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# Algorithmic Identification of the Best WLAN Protocol and Network Architecture for Internet-based Applications

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**Abstract:** This research developed a novel algorithm to evaluate internet-based services such as VoIP, Video Conferencing, HTTP and FTP, 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 good voice, video and data quality is guaranteed. Furthermore, it meets the acceptance threshold values for the VoIP, Video Conferencing, HTTP and FTP quality metrics. This algorithm was applied to various room sizes ranging from 2x3m to 10x14m and the number of nodes ranged from one to sixty-five. 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, Video Conferencing, HTTP, FTP, QoS, Performance Analysis, IEEE technologies.**

## 1. Introduction

Managing internet-based traffic such as VoIP, Video Conferencing (VC), HTTP and FTP is currently a massive challenge in the communication industry. With the rapid 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 (Kurose & Ross, 2010). WLANs are designed to boost these real-time traffics such as video streaming and online gaming. However, streaming high-quality videos over WLAN with limited bandwidth is still a challenge (Chang *et al.* 2015). Internet-based services such as web, email and file transfers affect the usage of WLANs in addition to voice over wireless networks. Exchanging traditional data such as news, text applications and file transfer has been successful using the Internet architecture. However, real-time applications are placing high demands on Internet architecture. This, in turn, affects the quality of the service and is particularly noticeable when WLAN is used, resulting in poor network performance (Timmerer & Hellwagner, 2005). Furthermore, providing precise QoS is considered as an issue for real-time multimedia applications. In order for real-time services to work adequately, the QoS parameters and characteristics performance have to be fulfilled (Seytnazarov & Kim, 2017).

### 1.1 Literature review

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. Many researchers have analysed the QoS parameters of internet-based services over WLAN technologies in a number of studies. (Garg & Kappes, 2003) 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 (Amir *et al.* 2005) 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 & Alkhoraidly, 2006) applied a novel simulation approach on a typical network of a small enterprise to evaluate the network readiness for supporting VoIP services. The VoIP QoS performance metrics were investigated by (Shi *et al.* 2008) 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 (Chen *et al.* 2011) to reduce the average delay time and jitter for VoIP application and the packet loss ratio for high-definition video. (Baldi & Ofek, 2000) analysed the end-to-end delay VC QoS metric in six system configurations obtained by combining three network architectures with two video encoding schemes in order to provide adequate end-to-end delay below 10ms.

Various efforts have been developed to evaluate the internet applications' QoS metric parameters that are configured over IEEE technologies. QoS parameters such as an end to end delay and throughput were observed by (Sharma *et al.* 2013) across two IEEE technologies 802.11, 11g and demonstrated that the IEEE 802.11a technology performed better across BSS network architecture. (Mehmood & Alturki, 2011) introduced an architecture that analysed an IBSS network for a mix of HTTP, voice and video applications over 802.11g technology to scale and provisions QoS. This architecture scales well with an increase in the network size and outperforms well-known routing protocols. VoIP QoS performance metrics were studied by (Sllame *et al.* 2015) using different routing protocols. For instance, they used only 15 nodes without considering the effect of physical layer technologies, spatial distributions, or network architecture. (Dadral, Vohra, & Sawhney, 2012) configured OFDM (802.lla) and Extended Rate PHY (802.llg) with High-Resolution VC application and evaluated them across three Mobile ad hoc networks (MANETs) routing protocols, in order to find the best performing one. However, both technologies, IEEE 802.11a and 11g, were configured by (Sharma *et al.* 2013) to observe the QoS metric parameters such as an end to end delay and throughput and demonstrated that the IEEE 802.11a performed better across BSS network architecture. In addition, (Circiumarescu *et al.* 2015) produced a comparative performance analysis to ascertain which protocol among RIP, OSPF, EIGRP and IGRP best suits the network. This study was conducted using QoS metric parameters such as packet delay variation, packet end-to-end delay and video traffic analysis to evaluate VC, E-mail, FTP and HTTP services using OPNET, and showed that the protocol that best suits VC is EIGRP. (Perez *et al.* 2015) introduced a scenario to evaluate IEEE 802.11e standard for a number of videos, voice and best effort nodes, varying from 5 to 45 nodes, and showed an increase in average delay for these services. In addition, (Cahyadi *et al.* 2019) produced a study investigates a comparison between Enhanced Distribution Channel Access (EDCA) against the "legacy" IEEE 802.11 Distributed Coordination Function (DCF) method for three traffic services e.g. voice, video streaming, and data, using an NS-3 simulator. (Dai & Xu, 2019) proposed a network stability model that can effectively reflect the network performance when the network is damaged in real time and give suggestions on how to maintain the network stability.

### 1.2 Related work

As noticed, methods such as (Pérez *et al.* 2015) and (Anouari and Haqiq 2013) have integrated their model using various nodes, 5-45 and 2-10, respectively, where metric parameters such as the average delay are predominant in the calculations of the optimum network configuration. However, their proposed approaches were only validated using BSS and WiMAX network architectures. Another drawback associated with the (Pérez *et al.* 2015) and the (Anouari and Haqiq, 2013) approaches, is that they only consider the evaluation of the algorithm using one IEEE standard, particularly IEEE 802.11e and 802.16. Similarly, (AlAlawi & Al-Aqrabi, 2015) and (Jabbar *et al.* 2014) evaluate different IEEE technologies using a varied number of nodes, while only considering one network architecture such as ESS and IBSS, respectively. On the other hand, methods such as (Salah, 2006) and (Sllame *et al.* 2015) evaluate the network on the basis of a fixed number of nodes, 9 and 15, respectively. However, their proposed approaches were only validated using BSS and IBSS network architectures. While (Chen *et al.*'s 2011) approach did not specify the number of nodes that got under evaluation analysis.

To the best of our knowledge, no previous work has evaluated the Internet-based 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 real-time 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. Moreover, as demonstrated in (Tramarin *et al.* 2015), the optimum performance of IEEE technologies deployed in real-time industrial communication systems is not always guaranteed for recent technologies (802.11n) rather than older ones (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 into issues of randomly choosing specific technologies then redesigning the whole configuration.

## 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 (IEEE Std. 802.11, 2007). 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 (Herdiniamy *et al.* 2019). In case of using a channel bandwidth up to 40 MHz, IEEE 802.11n can provide transmission speeds of up to 600 Mbps (IEEE Std. 802.11n, 2009). 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 (Babich, Comisso, & Crismani, 2014).

### 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 (Ksentini, 2005).

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 (Swain *et al.* 2015) (i.e. access point).

### 2.3 QoS performance metrics and Importance coefficient for Internet-based applications

Performance metrics are defined in terms of QoS metric parameters for the applications. For each application, a satisfaction criterion (acceptable threshold) for each QoS metric parameter is identified (Ghiata & Marcu, 2011; Hattingh & Szigeti, 2004) as shown in Table 1, which represents the key QoS requirements and recommendations for each application (bearer traffic).

Internet-based applications' quality is directly affected by the following QoS metric measurements:

- Packet End-to-End delay (sec): the time is 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.

**Table 1** QoS metric parameters importance for internet-based applications

| 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 |
| HTTP | Importance | M | VL | L | L |
| | Threshold | 1 | 0 | 30 | 10 |
| FTP | Importance | L | VL | M | H |
| | Threshold | 1 | 0 | 45 | 5 |

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

It is worth noting that an Important Coefficient is assigned to each application Parameter (ICP) in terms of its impact on the quality of the service. Table 1 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, 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 *(riverbed, 2012)* is used to build and analyse all applications 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 define the number of nodes that are needed in the network and spatial distribution. Technology specifications (standards) define the physical layer technologies and network architectures. The top part of Fig. 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 five groups (0-5, 6-10, 11-20, 21-40 and 41-65), spatial distribution which specifies the topology in which these nodes will be distributed – in a circular (oval) way, uniform way, or randomly scattered way. A considered number of nodes, up to 65, is in line with the literature Salah (2006), *(Mehmood & Alturki, 2011)*, (Perez et al. 2015) and (Anouari and Haqiq, 2013). On the other hand, it was found that all observed results obtained using these five groups of nodes are suitable for maintaining the network performance's quality; that is, a larger number of nodes in the network implies that a small amount of traffic will cause performance degradation in the network due to fixed network bandwidth capacity. This has been only validated using a room size of 2x3m to 10x14m since standard room size of a typical University/College/school laboratory is within this range.

The performances of different scenarios for each application have been investigated via an OPNET simulator, Figs. 2(a), (b) and (c) show some of these implemented scenarios. The IEEE MAC layer technologies used were 802.11 (FHSS), 802.11a (OFDM), 802.11b (DSSS) and 802.11g (OFDM). IEEE Technologies define the physical layer technologies that will be used to build many different 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. In addition, the VC traffic parameters configuration is: the frame interarrival time is 15 frame/sec and frame size information of 128x240 pixels (bytes). On the other hand, HTTP 1.1 is used along with 50 KB FTP file size.

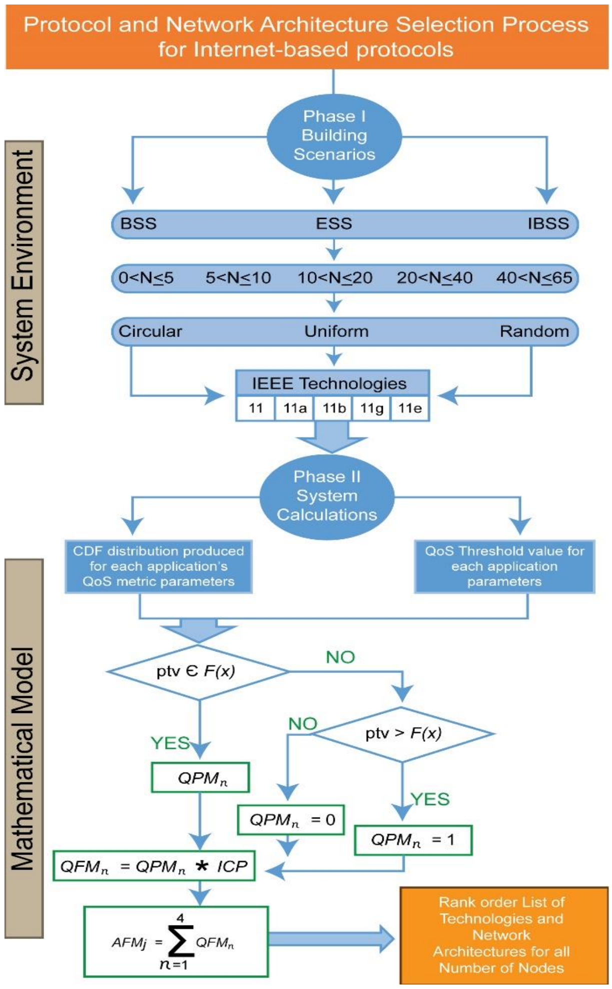


**Fig. 1.** Flowchart of the proposed algorithm

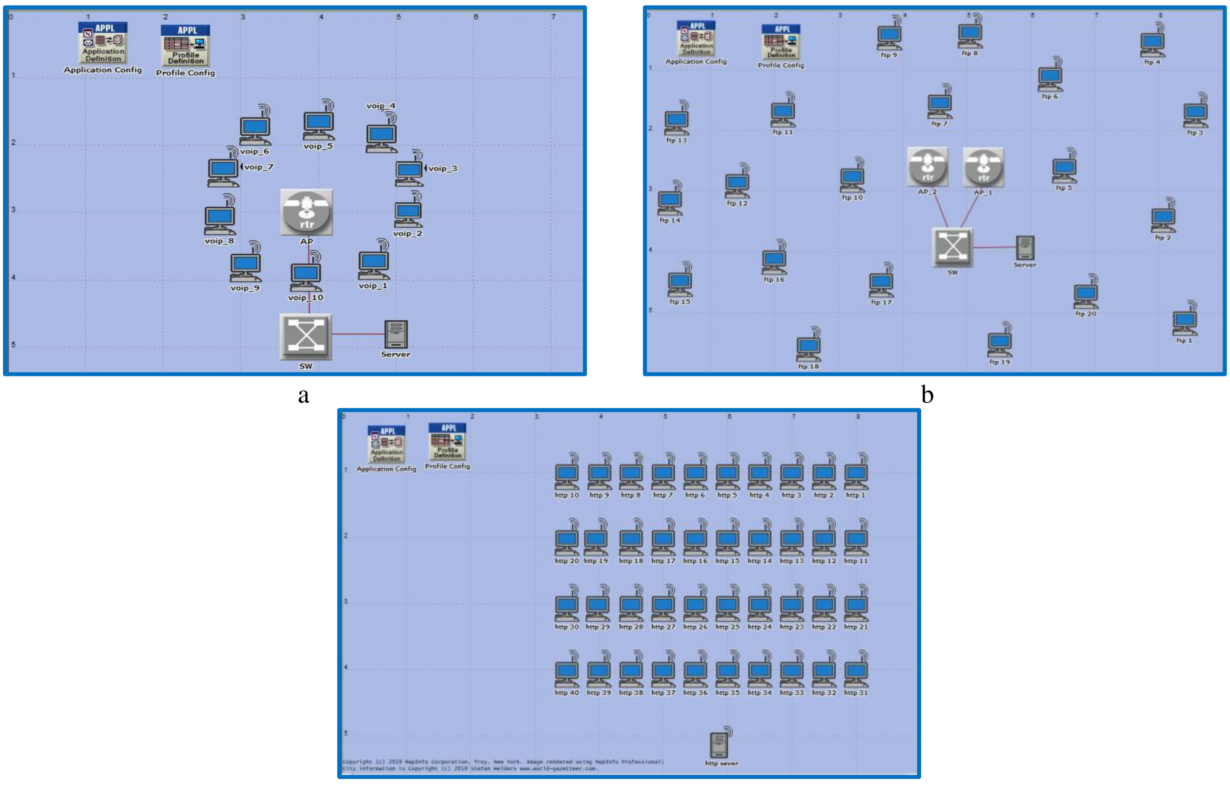


**Fig. 2.** Design of the three Network Architectures across three Spatial Distributions for VoIP, FTP and HTTP **(a)** Basic Service Set (BSS), **(b)** Extended Service Set (ESS), **(c)** Independent Basic Service Set (IBSS)

### 3.2 System model's calculation

The system calculations and the mathematical model are shown in phase II at the bottom part of Fig. 1. The inputs for the algorithm's mathematical calculations are QoS Threshold values for each application and Cumulative Distribution Function (CDF) distribution. Applications QoS Threshold values (satisfaction criterion) are taken from literature as shown in Table 1 (Ghiata & Marcu, 2011; Hattingh & Szigeti, 2004). 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. 3 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).

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

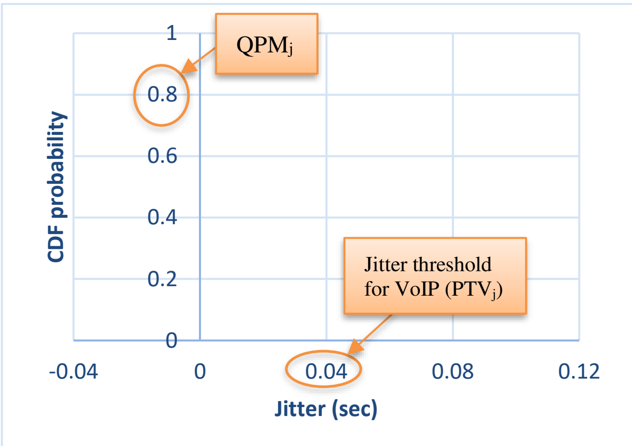


**Fig. 3.** QPM for Jitter

As predefined in Fig. 3 and Table 1, the acceptable threshold for jitter parameter for VoIP application is 0.04 sec, therefore 80% of the packets are delayed by less than 0.04 sec. which represent the QPM for this QoS parameter. Therefore, the QPM tells us what the probability is that each VoIP metric parameter is adequate.

- 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).

$$QFM_n = QPM_n * ICP \quad (2)$$

The importance coefficient for the same QoS parameter as shown in Table 1 is High (H=1), so the QFM is equal to 0.8 weighted by 1; that produces 0.8. That is the performance metric for jitter. So, 80% of adequacy multiplied by the importance coefficient (H=1).

- 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).

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

- 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.

The flowchart presented in Fig. 1 illustrates these mathematical steps which produce the AFM value for each IEEE MAC technology. As explained previously, CDF distribution *F(n)* (Yates & Goodman, 2014) 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 ICP 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 increased.
3. If *ptv* < *F(n)*: it means that the *QPM* value equals 0 and *QFM* will be initialized.

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 $\omega_i$ of a node *i* is the ratio of dropped voice packet $k_i$ to total voice packets $\rho_i$ multiplied by 100%, as demonstrated by (4).

$$\omega_i = ( ki/\rho_i) * 100\% \tag{4}$$

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 all five groups of nodes, 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.

It is appreciated that to guaranty the availability of all applications in the mix of applications being simulated the parameters (against which thresholds are applied) must be considered in their joint statistical relationships. It is, however, suggested that considering the individual (not joint) statistics of the parameters and combining them using the methodology proposed is likely to yield a useful (if not definitive) comparative metric for overall performance.

## 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. The results are divided into four main sections related to the internet-based applications (VoIP, VC, HTTP and FTP). All simulated scenarios are applicable to 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 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 flowchart results in Figs. 4, 6, 8 and 10 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 Fig. 1 and the IBSS result's flowchart described in Figs. 5, 7, 9 and 11 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 65 nodes.

### 4.1 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 five key groups of nodes, presented as follows:

1. The first category, where $5 \geq N > 0$, in the generic flowchart, as can be seen in Fig. 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 Fig. 5.
2. As shown in Fig. 4, when $10 \geqslant N > 5$, 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.

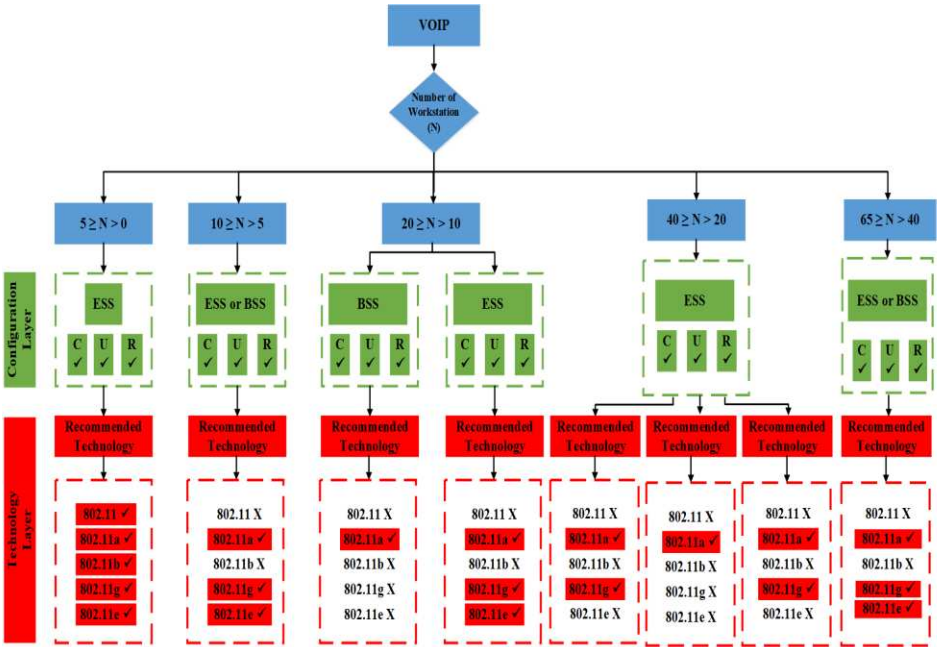


**Fig. 4** Generic flowchart of the proposed algorithm for VoIP

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 Fig. 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.
5. In the fifth category, where 65 ⩾ N > 40, in the generic flowchart, as can be seen in Figs. 4, 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. While, in the IBSS flowchart, the technologies 802.11a, 11g and 11e provide the user the best performance to use for all spatial distributions thanks to their higher throughput adequacy which makes the difference, as shown in Fig. 5.

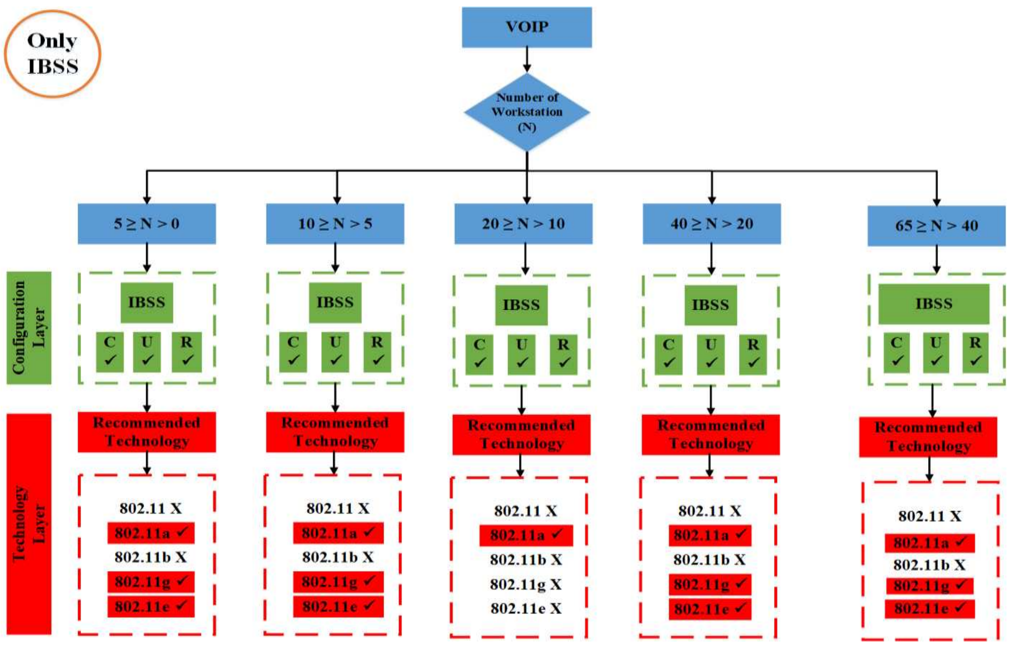


**Fig. 5** Flowchart of only IBSS's results for VoIP

### 4.2 Results of VC

1. In the first category, where 5 ≥ N > 0, as can be seen in Fig. 6, if the client is going to build a small network, then BSS is the best network architecture. Additionally, the client has a number of options to select. 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. This is because the packet delay's performance metric for both selected technologies yields a 100% adequacy. However, in the case of IBSS, the 802.11g technology provides the best performance which is configured randomly as shown in Fig. 7.
2. As shown in Fig. 6, 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 an optimum performance that is configured uniformly and 802.11g has been implemented. This is because the performance metric for packet delay variation yields 80% adequacy. But, in the case of IBSS, both technologies 802.11 and 11b provide the client with the best performance across all spatial distributions as shown in Fig. 7.
3. In 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 BSS provides the best option. Moreover, the client has a number of options to select according to the information provided in Fig. 6. IEEE 802.11a, 11g and 11e are acknowledged as the preferable solutions across three spatial distributions, because they provide higher throughput adequacy for both uplink and downlink than other technologies. On the other hand, in IBSS, both IEEE 802.11 and 11b perform well across all spatial distributions.
4. In the fourth category, where 40 ⩾ N > 20, both BSS and ESS provide a number of options. For BSS architecture, IEEE 802.11g and 11e technologies perform well only if the network is configured circularly and uniformly. Further, IEEE 802.11a technology performs well only if it is configured uniformly. On the other hand, ESS provides a number of options. IEEE 802.11a, 11g and 11e technologies are acknowledged as the preferable solutions only if the network is configured in uniform and random distributions. In addition, both IEEE 802.11a and 11b technologies provide the optimum performance if they are configured circularly or uniformly thanks to a slightly higher difference in their throughput performance metric adequacy, which is about 0.006, as shown in Fig. 6. While, in the IBSS results, both technologies 802.11 and 11b provide the user with the best performance to use for all spatial distributions.
5. In the fifth category, where 65 ⩾ N > 40, in the generic flowchart, as can be seen in Figs. 6, the optimum network architecture performance for this large network is ESS. Furthermore, the client has a number of choices if setting up this large network. 802.11a, 11g and 11e technologies provide the user the best performance to use for all spatial distributions. While, in the IBSS flowchart, the technologies 802.11a, 11g and 11e provide the user the best performance to use for all spatial distributions thanks to their higher throughput adequacy which makes the difference, as shown in Fig. 7.

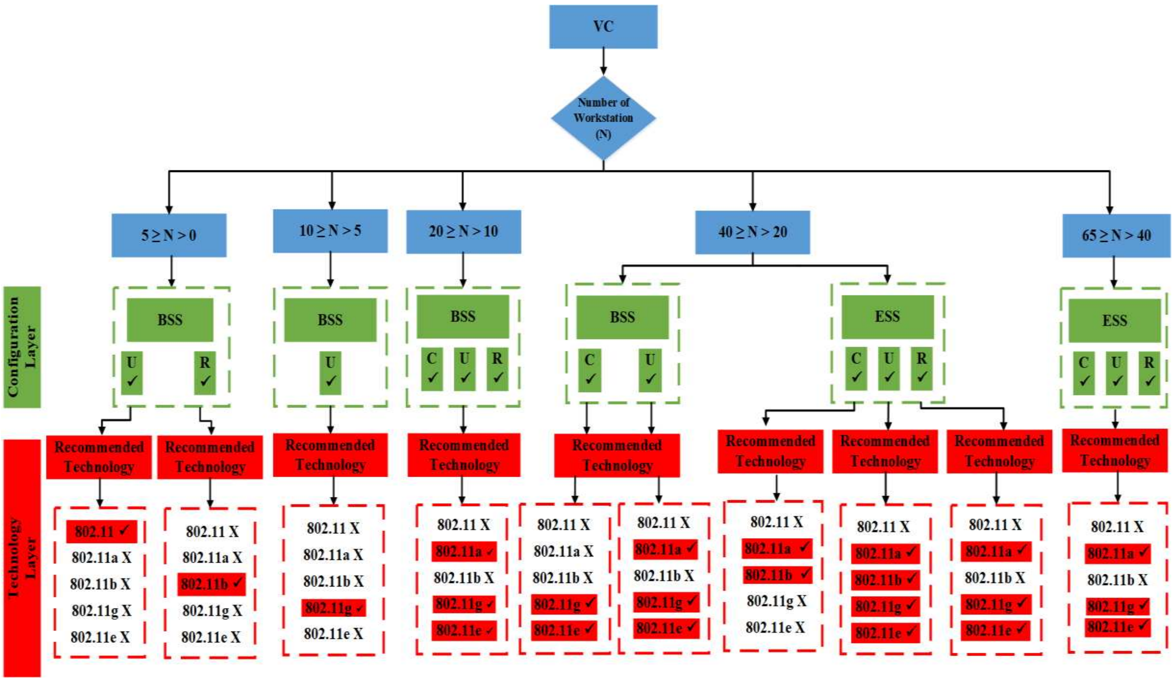


**Fig. 6** Generic flowchart of the proposed algorithm for VC

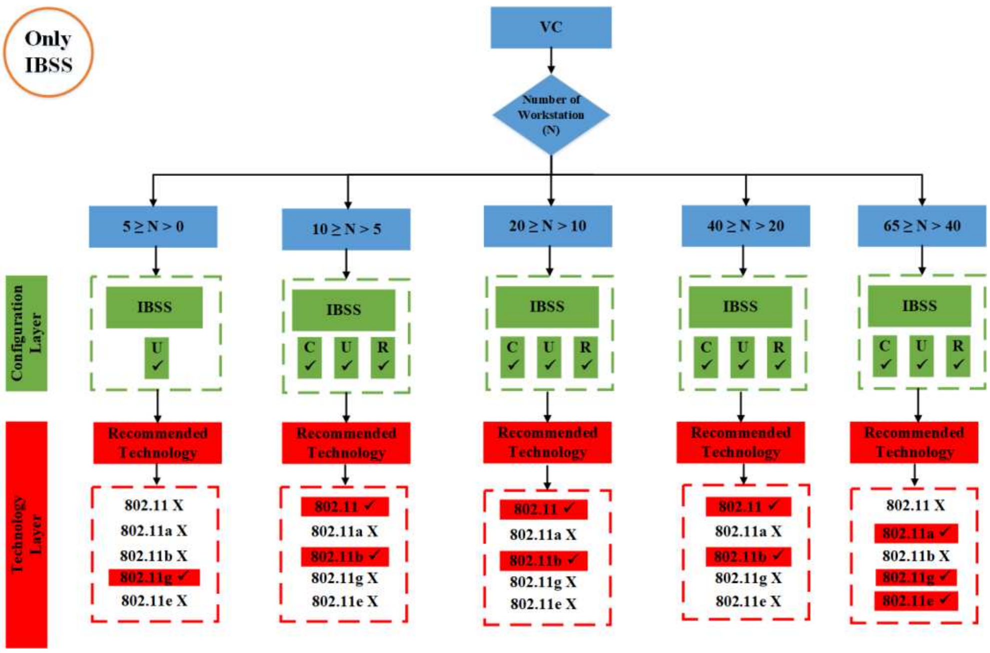


**Fig. 7** Flowchart of only IBSS's results for VC

### 4.3 Results of HTTP

1. In the first, second and fourth categories, where 5 ≥ N > 0, 10 ⩾ N > 5 and 40 ⩾ N > 20, respectively, in the generic flowchart, as can be seen in Fig. 8, both architectures BSS and ESS provide the best performance across all spatial distributions for all five technologies. However, in the case of IBSS, for the first group of nodes, the client has a number of options to select according to the information provided in Fig. 9. First, 802.11 is the optimal technology to use if it is only configured in uniform distribution. The second option is to use 802.11b technology which is configured randomly thanks to a slightly higher difference in their packet loss performance metric adequacy which is about 0.098. For the second group of nodes, IBSS provides a number of options. First, 802.11 technology is the optimum to use across all spatial distributions. In addition, both technologies 802.11b and 11g are optimal to use if the network is only configured in circular and random distributions, respectively.
2. The third category, where 20 ⩾ N > 10, in the generic flowchart, both BSS and ESS provide a number of options. For BSS architecture, the five technologies perform well across all three spatial distributions. However, IEEE 802.11, 11b and 11g technologies are acknowledged as the preferable solutions for ESS. On the other hand, according to the IBSS flowchart, for the third and fourth categories, all IEEE technologies perform well for all spatial distribution as can be seen in Fig. 9.

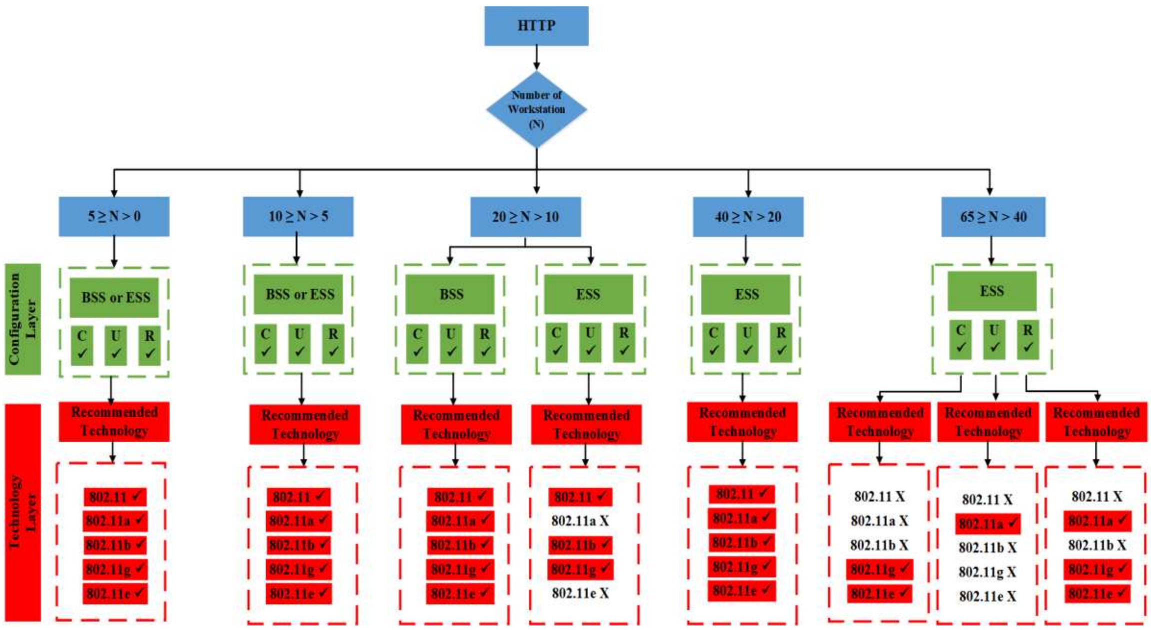


**Fig. 8** Generic flowchart of the proposed algorithm for HTTP

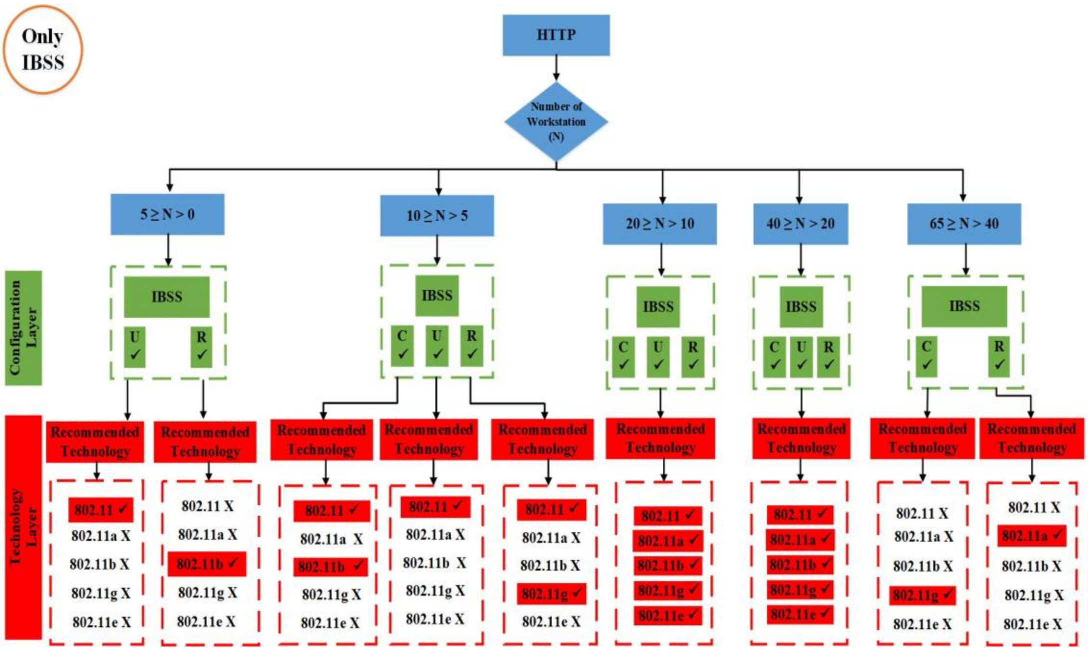


**Fig. 9** Flowchart of only IBSS's results for HTTP

3. In the fifth category, where 65 ⩾ N > 40, in the generic flowchart, as can be seen in Figs. 8, the best architecture for this large network is ESS. Subsequently, the client has a number of options to select. First, both technologies 802.11g and 11e 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 and randomly. On the other hand, in the IBSS flowchart, the client has a number of options to select. First, 802.11g is the optimal technology to use if it is only configured in circular distribution. The second-best option is to use 802.11a technology which is configured randomly, as shown in Fig. 9.

### 4.4 Results of FTP

1. In the first category, where 5 ≥ N > 0, in the generic flowchart, as shown in Fig. 10, BSS is the best network architecture. Both technologies 802.11a and 11e are optimal to use across all spatial distributions thanks to a slightly higher difference in their packet loss performance metric adequacy than other technologies. However, according to the IBSS flowchart, both technologies 802.11b and 11g are considered as preferable solutions only if they are configured in a circular and uniform way, respectively, as shown in Fig. 11.
2. In the second category, where 10 ⩾ N > 5, the BSS and ESS provide a number of options. BSS and ESS provide optimum performance if the network is configured circularly and uniformly, respectively, for all five technologies. However, according to the IBSS flowchart, all technologies perform well across all spatial distributions.

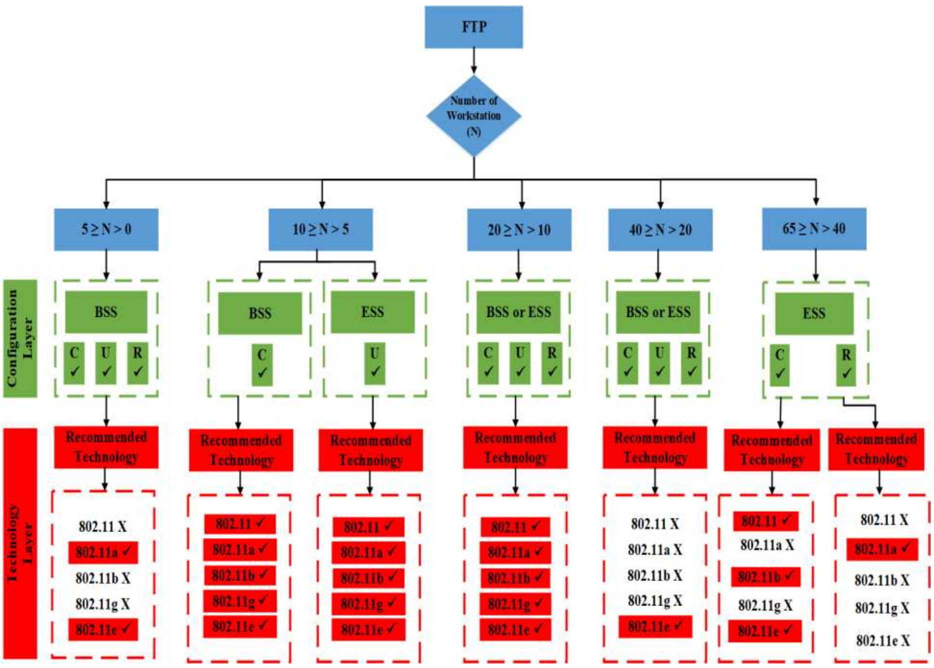


**Fig. 10** Generic flowchart of the proposed algorithm for FTP

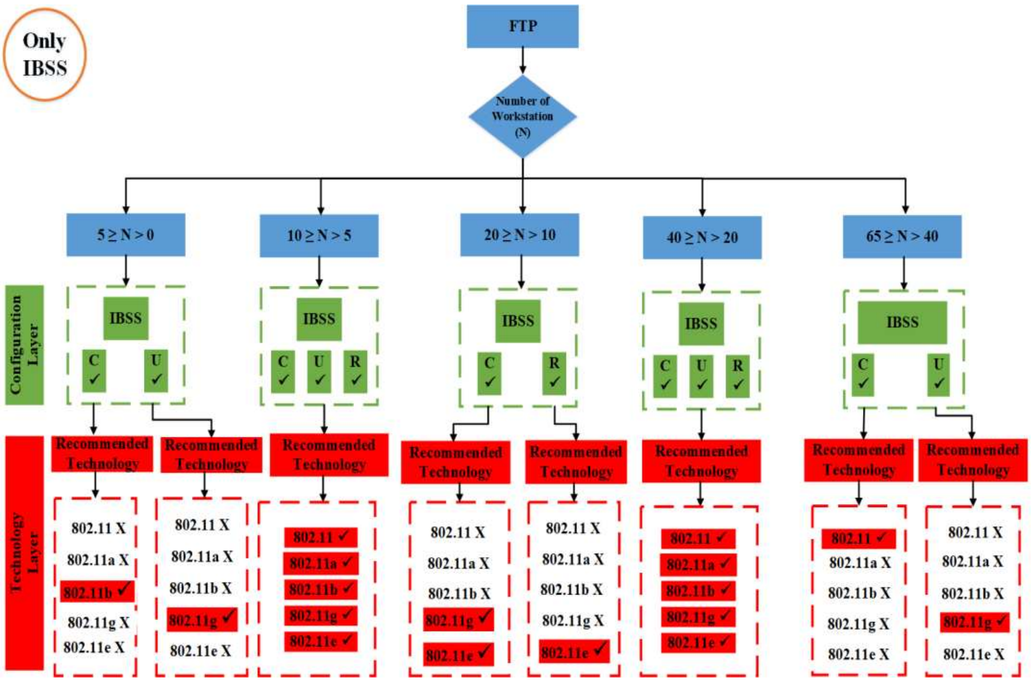


**Fig. 11** Flowchart of only IBSS's results for FTP

3. In the third category, where 20 ⩾ N > 10, as can be seen in Fig. 10, both architectures BSS and ESS provide the best performance across all spatial distributions for all five technologies. However, in the case of IBSS, the client has a number of options to select according to the information provided in Fig. 11. First, both 802.11g and 11e are the optimal technologies to use only if it is configured in circular distribution. The second option is to use 802.11e technology if it is configured randomly, thanks to a slightly higher difference in their packet loss performance metric adequacy.
4. While, for the fourth category, where 40 ⩾ N > 20, both ESS and BSS provide optimum performance across all three spatial distributions if they are implemented using only IEEE 802.11e technology. However, according to the IBSS flowchart, all technologies perform well across all spatial distributions as shown in Fig. 11.
5. In the fifth category, where 65 ⩾ N > 40, in the generic flowchart, as can be seen in Figs. 10, the best architecture for this large network is ESS. Subsequently, the client has a number of options to select. First, both technologies 802.11, 11b and 11e are optimal to use if the network is only configured in circular distribution; while the second-best option is to use IEEE 802.11a technology that is configured randomly. On the other hand, in the IBSS flowchart, the client has a number of options to select. First, 802.11 is the optimal technology to use if it is only configured in circular distribution. The second-best option is to use 802.11g technology which is configured uniformly, as shown in Fig. 11.

## 5. Conclusion

This work has developed a novel algorithm to assess internet-based applications 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 of VC and FTP applications show that it is only preferable to use the ESS network with a high number of workstations/nodes in both applications; 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, for VC, the uniform distribution is an option for all network architectures. While for FTP, almost all IEEE technologies work for all spatial distributions.

Furthermore, IBSS can be worked efficiently with both technologies 802.11 and 802.11b for almost all selected numbers of nodes for VC, whereas almost all technologies perform for FTP. On the other hand, ESS architecture has the same performance for all spatial distributions regardless of the network size for both applications, VoIP and HTTP. Notwithstanding BSS performance is degraded when the number of nodes is more than twenty in the case of VoIP, it works well with any number of nodes in the case of HTTP. Furthermore, the results of HTTP show that IBSS performs well with 802.11 technology in a small network size and with all technologies in bigger sizes, but the VoIP's result shows 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.

**REFERENCES**


Aagela, H., Holmes, V., Dhimish, M., & Wilson, D. (2017.). Impact of video streaming quality on bandwidth in humanoid robot NAO connected to the cloud. In Proceedings of the Second International Conference on Internet of things, Data and Cloud Computing (p. 134). ACM.

AlAlawi, K., & Al-Aqrabi, H. (2015). Quality of service evaluation of VoIP over wireless networks. GCC Conference and Exhibition (GCCCE) (pp. 1-6). IEEE.

Amir, Y., Danilov, C., Goose, S., Hedqvist, D., & Terzis, A. (2005). 1-800-OVERLAYS: Using Overlay Networks to Improve VoIP Quality. Proceedings of the international workshop on Network and operating systems support for digital audio and video (pp. 51-56). ACM.

Anouari, T., & Haqiq, A. ( 2013). Performance analysis of VoIP traffic in WiMAX using various service classes. arXiv preprint arXiv:1308.0223.

Babich, F., Comisso, M., & Crismani, A. (2014). Considerations on the multiplexing and diversity tradeoff in IEEE 802.11 networks. IET Communications, 1551-1559.

Bahr , M. (2006). Proposed routing for IEEE 802.11s WLAN mesh networks. Proceedings of the 2nd annual international workshop on Wireless internet (p. 5). ACM.

Baldi, M., & Ofek, Y. (2000). End-to-end delay analysis of videoconferencing over packet-switched networks. IEEE/ACM Transactions On Networking, 479-492.

Bertin, P., Lebeugle, F., & Journé, T. (2003). WLAN standards and evolutions. Annales Des Télécommunications, 337-368.

Cahyadi, E., R. Raihan, M., Danisya, A., & Hwang, M. (2019). The QoS Trade-off in IEEE 802.11n EDCA and DCF for Voice,Video, and Data Traffic. IEEE International Conference on Consumer Electronics. Taiwan (ICCE-TW): IEEE.

Calyam, P., & Lee, C.-G. (2005). Characterizing voice and video traffic behavior over the Internet. New Trends in Computer Networks, 83-92.

Chang, C.-Y., Yen, H.-C., Lin, C.-C., & Deng, D.-J. (2015). QoS/QoE support for H. 264/AVC video stream in IEEE 802.11 ac WLANs. IEEE Systems Journal, 2546-2555.

Chen, J.-L., Liu, S.-W., Wu, S.-L., & Chen, M.-C. (2011). Cross-layer and cognitive QoS management system for next-generation networking. INTERNATIONAL JOURNAL OF COMMUNICATION SYSTEMS, 1150-1162.

Circiumarescu, L., Predusca, G., Angelescu, N., & Puchianu, D. (2015). Comparative analysis of protocol RIP, OSPF, RIGRP and IGRP for service video conferencing, E-mail, FTP, HTTP. 20th International Conference on Control Systems and Computer Science (pp. 584-589). IEEE.

Dadral, P., Vohra, R., & Sawhney, R. (2012). Metrics improvement of MANET using reactive protocols approach. 2nd IEEE International Conference on Parallel, Distributed and Grid Computing (pp. 73-78). IEEE.

Dai, J., & Xu, X. (2019). A Analysis of Attack and Defense Mobile Ad Hoc Network Based on OPNET. IOP Conference Series: Materials Science and Engineering. IOP Publishing.

Dong, P., Wang, J., Wang, H., & Pan, Y. (2015). Boosting VoIP capacity via service differentiation in IEEE 802.11 e EDCA networks. nternational Journal of Distributed Sensor Networks.

El-Mougy, A., Ibnkahla, M., & Hegazy, L. (2015). Software-defined wireless network architectures for the Internet-of-Things. IEEE 40th Local Computer Networks Conference Workshops (LCN Workshops) (pp. 804-811). IEEE.

Garg, S., & Kappes, M. (2003). Can I add a VoIP call? IEEE International Conference on Communications (pp. 779-783). IEEE.

Ghannay, S., Gammar, S., & Kamoun, F. (2008). Comparison of proposed path selection protocols for IEEE 802.11 s WLAN mesh networks. Joint IFIP Wireless and Mobile Networking Conference (pp. 17-28). Springer.

Ghiata, N., & Marcu, M. (2011). Measurement methods for QoS in VoIP review. Ultra Modern Telecommunications and Control Systems and Workshops (ICUMT) (pp. 1-6). IEEE.

Hattingh , C., & Szigeti, T. (2004). End-to-End QoS Network Design: Quality of Service in LANs, WANs, and VPNs.

Herdiniamy, I., Cahyadi, E., Nugraha, E., Yuliantoro, P., & Hwang, M.-S. (2019). RTS Threshold Variation Study on Contention-based IEEE 802.11n EDCA for Real-time Services.

Hussain, T., Marimuthu, P., & Habib, S. (2014). Supporting multimedia applications through network redesign. International Journal of Communication Systems, 430-448.

(n.d.). IEEE Std. 802.11-2007, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY), June 2007. IEEE.

(n.d.). IEEE Std. 802.11n-2009, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 5: Enhancements for Higher Throughput, Oct. 2009.

IET Digital Library. (n.d.). Author Guide - IET Research Journals. Retrieved November 27, 2014, from IET Digital Library: http://digital-library.theiet.org/journals/author-guide

Jabbar, W., Ismail, M., & Nordin, R. (2014). On the performance of the current MANET routing protocols for VoIP, HTTP, and FTP applications. Journal of Computer Networks and Communications.

Kelly, G. (n.d.). 802.11ac vs 802.11n WiFi: What's The Difference?. Retrieved from. Retrieved from https://www.forbes.com/sites/gordonkelly/2014/12/30/802-11ac-vs-802-11n-wifi-whats-t difference/#684679413957.

Ksentini, A. (2005). Quality of service (QoS) in IEEE 802.11-based Wireless Local Area Networks (WLAN) . Cergy-Pontoise University.

Kurose, J., & Ross, K. (2010). A top down approach featuring the internet. Peorsoim Addison Wesley.

Lakrami, F., El-Kamili, M., & Elkamoun, N. (2016). Towards the Enhancement of QoS in 802.11 e for Ad Hoc Networks. International Symposium on Ubiquitous Networking (pp. 95-107). Springer.

Lampropoulos, G., Passas, N., Kaloxylos, A., & Merakos, L. (2007). A flexible UMTS/WLAN architecture for improved network performance. Wireless Personal Communications, 889-906.

Mehmood, R., & Alturki, R. (2011). A scalable multimedia QoS architecture for ad hoc networks. Multimedia Tools and Applications, 551-568.

Mohanty, S. (2006). A new architecture for 3G and WLAN integration and inter-system handover management. Wireless Networks , 733-745.

Perez, S., Facchini, H., Dantiacq, A., Cangemi, G., & Campos, J. (2015). An evaluation of QoS for intensive video traffic over 802.11 e WLANs. 2015 International Conference on Electronics, Communications and Computers (CONIELECOMP) (pp. 8-15). IEEE.

riverbed. (2012). Retrieved from opnet: www.opnet.com

Salah, K. (2006). Analytic approach for deploying desktop video conferencing. IEE Proceedings-Communications (pp. 434-444). IET.

Salah, K., & Alkhoraidly, A. (2006). An OPNET-based Simulation Approach for Deploying VoIP . International Journal of Network Management, 159-183.

Salah, K., Calyam, P., & Buhari, M. (2008). International Journal of Communication Systems. Journal of Network and Computer Applications, 921-943.

Seytnazarov, S., & Kim, Y.-T. (2017). QoS-Aware Adaptive A-MPDU Aggregation Scheduler for Voice Traffic in Aggregation-Enabled High Throughput WLANs. IEEE TRANSACTIONS ON MOBILE COMPUTING, 2862-2875.

Sharma, V., Malhotra, J., & Singh, H. (2013). Quality of Service (QoS) evaluation of IEEE 802.11 WLAN using different PHY-Layer Standards. Optik-International Journal for Light and Electron Optics, 357-360.

Shi, L., Fapojuwo, A., Viberg, N., Hoople, W., & Chan, N. (2008). Methods for Calculating Bandwidth, Delay, and Packet Loss Metrics in Multi-hop IEEE802.11 Ad Hoc Networks. IEEE Vehicular Technology Conference (pp. 103-107). IEEE.

Sllame, A., Raey, A., Mohamed, B., & Alagel, A. (2015). Performance comparison of VoIP over wireless ad hoc networks using different routing protocols and queuing techniques. International Symposium on Networks, Computers and Communications (pp. 1-6). IEEE.

Swain, P., Chakraborty, S., Nandi, S., & Bhaduri, P. (2015). Performance Modeling and Analysis of IEEE 802.11 IBSS PSM in Different Traffic Conditions. IEEE Transactions on Mobile Computing, 1644-1658.

Timmerer, C., & Hellwagner, H. (2005). Interoperable Adaptive Multimedia Communication. IEEE Multimedia, 74-79.

Tramarin, F., Vitturi, S., Luvisotto, M., & Zanella, A. (2015). On the use of IEEE 802.11 n for industrial communications. IEEE Transactions on Industrial Informatics, 1877-1886.

Wu, S.-L., & Tseng, Y.-C. (2007). Wireless Ad Hoc Networking—Personal-Area, Local-Area, and the Sensory-Area Networks. Taylor & Francis Group.

Yates, R., & Goodman, D. (2014). Probability and stochastic processes: a friendly introduction for electrical and computer engineers. John Wiley & Sons.

Zhou, L., Chen, L., Pung, H., & Ngoh, L. (2011). Identifying QoS violations through statistical end-to-end analysis. International Journal of Communication Systems, 1388-1406.