 1.22 ms. Finally, the standard with the highest j was the IEEE 802.11b with values that varied between 1.37 ms and 1.62 ms, with a median of 1.42 ms and an outlier of 2.43 ms.

d. Paquetes perdidos

Figura 6. Paquetes perdidos de la red para los estándares IEEE 802.11b/g/n



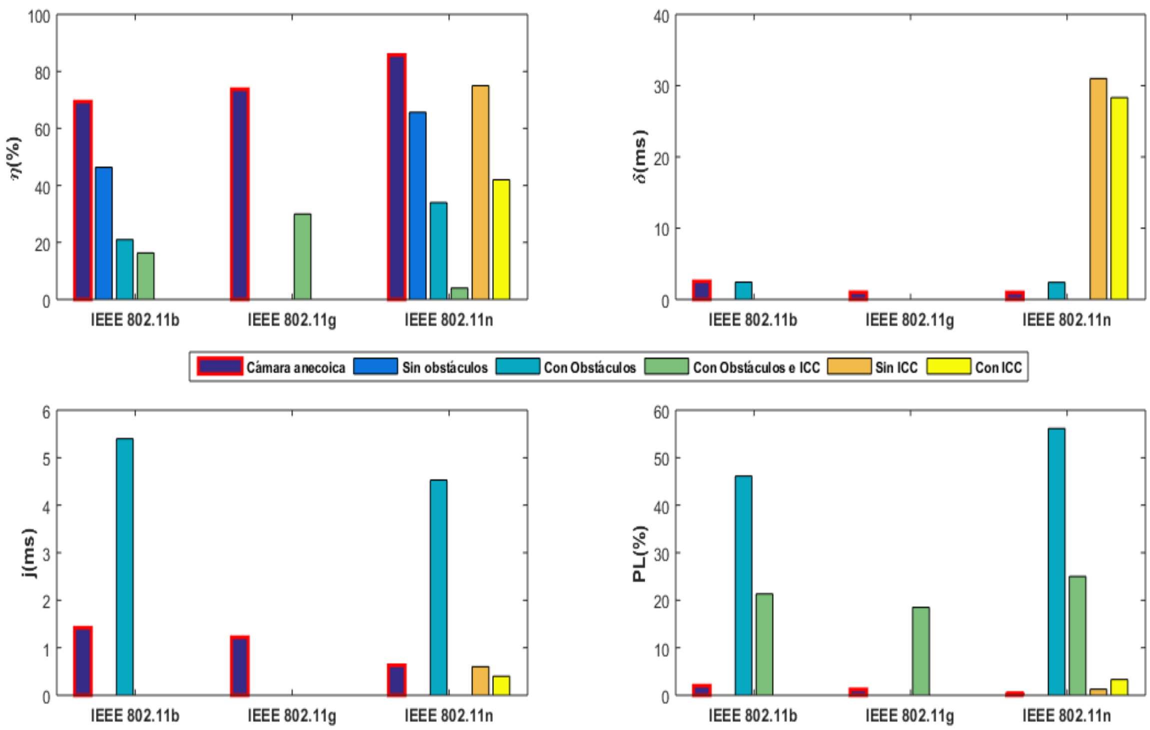
Nota: Las medianas están representadas por la línea roja.

Fuente: Elaboración propia

Figure 6 shows the results regarding the PL for the IEEE 802.11b / g / n standards. In this sense, it can be affirmed that the standard with the lowest PL was the IEEE 802.11n with values that were between 0.35% and 0.49%, with a median of 0.45%. In contrast, the IEEE 802.11g standard reached values between 1.01% and 1.32%, with a median of 1.24%, while the standard with the highest PL was IEEE 802.11b with values that fluctuated between 1.88% and 2.14%, with a median of 2%.

Finally, Figure 7 shows the totality of the metrics obtained grouped with works related to the IEEE 802.11b / g / n standards. In this regard, it should be noted that not all the referred works evaluated the standards indicated in the present study or all the performance metrics (ie, Ef, δ, j and PL), which is why some figures appear without some bars. Also, it should be noted that the legend for each contrast can be seen in the center of the figure.

Figura 7. Contraste con otros trabajos relacionados con los estándares IEEE 802.11b/g/n (el presente trabajo se enseña con barras de color morado y delineado rojo)



Fuente: Elaboración propia

Discussion and Conclusions

Figure 7 has been designed with the purpose of comparing the findings of the present investigation with others made previously. For this reason, the results obtained inside an anechoic chamber are presented below compared to scenarios that have been subjected to interference by obstacles and by ICC to determine the percentage in which each performance is degraded in comparison with our metrics.

- Regarding Ef in unimpeded scenarios, the performance of the IEEE 802.11b standard is degraded by 33.21%, while the IEEE 802.11n standard does it by 23.42% compared to the results obtained by Lara et al. (2016).
- In scenarios with obstacles, the performance of the IEEE 802.11b standard is degraded by 69.73% in terms of Ef, 4.55% in δ and 280.28% in j. In contrast, the

IEEE 802.11n standard presents a deterioration of 60.35% in terms of Eff, 148.45% in the δ and 619.05% in the j, in comparison with that reported by Lara et al. (2016).

- In scenarios without ICC, the performance of the IEEE 802.11n standard is degraded by 12.54% around the Ef, 3095.88% in the δ and 4.76% in the j, compared with Vallejo (2016).
- In scenarios with ICC, the performance of the IEEE 802.11n standard has a deterioration of 51.02% around the Ef, 2820.62% in the δ and 36.51% in the j, in contrast to Vallejo (2016).
- Finally, in scenarios with obstacles and ICC around the Ef, the performance of the IEEE 802.11b standard is degraded by 76.46%, the IEEE 802.11g standard suffers a 51.17% deterioration and the IEEE 802.11n standard degrades 95.34%, all these compared to the results collected by Sendra *et al.* (2010).

Presented these figures, it can be determined that the best performance was achieved by the IEEE 802.11n standard with 85.75% Ef, 0.97 ms δ, 0.63 ms j and 0.45% PL, followed by the IEEE 802.11g standard with 73.73% Ef, 1.01 ms of δ, 1.22 ms of j and 1.24% of PL. Finally, the standard that presented the lowest performance was the IEEE 802.11b with 69.37% of Ef, 2.53 ms of δ, 1.42 ms of j and 2% of PL.

With this background, and based on the results obtained in this work, it can be concluded that the interference produced by obstacles reduce the Ef of the link up to 69.73%, as well as a value of 51.02% under ICC and up to 94.34% under ICC with obstacles. With respect to δ, its deterioration is 148.45% with presence of obstacles and 2820.62% with ICC. As for the j, its degradation can reach up to 619.05% under a scenario with obstacles and up to 36.51% under ICC. Finally, regarding the PL, the results have not been contrasted because in this investigation it was taken as a principle that the PL rate was less than 3%, a value that is established for applications in real time. This has made comparisons impossible, because in this work this rate of packages does not change because there are no reasons why it should be modified to make a contrast with Lara et al. (2016), Sendra et al. (2010) and Vallejo (2016), a situation that would also not be advisable.

On the other hand, it is emphasized that all the values obtained are satisfactory because the tests were performed inside an anechoic chamber, which allowed working in an isolated environment of interference, so that the δ, j and PL complied with the recommendations established by ITU-T G.1010 (2001), ITU-T G.114 (2003) and ITU-T Y.1541 (2011) to provide QoS to applications in real time.

Even so, some lines of interest are still open, which should be taken over by specialists in the development of wireless communications. Consequently, it is proposed as future work to analyze the performance of the IEEE 802.11b / g / n standards in exteriors and evaluate the IEEE 802.11ac standard, which has not been considered for this investigation because our anechoic chamber did not support frequencies outside from the range of 2 GHz to 3GHz.

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