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WLAN PROTOCOL AND NETWORK ARCHITECTURE SELECTION FOR REAL-TIME APPLICATIONS

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Abstract - Wireless networks have been designed to provide provision for real-time applications such as voice over IP (VoIP) and video conferencing (VC). Evaluate the QoS metrics of real-time services for different IEEE 802.11 technologies in order to identify the optimum technology standard across different infrastructure and network architectures.In this paper, an algorithm scheme is proposed to evaluate real-time services of different IEEE 802.11 technologies in order to identify the optimum network architecture among Basic Service Set (BSS), Extended Service Set (ESS), and the Independent Basic Service Set (IBSS).Moreover, the proposed algorithm considers multi-criteria access network selection such as spatial distribution and number of nodes, hence to facilitate the provision ofthe best overall network performance and high quality services. The Quality of Service (QoS) metrics used were delay, jitter, throughput and packet loss.

Keywords - VoIP, Video Conferencing, IEEE technologies, Performance Analysis, QoS.

I. INTRODUCTION

Managing real-time traffic such as VoIP and VC is currently a massive challenge in the communication industry.Wireless LAN (WLAN)connects people and allow to access information over a distance without cables; it operates in an air interface.WLAN networkshave become one of the fastest growing sectors of the communication industry. The degree of freedom in movement and ability to spread services to various parts of homes or/and business infrastructure,there is a rapid interest towards WLAN networks, as it is currently considered vital to implement in real-time operations[1]. Internet-based services such as web, email and file transfers affect the usage of WLANs in addition to voice over wireless networks. Real-time applications as VoIP enables users to use the Internet as a transmission medium for by sending voice data in packets using Internet Protocol (IP) rather than by traditional circuit-switched Public Switched Telephone Network (PSTN). In IP networks, information data is digitized and spread as a stream of packets over a digital data network.In WLANs where multi-applications have been deployed, a number of factors that affect the network performance should be addressed and evaluated such as the wireless network architectures (BSS, ESS and IBSS) and IEEE MAC layer technologies [2]. However, providing precise QoS is considered as an issue for wireless networks in the existence of real-time multimedia applications andhas been the object of wide research [3]–[7]. Firoiu [3] produced a novel architecture realized with a combination of scheduling and queue management mechanismsthat classify WEB/TCP traffic as the drop-conservative queue achieving a lower loss, and VoIP/UDP traffic is scheduled into the delay-conservative queue, achieved a shorter delay. Two algorithms were introduced by Amir et al. [4] to improve the performance of a VoIP application and demonstrate how the packet loss effects can be eliminated to provide better VoIP performance. Whereas Salah and Alkhoraidly[5] applied a novel simulation approach on a typical network of a small enterprise to evaluate the network readiness for supporting real-time services; while the voice QoS performance metrics were investigated by Shi et al. [6] over IBSS network architectures. As an outcome of this, voice application is shown to provide better performance under light traffic. Furthermore, a QoS algorithm was proposed by Chen et al. [7] to reduce the average delay time and jitter for VoIP application and the packet loss ratio for high-definition video.
Various efforts have been developed to evaluate the applications forQoS metric parameters that are configured over IEEE technologies [8]–[10]. QoS parameters such as an end to end delay and throughput were observed by Sharma et al.[8] across two IEEE technologies 802.11, 11g and demonstrated that the IEEE 802.11a technology performed better across BSS network architecture.AlAlwai and Al-Aqrabi [9]Evaluated the performance ofVoIP in 802.11 wireless networks for 3-15 nodes in the ESS networks environment.Lakramiet al.[10] proposed a new algorithm over infrastructure wireless network to enhance the IEEE 802.11e in order to improve the QoS for voice and video services which gives better results for all performance metrics.

II. PRELIMINARIES

A.IEEE MAC Layer Technologies

The Institute of Electrical and Electronics Engineers (IEEE) developed the 802.11 group as a technology for WLAN technology. IEEE 802.11a operates in the 5 GHz frequency band and 802.11b operates in the frequency band 2.4 GHz, IEEE 802.11b supports transmission speeds of up to 11 Mbps and IEEE

802.11a provides a transmission speed of 54 Mbps [11]. IEEE 802.11g supports transmission speeds of up to 54 Mbps by applying Orthogonal Frequency Division Multiplexing (OFDM) in the 2.4 GHz band. IEEE 802.11 standard does not support time-sensitive voice applications but only best-effort services. After several refinements and with the increasing call for real-time applications, a new amendment named IEEE 802.11e was designed [12].

B. IEEE Network Infrastructures

IEEE 802.11 defines two basic modes of communication between WLAN nodes: Infrastructure and Independent which are known as Ad Hoc Networks [13].

Infrastructure BSS is a group of stations that connect to the same wireless medium and are controlled by a centralized coordination function or access point (AP). All stations can communicate directly with all other stations in a fixed range of the base station. The IEEE 802.11 infrastructure networks use APs. AP supports wave extension by providing the integration points necessary for network connectivity between multiple BSSs, thus forming an Extended Service Set (ESS). In addition, the IBSS or Ad-hoc network is a specified group of nodes in a single BSS for the purpose of internet working without the aid of a centralized coordination function [14] (i.e. access point).

C. QoS Performance Metrics and Importance Coefficient for Real-time Applications

Performance metrics are defined in terms of QoS metric parameters for real-time applications. For each application, a satisfaction criterion (acceptable threshold) for each QoS metric parameter is identified [15], [16] as shown in Table I, which represents the key QoS requirements and recommendations for each application (bearer traffic).

Application	Importance & Threshold	Delay (sec)	Jitter (sec)	Throughput (kbps)	Racket Loss Rate (%)
VoIP	Importance	H	H	M	L
	Threshold	0.15	0.04	45	5
VC	Importance	H	H	H	M
	Threshold	0.15	0.03	250	1

Where: H=High, M=Medium and L=Low

Table I Qos Metric Parameters Importance For Real-Time Applications

Real-time applications quality is directly affected by the following QoS metric measurements:

- Packet End-to-End delay (sec): the time taken by data/voice to travel from node A to node B on the network.
- Jitter (sec): the variance in delay caused by queuing.
- Throughput (bit/sec): the total rate at which packets are transferred from the source to the destination at a prescribed time period.
- Traffic Sent (packet/sec) and Traffic Received (packet/sec): used to calculate packet loss rate, which is the percentage of packets that get lost along the communication path after the packet is transmitted by the sender into the network.

It is worth noting that an Important Coefficient is assigned to each real-time application parameters (ICR) in terms of its impact on the call quality of the service. Table I shows the QoS qualitative importance of each QoS parameter and their related threshold values for each application. In order to be able to account for these qualitative factors in a simulation they have to be translated into numbers (H=1, M=0.5, and L=0.1).

III. PROPOSED ALGORITHM: PROTOCOL AND NETWORK ARCHITECTURE SELECTION

A. Building Projects (Simulation Environment)

In this paper, an OPNET simulation platform [17] is used to build and analyse all applications scenarios. Using OPNET Modeller, we have considered two main inputs for the user configuration stage, these are: the number of nodes and real-time application.Fig. 1. illustratesthe main factors of this algorithm. System specification definesthe environmental aspects that will be studied and analysed to build many different scenarios:network architectures, spatial distributions and QoS metrics.

Network architectures specify how different wireless components connect together in either of two modes: the presence of access points (BSS and ESS) mode or the absence of access points (IBSS) mode,spatial distribution which specifies the topology in which these nodes will be distributed – in a circular (oval) way, uniform (grid) way, or randomly scattered way, number of nodes needed in this network which breaks down to four groups (0-5, 6-10, 11-20 and 21-40). IEEE MACTechnologies defines the physical layer technologies that will be used to build many different scenarios.

All network architectures (BSS, ESS, IBSS) have been configured and implemented across all three spatial distributions (circular, uniform, random) for the four groups of nodes. Figs. 2(a), (b) and (c) show some of these implemented scenarios. The real-time applications' settings for the simulation run which lasted for 20 minutes, the VoIP traffic has been configured with the following parameters: voice frame per packet is 1, the encoder scheme is G.711, traffic type is an interactive voice. On the other hand, the VC traffic parameters configuration are: the frame interarrival time is 10 frame/sec and frame size information of 128x120 pixels (bytes).

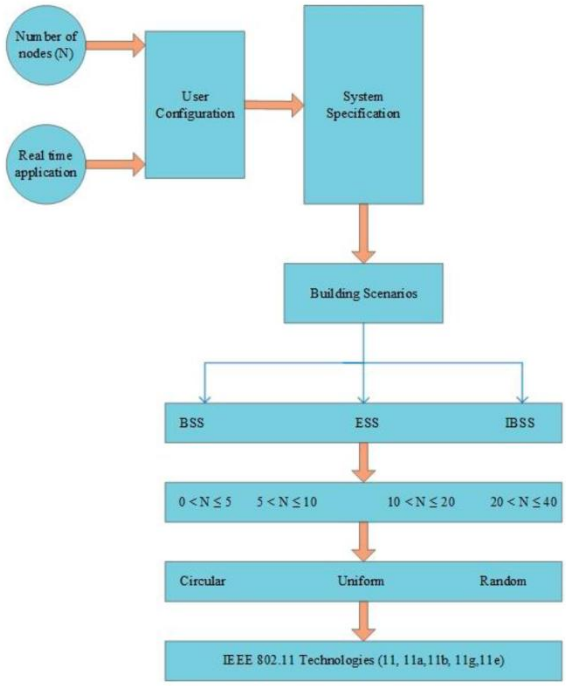

Fig. 1 Flowchart of the proposed algorithm

B. System Model's Calculation

The system calculations and the mathematical model are shown in Fig. 3. The inputs for the algorithm's mathematical calculations are QoS Threshold values for each application and Cumulative Distribution Function (CDF). Applications QoS Threshold values (satisfaction criterion) are taken from literature as shown in Table I [15], [16].

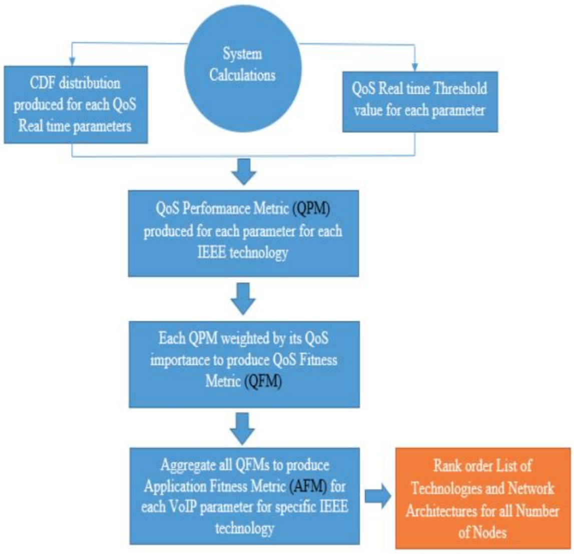

Fig. 3Algorithm's calculations flowchart

CDF distribution is produced for these QoS metric parameters from OPNET after running the simulation scenarios.

Mathematical calculations will be done to determine how a particular scenario has satisfied certain performance metrics for each application. The following steps are used to explain the calculations of this algorithm and to analyse the results for each of the above projects:

- QoS Performance Metric (QPM): as Fig. 4 illustrates, the value that is produced by applying the application QoS metric Parameter Threshold Value (PTV) for each QoS performance criterion n once is represented in CDF distribution F(n), which is given by (1).

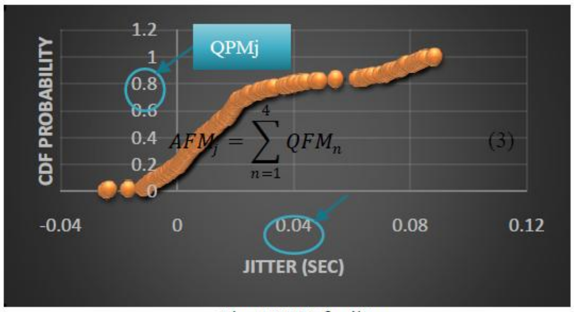

Fig. 4 QPM for jitter

- QoS Fitness Metric (QFM): the value that is produced by applying a weighting to the QPM (assigned by importance) for each QoS metric parameter (H=1, M=0.5 and L=0.1) is expressed by (2).

$$QPM_n = F(ptv) \quad (1)$$

$$QFM_n = QPM_n \times ICR \quad (2)$$

- The final step will be calculating the Application Fitness Metric (AFM) which is to aggregate all QFMs for n application QoS metric parameters (delay, jitter, throughput and packet loss), for each IEEE 802.11 technology j, as demonstrated by (3).
- Based on AFMs of the IEEE 802.11 technologies, the rank order of these five technologies will be produced for each of the three built network architectures. Hence, the best network architecture performance will be identified for all groups of nodes.

As explained previously, CDF distribution F(n) [18] is going to be produced for all applications QoS metric parameters from the OPNET Modeler simulation, then analysed against PTV as follows:

1. If ptv∈F(n): it means that the PTV has a specific value on its CDF distribution equal to QPM for this metric parameter. QPM is weighted by ICR to produce QFM. Then the aggregation of all QFMs yields AFM which is used to classify IEEE technologies.
2. If ptv > F(n): it means that the QPM value equals 1 and QFM has arisen.
3. If ptv<F(n): it means that the QPM value equals 0 and QFM will be initialized.

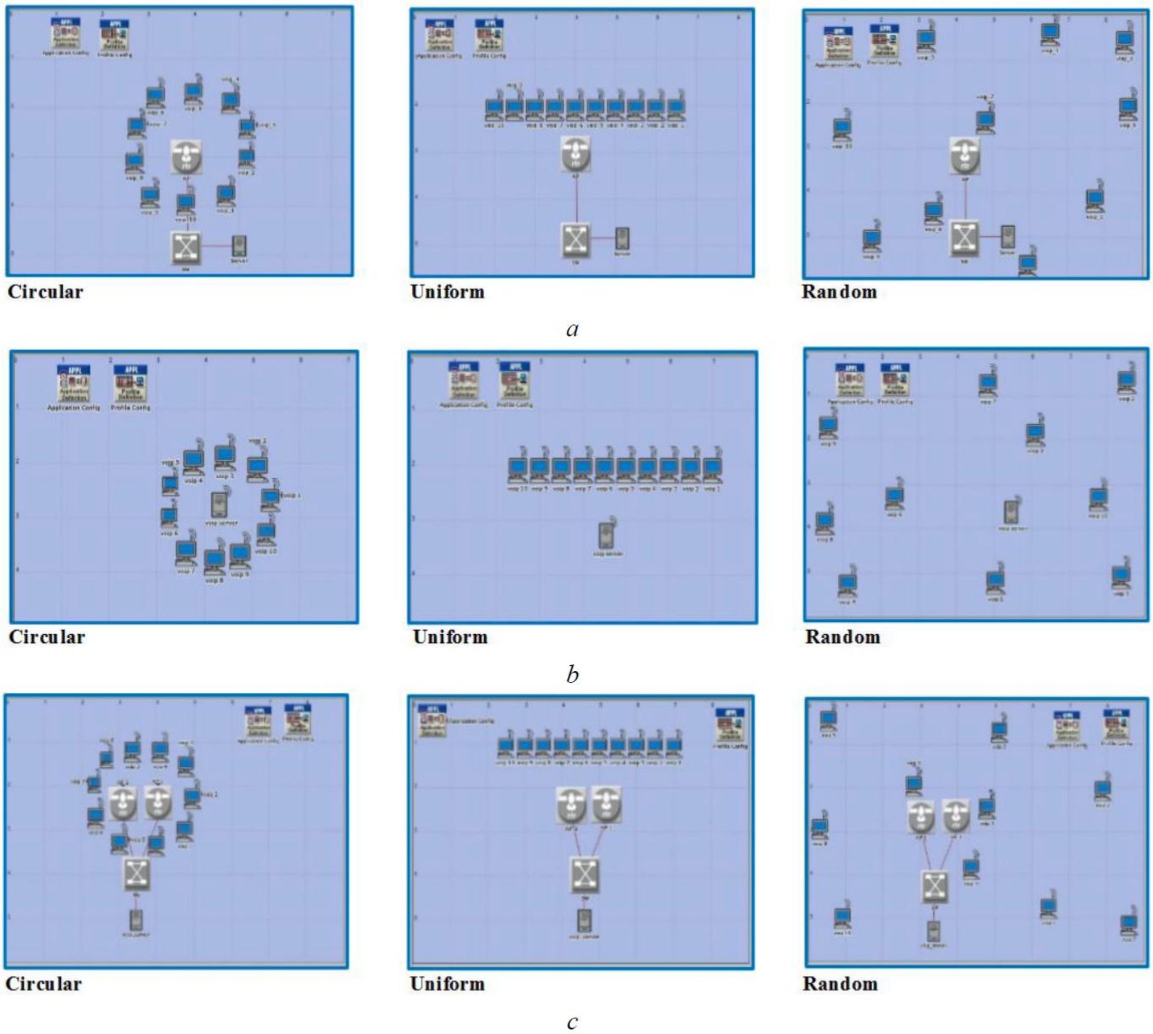

Fig. 2. Design of the three Network Architectures across three Spatial Distributions for VoIP.
(a) Basic Service Set (BSS), (b)Independent Basic Service Set (IBSS), (c) Extended Service Set (ESS)

The value generated for the applications QoS metric parameters (jitter, delay, throughput and packet loss) will contribute rank order of IEEE technologies for each network architecture. All applications QoS metric parameters will be calculated as explained in the previous sections except for a packet loss parameter. OPNET Modeler is designed to produce the result of the packet loss parameter as a Boolean value (0.0 or 1.0) that corresponds to the acceptance or rejection of a packet, respectively. However, this work requires a numerical value for the packet loss.

A code has been programmed using MATLAB software to develop a method to calculate the packet loss percentage for each application. This method is linked directly with the OPNET Modeler to produce a specific packet loss percentage for each application. Application packet loss rate ω_i of a node iis the ratio of dropped voice packetk_i to total voice packets$\rho_i$multiplied by 100%, as demonstrated by (4).

This requires the traffic received/send rate values from OPNET Modeler to be integrated to produce the total number of packets received and sent. Then, the exact packet loss ratio is produced and should be presented as a CDF diagram to enable identification of the values of QPM, QFM and AFM using the previously explained flowchart.

Identical calculation steps were applied for the other three groups of nodes (0-5, 11-20 and 21-40), to ascertain the best performing IEEE technology/technologies and to produce all values of QPMs, QFMs, and AFMs for all QoS metric parameters regarding each application in all network architectures across the three spatial distributions.

IV. RESULTS AND PERFORMANCE EVALUATION

In this article, the output of the proposed algorithm identifies the options available for a client (user) based on the tables of the results that have been produced for all scenarios across three network architectures. The results are divided into two main sections related to real-time applications (VoIP and VC). All simulated scenarios are applicable to the lab (room) sizes from 1x1m to 10x10m.

The format of the results is demonstrated based on the presence of an access point; therefore, the tables of the results are interpreted (translated) as: generic results and IBSS only, as will be demonstrated later for each application.

- In case there is at least one access point in the network, then the proposed algorithm in Fig. 1 and the result in Table II will be applied. This case is applicable to both infrastructure architecture layers (ESS and BSS). All scenarios are running in all five IEEE 802.11 technologies and three spatial distributions: circular, uniform, and random.

$$\omega_i = (ki/\rho_i) \times 100\% \quad (4)$$

- If the network is configured without any access points, then the proposed algorithm in Fig. 1 and the IBSS result's described in Table III will be used. All scenarios are running in all five IEEE 802.11 technologies and three spatial distributions: circular, uniform and random. Both results' tables start by identifying the number of nodes that will be used to configure the required network and work for the environment composed of 1 to 40 nodes.

A. Results of VoIP

Based on the user's configuration and the number of nodes required to set up the designated network, both results' algorithms classify four key groups of nodes, presented as follows:

1. The first category,where 5 ≥ N > 0, in the generic result, as can be seen in Table II, if the client is going to build a small network (number of nodes less than or equal to five nodes), then ESS is the best network architecture across all three spatial distributions. Furthermore, all five IEEE 802.11 technologies perform the same. However, in the case of the IBSS, all three technologies 802.11a, 11g, and 11e provide the best performance across all spatial distributions, according to Table III.

2. As shown in Table II, when 10 ⩾ N > 5, if the client is implementing a network using a number of nodes between 5 and 10, then both ESS or BSS provide optimum performance across all threespatial distributions if they are implemented usingonly three technologies including 802.11a, 11g, and 11e. In the case of the IBSS result's table, the technologies 802.11a, 11g, and 11e remain the optimum across all spatial distributions.

3. The third category, where 20 ≥ N > 10, if the client is going to build a medium size network with the number of nodes from 10 to 20, the BSS and ESS provide a number of options. For BSS architecture, IEEE 802.11a technology performs the ideal technology across all three spatial distributions. IEEE 802.11a, 11g, and 11e, are acknowledged as the preferable solutions for ESS architecture.However, according to the IBSS result, the IEEE 802.11a is the optimum technology to be used.

4. In the fourth category, where 40 ⩾ N > 20, the best architecture for this large network is ESS. Subsequently, the client has a number of options to select according to the information providedin Table II. First, both technologies 802.11a and 11g are optimal to use if the network is only configured in circular and random distributions; while the second-best option is to use IEEE 802.11a technology that is configured uniformly. On the other hand, in the IBSS result, all three technologies 802.11a, 11g, and 11e give an identicalperformance.

User Configuration	Real-time Application **VoIP**							
	Number of Nodes	5 ≥ N > 0	10 ≥ N > 5	20 ≥ N > 10	40 ≥ N > 20			
System Specification	Network Architecture	ESS	ESS or BSS	BSS	ESS			ESS
	Spatial Distribution	C U R	C U R	C U R	C U R	C U R		
IEEE Technology	802.11	802.11a 802.11a 802.11b 802.11g 802.11e	802.11a 802.11g 802.11e	802.11a	802.11a	802.11a 802.11g 802.11e	802.11a 802.11g	802.11g

TABLE IIBSS AND ESS GENERIC ALGORITHM RESULTS FOR VOIP

User Configuration	Real-time Application **VC**								
	Number of Nodes	5 ≥ N > 0	10 ≥ N > 5		20 ≥ N > 10	40 ≥ N > 20			
System Specification	Network Architecture	BSS		BSS		BSS			ESS
	Spatial Distribution	U R	UU	R	C R				
IEEE Technology	802.11 802.11b	802.11g		802.11	802.11	802.11b	802.11b 802.11b	802.11a	802.11g 802.11e

TABLE IVBSS AND ESS GENERIC ALGORITHM RESULTS FOR VC

User Configuration	Real-time Application VC				
	Number of Nodes	5 ≥ N > 0	10 ≥ N > 5	20 ≥ N > 10	40 ≥ N > 20
System Specification	Network Architecture	IBSS	IBSS	IBSS	IBSS
	Spatial Distribution	R	C U R	C U R	C U R
IEEE Technology	802.11g	802.11	802.11 802.11b	802.11 802.11b	802.11b
IEEE Technology		802.11e	802.11e		802.11e

TABLE VIBSS ALGORITHM RESULTS FOR VC

B. Results of VC

1. The first category, where 5 ≥ N > 0, as can be seen in Table IV, if the client is going to build a small network, then BSS is the best architecture network. Additionally, the client has a number of options to select according to the information providedin Table IV. First, 802.11 is the optimal technology to use if it is only configured in uniform distribution. The second-best option is to use 802.11b technology which is configured randomly. However, in the case of the IBSS, the 802.11g technology provides the best performance which is configured randomly as shown in Table V.
2. As shown in Table IV, when 10 ≥ N > 5, if the client is going to configure a network using a number of nodes between 5 and 10, then BSS provides optimum performance that is configured uniformly and 802.11g has been implemented. But, in the case of the IBSS, both technologies 802.11 and 11b provide the client with the best performance across all spatial distributions as shown in Table V.
3. The third category, where 20 ≥ N > 10, if the client is going to build a medium size network with the number of nodes from 10 to 20, then BSSprovidesthe best option. Moreover, the client has a number of options to select according to the information providedin Table IV. Both 802.11 and 11b arethe optimal technologies to use if they are only configured in uniform and random distributions. On the other hand, in the IBSS, both IEEE 802.11 and 11b perform well across all spatial distributions.
4. In the fourth category, where 40 ⩾ N > 20, the best network architecture for this network is ESS as shown in Table IV.Furthermore, the client has a number of choices if setting up this large network. First, 802.11b technology performs well if it is configured circularly. Second, all three technologies 802.11a, 11g, and 11e perform well when configured randomly. While, in the IBSS results, both technologies 802.11 and 11bprovide the user with the best performance to use for all spatial distributions.

V. CONCLUSION

In this paper, the rank order of different IEEE 802.11 technologies have been produced across different spatial distributions. The results of VC application show that it is only preferable to use the ESS network with a high number of workstations/nodes; this is due to the high packet loss and delay that might appear in the network owing to the increase in the number of workstations.Additionally,both uniform and random distributions had almost identical results. Furthermore, IBSS can be worked efficiently with both technologies 802.11 and 802.11b for almost all selected numbers of nodes. On the other hand, ESS architecture has the same performance for all spatial distributions regardless of the network size for VoIP. Moreover,BSS performance is degraded when the number of nodes is more than twenty. Furthermore, the results of VoIP showIBSS can be worked efficiently with the 802.11a, 802.11g and 802.11e technologies that implement the Orthogonal Frequency Division Multiplexing (OFDM) modulation technique, which uses subchannels to transmit different signals (image and sound) at the same band simultaneously.

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