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OPTIMUM WLAN PROTOCOL AND NETWORK ARCHITECTURE IDENTIFICATION FOR VOIP APPLICATION

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ABSTRACT

This research developed a novel algorithm to evaluate Voice over Internet Protocol (VoIP) metrics 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). The proposed algorithm will yield the rank order of different IEEE 802.11 technologies. By selecting the optimum network architecture and technology, the best overall network performance that provides a good voice quality is guaranteed. Furthermore, it meets the acceptance threshold values for the VoIP quality metrics. This algorithm was applied to various room sizes ranging from 2x3m to 10x14m and the number of nodes ranged from one to forty. The spatial distributions considered were circular, uniform, and random. The Quality of Service (QoS) metrics used were delay, jitter, throughput and packet loss.

Keywords: *VoIP, QoS, Performance Analysis; IEEE technologies*.

1. INTRODUCTION

Handling VoIP is currently a huge challenge in the communication industry. With the swift movement of business infrastructure and home users towards Wireless LAN (WLAN), it is vital to implement real-time traffic such as VoIP over WLAN. WLAN has become popular these days because it is easy and simple to deploy [1]. By providing reliable access to the network resources and implementing real-time traffic such as video and audio in business, institutional and home networks, WLAN has become service-dominant and has increased in popularity. WLAN performance directly depends on the signal strength that operates through the air and varies from topology to topology, which has contributed to bringing about the flexibility of the network establishment, the mobility of nodes, and cost reduction [2]. Internet-based services such as web, email, and file transfers affect the usage of WLANs in addition to voice over wireless networks. VoIP is a mechanism for transmitting time-sensitive voice over the packet-switched network [3]. VoIP has turned out to be a serious competitor to the traditional public switched telephone network (PSTN) [4]. However, providing precise QoS considered as an issue for real-time multimedia applications such as VoIP, video over IP and online games. In order for VoIP to work adequately, the QoS parameters and characteristics performance have to be fulfilled [5].

In WLANs where VoIP application has 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. Many researchers have analysed VoIP performance over WLAN standards. S. Mangold *et al.* [6] proposed a performance evaluation study of IEEE 80211e standard and compared it to the legacy 802.11 standard over BSS network architecture through building different simulation scenarios, and characterised their efficiency. The QoS parameters of VoIP services have been evaluated and monitored in a number of studies [7-11]. S. Garg and M. Kappes [7] studied the behaviour of VoIP over IP networks and demonstrated that the VoIP performance is reduced by clients' spatial distribution factor. They evaluate the VoIP over IEEE 802.11b network using 3 to 11 VoIP calls. Two algorithms were introduced by Y. Amir *et al.* [8] to improve the performance of VoIP application and demonstrate how the packet loss effects can be eliminated to provide better VoIP performance. Whereas K. Salah and A. Alkhoraidly [9] applied a novel simulation approach on a typical network of a small enterprise to evaluate the network readiness for supporting VoIP services; while the VoIP QoS performance metrics were investigated by L. Shi *et al.* [10] over IBSS network architectures. As an outcome of this, VoIP is shown to provide better performance under light traffic. Furthermore, a QoS algorithm was proposed by J. L. Chen *et al.* [11] to reduce the average delay time and jitter for VoIP application and its services. The relation between VoIP codec and QoS parameters was studied by Y. Labyad *et al.* [12] to investigate the best performance VoIP codec over IP network. At the same time, there are initiatives to monitor IEEE standards. On the other hand, QoS parameters such as end to end delay and throughput were observed by V. Sharma *et al.* [13] across two IEEE technologies 802.11, 11g and demonstrated that the IEEE 802.11a technology performed better across BSS network architecture. A. Mohd Ali *et al.* [14] aimed to build different scenarios to evaluate VoIP QoS characteristics and to examine the effect of enhancement on the QoS. The evaluation, carried out using the OPNET simulator, would involve the various parameters of the Wireless LAN802.11e to see if this improvement of distributed channel access improves the efficiency of the Wireless LAN 802.11 standard.

The evaluation, implemented using the OPNET simulator, will contain the different parameters of Wireless LAN 802.11e to see how this enhancement in distributed channel access increases the performance over the Wireless LAN 802.11 standard

Several schemes have been proposed to enhance VoIP services [15, 16]. T. H. Hussain *et al.* [15] examined VoIP services over an existing network. As a result of this study, it was shown that the packet loss rate decreased, while a new scheme was presented by P. Dong *et al.* [16] to enhance VoIP services, and an improvement in the VoIP capacity was guaranteed. An algorithm for assessing real-time services such as VoIP and video conferencing of various IEEE 802.11 technologies is proposed in A. Mohd Ali *et al.* [17].

Various efforts have been developed to evaluate the VoIP QoS parameters for the different number of nodes that are configured over IEEE technologies [18-20]. S. Pérez *et al.* [18] introduced a simulation scenario to evaluate the IEEE 802.11e standard for a number of VoIP nodes that varied from 5 to 45 nodes; as a result of this simulation scenario, it was shown that there is an increase in average delay for VoIP application. K. AlAlawi, H. Al-Aqrabi [19] evaluated two QoS VoIP parameters, end-to-end delay and throughput, over two IEEE technologies (802.11g and 11e), where it was shown that the VoIP services improved over the enhanced IEEE standard. However, VoIP QoS performance metrics were studied by A. M Sllame *et al.* [20] using different routing protocols. For instance, they used only 15 nodes without considering the effect of physical layer technologies, spatial distributions, or network architecture.

To the best of our knowledge, no previous work has evaluated the VoIP QoS metrics of different IEEE 802.11 technologies in order to identify the optimum technology standard across infrastructure and independent network architectures, which will be introduced in this article. The implementation of QoS parameters such as delay, jitter and packet loss over VoIP networks is also considered as an enormous challenge. At the same time, the existence of different IEEE 802.11 technologies requires a logical analysis to decide which technology should be used and put into practice. Furthermore, the availability of IBSS, BSS, and ESS have increased the difficulty of deciding which network architecture is best to use, regarding the assigned wireless network resources, to provide optimum network quality. Moreover, as demonstrated in A. Mohd Ali *et al.* [21] the optimum performance of IEEE technologies deployed in real-time industrial communication systems not always guaranteed to recent technologies (802.11n) over the older one (802.11g), for this exact reason our work provides an analysing study that suggests to the user the optimum technology/technologies and network architecture without wasting resources nor getting in the issues of randomly choosing specific technologies then redesigning the whole configuration.

This article looks into the possibilities of having any effects on network performance when using a different number of nodes and IEEE physical layer technologies implemented across various spatial distributions.

2. PRELIMINARIES

2.1 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 [22]. 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 802.11n uses Multiple Input Multiple Output Orthogonal Frequency Division Multiplexing (MIMO-OFDM) techniques to achieve transmission speeds of up to 300 Mbps. In case of using a channel bandwidth up to 40 MHz, IEEE 802.11n can provide transmission speeds of up to 600 Mbps [23]. 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 multimedia applications, a new amendment named IEEE 802.11e was designed [24]. Table 1 shows the main differences between the IEEE 802.11 standards.

Table 1: Summary of IEEE 802.11 standards

Standard IEEE 802.11	11	11a	11b	11g	11n
MAC protocol	DCF	DCF	DCF	DCF	EDCA
Data Rate (Mbps)	1, 2	Up to 54	1, 2, 5.5, 11	Up to 54	Up to 600
Modulation	FHSS, DSSS	OFDM	DSSS	ERP-OFDM	MIMO-OFDM
Frequency Band (GHz)	2.4	5	2.4	2.4	2.4 & 5
Channel Width (MHz)	20	20	20	20	20, or 40
Number of Spatial Streams	1	1	1	1	1, 2, 3, or 4

2.2 IEEE networks infrastructures

IEEE 802.11 defines two basic modes of communication between WLAN nodes: Infrastructure and Independent which are known as Ad Hoc Networks [25]. 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 [26] (i.e. access point).

2.3 VoIP QoS performance metrics and Importance coefficient

Performance metrics are defined in terms of QoS metric parameters for VoIP application. For VoIP, a satisfaction criterion (acceptable threshold) for each QoS metric parameter is identified [27, 28] as shown in Table 2, which represents the key QoS requirements and recommendations for VoIP (bearer traffic).

Table 2: VoIP QoS metric parameters importance

QoS for VoIP	Delay (sec)	Jitter (sec)	Throughput (kbps)	Racket Loss Rate (%)
Importance	H	H	M	L
Threshold	0.15	0.04	45	5

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

The VoIP 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, should be below 150 ms [27].
- Jitter (sec): the variance in delay caused by queuing, should be less than 40 ms [27].
- Throughput (bit/sec): the total rate at which packets are transferred from the source to the destination at a prescribed time period. The required throughput for a VoIP in one direction is 45 kbps [27, 28].
- 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, which should be below 5%.

It is worth noting that an important coefficient is assigned to each of the VoIP parameters (VIP) in terms of its impact on the call quality of the service. Table 2 shows the QoS qualitative importance of each QoS parameter and their related threshold values for VoIP 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, L=0.1, and VL=0).

3. PROPOSED ALGORITHM: PROTOCOL AND NETWORK ARCHITECTURE SELECTION

3.1 Building projects (Simulation environment)

In this paper, an OPNET simulation platform [29] is used to build and analyse all VoIP scenarios. OPNET is a discrete event system simulator that simulates the system behaviour by modelling each event happening in the system and processing it by a user-defined process. OPNET Modeler allows you to study communications networks, equipment, applications and protocols with ease and scalability. The most successful technology companies use the model to develop their research and development processes.

Using OPNET simulation, we have considered two main sources' inputs for this algorithm: user configurations and technology specifications (standards). User configurations defines the number of nodes that are needed in the network and spatial distribution. Technology specifications (standards) defines the physical layer technologies and network architectures.

The top part of Figure 1 defines these factors. 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, number of nodes needed in this network which breaks down to four groups (0-5, 6-10, 11-20 and 21-40), 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. IEEE MAC Technologies 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. Figures 2(a), (b) and (c) show some of these implemented scenarios.

The performances of different scenarios for VoIP applications have been investigated via an OPNET simulator. The protocols used and the application settings for the simulation are listed in Table 3.

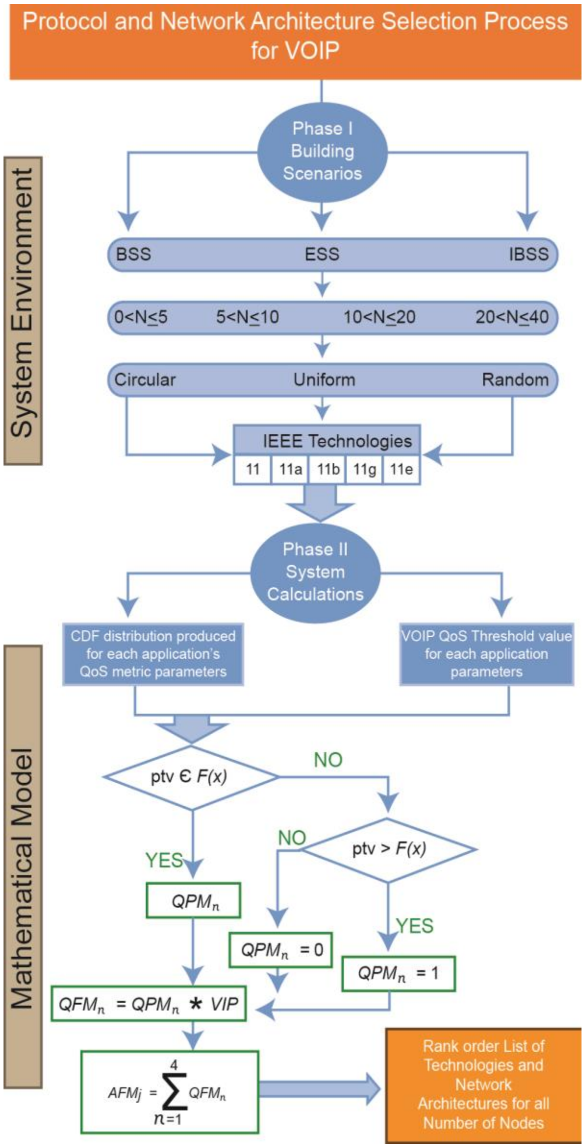
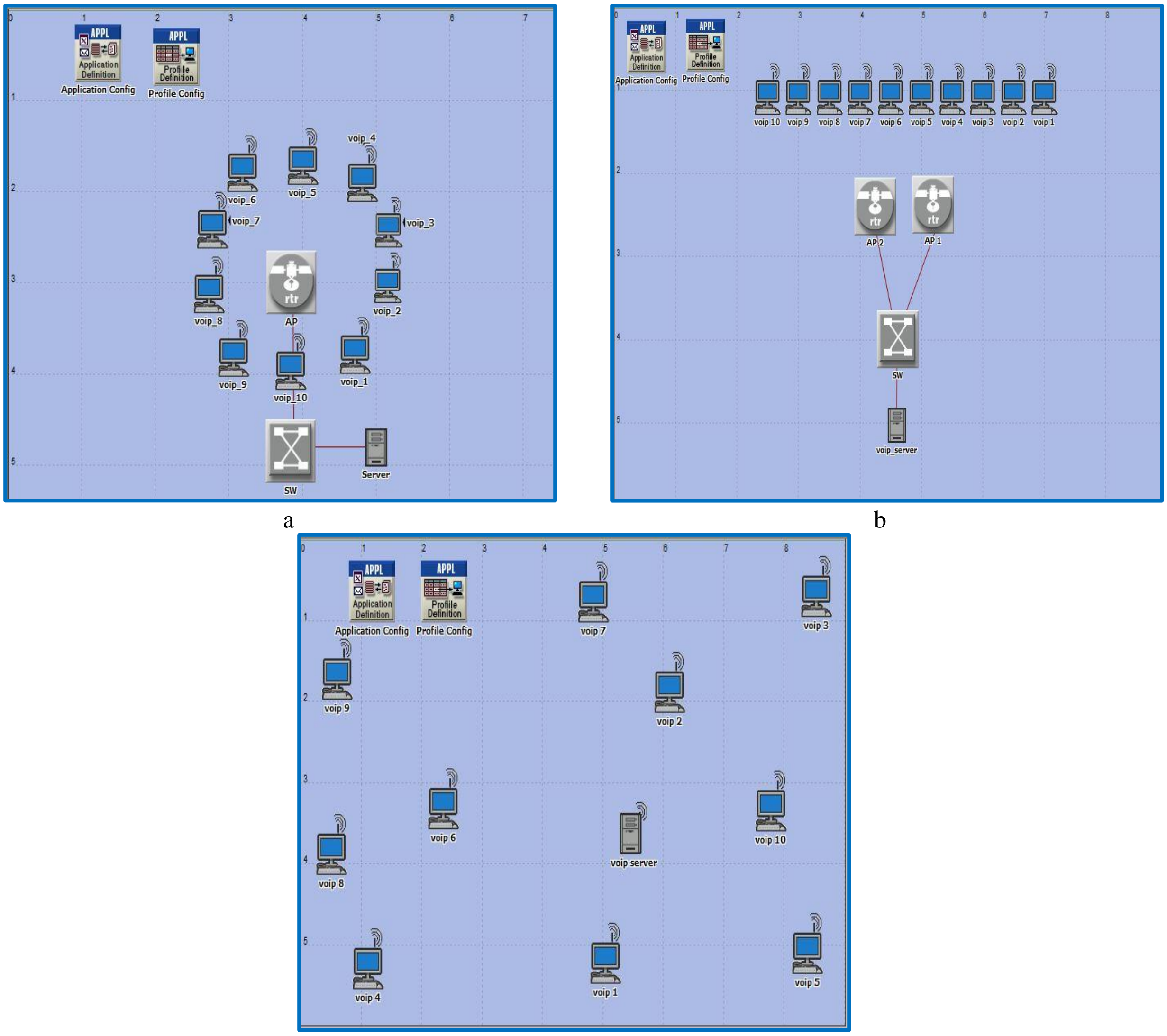


Figure 1: Flowchart of the proposed algorithm

Table 3: Simulated Application and Protocols

Parameters	Values
IEEE Technology	IEEE 802.11 (FHSS) IEEE 802.11a (OFDM) IEEE 802.11b (DSSS) IEEE 802.11g OFDM) IEEE 802.11e (QoS)
Voice frame per packet	1
Codec	G.711
Compression and Decompression delay	0.02 sec
Types of service (TOS)	Interactive voice



a

b

c

Figure 2: Design of the three Network Architectures across three Spatial Distributions for VoIP

(a) Basic Service Set (BSS), (b) Extended Service Set (ESS), (c) Independent Basic Service Set (IBSS)

3.2 System model's calculation

The system calculations and the mathematical model are shown in phase II at the bottom part of Figure 1. The inputs for the algorithm's mathematical calculations are VoIP QoS Threshold values and Cumulative Distribution Function (CDF) distribution. VoIP QoS Threshold values (satisfaction criterion) are taken from literature as shown in Table 2 [26, 27]. 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 VoIP 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 Figure 3 illustrates, the value that is produced by applying the VoIP 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).

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

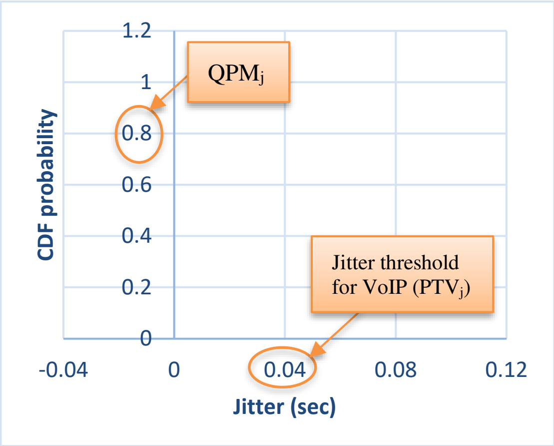


Figure 3: QPM for Jitter

- 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, L=0.1, and VL=0) is expressed by (2).

$$QFM_n = QPM_n * VIP \qquad (2)$$

- The final step will be calculating the Application Fitness Metric (AFM) which is to aggregate all QFMs for *n* VoIP QoS metric parameters (delay, jitter, throughput and packet loss), for each IEEE 802.11 technology *j*, as demonstrated by (3).

$$AFM_j = \sum_{n=1}^{4} QFM_n \qquad (3)$$

- 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 will be explained later in section 4.

The flowchart presented in Figure 1 illustrates these mathematical steps which produce the AFM value for each IEEE MAC technology.

As explained previously, CDF distribution *F(n)* [30] is going to be produced for all VoIP 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 VIP 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.

The value generated for the VoIP QoS metric parameters (jitter, delay, throughput and packet loss) will contribute to filling in Table 4 which leads to a rank order of IEEE technologies for each network architecture.

All VoIP 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.

Table 4: IEEE technologies calculation and rank order list for one project

Technology	**VOIP**				**AFM**	**Technology Rank order**
	Jitter	**Delay**	**Throughput**	**Packet Loss**		
802.11	QFM_J	QFM_D	QFM_{TH}	QFM_{PL}	AFM_{11}	Technology1
802.11a	QFM_J	QFM_D	QFM_{TH}	QFM_{PL}	AFM_{11a}	Technology2
802.11b	QFM_J	QFM_D	QFM_{TH}	QFM_{PL}	AFM_{11b}	Technology3
802.11g	QFM_J	QFM_D	QFM_{TH}	QFM_{PL}	AFM_{11g}	Technology4
802.11e	QFM_J	QFM_D	QFM_{TH}	QFM_{PL}	AFM_{11e}	Technology5

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

$$\omega_i = (ki/\rho_i) * 100\% \qquad (4)$$

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 VoIP application in all network architectures across the three spatial distributions.

4. 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. By options, the best performing technologies across all three network architectures (IBSS, BSS and ESS) is implied. All simulated scenarios are applicable to the lab (room) sizes from 2x3m to 10x14m.

The format of the results is demonstrated based on the presence of an access point; therefore, the tables of the results are interpreted (translated) in two results' flowcharts: generic flowchart and IBSS chart, as demonstrated in Figures 4 and 5, respectively.

- In case there is at least one access point in the network, then the proposed algorithm in Figure 1 and the result in Figure 4 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.

- If the network is configured without any access points, then the proposed algorithm in Figure 1 and the IBSS result's flowchart described in Figure 5 will be used. All scenarios are running in all five IEEE 802.11 technologies and three spatial distributions: circular, uniform and random.

Both results' flowcharts 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.

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 flowchart, as can be seen in Figure 4, 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 flowchart, all three technologies 802.11a, 11g, and 11e provide the best performance across all spatial distributions, according to Figure 5.
2. As shown in Figure 4, 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 three spatial distributions if they are implemented using only three technologies including 802.11a, 11g, and 11e. In the case of the IBSS result's flowchart, 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 flowchart, 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 provided in Figure 4. 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 flowchart, all three technologies 802.11a, 11g, and 11e give an identical performance.

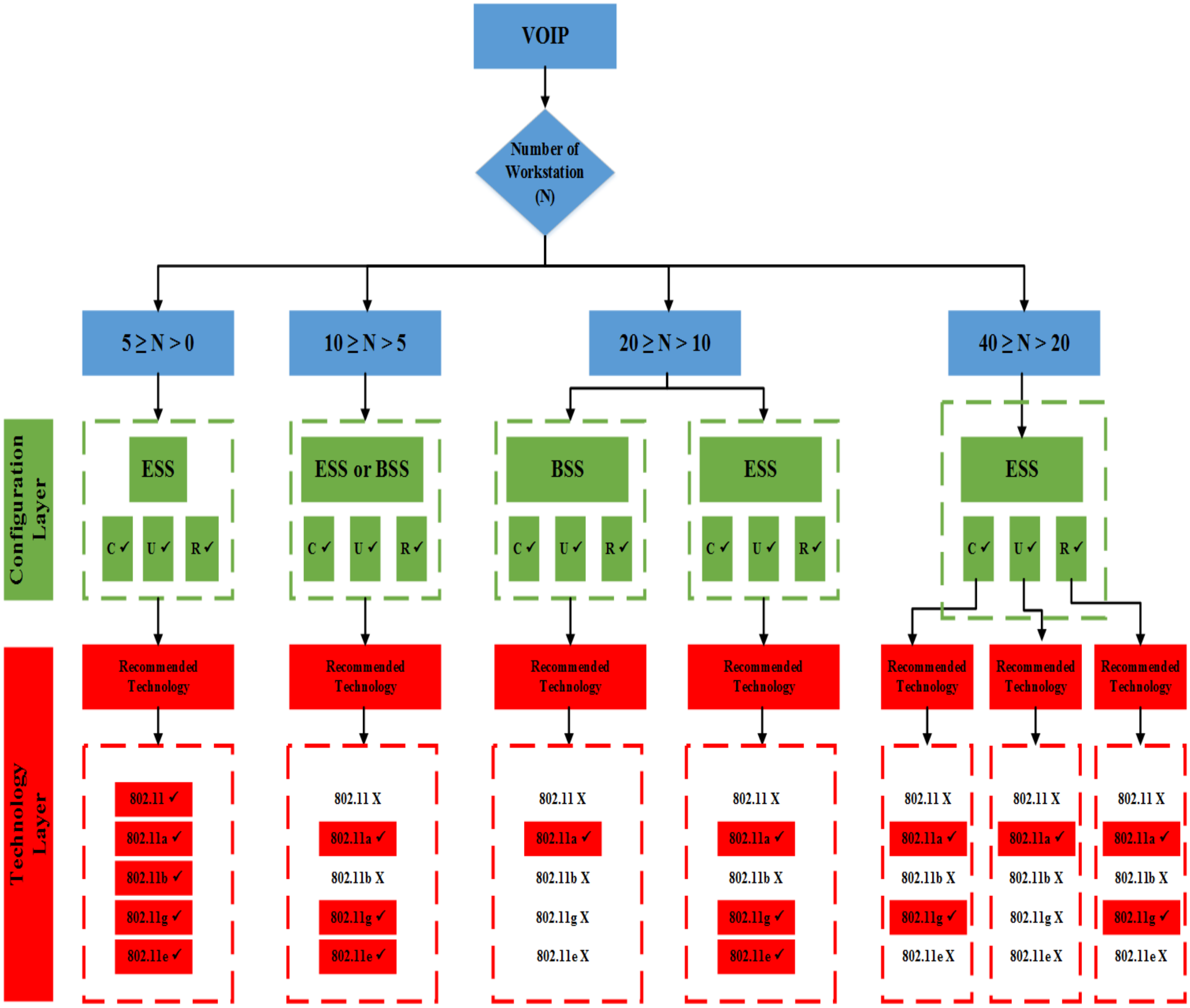


Figure 4: Generic flowchart of the proposed algorithm using various layers

5. COMPARATIVE STUDY

In this section, a brief comparison between our proposed method with multiple algorithms presented in [7, 10, 18-20, 31 and 32] will be offered. The following features have been compared and summarised in Table 5, features including: VoIP metric parameters, number of nodes, network architecture, IEEE technology, and the simulation model.

As noticed, methods such as [7] and [10] evaluates the network on the basis of fixed number of nodes, where metric parameters such as the packet loss is predominant in the calculations of the optimum network configuration. Similarly, [20, 31, and 32] evaluates different IEEE technologies on fixed number of nodes, while only considering one network architecture such as IBSS, ESS, and WiMAX.

Despite the fact that recent studies such as [18] and [19] have integrated their model using various nodes, 5-45 and 3-15, respectively. However, their proposed approaches were only validated using BSS and ESS network architectures. Another drawback associated with [18] and [19] approaches, that it only considers the evaluation of the algorithm using one IEEE standard, particularly IEEE 802.11e.

By contrast with above limitations, in this article, we present the development of a novel evaluation parametric approach that is capable of identifying the optimum network configuration using three different network architecture: BSS, ESS, and IBSS. The proposed approach has been evaluated using different node size (1 to 40) with respect to five

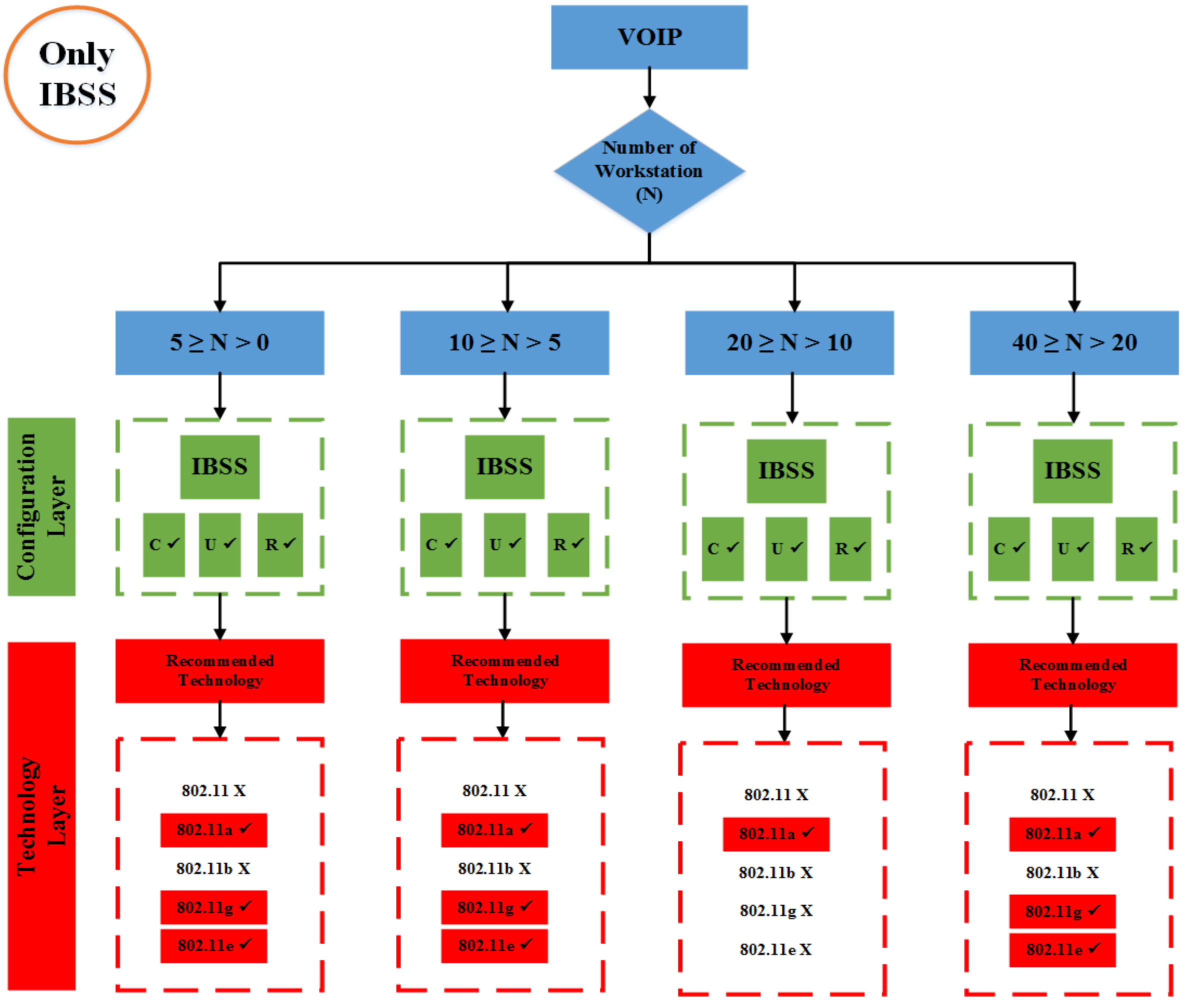


Figure 5: Flowchart of only IBSS's results

different IEEE technology standers including: 802.11, 802.11a, 802.11b, 802.11g, and 802.11e.

6. CONCLUSION

This work has developed a novel algorithm to assess VoIP QoS metrics of different IEEE 802.11 technologies in order to choose the optimum network architecture among BSS, ESS, and IBSS. The rank order of different IEEE 802.11 technologies has been produced across different spatial distributions. The results show that ESS architecture has the same performance for all spatial distributions regardless of the network size. In addition, BSS performance is degraded when the number of nodes is more than twenty. Furthermore, IBSS 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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Table 5: Comparative results between the proposed approach and several methods available in the literature

Reference	Approach	VoIP metric parameters	Number of nodes	Network Architecture	IEEE Technology	Simulation model
[7]	Study the limitations of the 802.11 (a/b) in supporting VoIP calls over a WLAN	Packet loss Jitter Round-Trip time	1	BSS	802.11b	NA
[10]	Study the problem of Voice application support in multi-hop IEEE802.11 ad hoc networks	Packet loss Bandwidth Delay	6	IBSS	802.11	OPNET
[18]	Evaluate EDCA 802.11e protocol conditions for supporting QoS in an 802.11a scenario at 36 Mbps	Average delay Queue size	5-45	BSS	802.11e	Möbius™
[19]	Evaluate the performance of VoIP in 802.11 wireless networks	End-to-end delay Jitter Throughput	3-15	ESS	802.11e	OPNET
[20]	VoIP QoS performance metrics were studied using different routing protocols	Jitter LAN delay Packets size	15	IBSS	802.11b	OPNET
[31]	VoIP performance was compared between LAN (802.3) and WLAN (802.11)	Packet loss Delay latency Jitter	5	ESS	802.11e	OPNET
[32]	Evaluate the performance of various VoIP codecs using different service classes	Throughput Average delay Jitter	2, 4, 6, 8 and 10	WiMAX	802.16	NS-2
Present study	Evaluate VoIP metrics of different IEEE 802.11 technologies in order to identify the optimum network architecture	Delay Jitter Throughput Packet loss	1-40	BSS ESS IBSS	802.11 802.11a 802.11b 802.11g 802.11e	OPNET

4553-4563, Nov. 2010, doi: 10.1109/TVT.2010.2068318.

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