Algorithmic Protocol and Network Configuration Selection for WLAN Performance Optimization Conditioned by Service Mix

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Copyright statement

In the memory of ***Mohammed*** *(26 October 2012) and* ***Yousef*** *(30 March 2019). Wonderful men with great affection who will be remembered fondly without a doubt.*

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Publications

Journal Articles

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3. Mohd Ali, A., Dhimish, M., Alsmadi, M., & Mather, P. (**2020**). Algorithmic Identification of the Best WLAN Protocol and Network Architecture for Internet-Based Applications. *Journal of Information and Knowledge Management*, *19*(1), 2040011.
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6. Mohd Ali, A., Dhimish, M., Alsmadi, M., & Mather, P. An Algorithmic Approach to Identify the Optimum Network Architecture and WLAN Protocol for VoIP Application. *Wireless Personal Communications. Submitted (under review).*

Conference Proceedings

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3. Mohd Ali, A., Dhimish, M., & Glover, I. (**2020**, January). WLAN Protocol and Network Architecture Identification for Service Mix Applications. In *Academicsera 57th International Conference* (pp. 13-19). World Research Library.

Awards

1. Academics World Excellent Paper Award for the paper entitled "WLAN Protocol and Network Architecture Selection for Real-Time Application" presented at the academic world international conference held in London, UK on 18^{th} – 19^{th} August **2019**.
2. Certificate of a technical session chair and invited speaker at the academic international conference held in Jeddah, Saudi Arabia on 14^{th} – 15^{th} November **2019**.

Abstract

This thesis has established a new algorithm to analyse both the real-time and the best-effort services of the different IEEE 802.11 technologies to describe the optimal networking architecture among Basic Service Set (BSS), Extended Service Set (ESS) or Independent Basic Service Set (IBSS). A ranking of the IEEE 802.11 technologies is provided by the proposed algorithm.

This is empirical research that involves modelling techniques and numerical data analysis, as well as a list of case studies and observations to address the reliability of WLAN optimization. This thesis provides an overview of five applications (VoIP, Video Conferencing, HTTP, FTP and Email) of differing proportions for three spatial distributions (Circular, Random, Uniform) as a research study. The stand-alone application refers to configurations and the implementations are all specific to a single application for that design. Mixed applications refer to a variety of services that are running and configured at predefined percentages in those specific scenarios. The algorithm has been implemented for various room sizes between 2x3 m and 10x14 m and the number of nodes varying between one and sixty-five. Delay, jitter, throughput, and packet loss are the Quality of Service (QoS) metrics used. Moreover, it fulfils the VoIP, Video Conferencing, HTTP, FTP and E-mail metrics acceptance threshold values.

A detailed review of existing methods showed that the optimal efficiency of IEEE technologies deployed in real-time industrial wireless communication is not always assured by modern technology (802.11n) as opposed to older technology (802.11 g). Furthermore, each IEEE 802.11 technology has its unique physical design and different parameters settings, such as Contention Window (CW), Transmission Opportunity (TXOP) and each standard in the 802.11 family has its strengths and weaknesses, which is precisely why this research offers an analysis report that recommends an optimal technology and network configuration for the user/client without wasting resources or getting involved in blindly selecting different technologies and then redesigning the whole system.

This research involves a range of variables and generates a list of choices for the client. A trade-off between speed and cost is likely to take place. It is not the case that clients should always select the highest data rate because it can be too expensive for them. What they want to see is the cost-performance data so that they can select a service at rates that they are able to accept at a price they are willing to pay.

The ultimate use of the results of this research leads to the development of a web-based tool linked to the results of this study, which uses a database generated by a comprehensive collection of system simulations to objectively select an acceptable wireless protocol based on user requirements. Algorithm results' feedback that been received from users includes universities, colleges, architect/engineer groups, and academics/students using the WPNAS algorithm shows that 61% of respondents prefer mixed services as suitable for their use. For the most portion, 27.2% favoured 40 VOIP services. While 39% of users preferred stand-alone services, the highest implementation rate was 23.8% for VoIP services. Furthermore, because participants adopted this category at a rate of 31.2%, the third group of nodes (11-21) is the most popularly used.

The novelty of the work described in this research is illustrated by the nature of the framework / algorithm and the ability to implement a method of network performance analysis to achieve the most efficient network configuration based on currently available technologies. In addition, to

define which IEEE technology and network architecture can be applied for potential online applications and services. The usability of this algorithm/website tool has been evaluated using a system usability scale (SUS). The average SUS score for the WPNAS web tool is 82.2, which is higher than the average usability (68). Besides, the internal reliability of the questionnaire for this analysis is 0.74, which demonstrates respectable internal consistency. Furthermore, the usability and learning derived from this assessment are 84.9 and 73.3, respectively.

Five different services (applications) were evaluated and analysed under various factors, such as spatial distribution, number of nodes and network architectures. A novel algorithm was developed to evaluate best-effort services such as HTTP, FTP, E-mail and real-time services such as VoIP and VC across different IEEE 802.11 technologies, while various QoS metrics were used and studied in the development of this algorithm. Namely; delay, jitter, throughput, packet loss, download response time, and page response time. The aim of this research is to construct many scenarios in order to rank the current IEEE 802.11 standards for stand-alone and mixed applications by inventing a coefficient of importance for the metric parameters of each application.

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CHAPTER 1 INTRODUCTION

1.1 Background

Nowadays, because of the advances in computer and Internet technologies, various applications such as video conferencing, e-commercial transaction, medical science, etc., are using online technologies more and more (Mohd Ali, Sibley, & Glover, 2017).

Wireless local area networks (WLANs) along with mobile networks have acted as the main traffic carrying wireless communications due to their high speed, simple deployment and low price. WLANs use the IEEE 802.11 standard as the medium access control (MAC) protocol which it allows. Besides, it provides an opportunity to share photos or videos around the world as well as facilitating syncing and loading of documents between people who are thousands of miles away from each other. All of these services and applications can be done using a WLAN carrier medium. Because there are different physical layer technologies it is difficult to decide which one offers the best performance (Cisco, 2017).

In addition, as shown in Tramarin, Vitturi, Luvisotto and Zanella (2015), the identification of the optimal performance of IEEE technology used in industrial communication networks, as opposed to old technology is not always guaranteed nor should be considered a default solution without conducting several kinds of research that provides a detailed analysis of these technologies. However, each standard has its strengths and limitations within the IEEE 802.11 family. For example, 802.11a is less likely to interfere with Radio Frequency (RF) than 802.11b or 802.11g. Given the greater bandwidth, this solution is more ideal for interactive audio, video and image services in densely populated areas than 802.11b. Nevertheless, the range is narrower than 802.11b and is not interoperable. For this exact reason this study analyses the best technology and efficient network for users and clients.

Researchers, companies, and standardization organizations are therefore increasingly concentrating on the main technologies and standardization mechanism of next-generation WLANs to respond to the rapid growth of traffic demands. The next generation WLAN protocol amendment is scheduled to be published by the Institute of Electrical and Electronics Engineers

(IEEE) as the most commonly used WLAN standard: IEEE 802.11ax (Afaqui , Garcia-villegas, & Lopez-aguilera, 2017). The IEEE 802.11ax project is currently at an advanced phase of development and is planned to be released in February 2021 (IEEE Working Group, 2020).

Generally, the bandwidth demands of real-time data applications are much higher than those made by traditional data applications, due to the high traffic loads and data density of the former. Therefore, it is critical that data transferred in real time is done speedily to help ensure that, at the other end, there is not an unacceptable delay in the reconstruction of the data.

At the same time, these new technologies require an assured transfer rate along the transmission path with some specified tolerance for bandwidth, delay or packet sequencing. Reliability and quality of these technologies are specified by a Quality of Service (QoS). QoS must be implemented across all wireless networks and it must be effective. In this thesis, a system to identify the best technology to be used in a particular WLAN context is described. The WLAN context accounts for the mix of applications expected and the physical network configuration.

1.2 Problem Statement

There has been a substantial amount of work aimed at supporting real-time data (video, audio, and data). The Internet can be used as a large shared network carrying integrated data and real-time applications. It is important therefore for implementing real-time data (AlAlawi & Al-Aqrabi, 2015).

However, there are several issues regarding transferring real-time data over the Internet. Transferring real-time data consumes more bandwidth than traditional (textual) data. Moreover, a shared network resource is the basic feature of the Internet, so the bandwidth is shared between all users (Sllame, 2017). In the case of real-time data, this is a considerable issue because the nature of these applications requires the reservation of the bandwidth while the transmission is established.

Voice over Internet Protocol (VoIP) converts sound from an analog signal to a digital signal, compresses it and breaks it into small packets to send over the network. The destination receives the packets and decompresses the data so that the data can be converted into an analog signal to drive a speaker. All these operations take time and affect delay because VoIP is a real-time service.

Any significant delay in the packet will cause a connection failure between users (El brak, El brak, & Benhaddou, 2014).

The use of the wireless network can lead to problems with delays in some places, including stores, airports, etc. There is a high amount of network traffic in these places since many people use the internet for various services. VoIP and services such as video conferencing (VC) and file transmission become more prevalent and significantly improve network transmission, but this form of traffic is difficult to manage because certain transmission rates, delay tolerances and packet sequences are required (Abou Haibeh, Hakem, & Abu Safia, 2017).

Managing this multi-service in wireless networks with QoS is already a huge challenge, thus the traffic metrics such as delay, jitter etc. need to be considered, recognized and implemented. It is also considered a tremendous challenge to implement QoS parameters such as delays, jitter and packet loss over real-time networks. Simultaneously, scientific analysis is needed to decide which technology to use and implement in the industry of WLANs of different physical layer technologies. On the other hand, the availability of Independent Basic Service Set (IBSS) Ad-hoc, Basic Service Set (BSS), and Extended Service Set (ESS) has increased difficulty in determining which network configuration is best used for the allocation of wireless network resources to provide high quality.

Under various factors such as spatial distribution, the number of nodes and network architectures, five different services (applications) were evaluated and analysed; whereas, in literature, the evaluation was conducted only on a single technology at a time. In addition, there is a lack of research that involves the assessment and study of mixed applications, including the best-effort and real-time services. In order to evaluate best-effort services such as HTTP, FTP, E-mail and real-time services such as VoIP and VC throughout different IEEE 802.11 technologies, a novel algorithm was developed, whereas various QoS metrics were used and studied in the development of this algorithm. Namely; delay, jitter, throughput, packet loss, download response time, and page response time. Analysis of the impact of node’s Spatial Distribution (i.e., Circular, Random, Uniform) on the network performance is for all six IEEE 802.11 technologies (11, 11a, 11b, 11g, 11e and 11n). The literature did not demonstrate this particular area of research such as the analysis made in Schmitt, Redi, Bulterman, & Cesar (2017).

The Boolean value (0.0 or 1.0) corresponding to the acceptance or rejection of the packet loss parameter is used to generate the performance of the OPNET Model. While in the literature, the evaluation of the packet loss parameter using OPNET Modeler was taken as a Boolean value and did not explain how to measure its exact percentages either for best effort or for real-time services on the OPNET platform. However, this study involves the value of packet loss as a numerical aspect. Two methods are developed to measure the percentage of packet loss of each application: one with Excel Office software and the other with MATLAB to code that as well. The code has been programmed on the basis of a mathematical definition of packet loss to develop a method for calculating its percentage for all applications and scenarios that have been established in this work, either mixed or stand-alone applications. Both methods can be directly related to the OPNET Modeler for a given application to generate a particular percentage of packet loss. This value has, however, been produced for each particular technology.

The objective of this research is to construct many scenarios in order to rank the current IEEE 802.11 standards for stand-alone and mixed applications by inventing a coefficient of importance for the QoS metric parameters of each application. For each application, the criterion of satisfaction (acceptable threshold) for each QoS metric parameter is defined where these threshold values are identified from the literature (Zawia, Hassan, & Dahnil, 2018); (Al-Shaikhli, Esmailpour, & Nasser, 2016). These qualitative variables will be translated into quantity figures as they are to be taken into account in the simulation. It is worth mentioning that, in terms of its effect on the quality of the service, an important coefficient is assigned to each application parameter (ICP) and a specific equation has been derived to measure this value for each QoS parameter for each application, either in stand-alone or mixed services for each IEEE technology. The literature review showed that neither previous work had calculated the value of the coefficient of importance for either of these metric parameters or any of the internet services.

Literature analysis has shown that no previous work has measured best-efforts (HTTP, FTP and E-mail) or real-time (VoIP & VC) QoS metrics of various IEEE 802.11 technologies for the purpose of establishing the best technology across infrastructure and independent network architectures. In addition, three different Network Architectures (Ad-hoc, BSS and ESS) were considered in this thesis, while up-to-date research is considered only a stand-alone network architecture. The literature did not demonstrate the performance of all three network architectures for the same inputs data for both types of services, stand-alone and mixed services.

As there is a lack of empirical research for a web-based tool that is readily accessible, effectively and easily functional, that provides all the options for users, planners and network designers for what type of WLAN technology, network configuration and spatial distribution they need once they decide to set up their networks. This work will result in a web-based application that uses a database to independently select an optimal wireless protocol based on user requirements, generated by a comprehensive collection of device simulations. In order to decide on the most suitable protocol for those inputs, this developed tool is directly linked to the outcomes of this work and accepts several inputs, such as a number of nodes, applications in a variety of proportions, node spatial distribution, physical layer technology and network configurations. In addition, a significant amount of critically important information about WLAN technologies and network architectures is collected, implemented and coordinated to address many barriers to implementation and facilitate more effective performance to achieve research aim and objectives.

The OPNET (Riverbed Modeler) license used for this research is the latest update of Riverbed Modeler Academic Edition (Riverbed, n.d.), which is a six-month renewable license and can be downloaded from the Riverbed website without charge. Riverbed Modeler Academic Edition has not yet embraced more recent technologies such as IEEE 802.11ac (IEEE Std 802.11ac , 2013) and IEEE 802.11ax (IEEE Draft std 802.11ax, 2017). However, in this study, we are considering taking these two technologies into account and analysing them both once they have been offered in OPNET (Riverbed Modeler) so that we can perform our proposed algorithm and mathematical calculations (derived equations) in order to provide a detailed analysis that incorporates all of these eight technologies under the same circumstances and is being studied in the same framework.

On the other hand, the IEEE 802.11b/g/n wireless technologies function in 2.4 GHz, and the IEEE 802.11a is running at 5 GHz. Optionally, IEEE 802.11n will also support the 5 GHz frequency band. However, IEEE 802.11ac only operates at 5 GHz. Therefore, all IEEE 802.11a/n/ac use the same 5 GHz, transmission band (Lopez-Aguilera, Garcia-Villegas, & Casademont, 2019).

In order to benefit from previous equipment after a new amendment has been adopted, backward compatibility between successive IEEE 802.11 technologies is a key feature. The IEEE 802.11ac protocol provides backward compatibility with IEEE 802.11a/n nodes so that new technologies can be applied easily and broadly. This means that nodes operating with IEEE 802.11a/n/ac specifications will coexist in the IEEE 802.11 WLAN, but the overall performance will be restricted to the performance of the older standard and will only have the full advantage of the Wireless AC (the router implements the wireless networking protocol 802.11ac) if you connect from IEEE 802.11ac to 802.11ac. Which involves an IEEE 802.11ac technology for both router and devices (Gao, Sun, & Dai, 2018).

Moreover, Gao, Sun, & Dai (2018) reported that the simulation results for a couple of studies have shown that the data rate performance of nodes in a newer 802.11ac standard could noticeably deteriorate compared with the single network scenario when coexisting with nodes of legacy IEEE 802.11a/n standards. It is therefore vitally important to explore how to maximize the efficiency of multi-standard IEEE 802.11 WLAN, which is precisely what our research work focuses on: researching mixed network configurations to rank the optimal technology and provide the best network configuration performance for different technologies.

Using theoretical speeds, IEEE 802.11 WLAN is often promoted and 802.11ac is able of 1300 Mbps, which is three times faster than the 600 Mbps speed assigned to 802.11n. These speeds are nonsense in real practice, this is a major point. Hardly anybody would be compliant with the theoretical speeds in the real world and the fastest real-world 802.11ac speeds achieved in experiments are around 720 Mbps. IEEE 802.11n, on the other hand, max at around 240 Mbps, so the three times faster claim is still valid, just much smaller (Trusted Reviews, 2018).

There is a potential for IEEE 802.11ac to accommodate up to eight antennas performing at more than 400 Mbps each. Many manufacturers have produced a fast router with only four antennas. The explanation is that antennas increase cost and take up space, and the smaller the device, the fewer antennas can accommodate, so adding more to a router becomes meaningless. Generally: 1 antenna for Smartphones (more recent smartphones have 4 antennas), 2 antennas for Tablets, 2 to 4 antennas for Laptops and 3 or 4 antennas for Desktop computers. This work includes many variables and offers the client a list of choices. A trade-off between speed and cost is likely to arise. So, as this could be too costly for them, it is not the case that clients can always select the latest technology that goes beyond what they actually need for their business or daily use. Cost-performance data is what they want to see so that they can choose a service or a mixed service with a particular technology that they can accept at a price that is affordable to spend.

In an effort to achieve Gigabit throughput speeds, a range of enhancements was proposed. Whereas some of the 802.11n features have been preserved for 802.11ac, several others, such as static and dynamic channel bonding and simultaneous data streaming, have been enhanced to permit broader channels and also more data streams to be supported (Bejarano, Knightly, & Park, 2013). Table 1.1, compares the specifications of IEEE 802.11n and 802.11ac.

Table 1. 1 IEEE 802.11n and IEEE 802.11ac Comparative study (Karmakar, Chattopadhyay, & Chakraborty, 2017)

Item	**IEEE 802.11n**	**IEEE 802.11ac**
Channel Width	20, 40 MHz	20, 40, 80, 160 MHz
Data Rate	600 Mbps	1 Gbps
MIMO steam	4 × 4	8 × 8
MAC Mechanisms	Frame Aggregation (A-MSDU and A-MPDU), Block Acknowledgement, Revers Direction (RD)	Enhanced Frame Aggregation (large sizes)
Modulation	BPSK, QPSK, (16, 64) QAM	BPSK, QPSK, (16, 64, 256) QAM
Frequency Band	2.4, 5 GHz	5 GHz
Maximum Coding Rate	5/6	5/6
Purpose	High Throughput (600 Mbps)	Very High Throughput (6.9 Gbps)

Therefore, 802.11ac somehow does not go much further beyond the 802.11n. In reality, 802.11ac utilizes the 5 GHz band, whereas 802.11n uses 5 GHz and 2.4 GHz. High frequencies bands are quicker but move farther with lower bands. Kelly (2014) has shown that there is very little difference in signal strength between 802.11ac over 5 GHz and 802.11n over 5 GHz and 2.4 GHz from testing experience in both technologies. Two main reasons for this; first, since 2.4 GHz is used for anything from cordless landlines to microwaves, and 5 GHz stayed fairly interference-free for a cleaner signal. Beamforming is the second core element. Usually, the wireless signal is just launched out of the router in all directions, like ripples. That's why it will indeed position the router as close and as high as possible to the centre of the home or office. It is different from beamforming. It is designed into the specification 802.11ac and is a smart signal that senses wherever connected devices are and precisely improves signal intensity in their location. Actually, locating a router centrally is always a smart idea, but somehow it ultimately makes it seem less vital.

Transmit beamforming is deemed an optional capability of IEEE 802.11ac. A higher Modulation and Coding Scheme (MCS) for a given range allows this process. Transmit beamforming is unable to expand the overall transmission range or increase the overall data rate. The transmission power in the 5 GHz band is restricted by regulatory standards and the benefit due to transmission beamforming is also restricted (Ravindranath, Singh, Prasad, & Rao, 2017).

The purpose of the IEEE 802.11ax amendment is to identify standard PHY and MAC layer improvements that result in at least one mode of operation design to accommodate, in a dense deployment scenario, at least four times the increase in throughput performance per station while retaining or enhancing power efficiency per station. IEEE 802.11ax, in specific, aims to optimize performance measures that demonstrate user experience. IEEE 802.11ax was designed to achieve maximum aggregate network throughput of at least 1 gigabit per second on the 5 GHz band. This is done by expanding the principles of the air interface followed by IEEE 802.11n: broader frequency band of the channel (20/40/80/160 MHz), more multiple-input multiple-output (MIMO) spatial streams (up to 8 antennas) and high-density modulation (up to 256 QAM). In specific, downlink (DL) multi-user (MU) MIMO (up to 4 users) technology has been developed to increase the efficiency of the spectrum by allowing the simultaneous transmission of multiple data frames to various stations. Table 1.2, shows the specifications of IEEE 802.11ax and compares them with both IEEE 802.11n and 802.11ac (Vijay & Malarkodi , 2019).

In May 2014, the IEEE 802.11ax task force started developing a new standard for high-performance local area wireless networks. The IEEE 802.11ax project is currently in a developing stage and is expected for release in February 2021 (IEEE Working Group, 2020). However, In January 2017, the preliminary 802.11ax 1.0 draft standard was voted on and obtained just 58% of positive votes compared to the 75% threshold level, and as many as 7334 formally submitted comments. Just 63% of the affirmative votes were earned in the second draft standard. With over 85% of supportive votes and 2154 views, only the third edition passed the ballot. Nevertheless, while the development process is obviously not yet completed and many significant concerns have to be resolved before completion, some solid milestones have now been identified (Khorov, Kiryanov, Lyakhov, & Bianchi, 2019).

Table 1. 2 Comparison of IEEE 802.11ax specifications with IEEE 802.11n and 802.11ac (Vijay & Malarkodi , 2019)

Item	**IEEE 802.11n**	**IEEE 802.11ac**	**IEEE 802.11ax**
Channel Width	20, 40 MHz	20, 40, 80, 160 MHz	20, 40, 80, 160 MHz
Frequency Band	2.4, 5 GHz	5 GHz	2.4, 5 GHz
Modulation	BPSK, QPSK, (16, 64) QAM	BPSK, QPSK, (16, 64, 256) QAM	BPSK, QPSK, (16, 64, 256, 1024) QAM
Multi-user (MU)	NO	Only downlink	AP-initiated uplink Tx plus downlink Tx
Modulation	OFDM	OFDM	OFDM, OFDMA
Data rates	72.2 Mbps (20 MHz, 1 SS) 600 Mbps (40 MHz, 4 SS)	433 Mbps (80 MHz, 1 SS) 6.9 Gbps (160 MHz, 8 SS)	600 Mbps (80 MHz, 1 SS) 9.6 Gbps (160 MHz, 8 SS)

Many manufacturers have developed and introduced some of the IEEE 802.11ax chipsets into the market, such as smartphone manufacturers that have added the IEEE 802.11ax technology to their handset's generation, Asus introduced the first 802.11ax router in August 2018 using Broadcom silicon, this router has 4×4 MIMO in both bands, and Huawei revealed an 802.11ax access point using 8×8 is based on Qualcomm hardware. On the other hand, several others, such as OPNET Modeler, have not yet adopted this technology into their Academic Edition Modeler (Weinberg, 2018).

The most prominent design trigger of IEEE 802.11ax is the awareness that WLAN machines are operated in very dense environments, described by having a large number of nodes clustered in geographically located environments. Company headquarters, public gatherings, outdoor hotspots, retail stores, airports, workshops, crowded apartment buildings, stadiums, etc. are all forms of dense environments, the coverage of which demands a plethora of access points (APs) that can also need to be functioned on (partially) overlapping networks. Three of those scenarios are depicted and described in Figure 1.1: a stadium, a train, and an apartment building (Bellalta, 2016). The overall throughput is no longer the key performance measure of concern in these environments; rather, the goal then is to maximize the throughput density, i.e., the throughput per area, known as the ratio of the total network throughput to the area of the network (Khorov, Kiryanov, Lyakhov, & Bianchi, 2019).

Scenario (area, m^2)	**Access Points**	**Nodes**	**Description**
Stadium (12500 m^2)	> 1000	> 50000	Large events that require many APs to provide a satisfactory connectivity service able to support video uploading/downloading.
Train (600 m^2)	< 10	> 1000	Full coverage inside a train to provide both work and entertainment services.
Apartment building- 4 floors, 6apartments/floor (2400 m^2)	> 120	> 480	Several short-range APs deployed in each apartment, offering full coverage and high data rates for bandwidth hunger entertainment applications, as well as connectivity for house appliances. Community APs may also be deployed in the corridors and shared spaces.

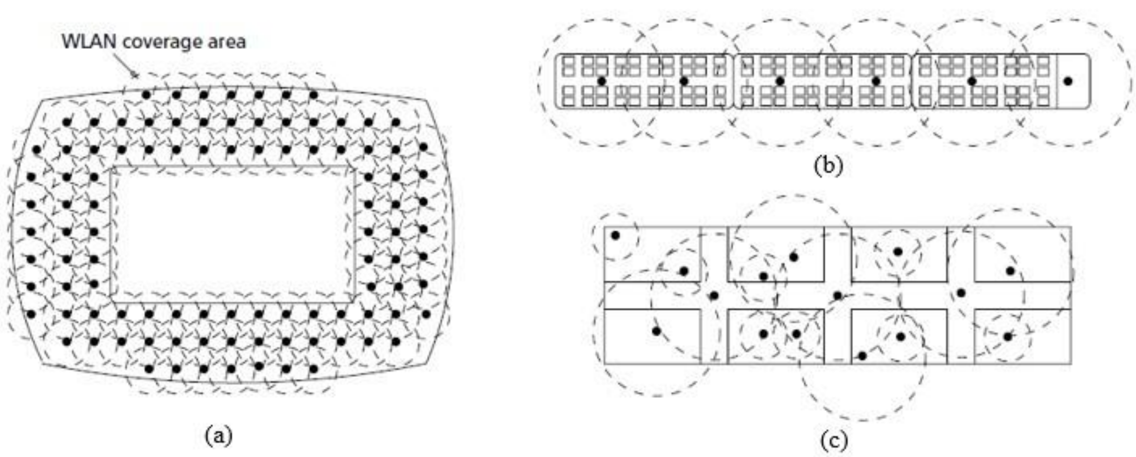


Figure 1. 1 IEEE 802.11ax WLANs key scenarios in next generation: (a) stadium; (b) train; (c) floor of a building with several apartments (Bellalta, 2016).

The most main concerns in these dense areas are interference challenges, that elevate the packet error ratio and minimize the level of simultaneous transmissions in a particular region by limiting the channel from being reached by adjacent WLANs. Besides, the existence of multiple nodes/stations in the same location raises the probability of two or more nodes' backoff indicators hitting zero at the same, leading to a collision (Bellalta, 2016). However, the algorithm proposed in this study was applied and implemented using a number of nodes ranging from one to sixty-five and different room sizes ranging from 2×3 m to 10×14 m, as the standard room size of the typical university/college/school laboratory is within this range based on the number of nodes used, so that the technologies used in this study are consistent with the objectives of this work. However, this does not refute the fact that this algorithm is applicable using recent technologies (IEEE 802.11ac/ax), and we plan to use it as soon as it is installed and deployed in the OPNET Academic Edition. Moreover, in dense environments, it is also interesting to examine and implement our proposed algorithm and to demonstrate how it performs using this advanced technology (IEEE 802.11ax).

1.3 Aims and Objectives

The aim of this work is to answer the question: For a given mix of applications in a given environment, what WLAN standard (or a mix of standards) will result in best overall performance?

This aim is broken down into the following:

Objective One: To build different representative scenarios with different user applications such as VoIP, File Transfer Protocol (FTP), Web Browsing (HTTP), VC, and E-mail aiming to evaluate QoS parameters such as throughput, packet loss, jitter and different types of delay.

Objective Two: To create and develop a clear algorithm that calculates the packet loss ratio in OPNET Modeler using the MATLAB program.

Objective Three: To rank the existing IEEE 802.11 technologies for both stand-alone and mixed network applications, setting an importance coefficient for each application statistics.

Objective Four: To build a systematic framework that provides the opportunity to identify and implement the optimal Ad hoc, BSS or ESS network configuration.

Objective Five: To create a readily accessible and readily usable web-based tool for clients, planners and network designers that gathers, integrates, and organizes a vast amount of critically important information about WLAN technologies and network architectures to overcome many implementation hindrances and promote more widespread use to achieve the research objectives.

1.4 The Research Contributions

The novel aspect of this research is to design an algorithm that identifies the best performing overall WLAN standard (or a mix of standards) for a given mix of applications in a given environment. Hence, a new algorithm has been developed for evaluating best-effort services, such as HTTP and FTP and real-time services, such as VoIP and VC of different IEEE 802.11 systems, to determine the best network architectures between the IBSS, ESS and BSS structures. The optimization model will rank different IEEE 802.11 technologies. Moreover, this work presents the analysis of these services for three spatial distributions (Circular, Random, Uniform) as its own case study. In addition, the effect of spatial distributions on each WLAN technology is deliberated.

On the other hand, the "technology", that is the PHY layer, is dependent on the hardware used and more capable hardware can automatically downgrade the PHY layer for a lower throughput and better robustness when the signal-to-interference-plus-noise ratio (SINR) is too low. This means that devices can automatically switch from 11g to 11b, for instance, if the conditions are bad, but still can’t upgrade automatically from 11g to 11e for instance. As an example, if the devices are valid for a certain bandwidth and it's required to upload an 8 Mbps video, at this point the device can’t upgrade itself to match the required bandwidth, so either it is necessary to upgrade it physically or downgrade the video quality to optimize the available bandwidth. However, this is exactly where this study is beneficial and provides its main contribution – that it maintains the resources (cost-efficient) and provides network optimization; it does not only consider the usage on its own.

Each IEEE 802.11 technology has its own unique physical design and different settings for parameters such as CW and TXOP. IEEE 802.11e is considered to be of critical importance for delay-sensitive applications but, for example, its CW ranged from 3 to 7 for VoIP, and this makes it possible for many collisions to occur if the network is configured with only one data type (voice); whereas smaller CWmin and CWmax stations are better served than other stations, they often wait for a shorter time before they are able to transmit. While CW ranged from 15 to 1023 for 802.11a technology, this means less collision and better performance. As a result, no default technology is considered to be the best solution or edged one, as there are other parameters to be analysed and studied, such as number of access points, number of nodes, type of data (or mixed types) in which the WLAN has been configured, so that we can identify the optimum technology and network architecture to be implemented. This means that in order to ensure user satisfaction, the contest must be handled through QoS mechanisms.

This work takes several variables and produces a list of options to the client. There is likely to be a trade-off between speed and cost. So, it is not the case that the clients will always choose the fastest data rate as this may be too expensive for them. What they want to see is the cost-performance data so they can choose the service at speeds they are willing to tolerate at a price they are willing to pay. The maximum data rate is nominal and often doesn't reflect actual delivered rates so would not be of much help to a potential client. Therefore, why use the maximum theoretical data rate whereby standard 802.11e is capable of 54Mbps, when in the real world no one gets close to theoretical speed.

In addition, IBSS, BSS and ESS have led to uncertainty of deciding which network architecture is best used for the allocation and efficiency of wireless network resources. This work 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.

This work will result in a web-based application that utilizes a data-base produced by a comprehensive set of system simulations to autonomously select an appropriate wireless protocol based on the user requirements. Therefore, the ultimate use for the results of this research contributes to the development of tools that are linked to the outcomes of this work that accept a number of inputs, such as number of nodes, applications in a variety of proportions, spatial distribution of nodes, physical layer technology, and network configurations, in order to make a decision on the most appropriate protocol for those inputs.

1.5 Thesis Outline

This thesis is structured in eight chapters detailing the progress that has been undertaken to accomplish the aims and objectives of this study. The thesis is set out as follows: Chapter 2 reviews the literature on WLAN technology and assesses the researches related to performance evaluation and deployment in real-time and best-effort environments. At the end of Chapter 2, the knowledge and solution gap is outlined in order to resolve it.

Chapter 3 describes the novel design of the protocol and network architecture selection framework used to rank order the existing WLAN 802.11 standards for mixed and stand-alone applications, as well as to identify the optimum network architecture among BSS, ESS, and IBSS.

Chapter 4 describes the process of implementing the protocol and network selection process and the implementation of applications that provide installation, configuration and contextualization capabilities. A performance evaluation of the stand-alone application is laid out in Chapter 5, followed by the results of mixed applications for both real-time and best-effort services, and the development of a practical application (end-user applicability) in Chapters 6 and 7 respectively.

Finally, in addition to the directions for future study, the conclusions, perspectives and impacts obtained during this study are addressed in Chapter 8, with a view to continuing and enhancing this field of research.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

There are several ways to transfer real-time data other than the Internet, such as dedicated physical links, and Asynchronous Transfer Mode (ATM). Dedicated physical links and cables are not a functional solution because they need special installation and new software. ATM is a good solution since it provides very high bandwidth but it is not commonly used among users or organizations because its standards have not been fully agreed upon; so switches, routers, and other network components need to be compatible with ATM infrastructure, leading to an increase in complexity and added cost (Gaddam, Lobial, & Lal, 2018).

Currently, the internet provides the best effort service class. There are several technical measures to evaluate the efficiency of network architecture, such as bandwidth, packet loss, and delay. Not all applications are affected similarly by these measures. For example, file transfer will not be greatly affected by a delay of a few seconds. On the other hand, the effect of delay on real-time data packets may be extreme.

2.2 Network Issues

By transferring data over the Internet, the data packet may suffer from several problems and issues that degrade its quality; some of these issues are:

1. Latency: which is a huge end-to-end delay which causes the transferred packets to overlap at the receiver system (Shah & Singh, 2016).
2. Delay: occurs when the packets arrive too late for their specific designated time (Shah & Singh, 2016).
3. Jitter: occurs when the transmission packet arrives at the destination with a wide range of packet delay (delay variance) (Shah & Singh, 2016).
4. Packet loss: through transferring, the packets may not reach their destination and be dropped in the middle of the transmission path.

5. Congestion: happens due to a huge amount of traffic in the network, so the receiver cannot serve it; therefore, it begins to drop or discard these data packets (Shah & Singh, 2016).

2.3 Wireless Networking

With minimized wireline installation, wireless communication technologies are a very effective way to create connectivity between network nodes. In order to run, a number of applications are based on technologies such as C-ITS (Cooperative- Intelligent Transport Systems) vehicle network applications, precision farming with mobile linked engines and a range of properties used on smartphones using mobile networks. The majority of these applications need mobile nodes to be supported thus optimizing throughput. Once communication technology is capable of achieving the highest possible physical data rate, the maximum throughput is achieved. In addition, to ease deployment and high transmission data rate, IEEE 802.11 WLAN have become a tremendous network solution for public locations such as airports and offices without worrying about wires and mobility (Sammour & Chalhoub, 2020).

2.3.1 Wireless LAN 802.11 Architecture

Wireless LAN 802.11 standard identifies the first two layers of the OSI model data link layer (L2) layer and physical (L1) layer, as shown in Figure 2.1. Wireless LAN 802.11 delivers services that are found in a typical wired network; the descriptions of both layers in terms of wireless standards are given in the section below.

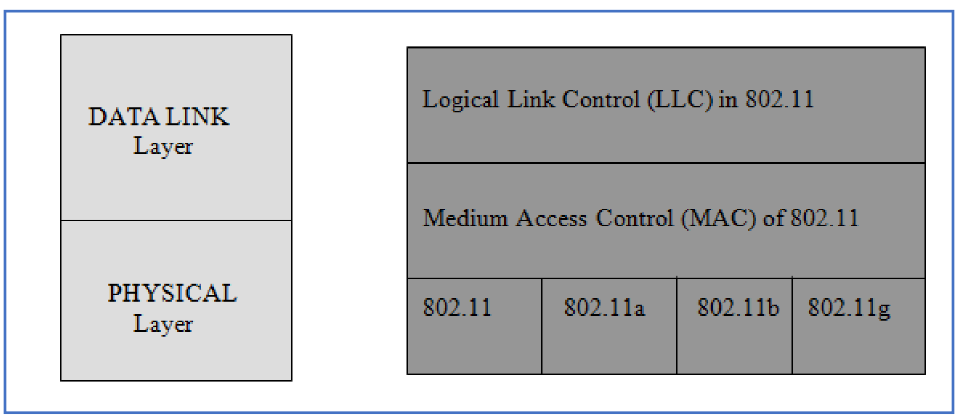


Figure 2. 1 Wireless LAN 802.11 MAC and PHY Layers (Oliveira, Rodrigues, Kozlov, Rabêlo, & Albuquerque, 2019)

2.3.1.1 Layer 1 (802.11 PHY)

The key function of the physical layer is to correctly transmit signals from the sender to the receiver. This transmitting process requires modulation and data encoding. The choice of coding technique is an influential factor that significantly affects the transmission of data within the stated standard. The more effectively data is coded, the faster data transfer can be achieved (Kaur, Kaur, & Arora, 2012).

Various encoding techniques are used in IEEE 802.11 standards. Different methods of data spread lead to different encoding techniques. Here are the most popular techniques:

FHSS (Frequency Hopping Spread Spectrum)

Transmission occurs within one frequency for a time, then jumps to a different frequency. This occurs at carrier and transmitter level. The carrier jumps frequency randomly over a period of time. The transmitter jumps frequency periodically according to a predefined sequence.

DSSS (Direct Sequence Spread Spectrum)

In DSSS technology the transmitted message is combined with a high data bit code, a pseudo-noise (PN) that encodes and splits data based on a spreading ratio. Each bit transmitted is associated with the chipping code which leads to increasing the signal’s resistance to interference, jamming, and relative timing between sender and receiver (Mehboodi, Jamshidi, & Farhang, 2018).

OFDM (Orthogonal Frequency Division Multiplexing)

The main idea came after the evolution of the communication system and the increasing demand for the need for speed of data transmission. Hence, the idea of FDM: this technique splits the channel into subchannels and divides the carrier into subcarriers to transmit more than two different signals on the same band at the same time, thus solving several problems. Before OFDM, the band used in transmitting one signal and then transmitting the other caused several problems, especially in television where transmitting the image then the sound causes the image to precede the sound, which means there is a delay between the two signals. The other problem is that should an error occur in the information that is transmitted, it would be so large that it would be difficult to handle (Wong, 2012).

2.3.1.2 Layer 2 (802.11 MAC)

The data link layer within 802.11 standards consists of two parts:

- Media Access Layer – MAC access control
- Logical Link Control – LLC

The 802.11 LLC ensures compatibility with any other network within 802 standards so it is similar to 802.2 layers, while the MAC layer is equivalent to the 802.3 (Ethernet) standard in wired networks. The MAC sublayer uses the (CSMA/CD) concept for fragmentation and error control so that it is redefined by standard 802.11 (L2).

2.3.2 Wireless LAN 802.11 Standards

The Institute of Electrical and Electronic Engineers (IEEE) developed the family of 802.11 standards for wireless LANs which are recognized throughout the world (Gao, Sun, & Dai, 2018).

- **802.11a standard**

802.11a operates in a frequency spectrum between 5.15 GHz and 5.35 GHz. 802.11a and has a wide range of bandwidth that allows products to transmit at rates up to 54 Mbps. It is much faster than 802.11b networks. However, 802.11a devices cannot function on 802.11b networks.

- **802.11b standard**

802.11b is the most popular standard. It provides 11 Mbps bandwidth in the 2.4 GHz frequency band. This speed is suitable for any business or home users.

- **802.11e standard**

802.11e is an enhancement of the 802.11a and 802.11b wireless LAN features. Using 2.4 GHz or 5.85 GHz bands, 802.11e provides QoS guarantees by giving high priority to data, voice, and video transmissions. Higher bandwidth, increased number of channels and decreased interference are all considered as vital advantages to the higher frequency range (Saleh, Shah, & Baig, 2015).

- **802.11g standard**

802.11g provides a data rate up to 54 Mbps in the 2.4 GHz frequency band. Since 802.11g devices are interoperable with 802.11b networks, it is backward-compatible with their systems. The throughput of 802.11b devices will not be improved, however, when used on an 802.11g network.

- **802.11n standard**

The transmission speeds of IEEE 802.11n could reach 300 Mbps and the channel bandwidth up to 20 MHz (Herdiniamy, et al. 2020). Multiple Input Multiple Output Orthogonal Frequency Division Multiplexing (MIMO-OFDM) approaches are used in IEEE 802.11n, which enables the transmission of speeds of up to 600 Mbps using up to 40 MHz channel bandwidth (IEEE Std 802.11n, 2009). Table 2.1 shows the main differences between WLAN standards.

Table 2. 1 Summary of Major 802.11 WLAN standard (IEEE Std 802.11, 2007) (Gao, Sun, & Dai, 2018)

Standard version	**Release date**	**Data rates (Mbps)**	**Modulation**	**Frequency band (GHz)**	**Channel width (MHz)**	**Number of spatial streams**
802.11	June 1997	1, 2	FHSS, DSSS	2.4	20	1
802.11a	July 1999	up to 54	OFDM	5	20	1
802.11b	July 1999	1, 2, 5.5, 11	DSSS, HR/DSSS	2.4	20	1
802.11g	June 2003	up to 54	ERP-OFDM	2.4	20	1
802.11n	Oct 2009	up to 600	MIMO-OFDM	2.4 & 5	20, or 40	1, 2, 3, or 4
802.11ac	Dec 2013	Up to 1300	MIMO-OFDM	5	20,40,80,160	8
802.11ax	Est. Feb 2021	Up to 9600	MIMO-OFDM	2.4 & 5	20,40,80,160	8

The original 802.11 standard identifies three physical layer encoding techniques as mentioned above: FHSS, DSSS and infra-red (IR). The IR PHY did not succeed commercially.

DSSS and FHSS support transmission speed-rates of 1 and 2 Mbps. A high rate DSSS (HR/DSSS), which supports speeds up to 11 Mbps, was first introduced in the 802.11b modification. The frequency band that 802.11b operates is 2.4 GHz, the same band as legacy 802.11. HR/DSSS produced improved transmission rates: Complementary code keying (CCK) and Packet binary convolution coding (PBCC) as shown in Table 2.2.

Table 2. 2 Modulation methods' in 802.11b (Coleman & Westcott, 2018)

Data rates (Mbps)	**Code**	**Modulation**	**System**
1	Barker code	DBPSK	DSSS
2	Barker code	DQPSK	DSSS
5.5	CCK	DQPSK	HR/DSSS
11	CCK	DQPSK	HR/DSSS

Both CCK which is a block code and PBCC which is based upon convolution codes yield data rates of 5.5 and 11 Mbps. The 802.11a modification was approved in the same period as 802.11b. 802.11a supports transmission speeds of up to 54 Mbps. There is a total of 52 sub-carriers in 802.11a, 48 of which are data sub-carriers and the remaining 4 are pilot sub-carriers (IEEE Std 802.11, 2007). In 802.11a, there are a range of transmission speeds of 6, 9, 12, 18, 24, 36, 48 or 54 Mbps; devices can use any one of them for transmission depending upon the modulation scheme as shown in Table 2.3.

Table 2. 3 802.11a Modulation schemes (Coleman & Westcott, 2018)

Mode	**Data rates (Mbps)**	**Modulation**
1	6	BPSK
2	9	BPSK
3	12	QPSK

4	18	QPSK
5	24	16QAM
6	36	16QAM
7	48	64QAM
8	56	64QAM

802.11a and 802.11g use OFDM instead of spread spectrum. 802.11a operates in the 5 GHz range and 802.11g operates in the 2.4 GHz with speeds of up to 54 Mbps using extended rate PHY (ERP). To avoid inter-symbol interference due to a multi-path, OFDM employs a guard interval (GI). GI is 800 ns with a legacy of 802.11a / g, while GI is 400 ns with 802.11n (Lopez-Aguilera, Garcia-Villegas, & Casademont, 2019). 802.11g operates in the Industrial Scientific Medical (ISM) band and is backwards compatible with 802.11b. To deal with the compatibility, 802.11g defines four PHYs, two of which are mandatory and two optional as shown in Table 2.4.

Table 2. 4 Details of 802.11g Physical layers (Coleman & Westcott, 2018)

PHYs	**Data rates (Mbps)**	**Mandatory**
ERP-OFDM	≤ 54	Yes
ERP-DSSS/CCK	1, 2, 5.5, 11	Yes
DSSS-OFDM	≤ 54	No
ERP-PBCC	22, 33	No

The physical Layer ERP-CCK / DSSS utilizes DSSS with speeds of 1 and 2 Mbps as well as the CCK with 5.5 and 11 Mbps and has been used when the 802.11g devices interact with the with 802.11b devices.

The ERP-OFDM physical layer is the same OFDM as the 802.11a, but optimized for the 2.4 GHz range when exchanging frames on two devices uses 802.11g standard.

There are two optional layers available: DSS-OFDM and ERP-PBCC. The first, DSSS-OFDM, is a modelling hybrid structure between DSSS and OFDM and does not need a security mechanism such as RTS / CTS to operate. The second one, ERP-PBCC, is a modelling system with a single-carrier that delivers 22 and 33 Mbps of modulation.

The 802.11n uses multi-input, multi-output (MIMO) methods and techniques, with rates of up to 300 Mb/s. MIMO systems comprise multiple transmitter and receiver antennas as well as RF chains. This provides the ability to achieve transmission rates of 600 Mbps (Coleman & Westcott, 2018).

2.3.3 Wireless LAN 802.11 Network Configurations

2.3.3.1 BSS and IBSS networks

WLAN 802.11 architecture includes different components that operate together to provide connectivity to the upper layers. The main component of 802.11 WLAN is BSS. A BSS, a group of wireless network communication stations that are managed by a Distributed Coordination Function (DCF) or a Points Coordination Function (PCF), is shown in Figure 2.2. However, because of the interference from adjacent stations reusing the same physical-layer, the transmission medium degrades, causing some stations to appear “hidden” from others. Data delivery, authentication, and privacy are all wireless LAN services that are provided by a station (Aragón-Zavala, 2017).

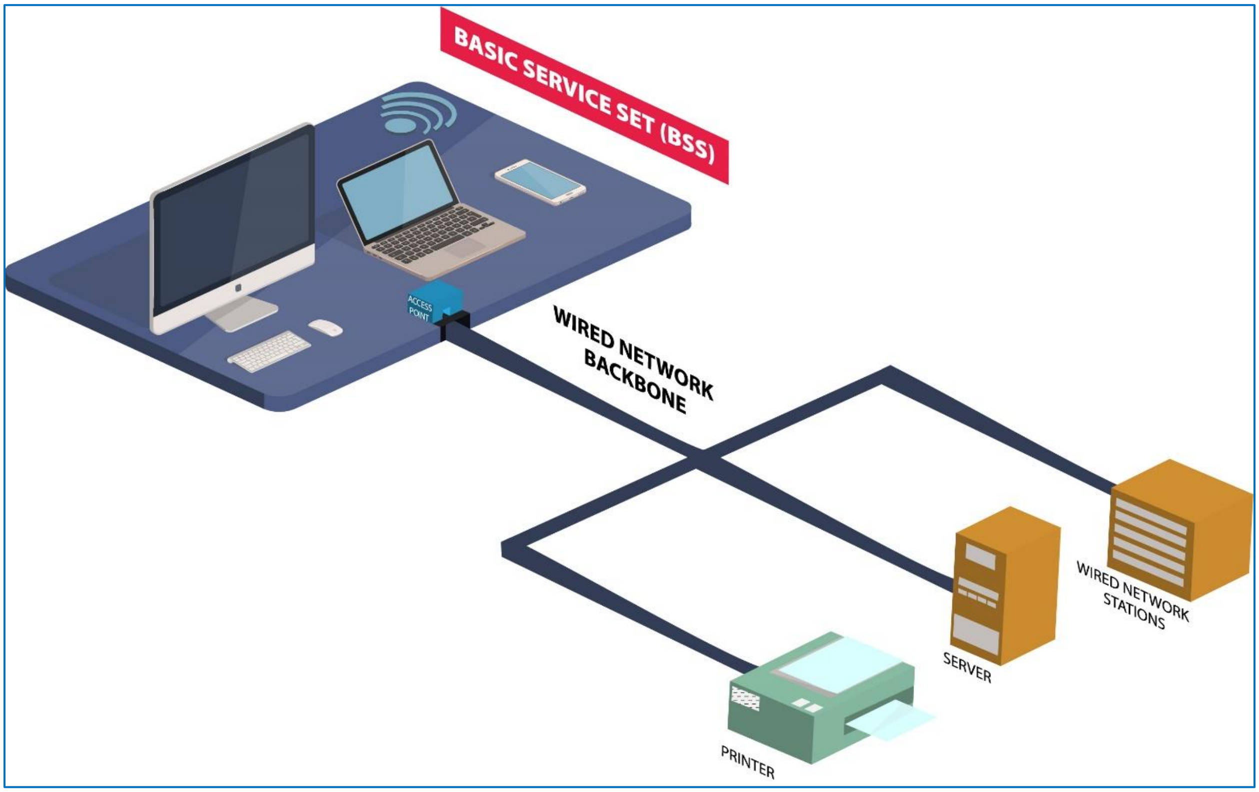


Figure 2. 2 Basic Service Set (BSS) (Biswas, et al., 2020)

IEEE 802.11 IBSS is officially called the Ad-hoc network. Without AP transmission, all stations can communicate with any BSS station directly, as can be seen in Figure 2.3.

Figure 2. 3 Independent Basic Service Set (IBSS) (Alani, Zakaria, & Hamdi, 2019)

2.3.3.2 ESS networks

A set of infrastructure BSSs is called an ESS. Infrastructure networks shall be built using APs that regulate the communication process. The Distribution System (DS) is the backbone of the wireless network, which is responsible for the transportation of the MAC Service Data Units (MSDUs), and is possibly responsible for setting up wireless and wired networks. Traffic in the ESS network is transmitted by DS from one access point to the next. Figure 2.4 demonstrates the Extended Service Set network with two BSSs connected by a distributed system (Swain, Chakraborty, Nandi, & Bhaduri, 2015).

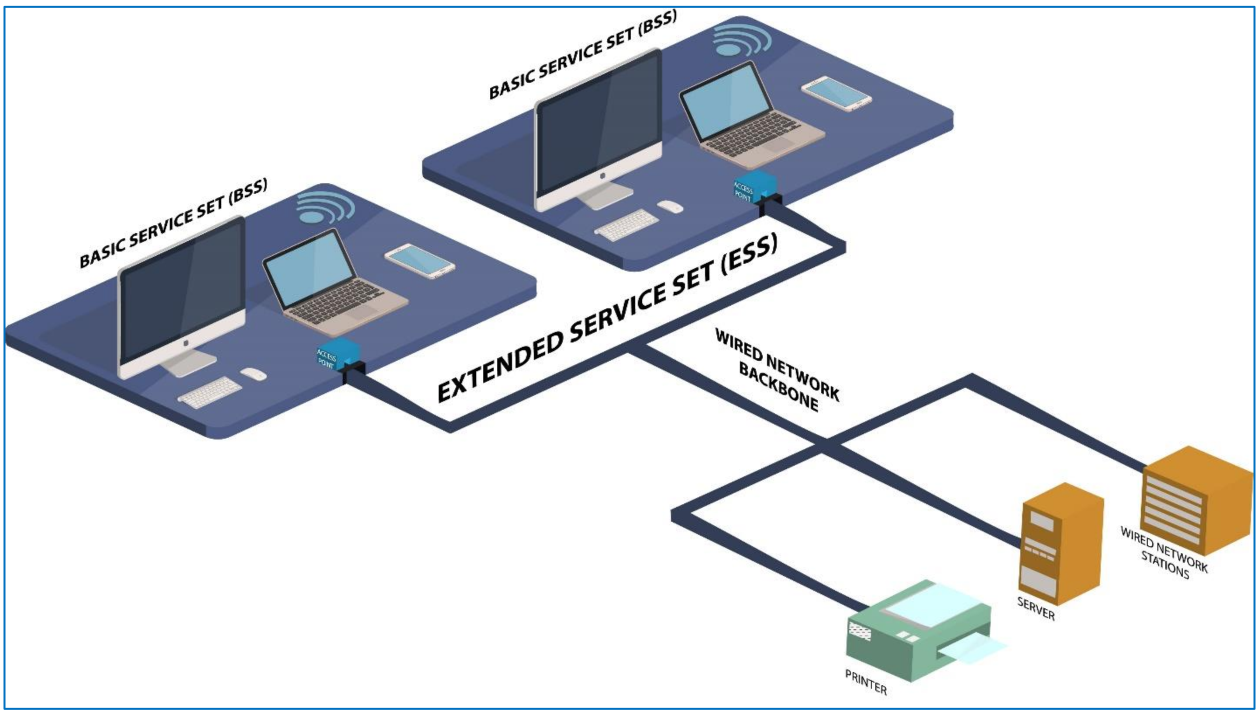


Figure 2. 4 Extended Service Set (ESS) (Aragón-Zavala, 2017)

The following procedure is followed to start an ESS:

1. The infrastructure network is identified by its extended service set ID (ESSID);
2. All APs will have been set according to this ESSID;
3. On power-up, stations will issue probe requests and will locate the AP that they will associate with (Aragón-Zavala, 2017).

2.3.4 WLAN 802.11 MAC Layer

There are a group of protocols in the Wireless LAN 802.11 MAC layer, as shown in Figure 2.5.

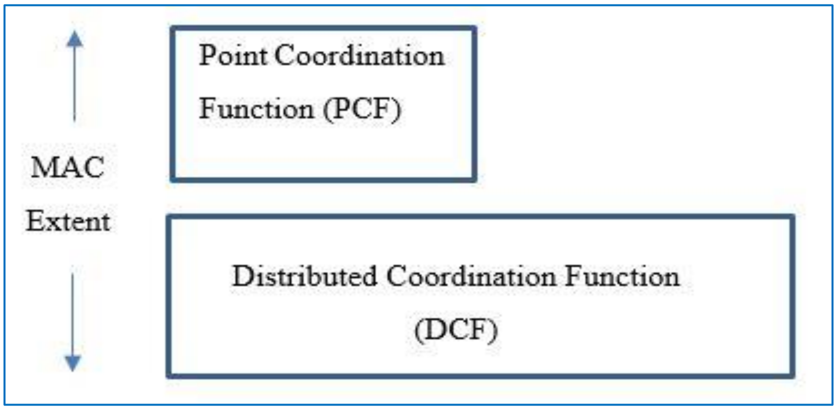


Figure 2. 5 WLAN 802.11 MAC Protocol Architecture (Refaet, Amed, Abed, & Aish, 2020)

The WLAN 802.11 MAC layer supports two data packet transmission modes: Distributed Coordination Function (DCF) and Point Coordination Function (PCF).

- **DCF (Distributed Coordination Function)**

DCF is based on a distributed mechanism. Each station works independently to contend for the medium if it needs to send data frames. DCF follows a Carrier Sense Multiple Access with Collision avoidance (CSMA/CA) scheme. All stations compete to access the medium; once a station sends a frame all other stations will wait until the sending process is completed. Random back off factor is used to avoid collisions by assigning stations different waiting transmission times (Refaet, Amed, Abed, & Aish, 2020).

Asynchronous service is provided only by DCF in the Ad-Hoc network. Distributed Inter Frame Spacing (DIFS) and Short Inter Frame Spacing (SIFS) are two DCF modes and this gives priority to traffic. The station listens to the medium in this protocol before sending a packet, and then sends a packet if the medium is clear. Then it determines how long this station will wait before its packet is allowed to transmit, called a back off factor. By using the back off factor, conflicts between the packets are reduced, as two stations are unlikely to use the same back off factor (Mishra, Gupta, & Upadhyay, 2019).

As the number of stations increases, the DCF functionality is well assessed and all of them seek to send data simultaneously over a channel or medium. If the delay increases as this number increases, then degraded voice creates another issue that should be implied as DCF does not prioritize traffic, indicating that there is no identification or discrepancy between data and voice packets.

Figure 2.6 illustrates the DCF transmitting mechanism, where the bandwidth in the station is assigned to the control frames; request to send (RTS) and clear to send (CTS). The sender station sends a short RTS packet, including information on the duration of the packet; the receiver station returns with a short CTS packet. The receiver sends a packet of acknowledgment (ACK) when the packet is received successfully as calculated by a cyclic redundancy check (CRC). Network Allocation Vector (NAV) is modified following RTS / CTS from both the sender and the receiver, which helps to tackle hidden terminal problems (Hara & Higaki, 2020).

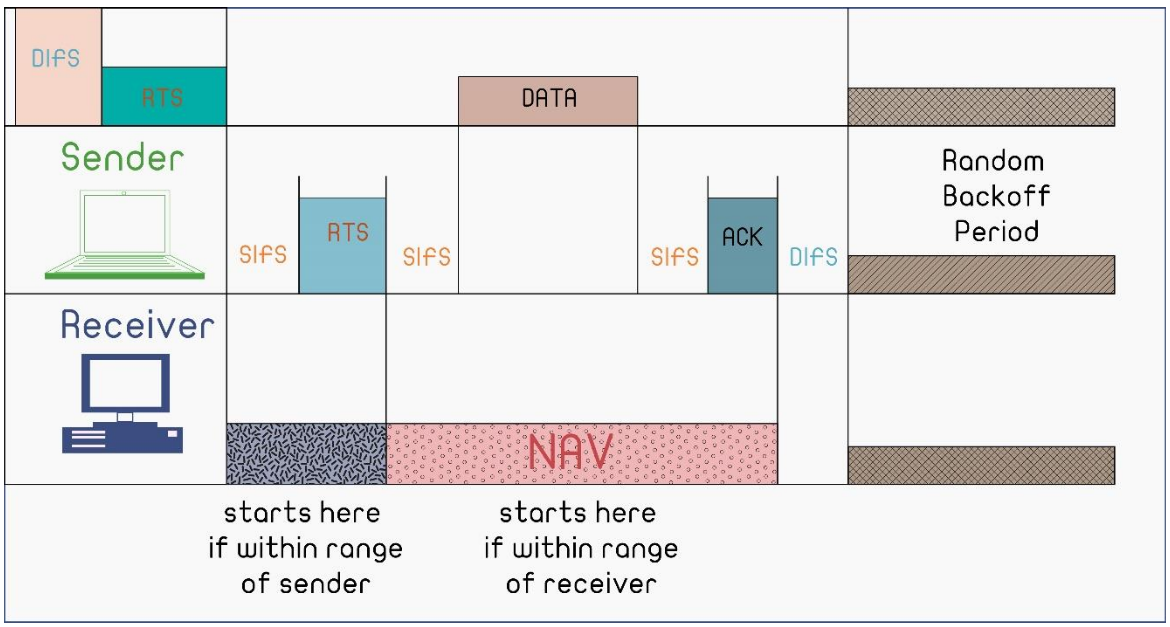


Figure 2. 6 DCF process (Coronado, Valero, Orozco-Barbosa, Cambronero, & Pelayo, 2020)

There is a hidden node problem associated with the back-and-forth exchange in the DCF process, illustrated in Figure 2.7, as demonstrated: station (A) can communicate with station (B), but cannot communicate with station (C). However, station (B) can communicate with station (C). While station (C) is transmitting to station (B), station (A) for instance, may sense the channel is clear, So the protocol explained above warns station (A) that station (B) is busy, so as a consequence it must wait before sending its packet.

The RTS and CTS frames cover the anticipated transmission length and thus warn all stations of how long the channel is to be used in the two stations. As a result, no transmissions begin for that time interval (SIFS) at all stations, including hidden stations. Essential data frames, including ACK and CTS, wait for a shorter SIFS interval than DIFS. SIFS is only available for management and control frames, not for data frames (Shah, Khan, & Baig, 2020).

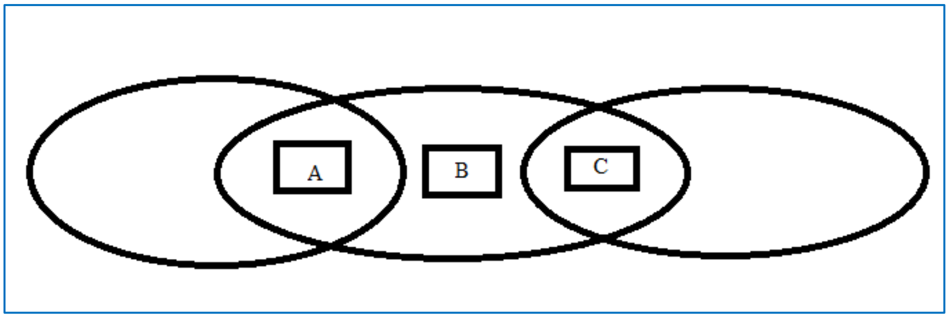


Figure 2. 7 Hidden Node Problems (Campos, Hernández-Solana, & Valdovinos-Bardají, 2020)

- **PCF (Point Coordination Function)**

PCF is used only in infrastructure WLAN. AP uses a centralized access function Point Coordinator (PC) to implement the polling process. In addition, the PC is an access point and a priority medium control. The PC uses the structure of the PCF Interframe Space (PIFS). Because PCF has a higher priority, as shown in Figure 2.8, PIFS is shorter than DIFS.

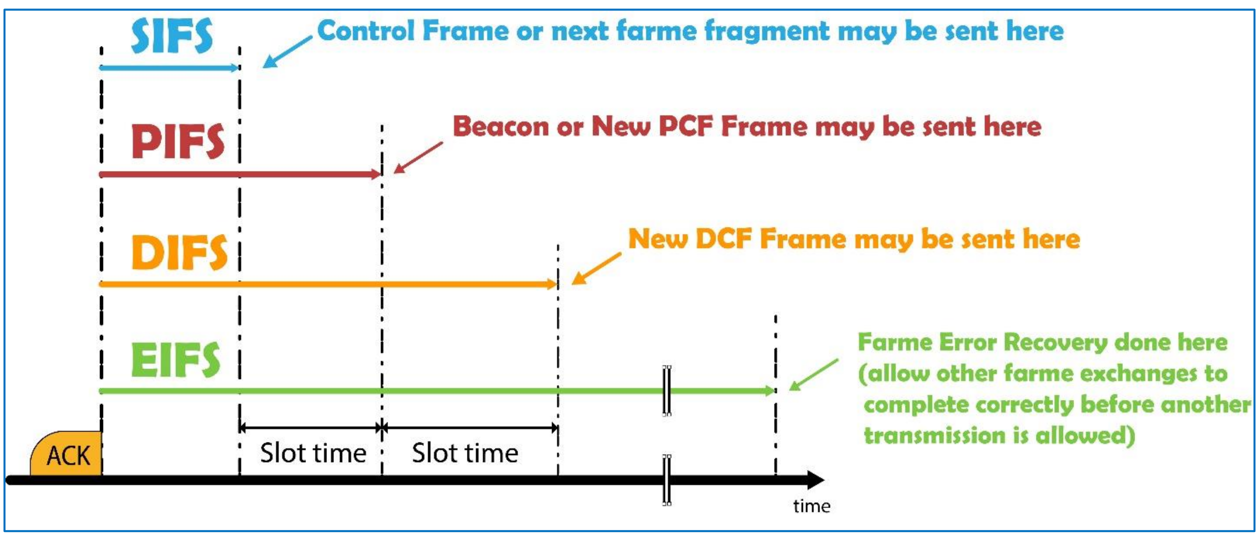


Figure 2. 8 Inter frame Spacing (Refaet, Amed, Abed, & Aish, 2020)

PCF involves the forming of a superframe that combines the Contention Free Period (CFP) and Contention Period (CP). The superframe is also described as the CFP repetition interval as indicated in Figure 2.9. Through sending a beacon frame AP within each BSS initiates the CFP repetition interval (CFP-Rate) for the purpose of synchronization and timing. The management framework advises all other stations not to initiate transmission for the duration of the CFP, except for the stations being polled. The pooling principle is used, allowing only stations polled to send during the CFP, while stations contending during the CP make use of DCF. The control frame, known as CF-End, is responsible for terminating the process (Refaet, Amed, Abed, & Aish, 2020).

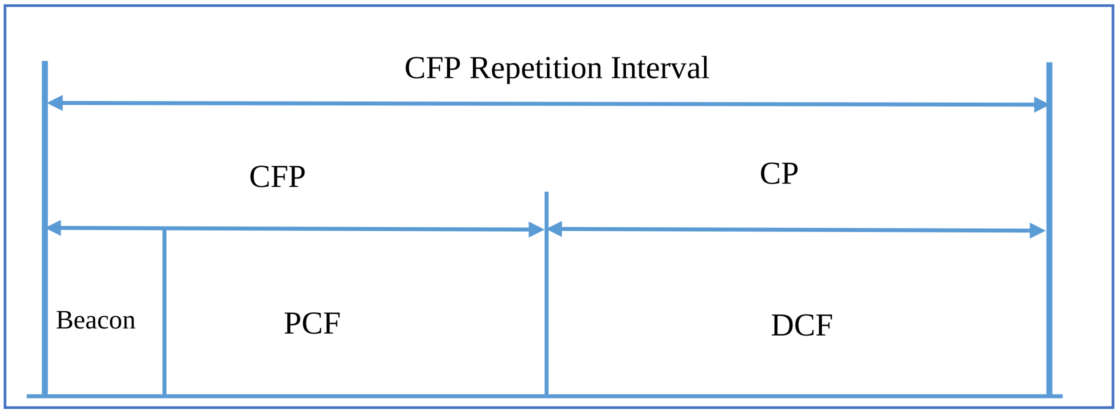


Figure 2. 9 CFP repetition interval (Refaet, Amed, Abed, & Aish, 2020)

2.3.5 QoS: Wireless LAN 802.11e

The new real-time applications are very sensitive to the latency, lost packets, and they need better bandwidth to increase the speed. To support these applications QoS was introduced to IEEE 802.11 MAC. QoS gives priority to certain traffic over other traffic. The QoS enhanced AP (QAP) and the QoS enhanced Stations (QSTAs) become available in the QoS enabled network. IEEE 802.11e standards provide two QoS mechanisms as follows:

- **EDCF (Enhanced Distribution Coordination Function)**

EDCF is an enhanced variant of the DCF access method. The legacy IEEE 802.11 MAC has deprived any kind of prioritization and differentiation between data frames. The EDCF offers differential channel access to the higher layer priority frames. To ensure some amount of QoS in the MAC layer, the EDCF has been implemented.

Before sending data, stations do two things: first, detect the medium to see whether it is clear or not; second, wait for a specified time, called Arbitration Interframe Space (AIFS), defined by the corresponding traffic category (TC) as shown in Figure 2.10. Comparably, as SIFS has defined higher priority for management and control frameworks, there is a variety of Interframe Space for each category. This is often referred to as Arbitration Interframe Space (AIFS) which relies on TC.

EDCF assigns different Access Categories (AC), Contention Window (CW) sizes, and Transmit Opportunity (TXOP). It uses the principle of priorities to assign and differentiate access to the medium (Erturk, Vollero, & Aydin, 2018).

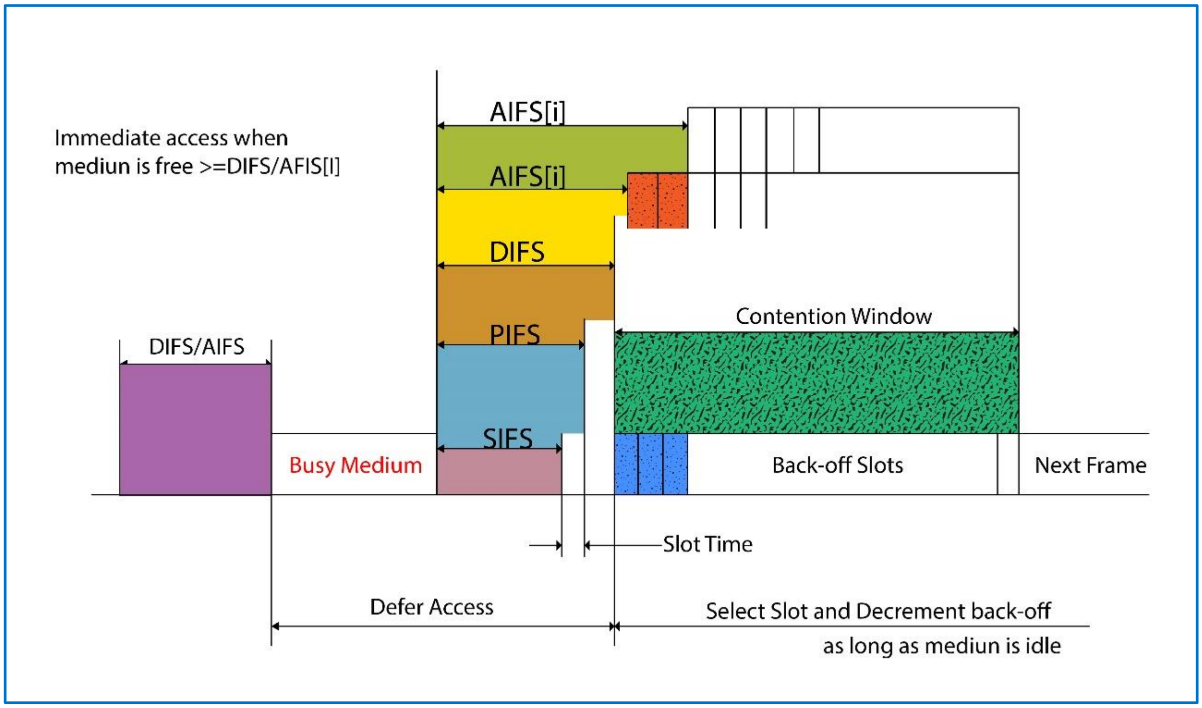


Figure 2. 10 Arbitration Inter Frame Space (AIFS) (Farej & Jasim, 2020)

A higher priority traffic category is accorded to a shorter AIFS than the longer AIFS. Stations with higher priority traffic would also wait a shorter period before trying to enter the medium than those with less priority traffic. However, EDCF defines four Access Categories (ACs) which provide support for traffic delivery, as shown in Table 2.5. So, each data packet assigned a specific priority value, then these values are mapped with Access Categories (ACs). As indicated, the relative priority 0 is place between 2 and 3 which is rooted from IEEE 802.1d MAC bridges standard. Several types of applications such as video traffic, voice traffic, and best effort traffic are mapped into these four ACs (Farej & Jasim, 2020).

Table 2. 5 Default Value of EDCA (Ali, Nauman, Bin Zikria, Kim, & Kim, 2020)

Priority	**Access Category**	**Designation**
1	0	Background
2	0	Standard
0	1	Best Effort
3	1	Excellent Effort
4	2	Streaming Multimedia
5	2	Interactive Multimedia
6	3	Interactive Voice
7	3	Reserved

- **HCF (Hybrid Coordination Function)**

In IEEE 802.11e HCF is an extension to the PCF scheme. HCF supports QoS applications requirements through managing the bandwidth and assigning TXOPs to QoS stations (STAs) (IEEE Std 802.11, 2012).

In the superframe of WLAN 802.11e, CP and CFP can also be used as two phases that rotate over time. EDCF is used only in the CP, while in both CP and CFP the HCF is used to make hybrid a new coordination function. After an idle time for PIFS, HC sends a QoS CF poll without back off. Consequently, HC will issue polled TXOPs inside the CP using its priority access media. However, during CFP, HC will determine the start and thus overall length of the TXOP with the CF-poll frames of QoS. HC grants TXOPs through the delivery of the polling frames during the CFP only. The CFP shall be ended either with the HC CF-end frame or through the beacon framework by the prescribed time (Feng, Jayasundara, Nirmalathas, & Wong, 2019) . The 802.11e superframe is shown in Figure 2.11.

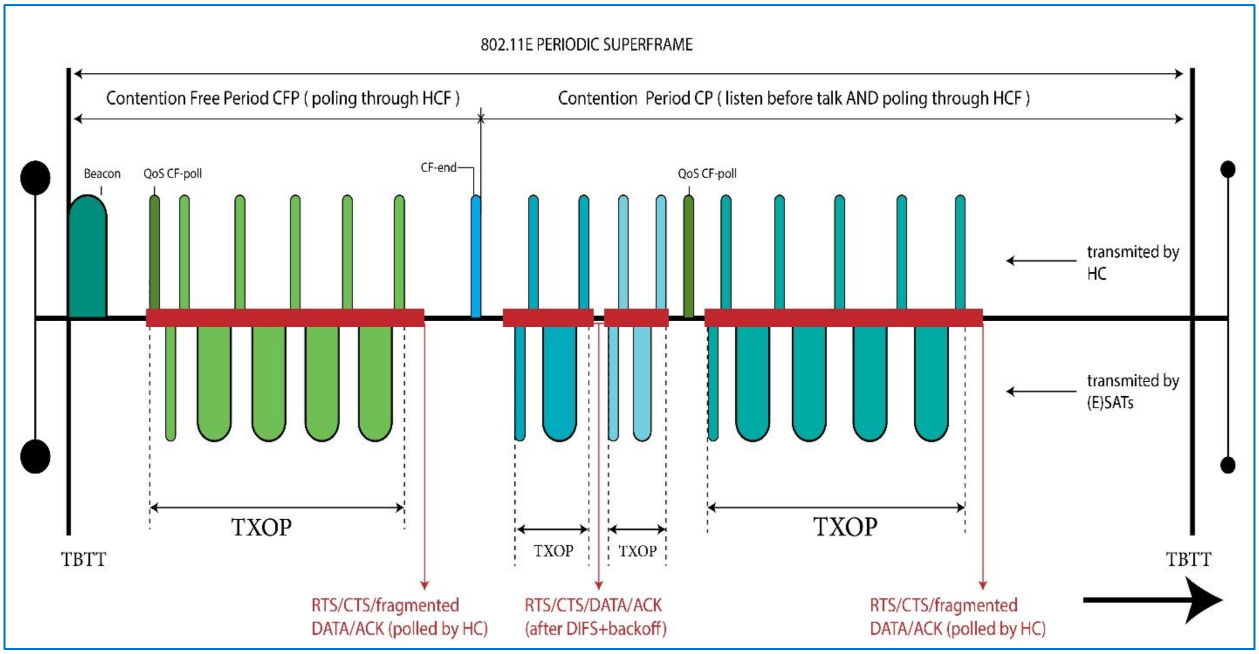


Figure 2. 11 802.11e superframe, HCF pooling (Feng, Jayasundara, Nirmalathas, & Wong, 2019)

HCF identifies two access functions: Enhanced Distributed Channel Access (EDCA) for contention-based transmission and HCF Controlled Channel Access (HCCA) for contention-free transmission. Through these two features, this combination was designed to enhanced legacy functions DCF and PCF. To ensure compatibility between various devices, the WLAN 802.11 permits coexistence of EDCA and HCCA with DCF and PCF (Sounni, Elkamoun, & Lakrami, 2017).

It is clear that the implementation of new technologies such as VC and VoIP, makes it difficult for network designers and managers to meet the specifications for bandwidth, latency and error rates. Networks will also regard these services as a high priority. QoS is committed to solving these emerging problems better, through reliability and efficiency. Some of the key technological problems with QoS is that work stations must be assisted in order to be effective. VoIP and VC must be guaranteed a minimum transmission rate so that they can work properly (Shah, Khan, & Baig, 2020) .

IEEE 802.11e is presented here as an orthogonal to the other MAC physical layers technologies (802.11, 11a, 11b, 11g, 11n). It defines QoS for 802.11 and provides Contention Free Bursts (CFB) which allow stations to send several frames in a row without contention, if the allocated Transmission Opportunity (TXOP) permits (IEEE Std 802.11, 2005). It defines a Hybrid Coordinator (HC) in the QoS enabled AP (QAP) that has an EDCA access mode similar to DCF but with different priority levels for different services (such as DiffServ). 802.11e requires both the AP and the STA to implement it. It can also co-operate with non-QoS (non-802.11e) STA devices.

2.3.6 802.11ac standard (Very High Throughput -VHT)

IEEE 802.11ac, Wi-Fi 5 (IEEE Std 802.11ac , 2013), an IEEE 802.11 wireless networking protocol, provides high throughput of over 5 GHz WLAN bands (Chen & Hsu, 2015). The Wi-Fi Alliance, which maintains and regulates the (Wi-Fi Certified) logo, which is only allowed on devices that have passed the test, has branded IEEE 802.11ac as Wi-Fi 5. Testing requires not just compatibility of radio and data standards, but also safety procedures, potential service quality testing and power management procedures. Certified Wi-Fi devices must prove that, in a situation similar to that found in day-to-day use, it can function well during communications with several other certified Wi-Fi devices that executing common services and applications (Feng Z. , 2017).

With the IEEE 802.11n amendment, MIMO was first adopted to the IEEE 802.11 technologies. This technology comprises a system of physical layers where several antennas are used by both the sender and the receiver. A maximum of four MIMO streams that can serve a single user at a time (an approach called single MIMO, SU-MIMO) with spatial multiplexing of up to four streams. IEEE 802.11ac, by comparison, was considered to be the first 802.11 amendment to launch multi-user MIMO techniques that support many stations at once. It also doubles the level of streams permitted from four to eight for SU-MIMO (Bellalta, 2016).

IEEE 802.11ac has at minimum 1.1 Gbps of multi-station throughput as well as 500 Mbps of single-link throughput. These are done by expanding the principles of the air-interface adopted in 802.11n: broader RF bandwidth (up to 160 MHz), MIMO streams (up to 8 streams), multi-user MIMO downlink (up to 4 users) and high-density modulation (256-QAM). The two principal characteristics that permit IEEE 802.11ac technology to reach gigabit speeds are (Rochim, Harijadi, Purbanugraha, Fuad, & Nugroho, 2020):

- Static and dynamic channel bonding.
- Multi-user multiple input multiple output (MU-MIMO).

The development of 802.11ac wireless devices was divided by the Wi-Fi Alliance into two stages or waves, called Wave1 and Wave 2, as shown in Table 2.6.

Table 2. 6 Wave 1 and Wave 2 of IEEE 802.11ac Comparison (Newell, Davies, Wade, deCaux, & Shama, 2017)

Attribute	**Wave 1**	**Wave 2**	**IEEE 802.11ac Specification**
Frequency Band	5 GHz	5 GHz	5 GHz
Channel width	20, 40, 80 MHz	20, 40, 80, 80-80, 160 MHz	20, 40, 80, 80-80, 160 MHz
Coding & Modulation	256 QAM	256 QAM	256 / 1024 QAM
Number of Spatial Streams (SS)	3×3	3×4	3×8
Beamforming	Vendor-Specific	Yes	Yes
Max PHY Rate	1.3 Gbps	2.5-3.74 Gbps	6.9 Gbps
Max MAC Throughput	845 Mbps	1.52-2.26 Gbps	4.49 Gbps
SU / MU-MIMO	SU-MIMO	MU-MIMO	MU-MIMO

The alliance started to certify Wave 1 802.11ac devices delivered by manufacturing firms on the basis of IEEE 802.11ac Draft 3.0, from the middle of 2013 onwards. The Wi-Fi Alliance developed and launched Wave 2 in 2016, that contains advanced capabilities such as MU-MIMO (down-link only), endorse to 160 MHz channel width, 5 GHz frequency band, and four spatial streams (with four antennas; compared to three in Wave 1 and 802.11n, and eight in the 802.11ax specification of IEEE). This implied that devices of Wave 2 would have greater bandwidth and efficiency than devices of Wave 1 (Gast, 2017). Table 2.7, addresses the mandatory and optional attributes of IEEE 802.11ac.

Table 2. 7 Mandatory and Optional Attributes of the IEEE 802.11ac Table (Gast, 2017)

Attribute	**Mandatory**	**Optional**
Channel width	20, 40, 80 MHz	160 MHz
Coding & Modulation	(BPSK 1/2 - 64 QAM 5/6) MCS 0-7	(256 QAM 3/4, 256 QAM 5/6) MCS 8, 9
Number of Spatial streams	1	2-8
Beamforming	NA	React to the sounding beamforming
Parity check	NA	LDPC Send and Receive
MU-MIMO	NA	Max of four spatial streams per user with the same Modulation and Coding Schemes (MCS).

The enhancements to the PHY layer of IEEE 802.11ac are including MU-MIMO, channel bonding, and Short Guard Interval (SGI).

- MU-MIMO, this principle is introduced in IEEE 802.11ac, which provides a list of wireless devices equipped with one or more antennas that can communicate and interact with each other. A sender with multiple antennas can simultaneously transmit data across multiple receivers. There can be one or more antennas in each receiver. The sender is thus fitted with MIMO antennas, and there are also MIMO spatial streams in each of the receivers.
- Channel bonding, by integrating several 20 MHz channels, channel bonding extends the bandwidth of the channel. It will double the data rate of the PHY layer for one device, but there will be fewer channels remaining for other devices.
- Short Guard Interval (SGI), It is the interval of time between the symbols sent. To avoid Inter-Symbol Interference (ISI) and to guarantee that transmissions belonging to various users do not interfere with each other, a guard interval is required. Whenever there is adequate symbol isolation in the wireless medium, SGI could really enhance the throughput. SGI contributes to more congestion in large network traffic situations and, hence, reduces throughput.

At the MAC level, the Aggregate-MAC Protocol Data Unit (A-MPDU) frame aggregation is a technique that can, in principle, minimize the overhead MAC layer and increase the throughput. A-MPDU has been implemented in IEEE 802.11n. A-MPDU frame aggregation involves creating and merging several data packets coming from the transport or application layer and constructing a very long data frame (Yazid & Ksentini, 2018).

In the IEEE 802.11, two access techniques are defined. DCF is the common technique, utilize Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). PCF is the other technique. The DCF MAC protocol was adopted by the IEEE 802.11ac standards. DCF also uses an optional RTS/CTS scheme to allocate the wireless medium between stations and recommends it for both static and dynamic reservation of bandwidth. (Gao, Sun, & Dai, 2018).

IEEE 802.11ac operates in a 5 GHz band and supports 20, 40 and 80 MHz channels as mandatory channels and a 160 MHz channel formed by two 80 MHz non-adjacent channels as an optional channel. Using the 80 MHz frequency channel efficiently in the 802.11ac standard is a hurdle for workstations because both 802.11a and 802.11n workstations still function as 802.11ac stations in the 5 GHz band. High-frequency channels, such as 80 MHz, are also assumed to be less likely to operate at their maximum bandwidth, as it would also share a medium with 802.11a/n 20 to 40 MHz networks operating in the same nearby region (Tuysuz, 2018).

Regular IEEE 802.11ac will achieve data rates from 6.5 Mbps to more than 6.9 Gbps. Through implementing further sophisticated MCS, these high data rates are accomplished. There is a specified MCS indicator for each connection on an 802.11ac WLAN. This indicator is a combination of a form of modulation (such as BPSK, 64 QAM) and a coding rate (2/3,3/4,5/6...), resulting in a fixed rate of data. The bigger the MCS index, the greater a node's data rate. The aim of the network interface card when selecting an MCS is to optimize the data rate while maintaining a reasonably low rate of packet error. The data rates for various MCS values at 802.11ac and various channel sizes are listed in Table 2.8 (Daldoul, Meddour, & Ksentini, 2017).

Table 2. 8 Data rates (Mbps), case of one Spatial Stream (Daldoul, Meddour, & Ksentini, 2017).

MCS	0	1	2	3	4	5	6	7	8	9
20MHz	7.2	14.4	21.7	28.9	43.3	57.8	65	72.2	86.7	-
40MHz	15	30	45	60	93	120	135	150	180	200
80MHz	32.5	65	97.5	130	195	260	292.5	325	390	433.3
160MHz	65	130	195	260	390	520	585	650	780	866.7

2.3.7 802.11ax standard (High Efficiency -HE)

IEEE 802.11ax, **Wi-Fi 6 (**also known as High Efficiency (HE)) was recently introduced (IEEE Draft std 802.11ax, 2017). In the IEEE 802.11family of WLANs, IEEE 802.11ax is considered as the sixth WLAN generation. It describes improvements to both the IEEE 802.11 PHY and MAC layers, that allow greater overall throughput for every device in densely deployed networks (Afaqui , Garcia-villegas, & Lopez-aguilera, 2017). The IEEE 802.11ax task force began designing a new standard for high efficiency wireless local area networks in May 2014. Developing the IEEE 802.11ax protocol follows the timeline shown in Figure 2.12, depending on the IEEE specification. The IEEE 802.11ax project is currently at an advanced phase of development and is scheduled to be released in February 2021 (IEEE Working Group, 2020).

It is developed to function in bands ranging from 1 to 6 GHz. IEEE 802.11ax is expected to provide a theoretical capacity of approximately 9.5 Gbps at 2.4 and/or 5 GHz and aims to have 4 times the throughput of IEEE 802.11ac. IEEE 802.11ax focuses predominantly on 2.4 and 5 GHz WLAN operations but is able to accommodate all-new 6 GHz, frequency bands. In the 6 GHz band, it will bring more bandwidth, better performance, reduced latency and faster speeds (Sanchez-Mahecha, Cespedes, & Bustos-Jimenez, 2018).

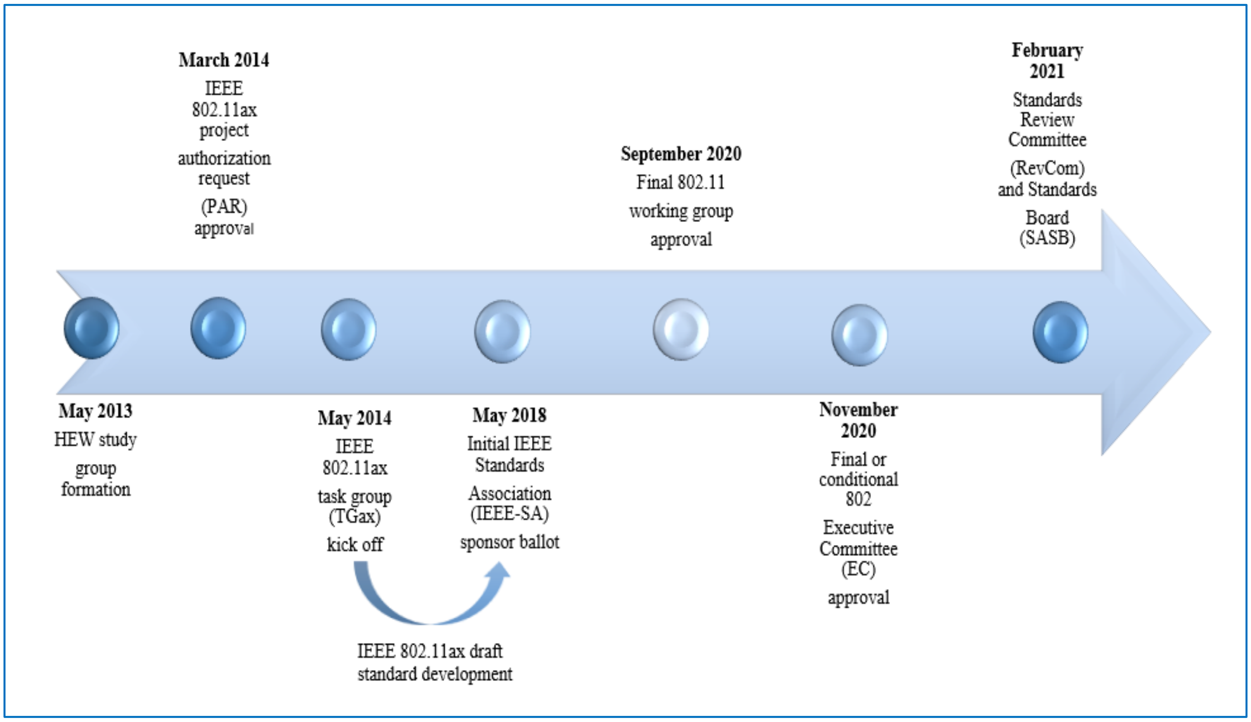


Figure 2. 12 Timeline of the development of the IEEE 802.11ax standard for HEWs (IEEE Working Group, 2020)

In addition, due to the growing number of devices currently used all over the world, standard Wi-Fi is suffering a spectrum shortfall and the introduction of 6 GHz would help to alleviate this issue. Once approved, 6 GHz would enable continuous improvement of Wi-Fi, as well as other benefits, such as wider channel widths and less interference from both Wi-Fi 4 (802.11n) and Wi-Fi 5 (802.11ac) devices (Jeffrey, 2020).

It should be highlighted that IEEE 802.11ax concentrates more on network efficiency and user experience in high-density implementation environments, including enhancements in single-user overall throughput and region throughput, compared to previous IEEE 802.11 standard reforms, most of which focused on improving the transmission rate. The ultimate goal of IEEE 802.11ax in high-density deployment environments is to dramatically improve user experience. IEEE 802.11ax introduces a range of critical technologies for both PHY and MAC layers in line with the rising implementation of the high-density scenarios and objective and functional demands (Yang, Li, Yang, Yan, & Ca, 2020).

1) PHY enhancements

New modulations and coding techniques are being implemented by IEEE 802.11ax. Initially, the overall transmission will be further increased with the implementation of the 1024 QAM. In principle, IEEE 802.11ax has a maximum transmission rate of 9.6 Gbps. Moreover, in both outdoor scenarios and uplink transmission, dual-carrier modulation (DCM) enhances the performance of transmissions. Eventually, in IEEE 802.11ax, low-density parity-check (LDPC) along with binary convolutional encoding (BCC) is picked as a mandatory coding method (Daldoul, Meddour, & Ksentini, 2020).

The 20 MHz bands of IEEE802.11ax is split into 256 subcarriers, four times the tradition of IEEE 802.11. This new mechanism for subcarrier division results in more accurate and effective scheduling of OFDMA resources and thereby performance improvement of the spectrum. Moreover, IEEE 802.11ax implements improved power control techniques to prevent interference with adjacent networks, OFDMA, 1024 QAM, and uplink (UL) direction introduced with the downlink (DL) of MIMO and MU-MIMO to further increase throughput, as well as improvements in power usage. The OFDMA partitions the channel into various resource units (RUs) and allows multiple users to transfer data at the same time across various RUs (Omar, et al., 2016).

2) MU-MAC enhancements

By implementing multi-user MAC (MU-MAC), spatial reuse (SR), and target wakeup time (TWT), IEEE 802.11ax greatly enhances MAC layer technologies, that enhances access efficiency and user experience in high-density network environments. There are three improvements to IEEE 802.11ax's MAC technology. In both the frequency domain and the spatial domain, the MU-MAC allows parallel transmissions and thus increases the performance of the single-BSS range and the robustness of both outdoor and uplink transmission. Also, the SR experiences high-density multi-BSS situations and strengthens the reuse of the spectrum and the control of interference. Ultimately, the IEEE 802.11 protocol implements the power management scheme to conserve power, which enables stations to operate in a power-saving or sleep mode by shutting down their transceivers without any data transmission engagement. The Target Wake Time (TWT) framework implemented in the IEEE 802.11ah protocol has significantly enhanced conventional power management. The station can communicate with its AP for TWT sessions, using the TWT structure in which the station remains awake to exchange information (Chen & Zhu, 2020).

With device density in view, IEEE 802.11ax is specifically designed and developed. In addition to other attributes intended to optimize raw data throughput abilities, the standard supports a number of new attributes that address density and wireless coverage, as shown in Table 2.9.

Table 2. 9 802.11ax Features and capabilities (Choi, Gong, Kim, Shin, & Lee, 2019)

Feature	**Description**	**Benefit**
Downlink and upline OFDMA	At a given time, the radio channel is divided into many smaller sub-channels, facilitating concurrent uplink transmissions from multiple stations to an AP and concurrent downlink transmissions from an AP to multiple stations.	Higher client density
Downlink and upline MU-MIMO	MU-MIMO, which allows applications to transfer data downstream to multiple devices simultaneously, was first implemented by IEEE 802.11ac. Furthermore, four spatial streams were supported, whereas IEEE 802.11ax improves this to eight and adds support for uplink MU-MIMO, allows various users to concurrently transmit to the AP.	Enhanced data speeds
Spatial reuse techniques	Users will be within the realm of different APs in dense environments. IEEE 802.11ax enables devices to connect to their associated AP for a particular identifier and adjust the transport properties accordingly.	Higher client and access point density
1024 QAM	The improvement of about 25% of PHY data rates is the consequence of the expansion from 512 QAM to 1024 QAM.	Enhanced data speeds

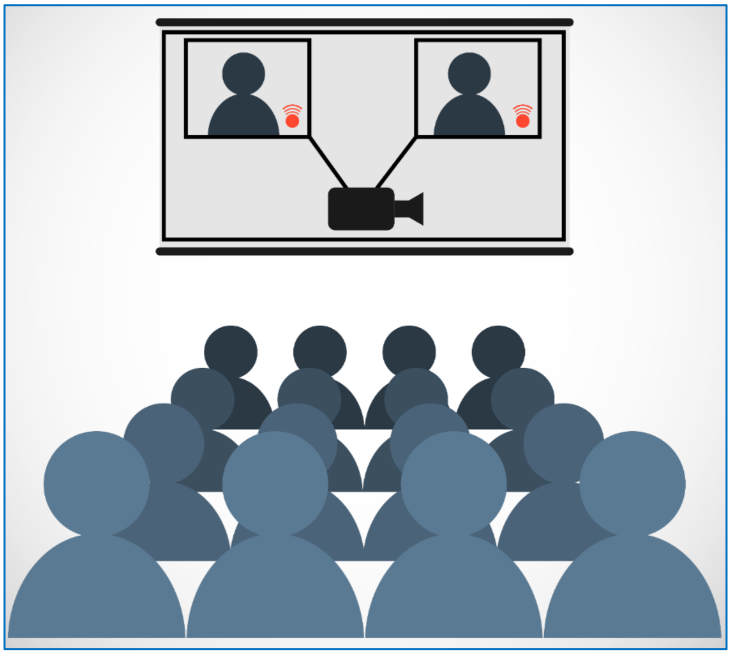
The introduction of IEEE 802.11ax, alongside decreased delay, lower power consumption and an improved overall user experience, this will contribute to a rise in the number of devices capable of connecting to a Wi-Fi network (Lee K.-H. , 2019).

2.4 Real-time Services

Real-time services such as VoIP and VC are currently a massive challenge in the communication industry. VoIP is a system and technology community for the transport of web-based voice and multimedia communication in packets that use IP instead of standard PSTN circuit transmissions, as illustrated in Figure 2.13 (a). As shown in Figure 2.13 (b), Videoconferencing implies that two or more individuals in different areas are connected live and visually. WLAN has become a proven and increasingly popular service by offering constant access to network infrastructure and incorporating real-time traffic such as video and audio on businesses, enterprise and household networks (Odjidja, Kabanda, Agangiba, & Annan, 2018).

Wi-Fi services are intended to improve real-time traffic, including social networking, live streaming and online games. However, it is still a challenge to stream quality video over WLAN with limited bandwidth (Chang, Yen, Lin, & Deng, 2015). The revolution in wireless technology and people's desire to be persistently connected has made wireless communication a key feature of everyday reality. A rise of high-quality digital content and a shift in the usage habits of end-users have occurred in the last few years. This reality, coupled with the IEEE 802.11 standard's flexibility, reasonable price and digital media capability, has driven Wi-Fi technologies to dominate the market and has generated hurdles in network efficiency and usability. The advent of media platforms such as YouTube and Netflix and others has boosted the growth of digital media delivery and streaming applications. These applications have a significant effect on the quality encountered by users in terms of delay, jitter, and throughput, if not properly treated (Coronado, Villalón, & Garrido, 2020).

(a)



(b)

Figure 2. 13 Real time services. (a) VoIP, (b) VC (Odjidja, Kabanda, Agangiba, & Annan, 2018)

Over the last few years, various networks have been established to manage voice, data and video. The packet-switched networks such as H.323 are a full suite of protocols developed by the International Telecommunication Union (ITU) to define how real-time services, such as VoIP and VC, can be exchanged. The H.323 Supplementary Services model uses an Internet architecture where network routing and applications operate at endpoints (e.g., personal computers, servers, and routers).

In real-time services, users can use the Internet as a means of communication through the use of the Internet Protocol (IP) through their use of Voice, Video and Data, rather than the Traditional Public Switched Telephone Network (PSTN). In IP networks, data is digitized and transmitted via a wireless data network as a packet stream. No channel reservation is available in this mode of communication if someone else wants to apply or utilize the channel simultaneously. VoIP technology is intended to crack the barrier between VoIP and PSTN networks. In contrast to the PSTN, VoIP has lower costs as well as superior versatility, management and support. For packet networks of real-time voice, the QoS specifications are clearly distinguishable from those for data-only networks. Data networks focus exclusively on the reduction of data error rates, but voice communications rely on the perceived quality of the resulting conversation. The key issue is, therefore, the identification of the ability to transport voice calls over an IP network, the digitization and packing of QoS voice streams, and the characterization of an infrastructure in which voice, video and data transmissions are combined into a single, common framework (Odjidja, Kabanda, Agangiba, & Annan, 2018).

The metric parameters and characteristics of QoS must be met to enable multimedia applications to operate appropriately (Seytnazarov & Kim, 2017). A variety of factors influencing network performance, such as wireless network architectures and IEEE MAC-layer technologies, should be discussed and evaluated in the WLANs where real-time applications have been deployed.

However, the provision of accurate QoS in real-time multimedia applications is regarded as a question for the wireless network and is the object of extensive research. The relation between VoIP codec and QoS parameters was studied by Labyad, Moughit, & Haqiq (2012) to investigate the best performance VoIP codec over the IP network. At the same time, there are initiatives to monitor IEEE standards.

Mehmood & Alturki (2011) introduced architecture which examines the IBSS network for a mix of 802.11g technology and QoS provisions with HTTP, voice and video applications. This architecture is perfect for an increasingly wide network and exceeds renowned routing protocols. Furthermore, to measure and monitor video quality, Develder, et al. (2012) demonstrated an automated test framework for the implementation, testing and evaluation of new video quality measurements. The key benefit of this method is that various tests can be carried out concurrently, thereby minimizing the total length of the experiment.

Several attempts were made to assess metric QoS parameters set by IEEE technologies throughout real-time services. The researchers Cahyadi, R. Raihan, Danisya, & Hwang (2019) discuss the relationship between Enhanced Channel Access for Delivery (EPACA), and the distributed coordinating framework (DCF) for three traffic services: audio, video streaming and data, using the NS-3 simulator. Dai & Xu (2019) suggested a model of network stability that can accurately reflect network performance when network failures occur in real-time and provide suggestions as to how network stability can be maintained.

Network architectures and real-time protocols have been investigated in recent studies and configured with VoIP services. Ifijeh, Idachaba, & Oluwafemi (2015) built an ESS network architecture to study the effect of various VoIP codecs; the authors in this article investigated the effects of various codecs on a VoIP over WLAN. ESS is the network architecture as two access points were used through the configuration of the scenarios. In Abdelrahman, Saeed, & Alsaqour (2016), the implementation of a VoIP network is configured. To get results related to the QoS metrics, VoIP application packets have been sent measured across the RTP, TCP, and UDP protocols. As a result of this examination, the packet loss rate was shown to be reduced over RTP.

Several frameworks have been introduced to enhance VC services and to evaluate its QoS metrics. Egilmez, Civanlar, & Tekalp (2013) proposed a framework over OpenFlow networks for dynamic rerouting of QoS flows to stream scalable coded videos. The proposed framework allows a major change in the entire performance of the distribution of usable encrypted videos in diverse coding settings and traffic congestion environments. In addition, Boushaba, Benabbou, Benabbou, Zahi, & Oumsis (2014) proposed an extension of MP-OLSR (multipath optimized link-state routing protocol) to improve QoS and Quality of Experiment (QoE) of video transmission. The enhanced protocol integrates two fuzzy systems. The first one is used to measure multi-restricted QoS metrics: delay, latency and signal to interference plus noise ratio (SINR). The second system is used to modify the cost functions using the Dijkstra multipath algorithm to achieve a significant versatility and interoperability study. However, the enhanced protocol achieved a significant improvement of the video streaming quality. Misra & Goswami (2015) predicted bandwidth utilization of the end-to-end video conference session by means of machine learning techniques including experimental features such as timing call, source, destination, type of call and the anticipated length.

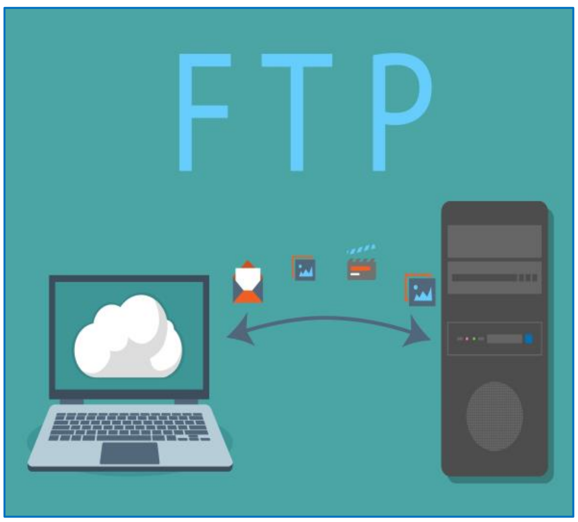
Furthermore, a comparative performance analysis was developed by Circiumarescu, Predusca, Angelescu, & Puchianu (2015), to determine the RIP, OSPF, EIGRP and IGRP protocols that are particularly fit for the network. The study using QoS metrics such as a variance packet delay, end-to-end delay and video traffic analysis was performed to test VC, Email, HTTP and FTP services through OPNET and demonstrated that the best protocol for VC is EIGRP. In the sense of a compilation of videos and voices with best-effort applications, nodes ranging from 5 to 45, an average delay for such services has been increased (Orfanou, Tselios, & Katsanos, 2015).

On the other hand, a new video streaming approach to avoid a video image freezing was implemented in Nagai, Okamawari, & Fujii (2016), to ensure that the mobile network's QoS control feature was used and very positive results were seen for video streaming users. Al-Maqri, Othman, Mohd Ali, & Hanapi (2016) presented a dynamic algorithm for supporting video traffics transmission over IEEE 802.11e wireless networks. Extensive simulation experiments were carried out. As a result of this study, it was shown that the packet delay was reduced and the channel utilization enhanced as well. Lakrami, El-Kamili, & Elkamoun (2016) 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.

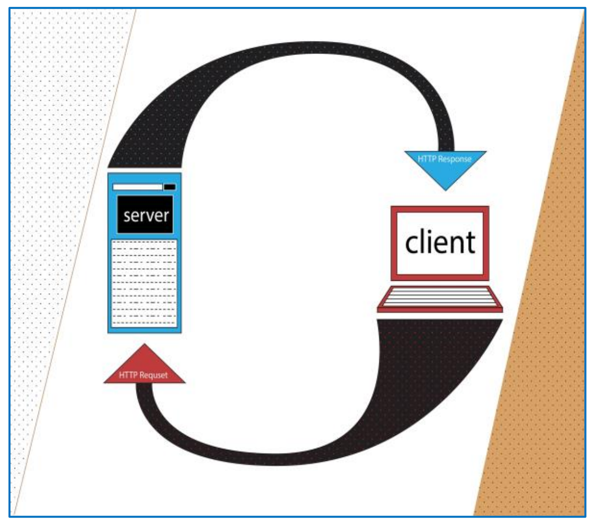
QoS and QoE are investigated in the newest studies and configured with real-time services. A new universal QoS scheme was proposed by Wu, Wang, & Zhang (2017) to classify web applications such as VC, VoIP, e-commerce and online games into different priorities. Furthermore, this scheme can satisfy various QoS metrics such as the low delay, low delay jitter and higher bandwidth requirement of some web applications while maintaining good network performance. Pal & Vanijja (2017) presented a mapping function from QoS to QoE for mobile video streaming services. Five QoS metric factors (variable initial delay, packet loss, jitter, bandwidth and buffering delay) were considered for this mapping process. Hence, all the existing mapping functions were analysed and compared to the mathematical results for this function in order to choose the optimal model.

2.5 Best-effort Services

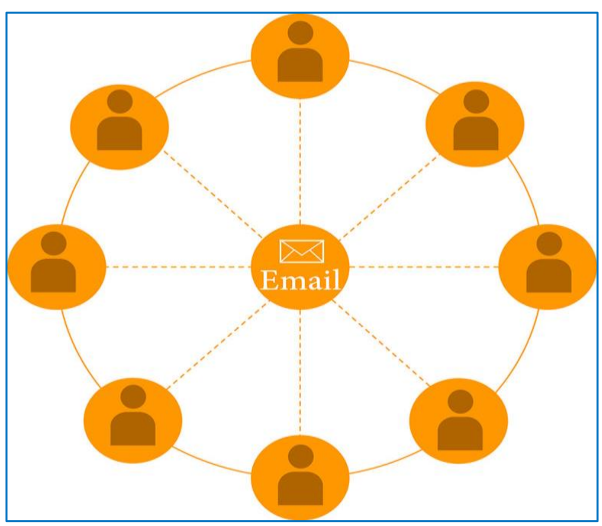
Best effort protocols are used to request/response pattern, and also work in Transmission Control Protocol (TCP) which is an equitably good service for all file transfer applications. File transfer, either explicit (FTP) or implicit such as web page download (HTTP) or E-mail (SMTP), constitutes the enormous majority of Internet traffic. FTP is a client/server protocol that is used for sharing or transmitting files between devices over the network. HTTP (Hypertext Transfer Protocol) is how messages are normally encoded and transmitted via a browser. Email services allow the sending and receiving of messages between people over communications networks. Figure 2.14. illustrates three best-effort services.



(a)



(b)



(c)

Figure 2. 14 Best-effort services. (a) FTP, (b) HTTP, (c) Email (Khiat, Bahnasse, EL Khail, & Bakkoury, 2017)

TCP and UDP are the two most common transport protocols on the Internet. Several studies have therefore been performed in various applications to determine the overall performance of these two protocols. These studies compared these two protocols to evaluate its performance by transferring optimized data (video, audio, and data) (Vivekananda & Chenna Reddy, 2018). Table 2.10 summarizes the differences between them.

Table 2. 10 Comparison between TCP and UDP (Vivekananda & Chenna Reddy, 2018)

Item	**TCP**	**UDP**
Name	Transmission Control Protocol	User Datagram Protocol
Protocol Type	Connection-oriented protocol (set up the connection before transmission)	Connectionless protocol (no need to set up the connection)
Reliability	Reliable (guarantee that data transferred and arrived at the destination)	Unreliable (delivery of data cannot be guarantee)
Sequence No	Provide sequencing of data	No sequencing of data
Retransmission	Retransmission if packet lost	No retransmission if packet lost
Flow Control	Manage flow control	No manage of flow control
Acknowledgement	Provide data Acknowledgment	No data Acknowledgment
Speed	Slow, due to the retransmission and acknowledgement mechanisms	Fast, due to less overhead and not such reliability functions
Workspace	Suitable for wired environments	Suitable for wireless environments

From the above table, the studies infer that UDP can be used to get better performance for real-time applications as IP telephony and VC than TCP. TCP has retransmission, acknowledgement, and high error checksum that congests the network and increases the delay, which makes it slower. For these reasons, the optimized data packets are usually transmitted using UDP (Awang Nor, Alubady, & Abduladeem Kamil, 2016).

The Internet Architecture was effective in exchanging traditional information, including news, text applications and transmission of files. Currently, the internet provides a best-effort service class. There are several technical measures to evaluate the efficiency of network architecture, like bandwidth, packet loss, and delay. Not all applications are affected similarly by these measures. For example, the file transfer will not be greatly affected if it delays for some seconds. On the other hand, the optimized data packets will suffer extremely if they face such delays.

However, the delivery of these services creates strong demands on the infrastructure of the Internet for both the number of hosts connected and the quality of their data connections. This affects service quality and is particularly noticeable when using WLAN, which contributes to poor network performance Babay, et al. (2017). However, providing precise QoS is considered an issue for best-effort services in the existence of real-time multimedia applications and has been the object of wide research. An article by Wei, Hong, and Shi (2016) analysed the efficacy for five users of HTTP and FTP protocol. The study has been performed utilizing two metrics, average queuing time and TCP delay parameters, yet it was found that the HTTP protocol is more powerful than the FTP protocol. Seytnazarov & Kim (2017) have shown that, in order for real-time services to function properly, the QoS parameters and performance characteristics have to be met, and they stated that the total throughput on the 802.11n network configured has decreased over 20 nodes.

2.6 The State-of-the-art WLAN standards (IEEE 802.11ac/ax)

The development of an effective link adaptation mechanism for IEEE 802.11n/ac networks to achieve theoretically achievable throughput/performance in practical scenarios is a challenge. However, the performance analysis of IEEE 802.11n and IEEE 802.11ac networks is actually addressed in a significant lot of studies, which indicate that higher PHY and MAC data rates do not usually convert into identical higher layers throughput, such as transport and application layer (Karmakar, Chattopadhyay, & Chakraborty, 2017).

Due to the very wide amount of possible configuration options in IEE 802.11n/ac standards, several efforts have been reviewed to evaluate the effect of separate or mixed parameters on the performance of the network. Using the concept of decoupling access classes (AC) and Downlink (DL) MU-MIMO, a new scheduling mechanism called DEMS was introduced by Kosek-Szott (2018). The DEMS mechanism's results demonstrate that it helps to improve the overall performance characteristics while reducing latency.

Zeng, Pathak, & Mohapatra (2017) produced an experimental assessment of 802.11ac throughput characteristics using three factors: greater channel width (80/160 MHz), 256 QAM, and an extended level of MIMO spatial streams. In addition, they use a real 802.11ac testbed to analyse the impact of these factors. However, contrary to the popular belief, they find that larger channels, in particular 80 MHz channels, consume more in the idle state which contributes to driving down its efficiency. The findings have shown that the correct configuration of the MAC parameters will lead to significant energy savings while preserving the same throughput efficiency.

On the other hand, Tuysuz (2018) stated that, since Wi-Fi-based power consumption has increased rapidly due to the immense variety of applications that provide access to the network and internet, it is a major concern, especially for smartphones and tablets. As a result, energy limitation as the transmission rate has also become one of the mobile device design's worth-stressing obstacles. Detailed and comprehensive experimental performance characterization of IEEE 802.11ac specification for indoor WLANs using actual testbed implementations as well as a statistical analysis was provided by Kriara, Molero, & Gross (2016). It included development and implementation of two indoor wireless testbeds used under two separate interference conditions to conduct repetitive, thorough experimental jitter, throughput and fairness efficiency 802.11ac WLANs. In the experimental results, multiple linear regression has been used to demonstrate how the jitter and throughput are greatly influenced not only by the choice made for a particular measure but also by the shared effect of many measures. By integrating wider channels, more spatial sources, and higher density modulation relative to the 802.11n standard, they find that 802.11ac delivers higher efficiency.

Considering the occurrence of collisions with both saturated and non-saturated traffic loads, the IEEE802.11ac throughput obtained was analysed in Kim, Ropitault, Lee, & Golmie (2017). Using a network analytical model at a rather delicate level of abstraction, considering each single frame transmission in a fully connected and saturated network, that is, all adjacent nodes often have backlog frames waiting to be sent. Besides, they showed that performance declined as high-load WLANs shared their secondary channels with more than one WLAN, while overall system load was still the same.

A mathematical framework has been developed in Han, Khairy, Cai, Cheng, & Hou (2020) to review the effectiveness of the opportunistic multi-channel bonding protocol in the IEEE 802.11ac specification that promotes time-sensitive platforms. In particular, a multi-channel scenario is defined in which IEEE 802.11ac users and conventional users communicate on all channels, including primary and secondary channels. Together with the bonding probability of IEEE 802.11ac users and the service delay of both IEEE 802.11ac users and traditional users, the probability of active channel bonding has been derived. Numerical findings suggest that channel bonding often cannot provide network capacity advantage as well as it presented the network capability, which quantifies the maximum number of multimedia flows that can be enabled with guaranteed delay. In addition, they have stated that, in order to achieve the required performance, when competition from traditional users exceeds a certain threshold in secondary channels, the bonding function should be disabled.

Khairy, Han, Cai, Cheng, & Han (2019) developed an analytical model to evaluate the performance of IEEE 802.11ac dynamic channel bonding and IEEE 802.11ax non-contiguous channel aggregation with co-existing single-channel legacy users. The bonding probability of multi-channel users, as well as the throughput of multiple users in each channel, is extracted by modelling the transmissions of single-channel and multi-channel users with and without channel bonding as a two-level renewal process. Their analysis reveals that multi-channel users can increase their throughput at the cost of legacy users' diminished throughput. Furthermore, it can be asserted that 802.11ax produces improved spectrum utilization contrasted to 802.11ac, while 802.11ac offers a more friendly coexistence of single-channel users. The analysis is verified by extensive simulations using NS3 and the effectiveness of the proposed channel selection algorithm is demonstrated. The advantages of using wider channels in high-density, saturated WLANs are being tested in a testbed of 12 AP station pairs in Simić, Riihijärvi, & Mähönen (2017). They found that 80 MHz channels were perfectly adapted to high-density networks, whereas lower-density networks, by having independent simultaneous transmissions, can take the higher performance of discrete 40 MHz and sometimes 20 MHz channels.

Peng, Kai, & Wang (2020) introduced a channel bonding approach to regulate channel contention and increase throughput, in which the channel bandwidth is constrained related to performance analysis that can be achieved. Initially, as per the topology of the network, the channel contention relationship between BSSs is obtained. The obtainable throughput can be estimated based on the current contention graph and the maximal clique algorithm in each possible channel bonding and channel allocation scheme. NS3 Experimental results showed that better performance is obtained by the proposed constrained channel bonding than all conventional channel bonding algorithms; Always-max and Waterfilling algorithms.

Many papers assessed the performance and features of IEEE 802.11ax. In Khorov, Loginov, & Lyakhov (2016) the authors presume a network of traditional stations and IEEE 802.11ax stations and discuss issues of fairness between the two groups of stations. They argued that the simplicity of the use of OFDMA trigger-based transmissions was neither effective nor equitable and established a new model that would allow 802.11ax stations to use OFDMA transmissions and traditional stations primarily to gain access to the channel as recurrently as with the traditional AP. The framework was used to demonstrate the high efficiency and fairness of the method developed.

Ali, Misic, & Misic (2019) utilises MU-MIMO and single-stream transmissions to assess uplink (UL) throughput. It examines the empirical data indicated that the performance of the network is greatly enhanced by the MU-MIMO uplink. During the transition from non-High Efficiency to fully High Efficiency-compatible networks, it was proposed to change the uplink transmission procedure for a single user (SU) to substantially reduce the bottleneck. The researchers developed in Lin, et al. (2016) an access protocol based on MU-MIMO and OFDMA PHY over the Uplink of an IEEE802.11ax WLAN. They introduce a MAC protocol that combines OFDMA, MU-MIMO, non-continuous channel bonding and link adaptation and therefore evaluates its efficiency. The findings of the analysis reveal that IEEE 802.11ax clearly has greater throughput, better QoS and greater multi-channel quality. Bankov, Didenko, Khorov, & Lyakhov (2018) explores the efficiency of various scheduling policies of uplink OFDMA, such as max-rate, proportional fair and shortest remaining processing time. Instead of having an effect on the downlink, these systems focus solely on the efficiency of uplink transmissions. In addition, the results obtained show that the use of OFDMA can be very beneficial for the transmission of uplink data, allowing data flow to be served almost twice as quickly.

In Qu, et al. (2019), the study evaluated 802.11ax with 802.11ac, employing systems and link-level integrated simulation platform (SLISP). The findings show that IEEE 802.11ax meets the main purpose of dramatically enhancing user experience in high-density application domains and meeting single user efficiency requirements. For various channel widths, they measure the UL and DL throughput of both OFDMA and MU-MIMO. They demonstrate that indoor UL OFDMA without MU-MIMO can outperform single-user transmissions by 273 per cent, and the use of both UL OFDMA with MU-MIMO can increase WLAN efficiency by 474 per cent at 160 MHz channel width. Outdoor, however, despite using the same channel width, they perform almost the same 292 per cent, 299 per cent, respectively. This assessment is conducted in a WLAN where the stations are allocated and transmitted randomly using various MCS indexes and RU sizes.

In contrast to MIMO approaches, OFDMA would not have any capacity gains on its own; alternatively, the data rate of each user will fall as the channel bandwidth is shared with those around it, leading to a longer transmission time. However, it greatly decreases overhead contention and preamble, and these savings are especially suitable and efficient for dense types of networks in which large numbers of users generate extreme channel contention. Adequate allocation and scheduling of resources can be used to generate higher OFDMA benefits. Efficient allocation of OFDMA resources under various WLAN configurations has been discussed in several studies. An adaptive EDCA mechanism for OFDMA resource scheduling was being used in R.M & Palaniswamy (2018), based on station requirements using the contention window and RU limit values for each station.

Qu, Li, Yang, Yan, & Zuo (2017) presented full-duplex technology to OFDMA MU access and developed a MAC protocol called MU-FuPlex for MU full-duplex OFDMA, which could significantly increase the throughput. The results of the simulation indicate that MU-FuPlex greatly increases the saturation rate compared to IEEE 802.11 DCF by up to 200 per cent. IEEE 802.11ax adopts OFDMA access based on centralized scheduling in AP as a result of the easy method of centralized scheduling in AP. OFDMA is enabled by IEEE 802.11ax for uplink transmissions where stations access randomly selected resource units in a distributed environment. Joo, Kim, Song, & Pack (2020) suggested an analytical platform that would allow MU-MIMO for each RU to minimize the likelihood of collision between stations and also improve overall network efficiency.

A further assessment of the 802.11ax can be obtained in Lee K.-h. (2019). In the context of the existence of traditional stations contesting the use of EDCA, this research offers analytical and simulation performance of UL OFDMA throughput and delay. This research reveals that, due to a large proportion of traditional stations, access time is not shared equally between OFDMA and single-user transmissions.

The performance of Uplink OFDMA was assessed by Naik, Bhattarai, & Park (2018). In IEEE 802.11ax, they include an overview of the uplink MU OFDMA and evaluate different numbers of random access (RA) RUs and contending stations. An empirical model for the 802.11ax MAC layer performance characterization was introduced to analyse the trade-off between the provision of high network efficiency. The main drawback of this work is that 802.11ax is not consistent with the transmitting technique. Consequently, the findings obtained do not indicate the actual performance of uplink OFDMA in high-efficiency environments. Lee, Deng, & Chen (2018) introduces a MAC protocol to broaden the use of the OFDMA resource allocation window. First of all, 802.11ax MAC and its random-access protocol are presented along with its system's potential limitations. Moreover, they proposed a proactive and effective approach with OFDMA Hybrid Channel Access (OHCA), and their findings suggest that the proposed scheme supported a low collision rate, short access latency, greater fairness and much more effective use of bandwidth.

The new 802.11ax power-saving technique called Target Wake Time (TWT) is proposed and evaluated in Nurchis & Bellalta (2019). They address a number of potential uses of TWT to enhance service delivery efficiency, spatial reuse, challenges to co-existence and multi-AP collaboration for next-generation WLANs. In addition, by specifically providing a collision-free service, they suggested several new disruptive uses of TWT to boost the operation of next-generation WLANs.

2.7 WLAN standards (IEEE 802.11a/b/g/e)

As noticed, methods such as Sllame (2017), Gunkel, Schmitt, & Cesar (2015), and Schmitt, Redi, Bulterman, & Cesar (2017) showed that the network will be evaluated on the basis of fixed node numbers where metric parameters, for example, packet loss, are prevalent in determining the optimal network configuration. In similar circumstances the evaluation has been measured of the different IEEE technologies for the fixed number of nodes in Schmitt, Redi, Cesar, & Bulterman

(2016), Neupane, Kulgachev, Elam, Vasireddy, & Jasani (2011) and Anouari & Haqiq (2013); taking one IBSS, ESS and WiMAX network architecture into consideration.

Although other studies, such as Mehmood & Alturki (2011) and Orfanou, Tselios, & Katsanos (2015) have integrated their models using different nodes, ranging from 9 to 49, their proposed approaches have only been validated using IBSS and BSS network architectures. In addition, the models in studies such as Orfanou, Tselios, & Katsanos (2015) and AlAlawi & Al-Aqrabi (2015) were combined with different nodes, 5-45 and 3-15, respectively. Besides this, their solutions have been validated only through BSS and ESS architectures. Another drawback associated with Mehmood & Alturki (2011) and Orfanou, Tselios, & Katsanos (2015) is that the assessment of algorithms using only one IEEE standard is considered, in particular IEEE 802.11 g and 11e, respectively.

Nevertheless, only an application using one IEEE Standard, in particular 11e, is being considered by Orfanou, Tselios, & Katsanos (2015) and AlAlawi & Al-Aqrabi (2015). AlAlawi & Al-Aqrabi (2015) 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, efficiency metrics of VoIP QoS were investigated using various routing protocols by Sllame, Raey, Mohamed, & Alagel (2015). For example, only 15 nodes were used, without the effects of physical layer technologies, spatial distributions or network architecture being taken into account. Hussain, Marimuthu, & Habib (2014) 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 Dong, Wang, Wang, & Pan (2015) to enhance VoIP services, and an improvement in the VoIP capacity was guaranteed.

Various efforts have been developed to evaluate and enhance WLAN networks services. Software-defined networking (SDN) tools were used by El-Mougy, Ibnkahla, & Hegazy (2015) to address and analyse some of the IoT challenges such as managing resources of wireless sensor networks and mobile networks and maximizing the utilization of large interconnected wired and wireless networks. Further, it provides possible architectures and solutions for the IoT based on SDN.

Wireless mesh networks provide more flexibility, reliability and improved WLAN performance. The paths to wireless forwarding are laid out in IEEE802.11s so that route optimization protocols provide routes and respond to changes in the topology that allow mesh devices to be connected, even if not in an explicit wireless communication scope, to make the WLAN mesh network widely applicable to many wireless network implementation scenarios. In this context, it's linked to both ESS and ad hoc network architectures which were configured using multiple wireless hops which will help us to provide the efficient routing protocols path and react to dynamic changes in the topology.

In order to enhance overall network efficiency, perfect modelling structure can significantly improve networking protocols in addition to performance assessment. Lee, et al. (2016) proposed the so-called Optimal DCF to accomplish this purpose. In an attempt to increase the fairness or use of the network, ODCF adjusts the MAC parameters of a node, such as a backoff time and transmission duration. Although the adjustment is measured for each node in a distributed way, an approximation of global evaluation criteria is needed. The Throughput Optimal DCF (TO-DCF) described in Fitzgerald, Körner, & Landfeldt (2017) requires specific metrics. TO-DCF often prefers nodes with greater queue build-up, but rather to reflect the different priorities, it incorporates node weights. Higher-weight nodes reduce their back-offs more rapidly, achieving a higher priority for transmission. Although O-DCF could be introduced as a software upgrade directly to an existing 802.11 chipset, TO-DCF adjusts the DCF technique and introduces a new DCF-based scheme.

On the other hand, Network Inter-operating Agent (NIA) was used by Mohanty (2006) to produce a scalable architecture to integrate the 3G systems and WLANs of different providers with or without bilateral SLA among them. In this way, in order to decide the best WLAN technology and network configuration based on users' requirements, a new horizon can be developed for the potential integration of WLAN with the rapidly evolving 5G technology in our proposed algorithm.

2.8 Summary

Wireless networks are the most exponentially growing communication technology. In providing QoS service to stations, Wireless LAN 802.11 standard has several problems in this field. Neither best-effort services (HTTP, FTP and E-Mail) nor real-time services (VoIP & VC), have been examined by any previous research to establish optimal technological standards for various IEEE 802.11 technologies across the infrastructure and the independent network. Three different Network Architectures (Ad-hoc, BSS and ESS) have been considered, while up to date research considered only a stand-alone network architecture.

Five different services (applications) have been evaluated and analysed under different factors such as spatial distribution, number of nodes and network architectures; whilst in literature, the evaluation has been done only on a particular technology at a time. Moreover, there is a lack of research which contains the evaluation and the analyses of mixed applications including the best-effect and real-time. The analysis was done on the impact of node’s Spatial Distribution (i.e., Circular, Random, Uniform) on the network performance for all six IEEE 802.11 technologies. The literature did not demonstrate this particular area of research.

The Wireless LAN 802.11 standard specified the Point Coordination Function (PCF) to provide reliable service to stations. However, Wireless LAN 802.11 Task group come with a new version called the Wireless LAN 802.11e to overcome several problems that appeared on the PCF technique and provide QoS to the requesting stations. Wireless LAN 802.11e includes two new schemes, EDCF and HCF. A literature review of its characteristics and protocols is presented in this chapter. As well, it provides some details on the WLAN standards and feature.

CHAPTER 3 METHODOLOGY

3.1 Introduction

The methodology used to rank the current WLAN 802.11 standards for both the stand-alone and mixed application networks is defined in this chapter. The coefficient of importance for each statistic shall be given for each application. The algorithmic approach gives the opportunity to determine which network topology, IBSS (Ad-hoc), BSS, or ESS, gives the best overall performance to be implemented in real practice. This chapter will cover and explain the following aspects: configuration of the network, parameters and simulation scenarios, performance metrics and flow charts.

Within the following journal articles the algorithm, data analysis and mathematical model of this chapter have been published (Mohd Ali, Dhimish, Alsmadi, & Mather, 2020); (Mohd Ali, Dhimish, & Glover, 2020); (Mohd Ali, Dhimish, & Glover, 2020).

In WLAN performance evaluation, the three main approaches are modelling, simulation, and experimentation. It should be quite clear when choosing the right methodology for a given problem, that there are essential trade-offs that are truly crucial to each of them. Improving the key performance method is most often the main objective, as well as the strategic goals that need to be achieved. We, therefore, address the three compromises of each strategy instead of analyzing the approaches separately. After a considerable review of these compromises, the successful evaluation method for which implementation could be quite evident and absolutely obvious.

i. Fidelity

Analytical or mathematical models that have a closed-form solution, that means the solution to the equations used to define modifications in a system, thusly, it is supposed to provide a certain range of streamlining hypotheses. Furthermore, a model's fidelity should be applied, ensuring that fidelity and reliability are as significant as the proposed use of the model requires. The simulation could also be seen as a model that is extremely detailed and completely automated. That's why they are somewhere between mathematical/analytical models and experiments, because they often merely model portions of the actual performance of the network, yet their amount of detail makes them pretty close to experimental research. However, commonly used as an execution appraisal tool compared to theoretical and experimental work. IEEE 802.11 technologies are becoming increasingly ubiquitous and relatively affordable over the last few years, providing an opportunity for a better phase of experimental WLAN measurement. Recently, testbeds are increasingly common and are installed in a variety of environments and situations. The fidelity of experiments may be less common to challenge since it would be reasonable to say that nothing is ever relevant to the actual program/scheme but to the program/scheme on its own.

ii. Cost

The cost of an approach to performance appraisal typically refers to time and resources. It takes a considerable amount of time and expert knowledge to construct an analytical model and to be avoided whenever immediate results are required. Even so, when the model is completely developed, it is typically considerably quicker to achieve performance than in experiments or simulations. Moreover, in completely open-source environments, analytical models can be developed and therefore require virtually no extra funds. Simulation tools usually take a little time to learn, as well as several wireless simulation tools are easily and freely available. For analytical models and simulation configurations, the cost of equipment is typically identical, the advantage of the simulation would be that the code that re-creates the performance of the system would be previously generated. Nevertheless, simulations may have an extremely long run-time if no parallelization is feasible, based on the complexity of the simulated network. Experimentation is traditionally the most expensive technique, as not only are facilities likely to be very expensive but knowledge important to adequately design and implement experimental work requires a much decent amount of time than mathematical models or simulations platforms.

iii. Scalability

Simulation and analytical models get a dominant position over experimental work in relation to scalability and large implementations. Expanding the infrastructure to hundreds of APs often requires very few code changes in simulation. However, it must be acknowledged that it will take longer to carry out large-scale simulation and modelling and may therefore require a considerable number of technical resources.

Eventually, each approach to performance assessment has its benefits and suitable implementations. Quick and inexpensive outcomes most frequently call for network simulation and modelling. When it is important to keep production connected and close to a realistic wireless network, experimenting always seems to be the correct option. Besides that, there is something widely accepted among all strategies: they provide plenty of fortuitous and worthy findings.

- **Thesis Statement**

This work presents a way of analysing network performance to achieve the most optimized network set up based on the currently available technologies. In addition, to identify which technology and network architecture can be implemented for internet applications and services. An algorithm based on the measurements has been introduced because the relationship between hardware compatibility and user/environment requirements is fundamentally interlinked. Although this method based on the measurement and extensive simulations is time-and working-intensity, the optimized automation of the measurement system and the process can actually reduce it. Conversely, the development of analytical models for the performance assessment of IEEE 802.11 wireless network output involving more than two stations is very difficult due to multi-station dynamic behaviour and does not capture all the variables/parameters of real systems. As a result, several leading network researchers have adopted simulation platforms for communication and computer network efficiency studies.

In view of the variations between the different approaches of the evaluation process, we have chosen to build a comprehensive set of WLAN system simulations that permit us to be very flexible and scale the framework with improved efficiency at a reduced cost. In this thesis, the works provided a more global perspective on the network. We, therefore, decided to model and simulate the entire network as a group of nodes for the three different network configurations, rather than modelling the processes within each node on its own. Moreover, the key feature of our approach is that it incorporates Riverbed's large standard model library to accommodate a wide range of network models, protocol configurations, and spatial distributions. The Riverbed Platform library has incorporated the distribution patterns for three spatial distributions (circular, random, uniform) and Riverbed (OPNET) through its Rapid Configuration features and will automatically build the required distribution based on its C or C++ source codes based on user requirements.

To achieve our contribution, which is to answer the question: What WLAN standard (or a mix of standards) will result in the best overall performance for a given mix of applications in a given environment? we built a comprehensive set of system simulations to independently select an appropriate wireless protocol based on user requirements. As well as invent a coefficient of importance for each of the QoS parameters for each application. More than 8000 scenarios have been developed that include five applications (VoIP, VC, HTTP, FTP, Email) configured as stand-alone (all nodes are run and configured for one application) or mixing services where five mixed percentages have been introduced that cover almost all distribution options for these services, six IEEE technologies (11, 11a, 11b, 11g, 11e, 11n) supported by OPNET academic licenses, three network configurations (BSS, ESS, IBSS), in the meantime, all scenarios run in all possible spatial distributions (circular, random, uniform) not just one. All of these scenarios were applied in five groups of nodes.

Furthermore, our derived mathematical Equations (4.4) to (4.11) were applied to each QoS parameter in both stand-alone and mixed services for each of the 8100 scenarios used to calculate QFM, AFM and SFM along with the MATLAB code that was specifically programmed to calculate the packet loss value for all of these scenarios (8100) in order to achieve the main aim of this research. Therefore, our approach to achieving our aim depends on a comprehensive set of system simulation scenarios, while eight equations were derived to calculate the QoS parameters for each application configured for each specific IEEE technology, as shown in Figure 3.1. As well, we used mathematical optimization embodied in the MATLAB code to calculate packet loss percentages for each application implemented and configured for each technology in three network architectures and three spatial distributions.

Circular

		802.11	802.11b	802.11a	802.11g	802.11e	802.11n
EMAIL	DR	0.02	0.04	0.1	0.1	0.1	0.1
	TH	0.1	0.099	0.099	0.099	0.099	0.099
	PL	0.077	0.078	0.1	0.088	0.077	0.1
FTP	DR	0	0	0.1	0.1	0.1	0.1
	TH	0.5	0.5	0.5	0.5	0.5	0.5
	PL	1	1	1	1	1	1
HTTP	PR	0.25	0.35	0.5	0.5	0.5	0.5
	TH	0.1	0.1	0.1	0.1	0.1	0.1
	PL	0.1	0.096	0.1	0.1	0.1	0.1
VC	DV	0	0	0	0	0	0
	D	0	0	0	0	0	0
	TH	0.259	0.259	0.251	0.251	0.285	0.262
	PL	0	0	0	0	0	0
VOIP	J	0	0	1	1	1	1
	D	0	0	0	0	1	1
	TH	0.45	0.43	0.13	0.13	0.14	0.13
	PL	0	0	0	0	0.1	0.1
SFM		0.5712	0.5904	0.796	0.7936	1.0202	1.0182
Rank		802.11e	802.11g	802.11a	802.11b	802.11	802.11

Uniform

		802.11	802.11b	802.11a	802.11g	802.11e	802.11n
EMAIL	DR	0	0	0.1	0.1	0.1	0.05
	TH	0.099	0.099	0.1	0.099	0.099	0.099
	PL	0.086	0.09	0.1	0.1	0.1	0.082
FTP	DR	0	0	0.1	0.1	0.1	0.1
	TH	0.5	0.5	0.5	0.5	0.5	0.5
	PL	0.78	0.68	1	1	1	1
HTTP	PR	0.252	0.15	0.325	0.5	0.5	0.325
	TH	0.1	0.1	0.1	0.1	0.1	0.1
	PL	0.1	0.072	0.1	0.1	0.1	0.1
VC	DV	0	0	0	0	0	0
	D	0	0	0	0	0	0
	TH	0.259	0.259	0.251	0.251	0.285	0.262
	PL	0	0	0	0	0	0
VOIP	J	0	0	0.95	0.9	1	1
	D	0	0	0	0	1	1
	TH	0.45	0.43	0.13	0.13	0.14	0.13
	PL	0	0	0	0	0.1	0.1
SFM		0.5252	0.476	0.7512	0.776	1.0248	0.9696
Rank		802.11e	802.11g	802.11a	802.11b	802.11	802.11

Random

		802.11	802.11b	802.11a	802.11g	802.11e	802.11n
EMAIL	DR	0	0	0.1	0	0.1	0.05
	TH	0.1	0.1	0.099	0.099	0.099	0.099
	PL	0.077	0.078	0.1	0.078	0.1	0.1
FTP	DR	0	0	0.1	0.1	0	0.1
	TH	0.5	0.5	0.5	0.5	0.5	0.5
	PL	0	1	1	1	1	1
HTTP	PR	0.15	0.252	0.375	0.5	0.5	0.33
	TH	0.1	0.1	0.1	0.1	0.1	0.1
	PL	0.08	0.088	0.1	0.1	0.1	0.1
VC	DV	0	0	0	0	0	0
	D	0	0	0	0	0	0
	TH	0.259	0.259	0.251	0.251	0.285	0.262
	PL	0	0	0	0	0	0
VOIP	J	0	0	0.95	0.7	1	1
	D	0	0	0	0	1	1
	TH	0.45	0.43	0.13	0.13	0.14	0.13
	PL	0	0	0	0	0.1	0.1
SFM		0.3432	0.5614	0.761	0.7116	1.0048	0.9742
Rank		802.11e	802.11b	802.11a	802.11g	802.11	802.11

IBSS_65 | ESS_65 | BSS_65 | BSS_40 | IBSS_40 | ESS_40 | BSS_20 | IBSS_20 | ESS_20 | BSS_10 | IBSS_10 | ESS_10 | BSS_5 | IBSS_5 | ESS_5

Figure 3. 1 Calculation of the QoS parameters for each application in all three network configurations for each particular IEEE technology for all 5 groups of nodes

3.1.1 Optimization Techniques for Best WAN Selection

The 802.11 specifications for WLAN were published in 1997 by the Institute of Electrical and Electronics Engineers (IEEE). The amendment to the 802.11 standards is a set of enhancements and specific strategies to be applied in view of the foregoing 802.11 standard that enables higher data rates to be used, the addition of specific safety criteria or the adaptation of specific environment settings.

The IEEE 802.11a amendment, for instance, added a large transmission rate and a new carrier frequency, IEEE 802.11i intends to optimize 802.11 MAC security and authentication procedures as well as to improved transmission protection, IEEE 802.11f establishes an Inter-Access Point protocol to enable stations to move across multi-vendor APs, and the IEEE 802.11p adapted WLANs to the vehicle climate.

Moreover, new PHY layer features have been presented in IEEE 802.11a, IEEE 802.11b and IEEE 802.11g, while new MAC standards in IEEE 802.11e and IEEE 802.11s have been produced. In addition, to fulfil heavy demands for capacity and physical data rates, Wi-Fi technology has been enhanced to IEEE 802.11n, IEEE 802.11ac and IEEE 802.11ad. These improvements are referred to as High Throughput Wireless Local Area Networks (HT-WLANs).

The MAC and the PHY layer of the open system interconnection (OSI) network reference model is defined by the IEEE 802.11 WLAN standard. The IEEE 802.2 specification defines the logical link control (LLC) sub-layer. This architecture gives users of the higher layer a clear interface: the stations can be transferred, moved across the 802.11 WLAN and still appear as stationary to the 802.2 LLC sublayer and above. This enables current TCP/IP protocols to operate much like wired ethernet implemented over IEEE 802.11 WLAN. Figure 3.2, illustrates various standardization operations performed on the PHY and MAC layers of IEEE 802.11 (Lopez-Perez, Garcia-Rodriguez, Galati-Giordano, Kasslin, & Doppler, 2019).

Three types of options in the PHY layer were given by IEEE in 1997, which are an Infrared (IR) baseband PHY, an FHSS radio and a direct DSSS radio. Each of these options endorses a PHY rate of 1 and 2 Mbps. Two high-rate modification were specified by IEEE in1999: IEEE 802.11b in the 2.4 GHz band with DSSS-based data rates of up to 11 Mbps; and IEEE 802.11a in the 5 GHz band with OFDM-based data rates of up to 54Mbps. IEEE 802.11g expands the PHY layer of 802.11b to allow data rates in the 2.4 GHz band of up to 54Mbps. IEEE 802.11e was the very first enhancement to the MAC layer to optimize 802.11 WLAN QoS performance (Mammeri, Yazid, Bouallouche-Medjkoune, & Mazouz, 2018).

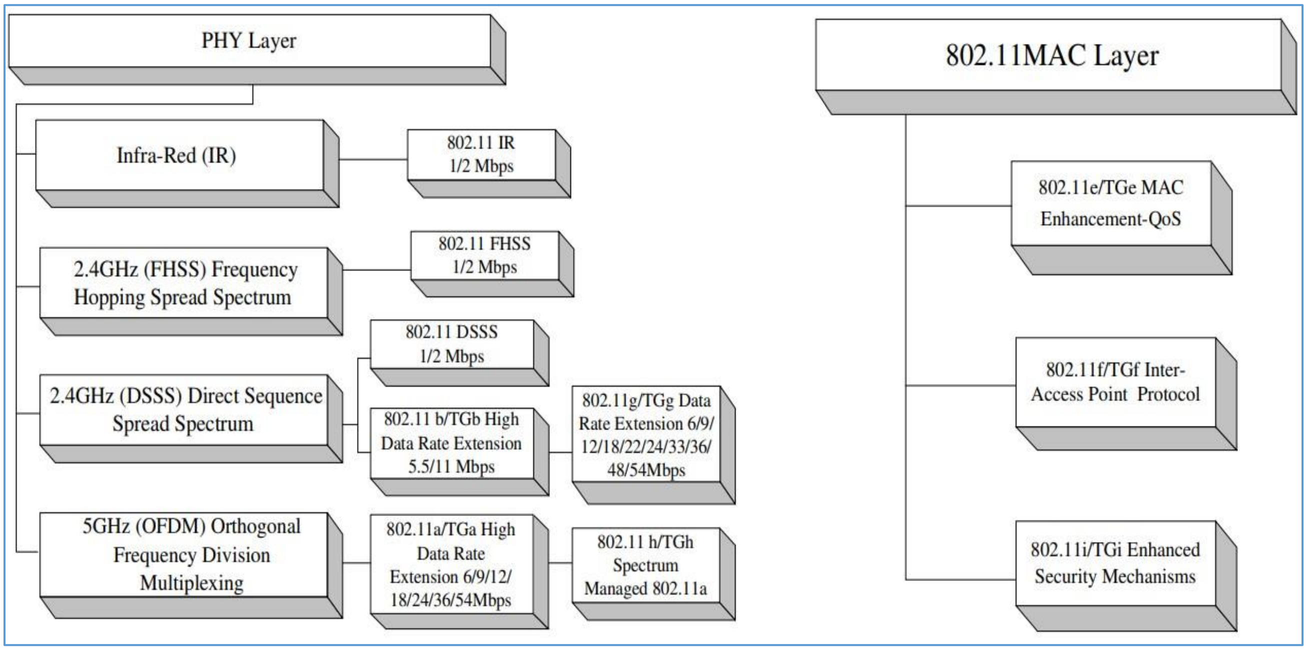


Figure 3. 2 PHY and MAC standard operations (Zawia, Hassan, & Dahnil, 2018)

In 2009, IEEE 802.11n was introduced with the objective of reaching a theoretically high data rate of up to 600 Mbps due to the new high-performance WLAN transfer technology. The continually rising PHY guarantees sufficient bandwidth for video streams to sustain such high-capacity transmission. Creative structures for MAC, error recovery and channel access mechanisms, along with modifications to PHY layers, should also be carefully developed to promote seamless video transmission over WLANs. The two revised IEEE 802.11e and IEEE 802.11n specifications were committed to improving the performance of MAC layer video data transmission. A new distributed coordination function recognized as EDCA is defined in IEEE 802.11e where a collection of higher priority video stream channel access is used to minimize transmission latency, whereas IEEE802.11n defines a modern aggregation, block acknowledgement and reverse direction improvements for high-throughput WLAN transmission (AL-Maqri, Alrshah, & Othman, 2018).

Over the years, the IEEE 802.11 standard has been developed and various improved mechanisms in the PHY and MAC layers have been implemented, as shown in Figure 3.3. Improvements to the PHY layer, such as the use of MIMO approaches, much further bandwidth, space-time block coding, shorter guard periods, and beamforming.

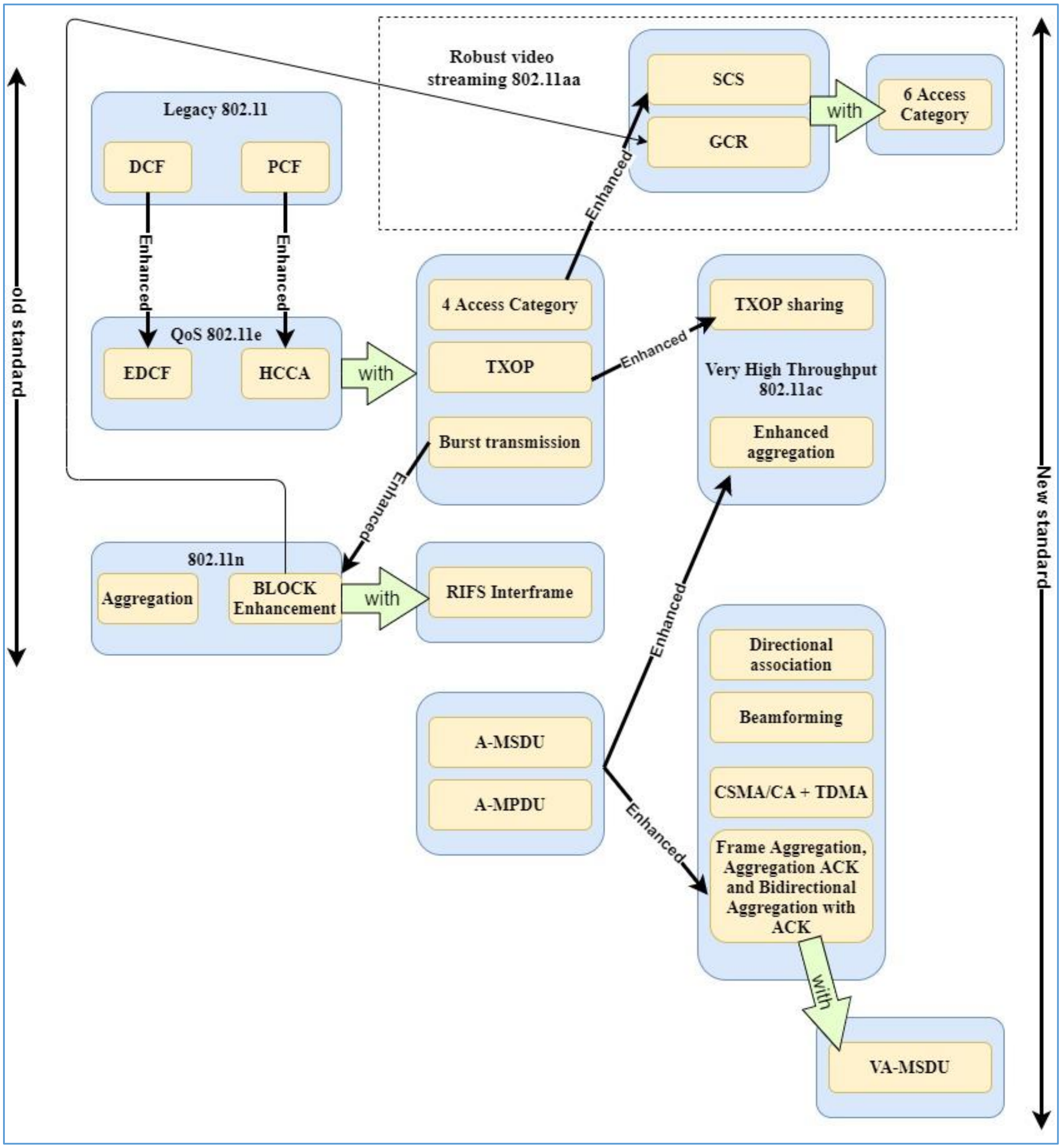


Figure 3. 3 IEEE 802.11 enhancement mechanisms (Zawia, Hassan, & Dahnil, 2018)

The improved attributes are there to provide high data rates for transmission. Simultaneously, many other improved MAC layer approaches have been applied, including priority access strategies such as the functions of TXOP, AIFS, and HCF, block acknowledgement, and aggregation of frames. Developed MAC techniques enable the network to use network resources much more effectively, leading to higher channel throughput.

One of the biggest overheads a node encounter is going to wait for medium access in IEEE 802.11 standards. Traditional IEEE 802.11 specifications transfer frames one by one, which means that, rather than actively sending information, the node gets to spend a substantial period of time attempting to access the medium. Delivering several frames as a single aggregate frame is a straightforward way to solve this issue. Two kinds of frame aggregation are proposed under IEEE 802.11n: Aggregate MAC Service Data Unit (A-MSDU) and Aggregate MAC Protocol Data Unit. A-MSDU is a set of many MSDUs that have the same MAC header and DCF overhead, leading to the really effective use of the network. A-MPDU aggregation is somewhat less efficient since the DCF overhead is shared by many MPDUs, but each MPDU has its own MAC header. Nevertheless, A-MPDU helps the recipient to identify MPDUs separately and efficiently under conditions that appear to be susceptible to failure, contributing to increased throughput than when using A-MSDU (Nosheen & Khan, 2020).

Two medium access coordination functions, the basic DCF and the optional PCF are defined by the IEEE 802.11 MAC sub-layer. 802.11 supports two types of transmissions: asynchronous and synchronous and can operate both in access functions. DCF, which is mandatory for all 802.11 stations, provides asynchronous transmission. The PCF provides synchronous service that essentially performs polling-based access (Wen, Xiaofeng, & Defeng, 2018).

The IEEE 802.11 DCF utilizes a Binary Exponential Backoff (BEB) scheme that, irrespective of its distinction, provides equal transfer potentials to all contending nodes. (Bianchi, 2000) uses Markov chain techniques to examine the IEEE 802.11 DCF throughput and packet transmission probability under optimal channel conditions. It implies in their work that if they have the very same bit rate and follow the same packet size, the DCF provides all nodes with throughput fairness. Nevertheless, the traditional IEEE 802.11 specifies several bitrates and the nodes can use various bitrates in actual implementations, as per their scenarios.

A number of factors, such as hardware configuration and the current channel environment, may influence the bitrate of the node. A node can select a reasonable transmission bitrate in order to optimize its throughput and to limit the bit error rates (BER) at a reasonable threshold. Therefore, because of the equitable transmitting conditions created by the 802.11 DCF scheme, the scenario of multiple bitrates coexisting often contributes to the problem of performance anomaly. Therefore, since the shared channel is overused by the low bitrate nodes, high bitrate nodes cannot get the corresponding higher throughput, which deteriorates the overall efficiency, particularly in dense environments (Lei, Tao, Huang, & Xia, 2019).

A series of QoS enhancements on the MAC layer for WLAN applications is specified by IEEE 802.11, as shown in Figure 3.4. The QoS attribute in IEEE802.11e includes an additional coordination function called the HCF. This attribute incorporates both features of both PCF and DCF. The HCF has implemented some improved frame subtypes and QoS-specific mechanisms to allow the use of a standardized assortment of frame exchange sequences for QoS data transfers during both the Contention Period (CP) and the Contention Free Period (CFP). HCF uses a contention-based channel access technique, namely EDCA, for contention-based transfer, whereas it employs a controlled-channel access process, called HCCA, for contention-free transfer (AL-Maqri, Alrshah, & Othman, 2018).

HCCA schedules QoS station (*QSTAi*) traffic based on average QoS specifications, calculated by Eq. (3.1):

$$TXOP_i = max\left(\frac{N_i \times L_i}{R_i} + O, \frac{M}{R_i} + O\right) \tag{3.1}$$

Where N_i is the number of MAC service data units (MSDU) that can travel at the traffic rate, L_i and M are the $QSTA_i$'s nominal and maximum MSDU, and the physical rate and overhead are R_i and O (Al-Maqri, Mansoor, Sabri, Ravana, & Yaseein, 2020).

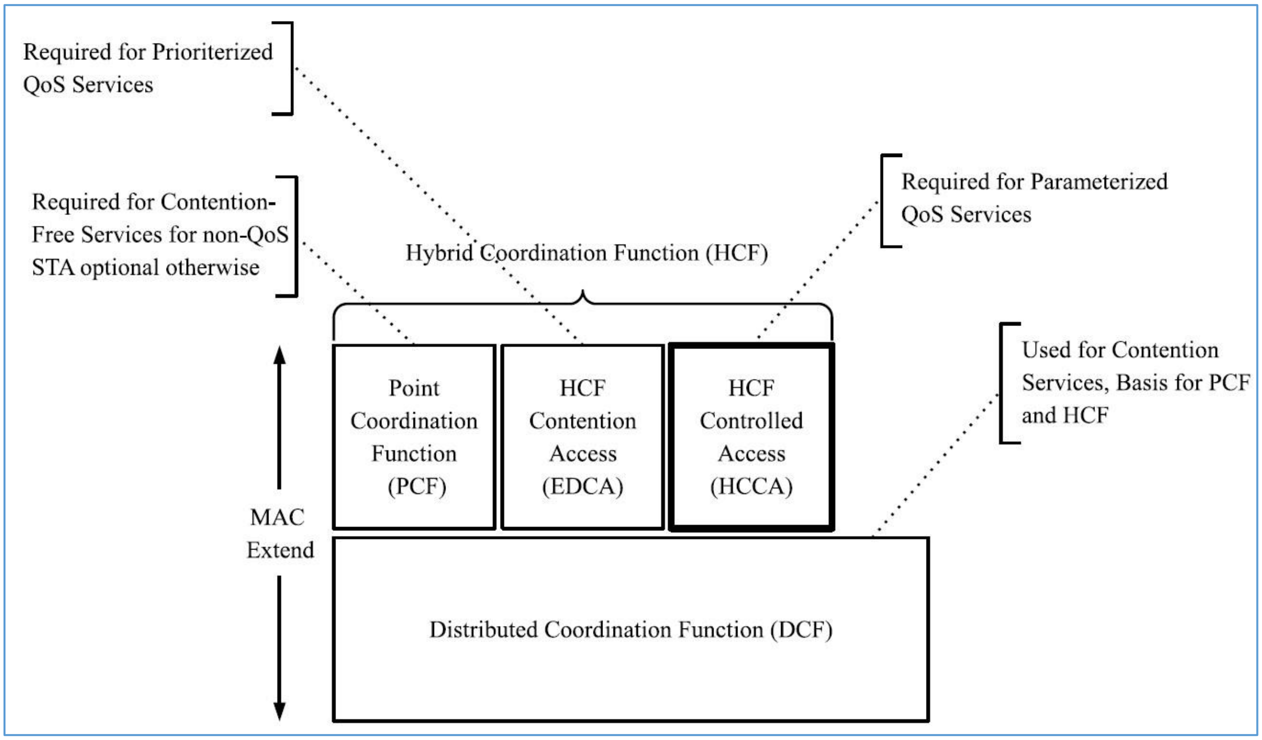


Figure 3. 4 MAC IEEE 802.11e (AL-Maqri, Alrshah, & Othman, 2018)

3.1.2 TDMA Over MAC (CSMA/CA)

Wireless networks and associated innovative technologies have been commonly used in industrial and commercial services such as remote monitoring systems, machine learning, robotic applications and IoT. Such services have strict timing and reliability specifications (Tramarin, Mok, & Han, 2019). Several forms of study, such as multi-path routing (Koutsiamanis, et al., 2018) and scheduling policies (Xu, Guo, Zhang, & Yang, 2018), have been applied to enhance the real-time and efficient data transmission of wireless and telecommunications networks. Nevertheless, in wireless communication networks, particularly in public environments where multiple networks interfere with each other, latency and high packet loss rates due to co-channel interference have always been significant issues.

Wi-Fi systems adopt CSMA/CA on the basis of the DCF structure, resulting in a non-deterministic delay. Although contention-based protocols have distinctive features, such as random access and ease of handling and implementation, they have issues with network instability, particularly when traffic is heavy. Various methods for resolving these problems of instability, including fixed assignment (in frequency or time), polling, passing tokens, or dynamic reservation, have been proposed. Typically, fixed assignment procedures are based on Time Division Multiple Access (TDMA) in which each station can send information avoiding collisions at the beginning of its specified time. It is well known that the TDMA approach is more efficient for the wireless industry (Guo, et al., 2020).

CSMA/CA has no assurance of delay in the delivery of data and is not feasible as with most implementations of industrial automation. A large amount of literature has been published to tackle this issue. It is possible to divide these schemes into two classes. The objective of the first class is to optimize the traditional MAC layer of 802.11. Some 802.11 MAC default parameters, such as the contention window and back-off mechanism, are enhanced to maintain growth for industrial applications. However, the unforeseeable delay caused by CSMA/CA still cannot be avoided. The second class replaces the traditional 802.11 MAC standard with the TDMA MAC (CSMA/CA) layer (Cheng, Yang, & Zhou, 2017).

A new device architecture is proposed to incorporate TDMA along with CSMA/CA rather than only fine-tuning the specifications of CSMA/CA to optimize its performance. The following main functions are part of this new MAC protocol (Lee & Cho, 2017):

- Depending on the 802.11 MAC enhanced time synchronization (TSF) function, node synchronization is produced.
- In order to eliminate the hardware-based retransmission in the 802.11 MAC, software retransmission is introduced. Packet transmission and reception may be limited to a fixed time slot that is dependent on software retransmission and therefore prevents slot border crossing.
- To organize packet transmissions at different nodes in wireless mesh networks, a distributed scheduling system has been proposed. QoS is taken into account in this scheduling scheme's time slot allocation.

TDMA holds a number of strengths over CSMA/CA. First, it will still be compatible with CSMA/CA. Moreover, due to its TDMA mechanism, it may be able to support a number of other protocols, such as mobility management, transport and routing. Furthermore, does not have the familiar CSMA/CA issues, so especially in comparison to CSMA/CA, QoS, performance, and fairness of wireless mesh networks based on such a MAC protocol are much enhanced. Eventually, since channel selection and switching are organized in a TDMA pattern, its multichannel model performs a far more efficient multichannel operation than other current MAC strategies. Table 3.1 summarizes further descriptions of the optimized techniques.

Table 3. 1 Further of optimized techniques between traditional and enhanced WLAN configuration (Zawia, Hassan, & Dahnil, 2018)

IEEE 802.11 standard	**IEEE 802.11 Optimized techniques**	**Discussion**
Traditional 802.11 DCF	EDCA	IEEE 802.11e EDCA is a standard 802.11 DCF improvement to include four separate access categories rather than only one access category.
Traditional 802.11 PCF	HCCA	IEEE802.11e HCCA is an enhancement of IEEE 802.11 HCF based on a resource reservation mechanism to cover the identification of traffic streams.
QoS with TXOP 802.11e	Very High Throughput (VHT) with TXOP sharing 802.11ac	Although EDCA has the privilege to transfer to the media throughout TXOP, TXOP can be shared by all VHT-associated ACs which have data to transmit. EDCA TXOP, on the other hand, can transmit the related AC just during TXOP transmission.
IEEE 802.11e Burst Transmission	HT 802.11n Block Acknowledgment (BA)	IEEE 802.11n BA is an IEEE 802.11e Burst Transmission enhancement, aggregating more than one ACK into a single frame, to increase the quality of the channel.
HT with A-MSDU and A-MPDU 802.11n	VHT Enhanced Aggregation 802.11ac	Enhanced Aggregation
HT with A-MSDU and A-MPDU 802.11n	VHT Frame Aggregation Scheme (FAS) with VA-MSDU	FAS, Aggregation-ACK, Bi-directional aggregation with ACK

3.1.3 Optimization Algorithms for WLAN Planning — Genetic Algorithms (GAs) and Simulated Annealing (SA)

GAs are evolutionary algorithms designed to perform the selection operation as it occurs in nature. GAs start with a preliminary number of individuals, which implies acceptable solutions to a problem with the fitness value associated with each solution, which indicates how to match it relative to the others. Consequently, just like in natural environment, in which natural selection, replication, and mutation processes occur, the GA conducts a similar means of evaluating, choosing, traversing, mutating, and substituting the next generation of individuals. The procedure is iterated until, along with generations, a number of generations have passed or the effective approach has not modified. Due to the extremely dynamic environmental conditions that make parameter optimization a complex activity, the design of wireless networking is challenging. Modern wireless networking technologies are increasingly depending on machine learning and artificial intelligence techniques due to complex and often unknown operating conditions. A well-established architecture for the implementation of artificial intelligence tasks such as classification, learning, and optimization is provided by genetic algorithms (GAs). GAs are renowned for their exceptional universality and flexibility and have been implemented across wireless networks in a wide variety of situations (Verma, Sood, & Sharma, 2019).

The implementation of GAs to solving several problems of computational matrix multiplication optimization has been demonstrated. Obviously, the GAs are excellent fits to effectively solve the design issue of wireless mesh networks. There are several variables that need to be addressed when using GA to solve different actual issues, such as encoding methods, initial populations, fitness function selection, crossover operation, mutation operation, and well-chosen variables (Mehboob, Qadir, Ali, & Vasilakos, 2016).

In diverse disciplines, such as computer science, applied mathematics, engineering and organizational analysis, the SA technique is a probabilistic search tool commonly used. These SA-based methods laid the foundation of innovative CSMA techniques and contributed to the evolution of multiple variants to fit various modern communications and more practical system circumstances to attain the optimum performance of the system. SA has been used in recent years to address optimization issues. This method is based on a thermal theory, where a system is gradually cooled to reach its minimum state of energy. By integrating a probability function in approving or rejecting creative approaches, SA has the potential to avoid local minimal. For a given optimization problem, it is a randomized strategy to approximate the optimal solution.

SA's algorithmic method is simple and easy. The state of the trial is randomized at each stage and its output target is assessed. The real benefits of SA are the relative simplicity of execution and the potential to deliver effective results for any ambiguous structures and the problem of optimization with proven guarantees. Most of the activities implicitly presume that these text interactions are ideal in the case of wireless resource management for which SA is being implemented. Apart from this, because of unreliable wireless connectivity (interference and fading), the exchange of information on an effective assessment cannot always be successfully transmitted and therefore cannot obtain information at a specific time when the algorithm is working (Kwak & B. Shroff, 2018).

Most works expressly presume that these communication transmissions are ideal for wireless resource allocation issues to which SA is applied. However, because wireless communication due to fading and interference is generally unreliable, the message transmissions comprising the appropriate assessment information are not always accurate, leading to failure to acquire the information at the algorithm's planned duration. In the research field, a platform for CSMA-type strategies has lately got a lot of interest. These methods are considered to be optimal in performance and can be easily achieved in a distributed manner that demonstrates minimal overhead messages. Using an SA-like technique to obtain the max-weight issue is the primary enabler of this performance. Although the goal of achieving an optimum performance solution is to produce a set of timetables so that any feasible arrival rates can be matched by long-term service rates, the fixing of max weight issues plays an important role in this work and can therefore be effective (Kwak & B. Shroff, 2018).

3.2 Simulation and Modelling

In deciding whether simulation should be part of a project aimed at understanding, modifying, or designing the operation of any system, it is important to keep in mind:

- First, simulation can be a method of last resort for problems that are mathematically complex by any other techniques.
- Second, even for problems that are mathematically tractable, simulation can often provide a higher level of detail than can other techniques.
- Finally, simulation can sometimes provide (approximate) answers at a lesser cost (or effort) to some problems that are fully tractable mathematically but whose solution may be cumbersome and time-consuming.

It is obvious that simulation is based on experiments and depends on important steps as shown in the flowchart in Figure 3.5. There are several advantages of simulation; first, it abbreviates a huge amount of time and makes it possible to perform what would, in reality, be very expensive experiments with very expensive systems. Expensive is used here not only in the sense of costly but also of high risk in physical respect. Simulation packages, therefore, may soon be providing the only available testing ground for some of these experiments.

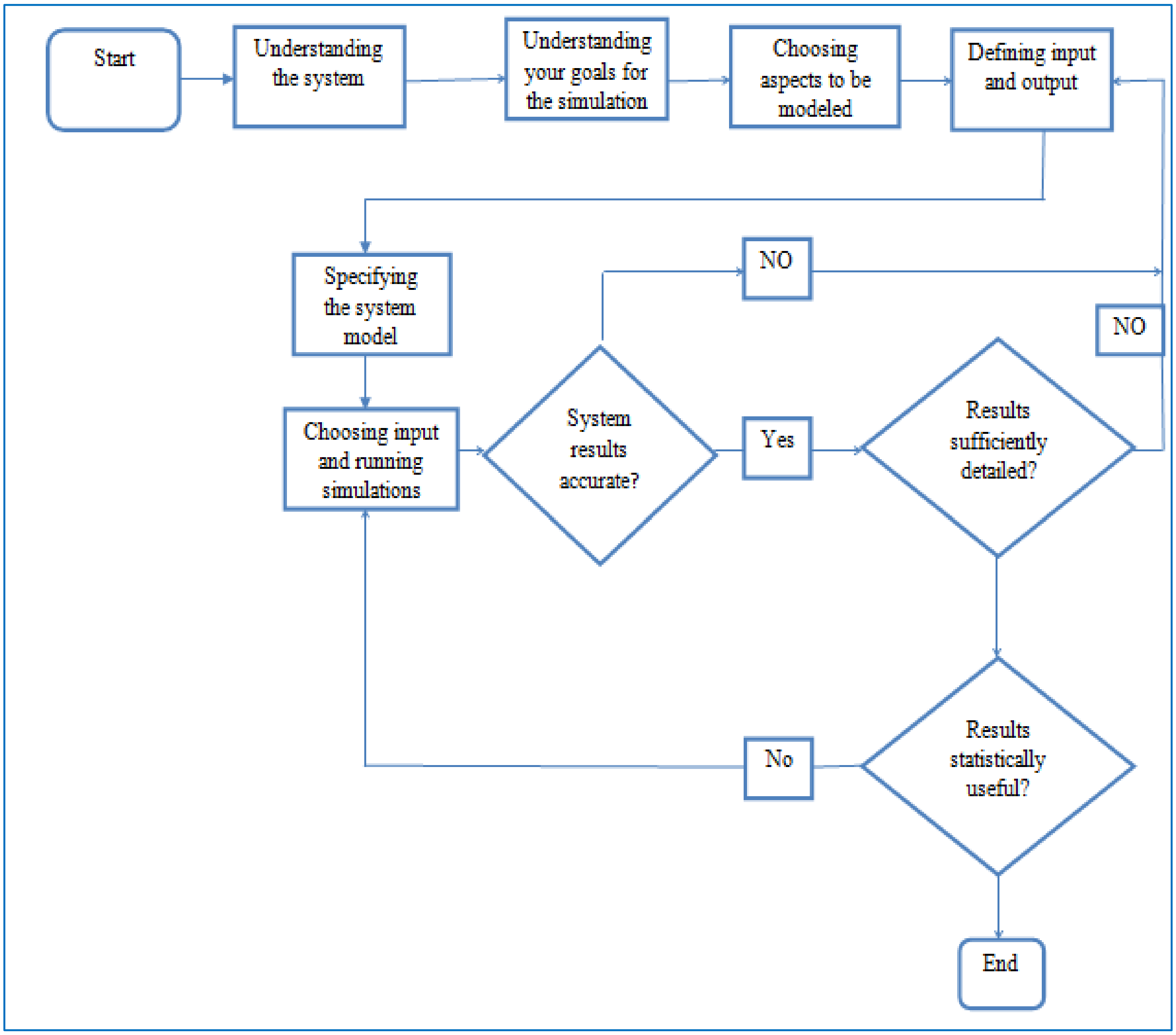


Figure 3. 5 Proposed Technique Simulation Flow Chart

3.3 OPNET Modeler

OPNET Modeler (Riverbed, 2017) is renowned in the industry for modelling and simulating networks. Ease and scalability are the most important features of Modeler that enables industrial companies and organizations to study and research connection networks, devices, standards and technologies.

The most productive technology companies use this modeller for their data analysis product development. The approach associated with graphical editors integrated object-oriented Modeler simplifies the composition of networks and equipment. This makes it easy to achieve a match between your system and your data model (Palitefka, Papaj, & Doboš, 2016).

3.3.1 OPNET Modeler Editors

OPNET Model is based on a group of editors which parallelize the hierarchical structure of real network facility as depicted in Figure 3.6.

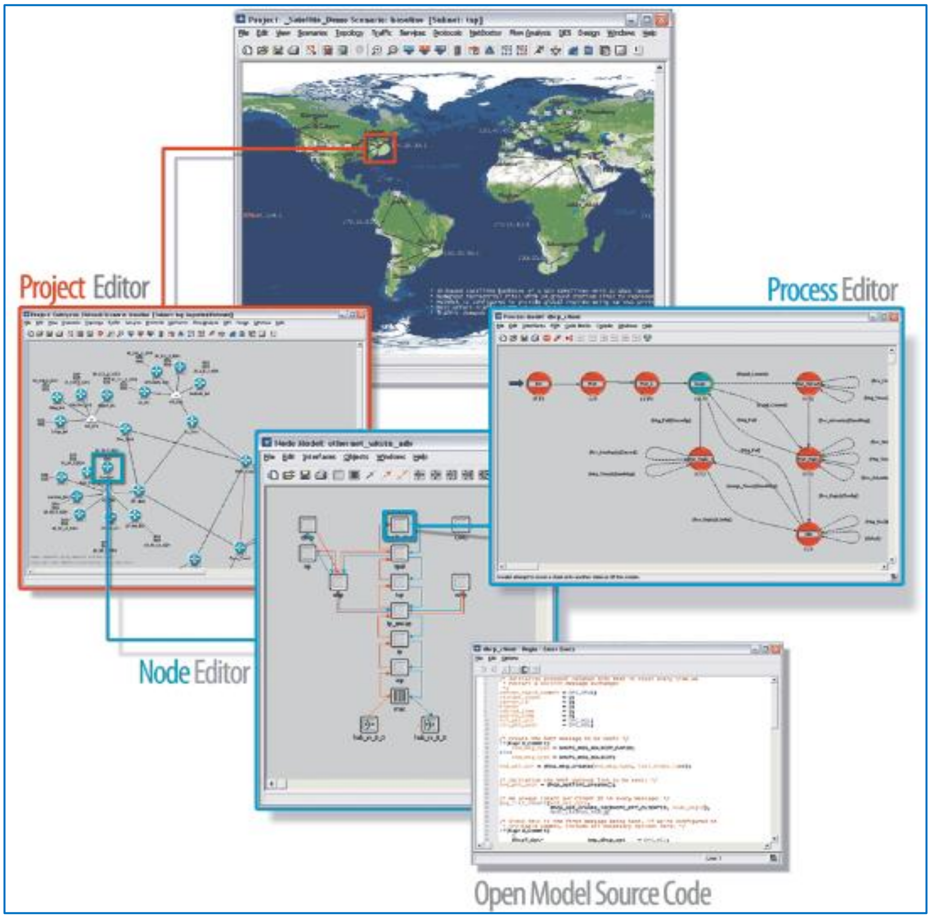


Figure 3. 6 OPNET Modeler Editors (Riverbed, 2017)

3.3.1.1 The Node Editor

The necessary sources for the model are offered by Node Editor. Figure 3.7 is an example of a node editor view.

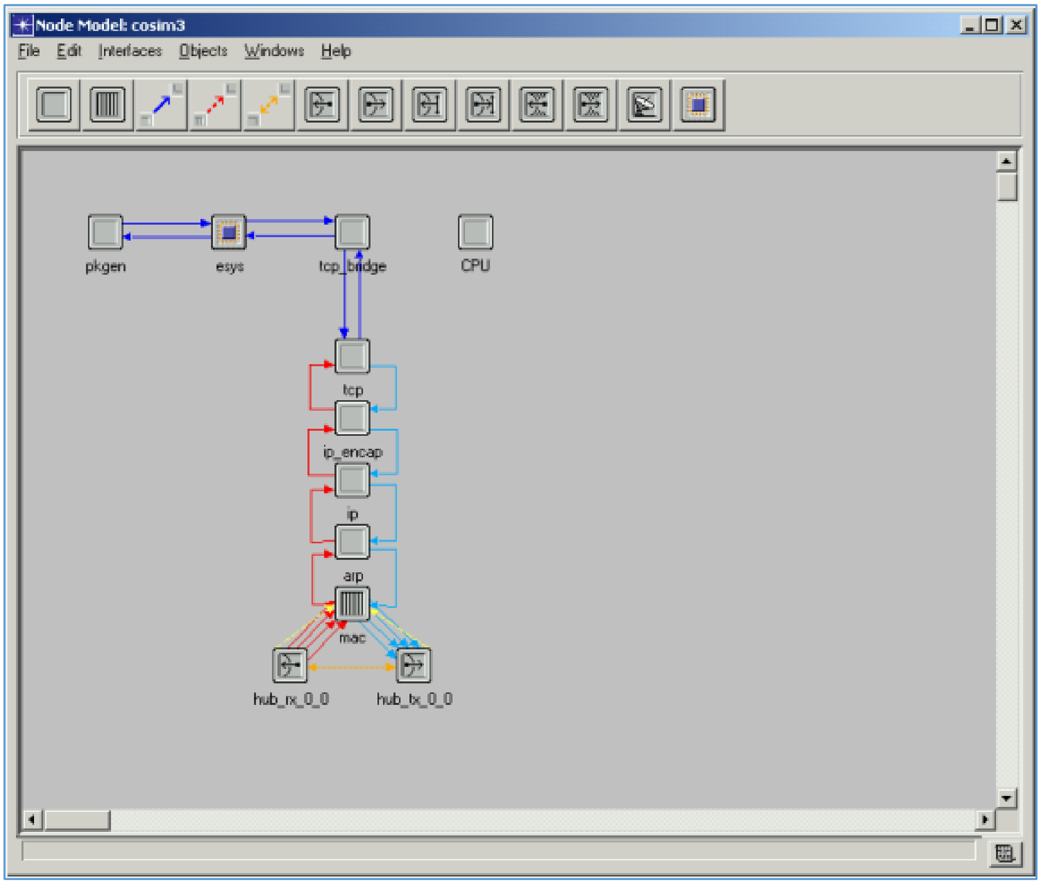


Figure 3. 7 Node Editor View (Riverbed, 2017)

3.3.1.2 The Project Editor

The project editor is a graph of the topology of the communications network. The project editor is made up of objects and equipment connections configurable via dialogues.

The methods of copy and paste facilities and links from pallets objects allow the publisher to carry the network. It is also possible to use the Quick Import function of the entire configuration. It is possible to use the OPNET library or make your own palette incorporating your own devices and links. The project editor also includes a geographical environment with dimensional features containing relevant components for modelling wired or wireless networks. Figure 3.8 is an example of project editor view.

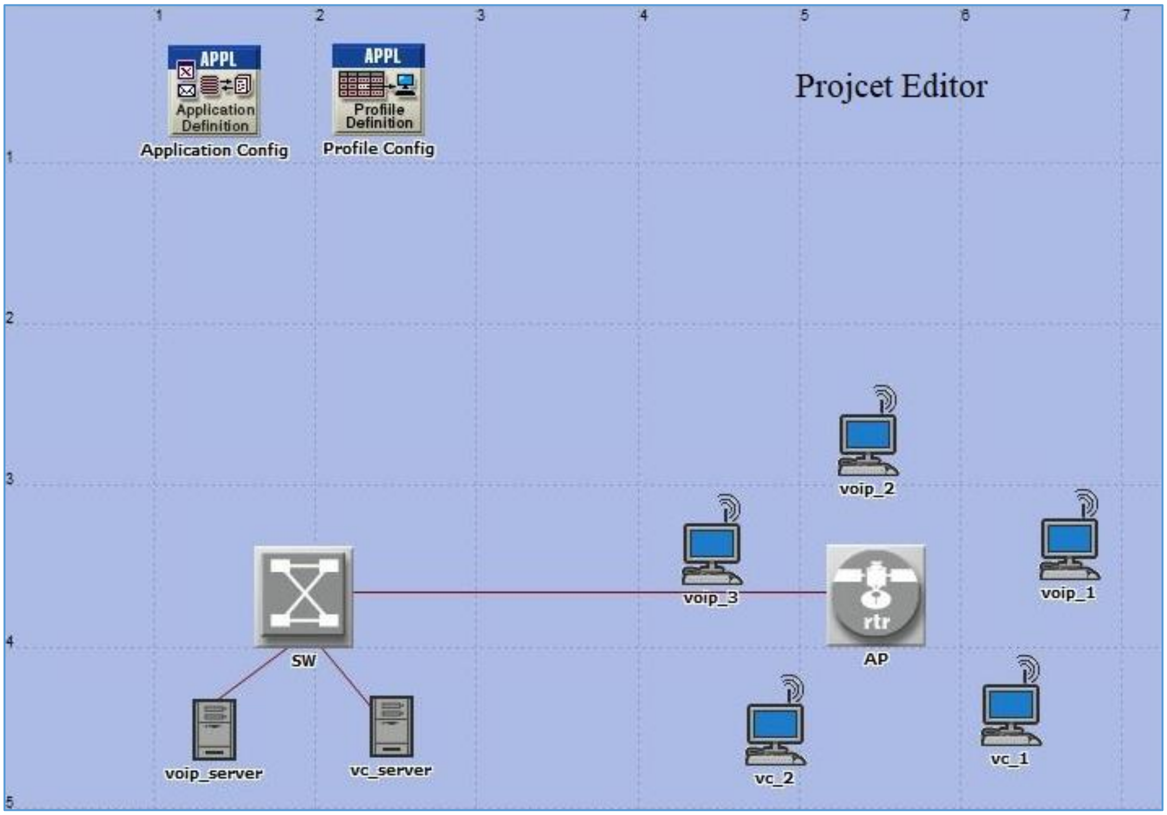


Figure 3. 8 Project Editor View (Riverbed, 2017)

3.3.1.3 The Process Editor

The process editor uses a powerful Finite State Machine (FSM) to provide specialized requirements for applications, protocols, and queuing policies. Each step of the process model includes C / C + + supported by a library of functions defined by the logical protocols. Each FSM can define state variables and can make calls to the codes available in bookstores. FSM is dynamic and greatly simplified protocol specifications that manage resources such as TCP and ATM.

The process editor is used to enhance a completely new model of the process starting from the paper specifications. Frameworks for process modelling support the complete multi-threaded processing and computers with parallel architectures. Figure 3.9 is an example of the process editor view.

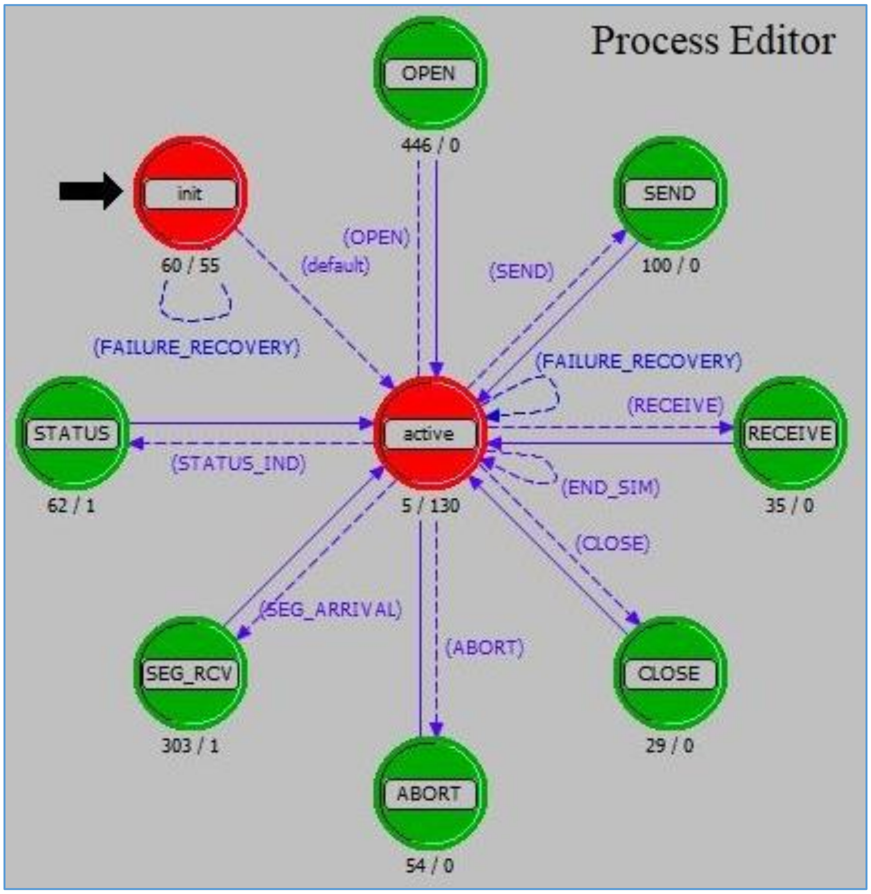


Figure 3. 9 Process Editor View (Riverbed, 2017)

3.3.2 The Main Features

Following are the main features of OPNET Modeler that were originally enhanced at Massachusetts Institute of Technology (MIT) and marketed in 1987 as the first network simulator (Chong, YanQin, & Fen, 2018):

- The hierarchical network model operates with complex topologies in an unlimited number of nested networks.
- Full support for producing protocols. More than 1000 functions are included and libraries provide support for the implementation of protocols.
- Completely open, Modeler has API additions to complementary programs. To ensure the confidentiality and protection of knowledge, models can be encrypted. The source code is available for all models.
- Integrated Debugger: Allows quick validation of a simulation or finding problems.

- Integrated analysis tool: Simple interface to visualize simulation results. Interface for viewing sets, curves, probability functions. All exportable balance sheet or XML format.
- Entertainment: It is possible to visualize the behaviour of a model in the form of animation. It is possible to graphically display the statistical data during the execution of the simulation.
- Financial analysis of the cost of equipment. Export costs in the form of presentation of the balance sheet with total costs.
- Network equipment. The library of standard models includes many equipment manufacturers in a generic form including routers, switches, workstations, generating packets all assembled quickly to make your own templates using the “Device Module creator”. It is possible to accept traffic from a LAN in a cloud network.
- Modelling of mobile networks. There are models of cellular networks, mobile ad hoc, wireless LAN Wi-Fi, WiMAX wireless networks, Long Term Evolution (LTE), and many networks based on equipment related to mobiles. Control of each device, dynamic position or predefined path.

3.3.3 Component Libraries

The components of the standard libraries as shown in Figure 3.10 can quickly create network architectures; using this library can do the following:

- Generate traffic (workstations, servers, workstations) with or without profiles uses.
- Network equipment (hubs, bridges, switches, routers, etc.).
- Links (SONET, PPP, FDDI, 10BaseT, ISDN, xDSL, wireless, etc.).
- Model manufacturers (Cisco, 3Com, Lucent, HP, 3Com, Ascend, Bay Networks, Cabletron, Foundry, Hewlett Packard, Juniper Networks, Lucent, NEC, New bridge, Nortel etc.).

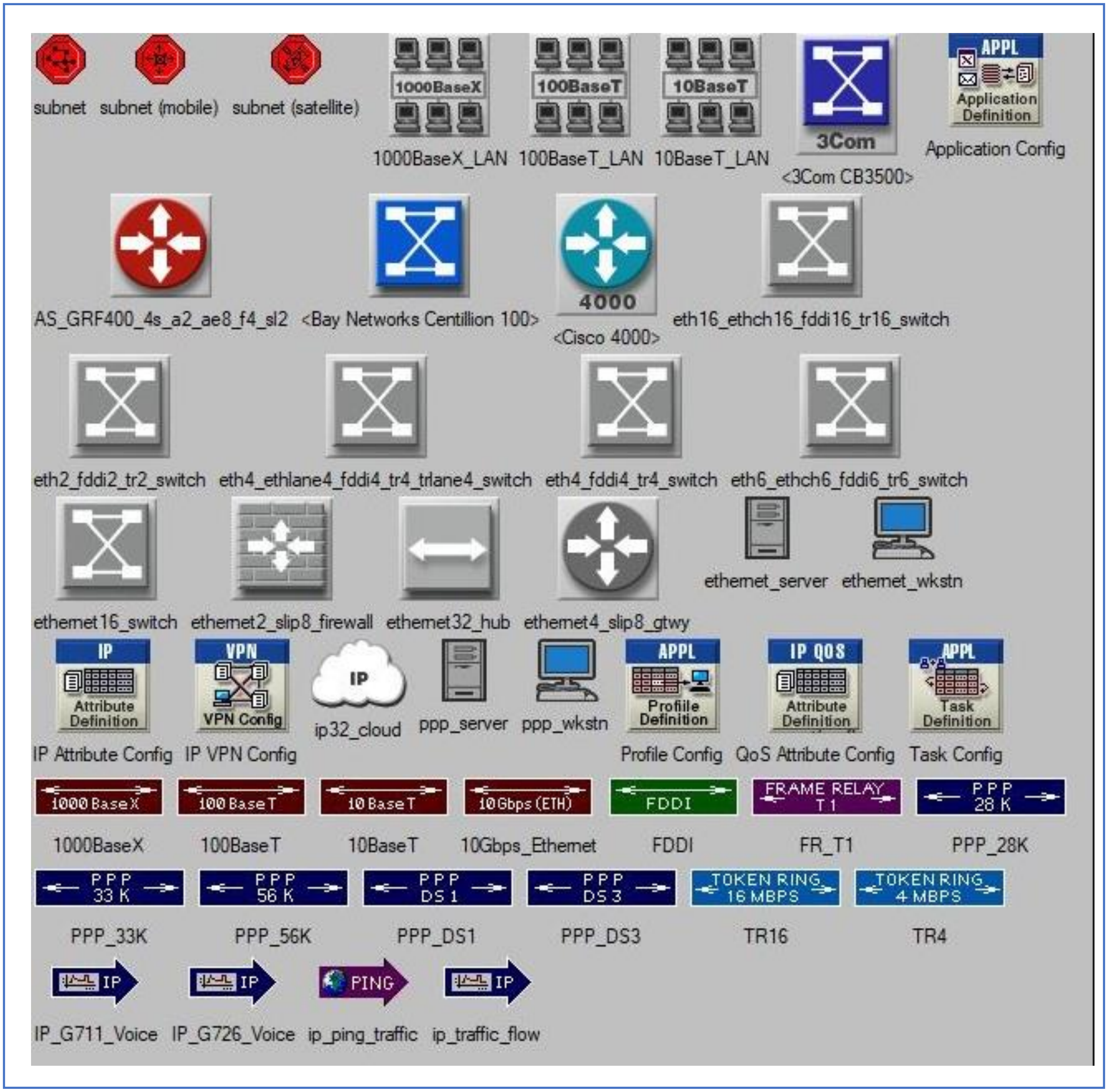


Figure 3. 10 Library Components of OPNET (Riverbed, 2017)

3.3.4 OPNET Workflow

When using OPNET the workflow must be outlined as shown in Figure 3.11.

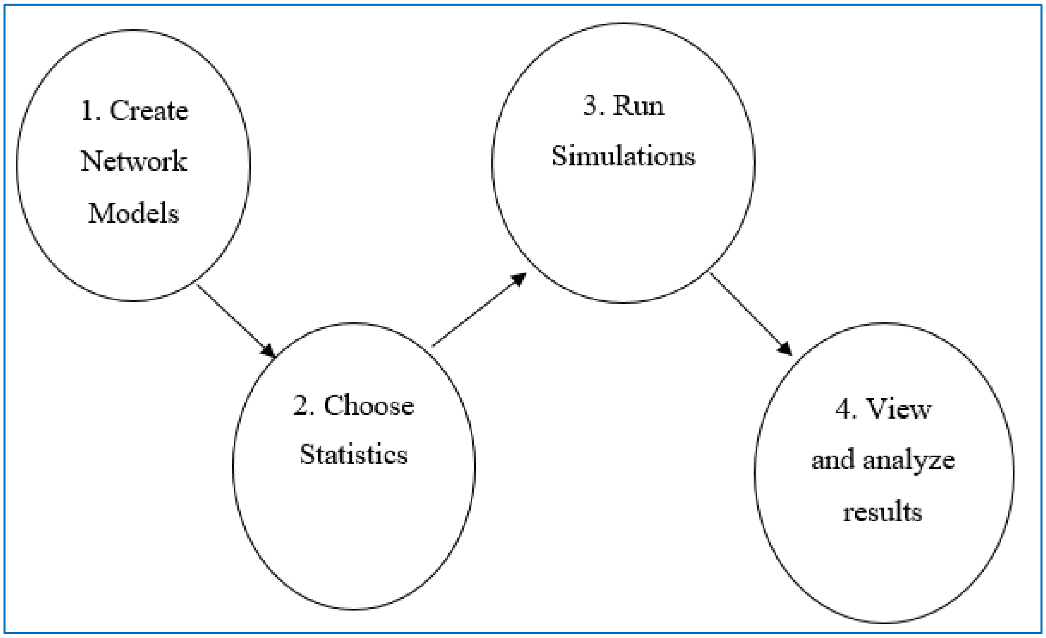


Figure 3. 11 OPNET Workflow (Bhatt, Kotwal, & Chaubey, 2019)

1. Create a Network Model: this is the first step in the OPNET model. This step should do two things:
    - Create a new node model in Node Editor.
    - Create a new network (with a single node) in Project Editor.

2. Choose Statistics: Statistics must be selected before running a simulation, as OPNET does not automatically collect all statistics.
3. Run Simulations: set the simulation parameters and run them. May alter the default length and the random number of the seed for the simulation.
4. View and analyse results: the result can be shown from the Project Editor or the Analysis Tool.

3.3.5 OPNET (Riverbed Modeler Academic Edition) License

The type of OPNET (Riverbed Modeler) licence this research work requires is Riverbed Modeler Academic Edition (Riverbed, n.d.), which is a six-month renewable licence and downloadable form Riverbed website at no charge.

3.4 Research Platform

The aim of this work is to answer the question: What WLAN standard (or a mix of standards) would result in the best overall performance for stand-alone applications or a given mix of applications in a given networked environment?

The methodology defines the way to achieve a ranking order and how the best overall performance is to be calculated on a network configuration (architecture).

At first, the work will focus on the creation of a whole series of simulated scenarios covering nearly all the various types of scenarios, as seen in Figure 3.12. The research platform will be broken down into two main parts: stand-alone applications and mixed applications. The stand-alone application refers to configurations and the implementations are all applicable to one application for that particular design, five IEEE 802.11 technologies (802.11, 11a, 11b, 11 g, 11e) were evaluated. Mixed applications refer to a number of applications running and configured at predefined percentages in those particular scenarios; the six above IEEE 802.11 technologies including 11n have been evaluated.

Figure 3. 12 Research platform

Scenarios are defined according to a number of factors as follow:

1. A number of nodes (5, 10, 20, 40, 65)
2. Applications in a variety of proportions:
    a. VoIP
    b. Video conferencing
    c. FTP
    d. HTTP
    e. Email
3. Spatial distribution of nodes:
    a. Uniform (Grid)
    b. Random
    c. Circle (Ring)
4. IEEE 802.11 technologies and data rate specified in 802.11, 11a, 11b, 11g, 11e, and 11n standards.
5. Network Configuration (Architecture):
    a. IBSS (Ad-hoc) network.
    b. BSS network.
    c. ESS network.

- Room size: the room sizes range from 2x3m to 10x14m since the standard room size of a typical University/College/school laboratory is within this range based on the number of nodes been used.

Within the three network architectures, there are multiple application mixes, and each set of nodes (5, 10, 20, 40, and 65) is configured up with the following application mixes for all three spatial distributions.

Mixed applications are studied as follows: (where % is the percentage of nodes in each considered application), as illustrated in Figure 3.13.

1. 20% VoIP, 20% VC, 20% HTTP, 20% FTP, 20% Email.

2. 50% VoIP and 50% VC (Real-time applications).

3. 40% HTTP, 30% FTP, 30% Email (Best-effort applications).

4. Majority of the traffic as Best-effort (60% HTTP, 20% VoIP and 20% VC).

5. Divide the traffic similarly – 50% Real time and 50%best-effort (40% VoIP, 10% VC and 30% FTP, 20% HTTP).

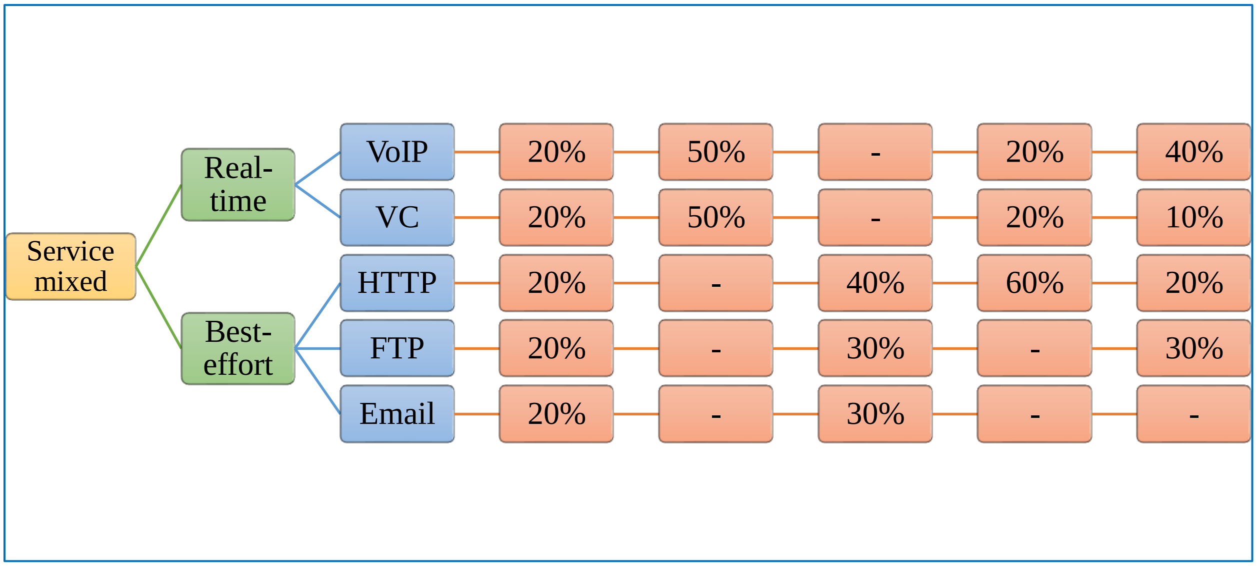


Figure 3. 13 Summary of mixed applications

This work presents the analysis of each best-effort application (HTTP, FTP, Email) and real-time application (VoIP and Video Conferencing) for three spatial distribution (Circular, Random, Uniform) as its own case study. In WLANs, there are typically several kinds of node distributions, namely circular, the semi deterministic node placement (Biased Random), the non-deterministic (stochastic) node placement (Simple Diffusion and Random) and the deterministic node placement (uniform/grid).

The distance can be determined between every node under the uniform configuration. Figure 3.14 shows an example of a uniform layout and, obviously, the distance between the nodes is fixed. The selection of layout type based on the intended use, so that nodes are typically scattered by aeroplanes over military zones for military purposes, while uniform distribution is adopted in the case of underwater sensors. The nodes are positioned on precise, predetermined points on the grid or, in particular, on sections of the grid under deterministic node placement. Deterministic or managed node positioning typically determines the shape of the node, the environment in which the node is positioned, and the application. Therefore, the application nodes in Sensor Indoor

Surveillance Systems or Building Control must be positioned manually. On the other hand, under semi-deterministic placement, single nodes are placed on the network (random) in a non-deterministic manner that encompasses the nodes of the regions (Norouz & Zaim, 2014).

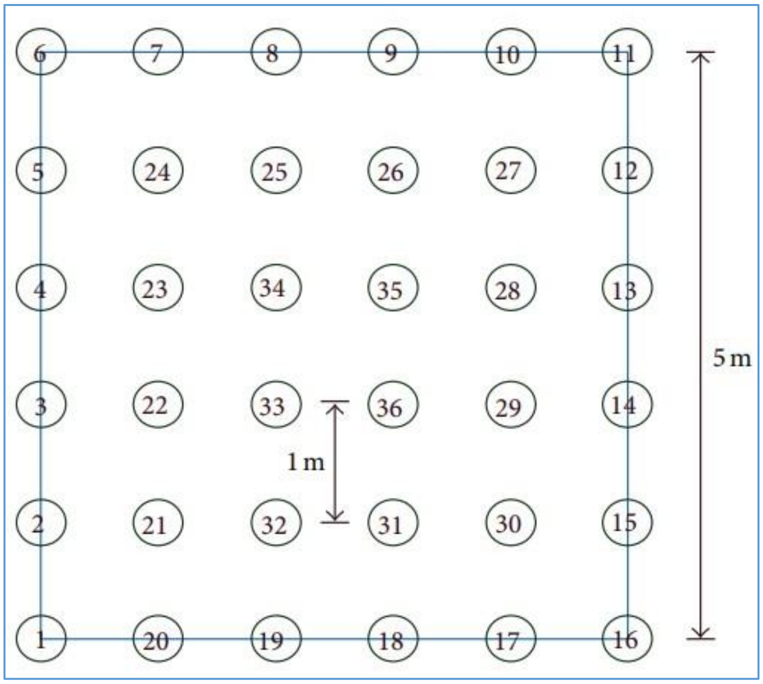
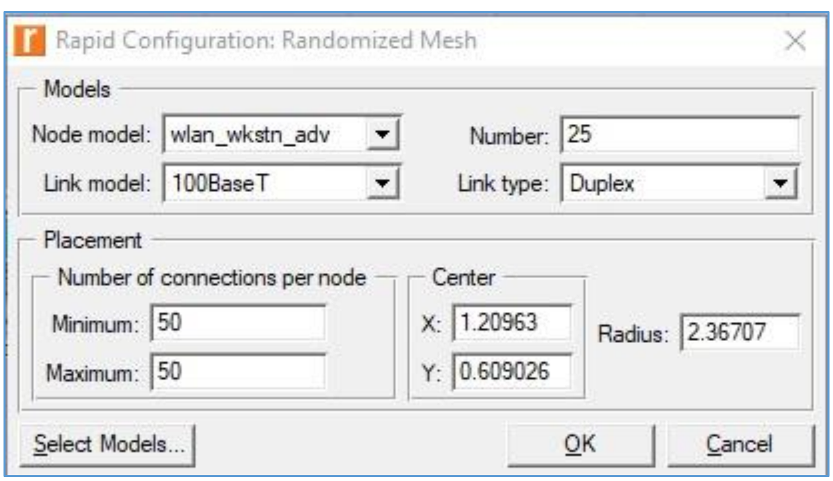


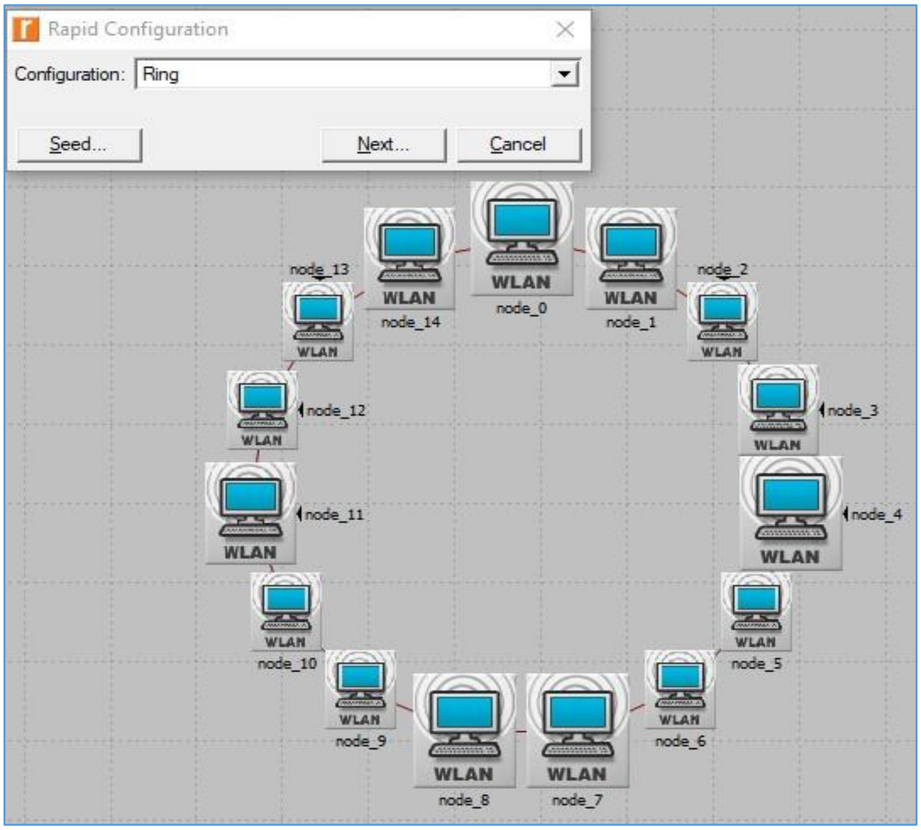
Figure 3. 14 Uniform/ Grid layout of WLAN nodes (Norouz & Zaim, 2014)

Network efficiency is greatly influenced by the spatial distribution of nodes in wireless networks. Many researchers have recently used stochastic geometry to model and examine wireless networks, because traditional methods are impractical and difficult to implement, taking into account the regular hexagonal lattice or the Wyner model. The distribution of Poisson is helpful in evaluating various kinds of random phenomena; through this, binomial probabilities are measured. In addition to the distribution of an estimator, the distribution of Poisson is a valuable probability model for events occurring spontaneously, either in place or time (Kong, Flin, Wang, Niyato, & Privault, 2017). Typically, the Poisson distribution is used for a comprehensive analysis of wireless networks and simulation, including its use in the Riverbed Standard Model Library in Unconnected Net Mode in the Rapid Configuration feature that has been implemented and analyzed in the extensive scenarios of this work.

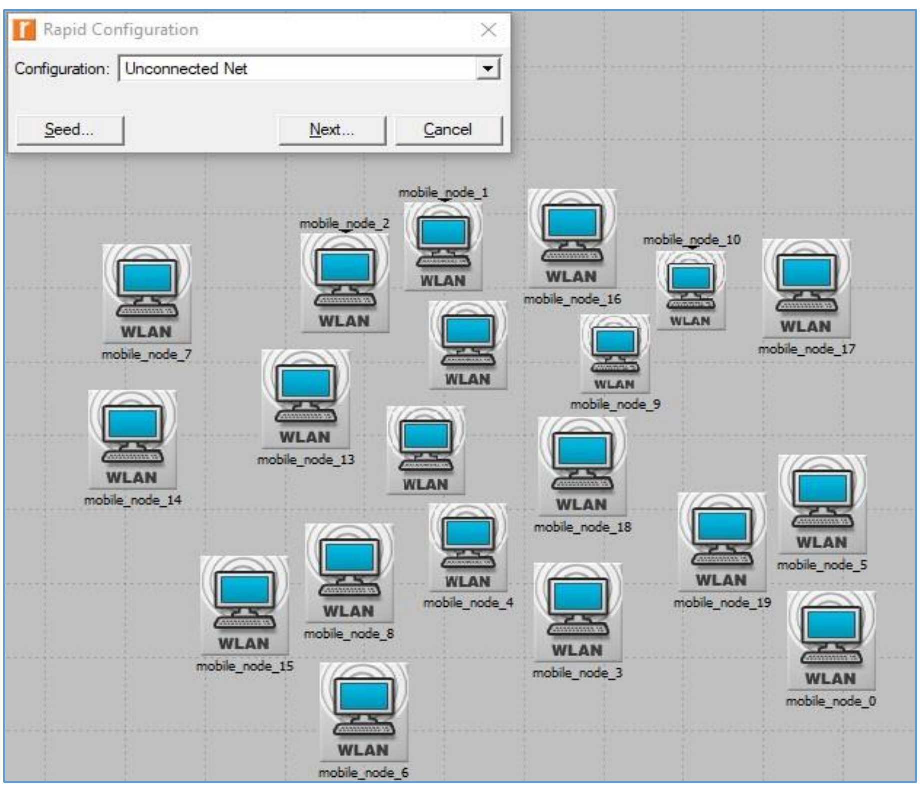
In addition, the effect of spatial distributions on each WLAN technologies is deliberated so we have not chosen particular spatial distributions, actually we tried to provide all node’s spatial distributions; circular, random, and uniform. If a university or school need to set up a lab, we thought that nodes will be distributed in one of these three possibilities. The same approach will be for a company or firm if its request to set up a room containing a number of machines to be a meeting or videoconferencing room, all the machines distributed possibilities have been taken into consideration; circularly, uniformly, and randomly. Our network models consist of a series of C-implemented Finite State Machines (FSMs) addressing the Riverbed Discrete Event Simulation (DES) Runtime (OPNET) modeller. The main aspect of our strategy is that it integrates the vast standard model library of OPNET (Riverbed) to accommodate a wide variety of network models and configurations of protocols. For three network configurations (BSS, ESS, IBSS) and OPNET, we also include a brief overview of stand-alone and mixed networks to constitute the backbone for the model architecture provided in detail in the following sections. Riverbed models are hierarchical: network models are composed of node and connection model instances, and node models are composed of process model instances. An FSM describes each process model, the action of which is completely defined in the source code of C or C++. A significant characteristic of Riverbed is that it comes with a comprehensive standard model library that includes a broad range of hardware, protocols and spatial distributions for the network. For three spatial distributions (circular, random, uniform) and Riverbed (OPNET), the Riverbed Platform library has integrated these distribution patterns through its Rapid Configuration features and will automatically build the required distribution based on the user requirement based on its C or C++ source codes, as shown in Figure 3.15.



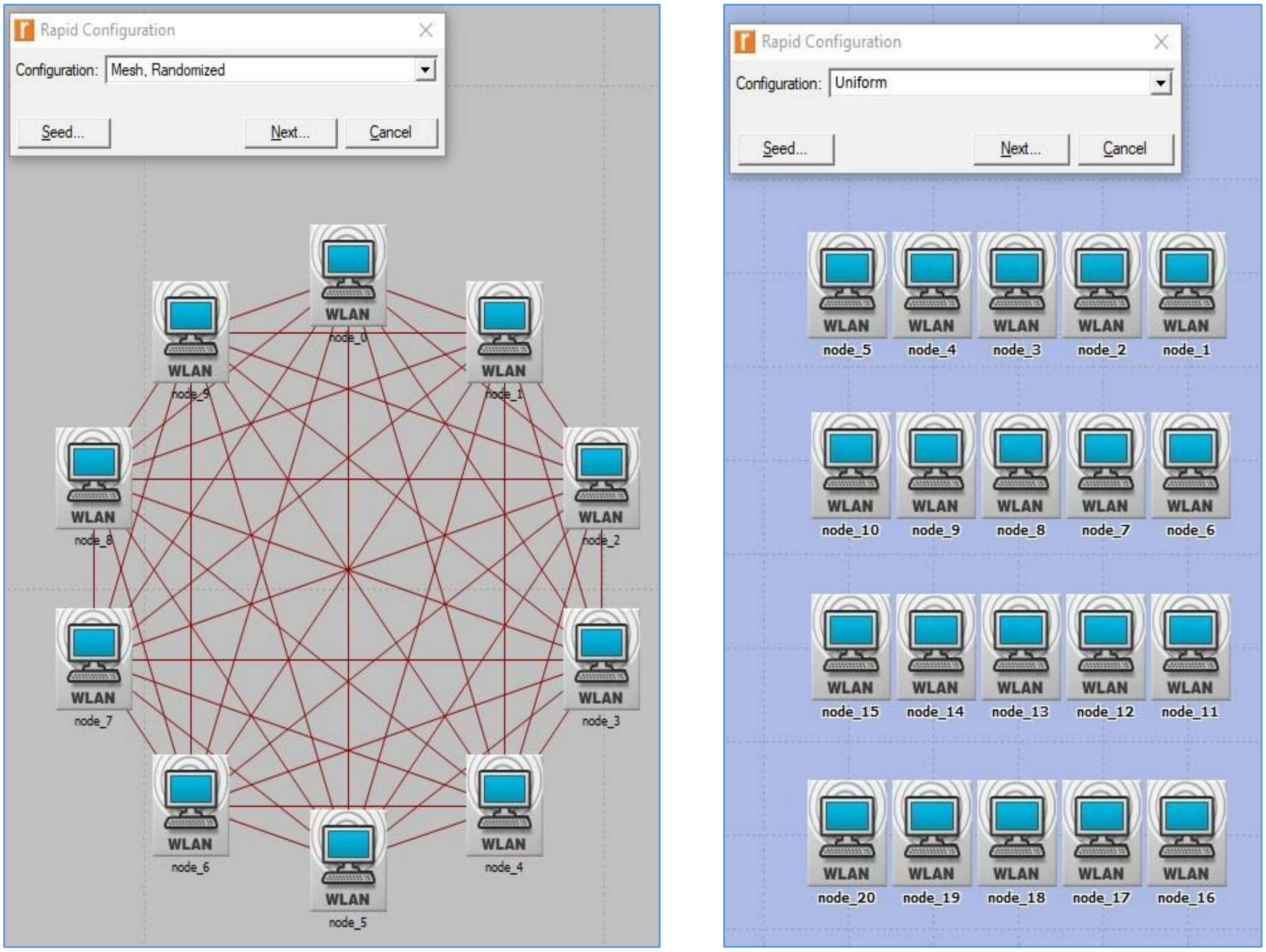
(a)


Rapid Configuration
Configuration: Ring
Seed...
Next...
Cancel
node_0
node_1
node_2
node_3
node_4
node_5
node_6
node_7
node_8
node_9
node_10
node_11
node_12
node_13
node_14
WLAN

(b)


Rapid Configuration
Configuration: Unconnected Net
Seed...
Next...
Cancel
mobile_node_0
mobile_node_1
mobile_node_2
mobile_node_3
mobile_node_4
mobile_node_5
mobile_node_6
mobile_node_7
mobile_node_8
mobile_node_9
mobile_node_10
mobile_node_13
mobile_node_14
mobile_node_15
mobile_node_16
mobile_node_17
mobile_node_18
mobile_node_19
WLAN

(c)



(d) (e)

Figure 3. 15 (a) Riverbed Rapid Configuration, (b) Circular (Ring), (c) Unconnected Net (Random). (d) Mesh, Randomized, (e) Uniform (Riverbed, 2017)

Figure 3.16 explains the algorithm's input sources and the procedure used in this research work for building different projects and scenarios.

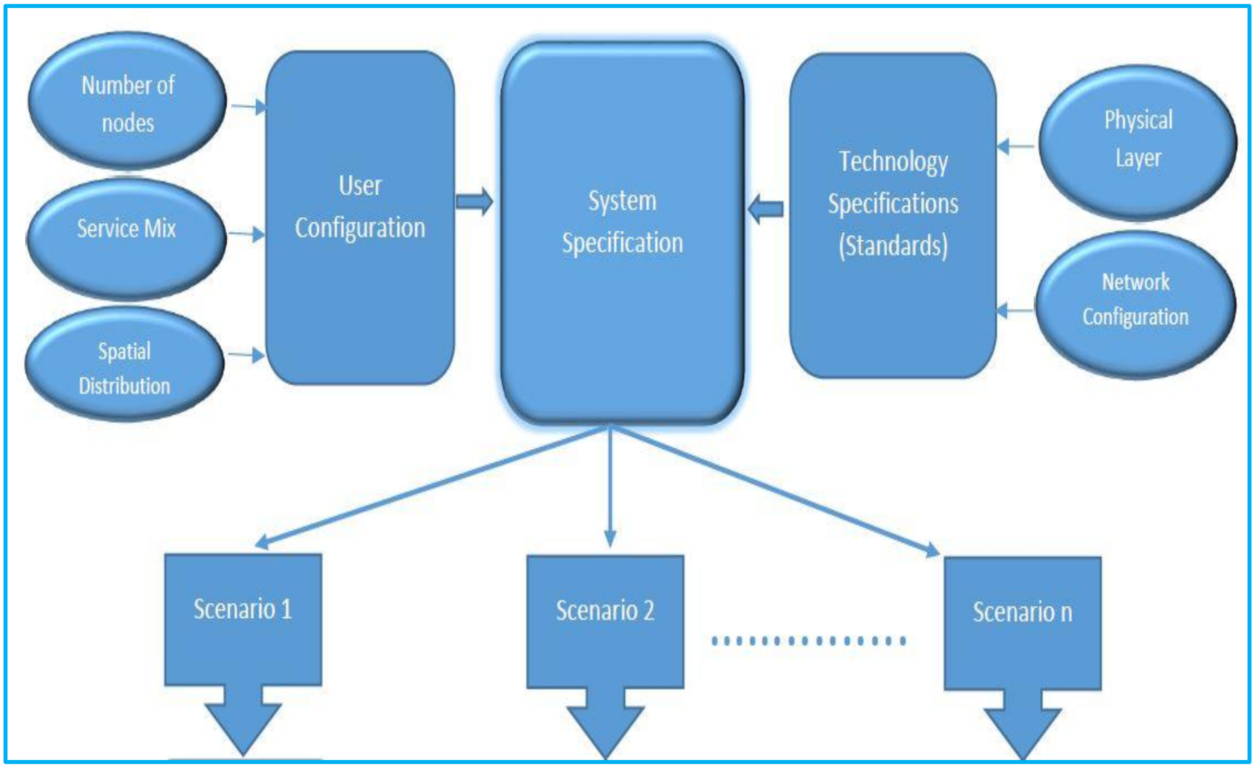


Figure 3. 16 Algorithm's Inputs

For this algorithm, there are two key sources of input; User configurations and Technical specifications (standards). User configurations depending on what the user (client) actually requires, determine number of factors, such as the Number of nodes he needs in his network, the Service mix defining the applications needed in this environment, and the Spatial distribution determining the topology in which those nodes should be distributed: circular (ring), uniform (gird) or randomly. Technical specifications describe the Physical layer framework used for several design scenarios and Network configurations, suggesting the communication between different wireless components in one of two forms: the absence of the access point (Ad-hoc) or the presence of the access point (BSS and ESS).

3.5 Scenarios Architecture

In order to achieve the objectives of this research, different projects and scenarios are built and analysed. Figure 3.17 explains the scenarios' architecture of this work and the guidance of the projects and scenarios that should be built. The work starts by building three main network architectures IBSS, BSS, and ESS. Many scenarios for the number of nodes will be developed for each. Five different applications will be configured in these groups of nodes. These applications are configured in a variety of proportions (as explained above) across all five groups of nodes. Six scenarios for the application mixes will be configured for the six IEEE technologies (802.11, 11a, 11b, 11 g, 11e and 11n). Whereas the five scenarios of IEEE technologies (802.11, 11a, 11b, 11 g and 11e) will be developed for stand-alone applications. These scenarios will be classified into three types of spatial distribution (circular, uniform, and random). Once all scenarios have been constructed across all three key network architectures and the results have been created, the algorithm and its calculations will be implemented.

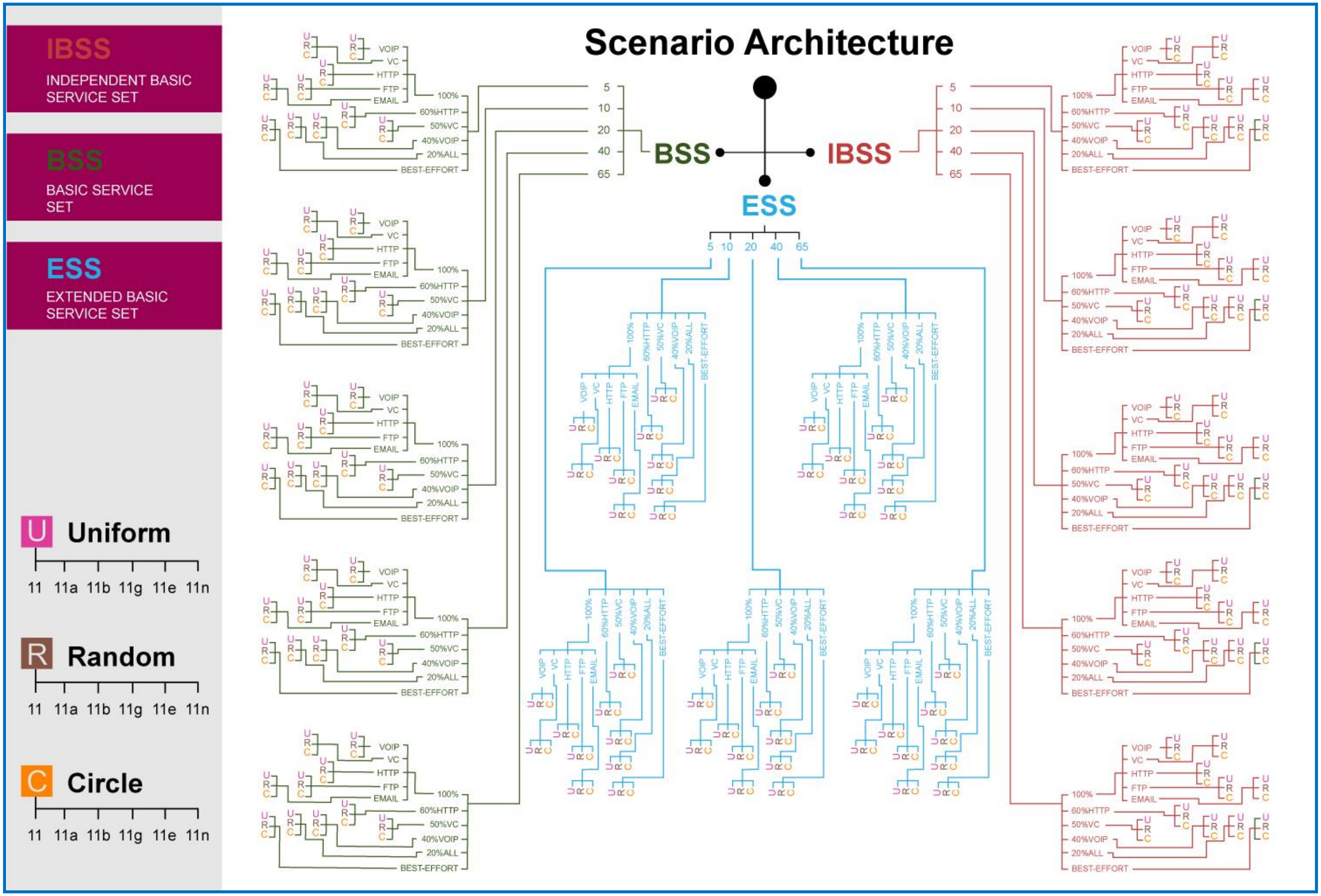


Figure 3. 17 Scenario Architecture of the research

3.5.1 Case Study BSS

In this case, several scenarios have been built according to a number of factors such as the number of nodes, applications in a variety of proportions, the spatial distribution of nodes, and physical layer technology.

This study applies and uses a single access point, the number of servers that depend on the number of applications used in a particular scenario, and the workstations equipped with client-specific applications for each node in the scenario. These scenarios apply to all five and six WLAN technologies for stand-alone and mixed applications, as well as to three spatial distributions: circular, uniform and random.

Here is a diagrammatic representation of a BSS network configuration in Figure 3.18.

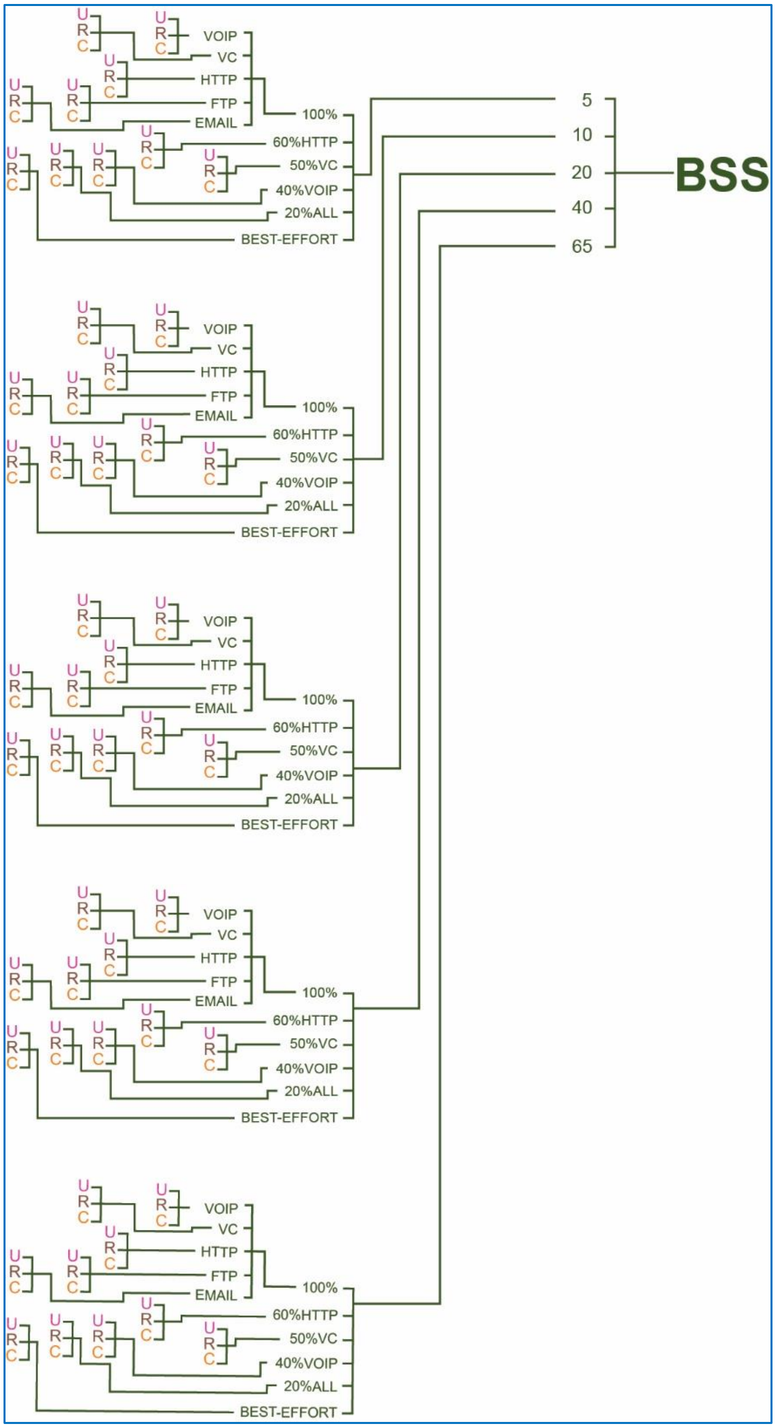


Figure 3. 18 Diagrammatic representation of BSS

Figure 3.12 shows the projects and scenarios that will be built. As an example, the name of one of these projects is (BSS_5_100VoIP); that means the project will be built for the case study (BSS), with 5 nodes (scenarios for VoIP application built for five groups of nodes 5, 10, 20, 40, and 65), with 100% of the nodes configured with VoIP across all three spatial distributions. As it is a stand-alone application, the five IEEE technologies (802.11, 11a, 11b, 11g, 11e) will be used across each scenario. Another project name is (BSS_10_60HTTP) where scenarios will be built for a variety of applications such as 60% HTTP, which represent the mix of applications (mix of service); 60% HTTP means that the proportion of nodes across the 10 groups of nodes (and all groups of nodes) will be as follow: 60% of nodes will be configured with HTTP, 20% of nodes will be configured with VoIP, and 20% of nodes will be configured with VC. Also, all of the scenarios for this mix of services will be configured for all six technologies (802.11, 11a, 11b, 11g, 11e, 11n) across three spatial distributions.

After applying the algorithm to these scenarios, the rank order list of the technologies will be issued for each group of nodes for each spatial distribution. And that will be applied also for all other applications or (mix of applications).

The graphical representations of BSS network configuration across all three spatial distributions are illustrated in the Figures as follow:

A) BSS network configuration in a uniform distribution is shown in Figure 3.19:

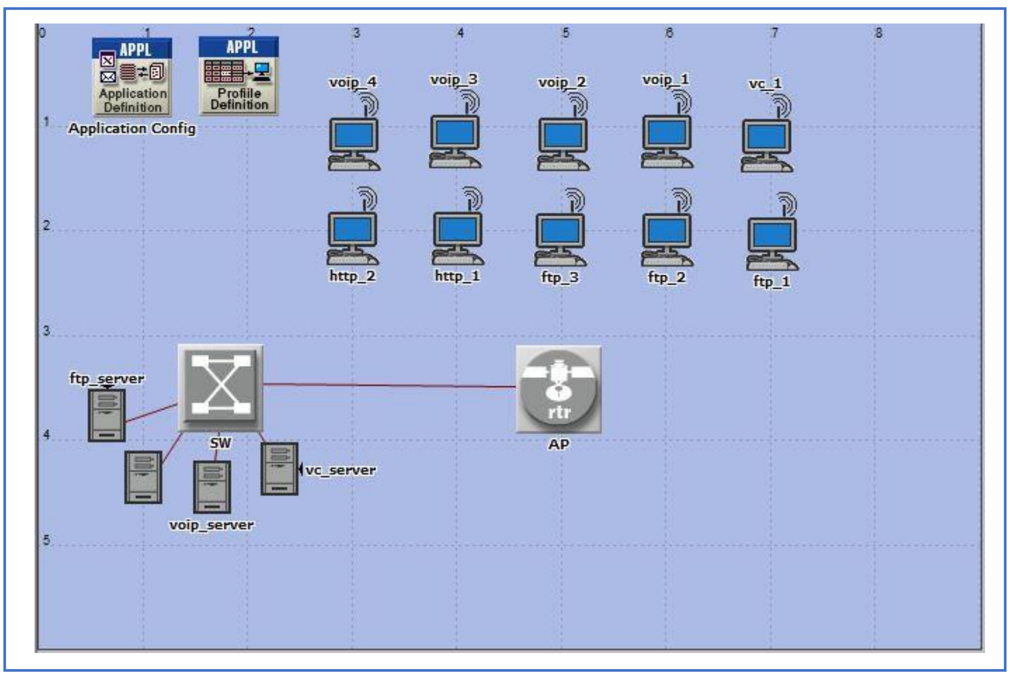


Figure 3. 19 BSS in a uniform distribution

B) BSS network configuration in a random distribution is shown in Figure 3.20:

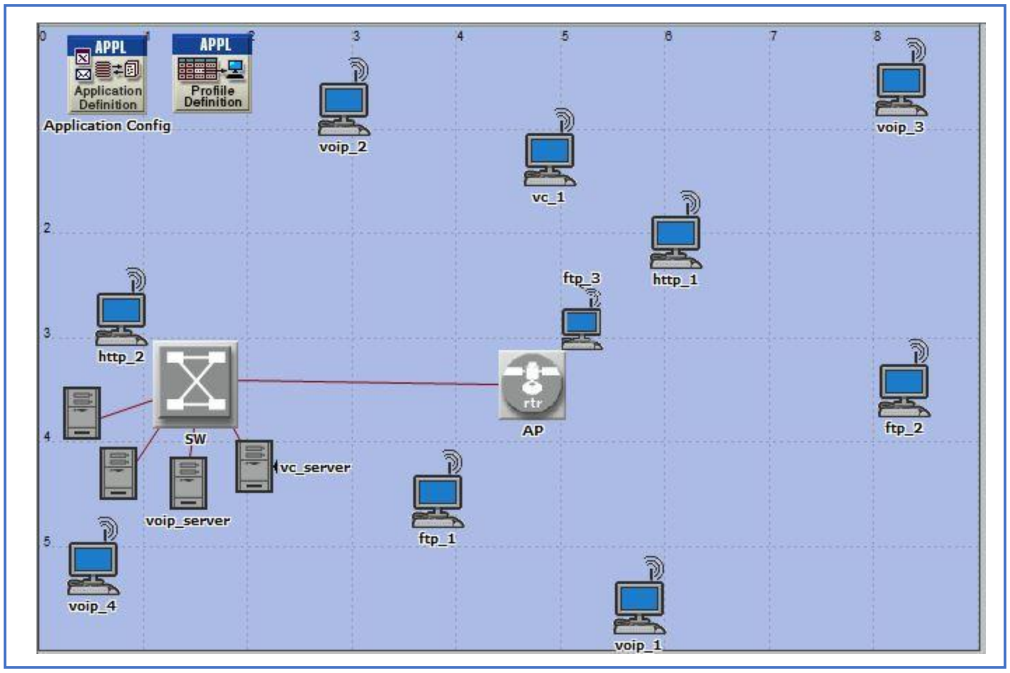


Figure 3. 20 BSS in a random distribution

C) BSS network configuration in a circular distribution is shown in Figure 3.21:

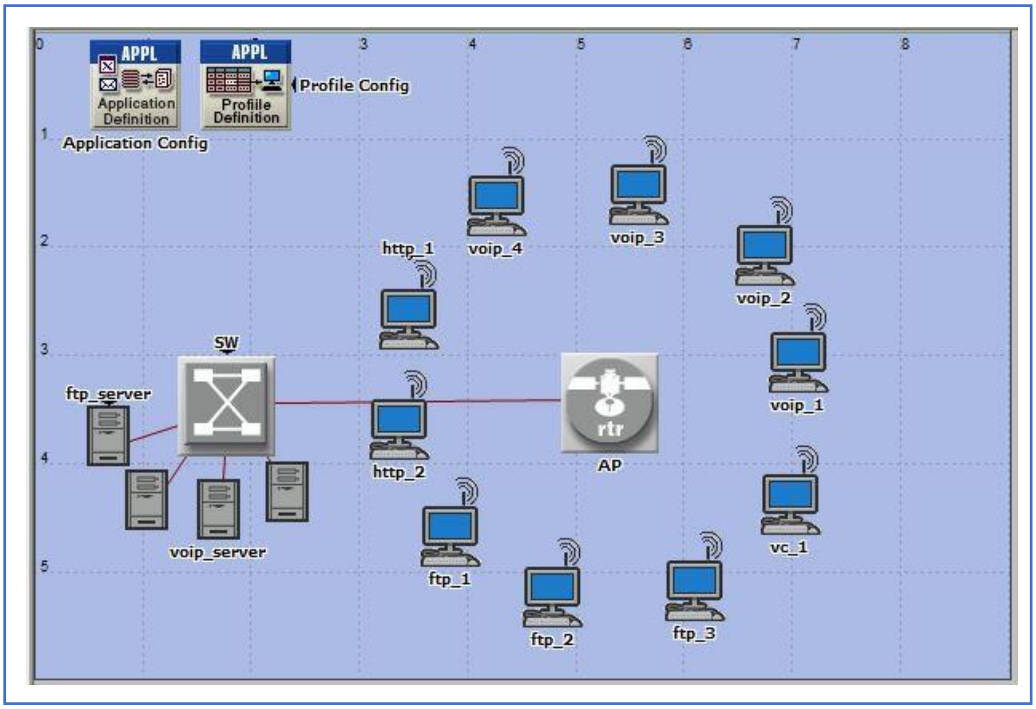


Figure 3. 21 BSS in a circular distribution

3.5.2 Case Study IBSS

In this case, several scenarios have been built according to a number of factors such as the number of nodes, applications in a variety of proportions, the spatial distribution of nodes, and physical layer technology.

No access points were used for this case study in configurations, a number of servers depending on the number of applications used in a given situation, and workstations equipped with applications specific to the individual client. Such scenarios apply to all five and six WLAN technologies for stand-alone and mixed applications.

Here is a diagrammatic representation of the IBSS network configuration in Figure 3.22:

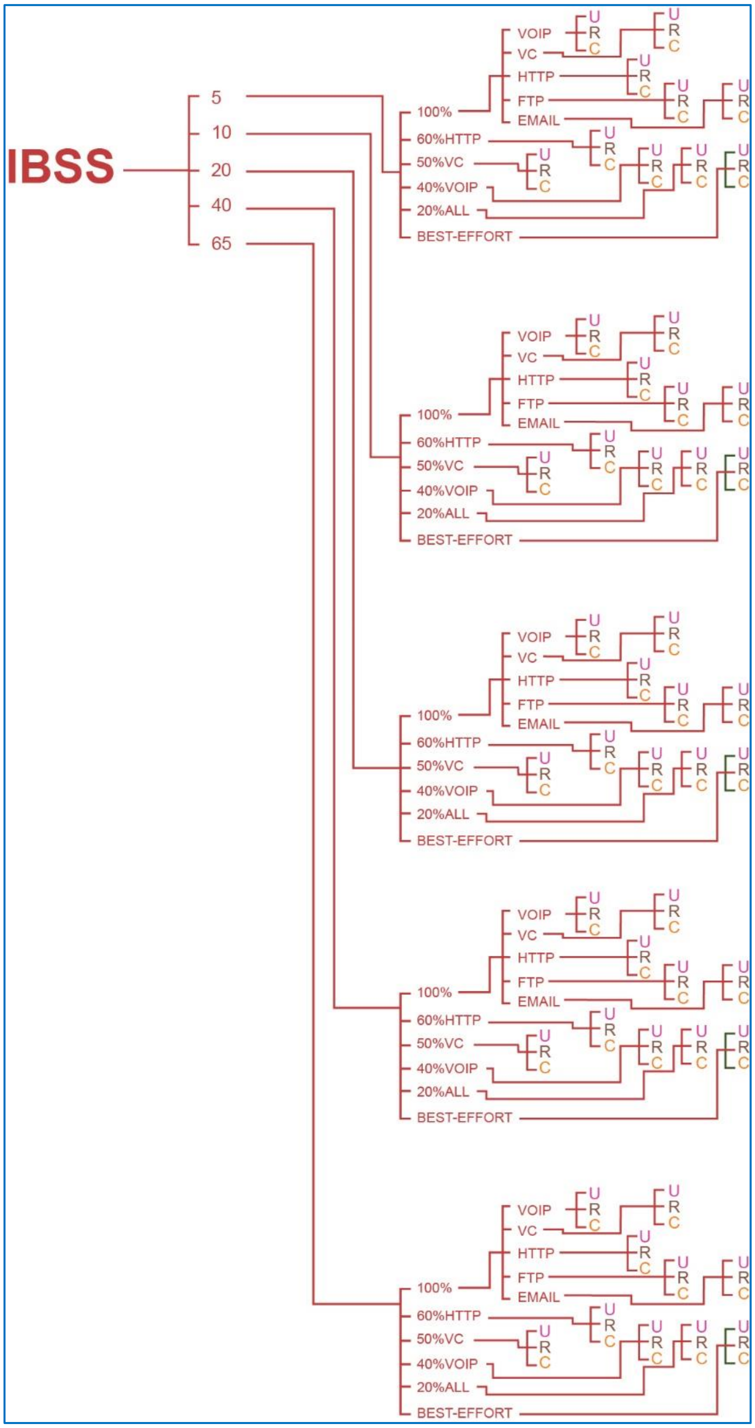


Figure 3. 22 Diagrammatic representation of IBSS

The graphical representations of IBSS network configuration across all three spatial distributions are illustrated in the Figures as follow:

A) IBSS network configuration in a uniform distribution is shown in Figure 3.23:

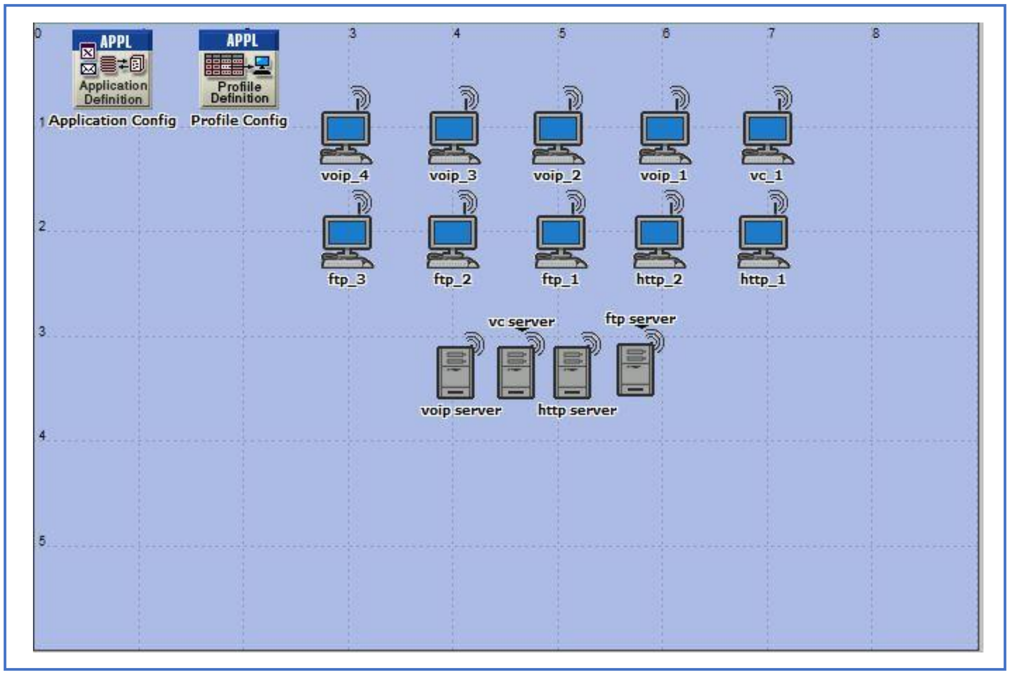


Figure 3. 23 IBSS in a uniform distribution

B) IBSS network configuration in a random distribution is shown in Figure 3.24:

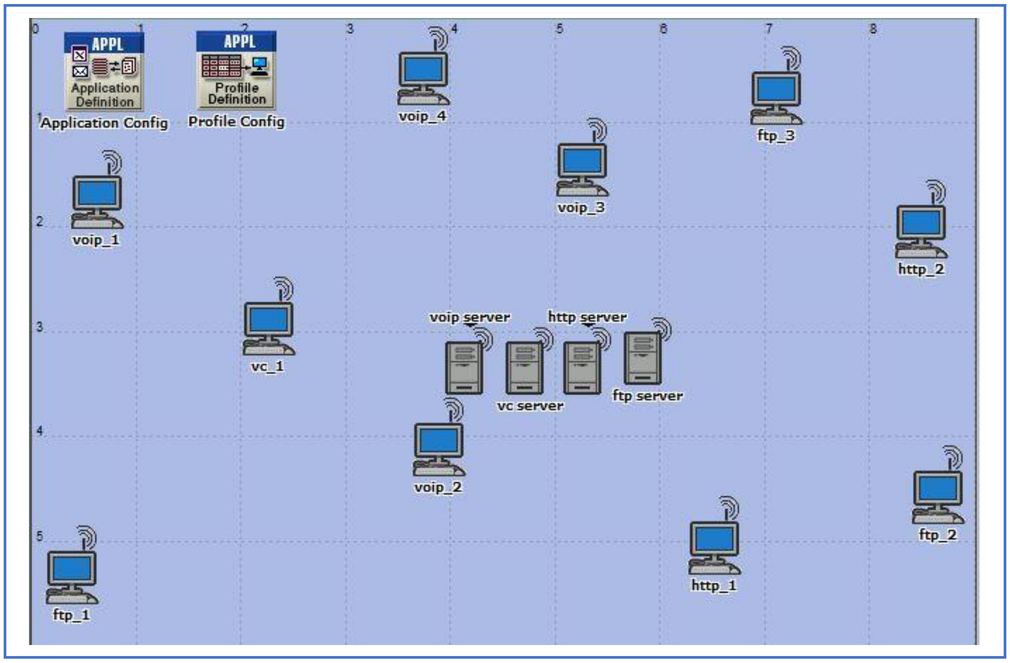


Figure 3. 24 IBSS in a random distribution

C) IBSS network configuration in a circular distribution is shown in Figure 3.25:

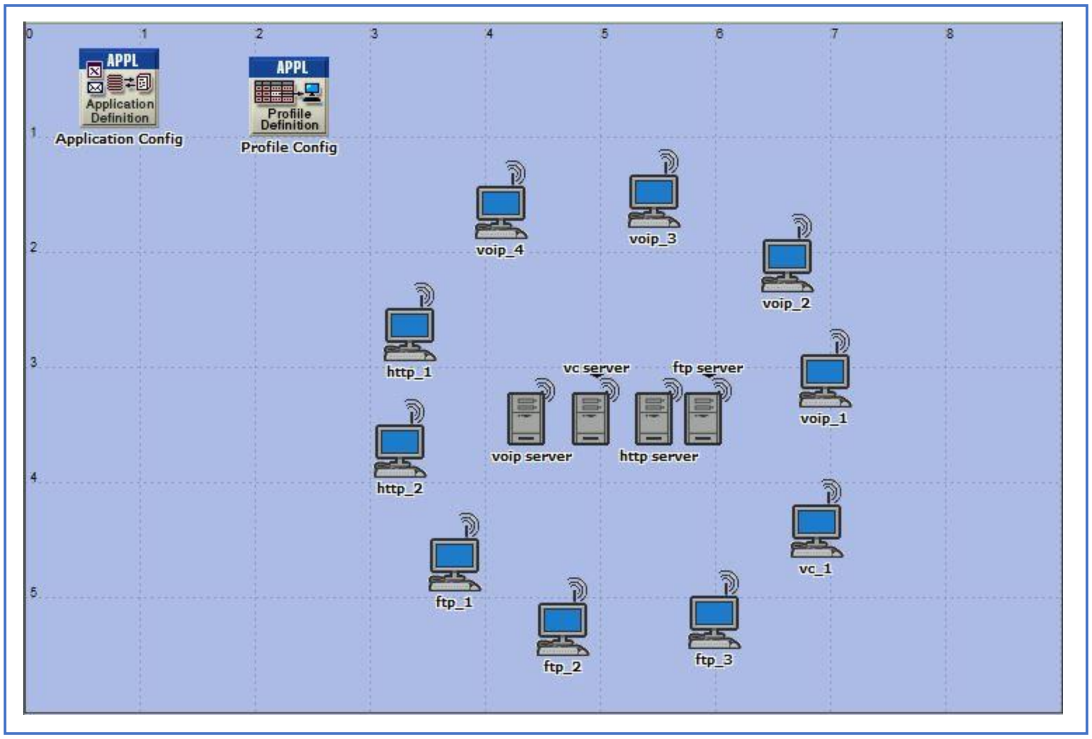


Figure 3. 25 IBSS in a circular distribution

3.5.3 Case Study ESS

In this case, many scenarios have been built according to the number of factors such as a number of nodes, applications in a variety of proportions, the spatial distribution of nodes, and physical layer technology.

This study uses more than one access point in scenarios, the number of servers, depending on how many applications in a given scenario are used and the number of workstations with client-specific applications. Such scenarios run for stand-alone and mixed application for all five and six WLAN technologies, respectively. Here is a diagrammatic representation of the ESS network configuration in Figure 3.26:

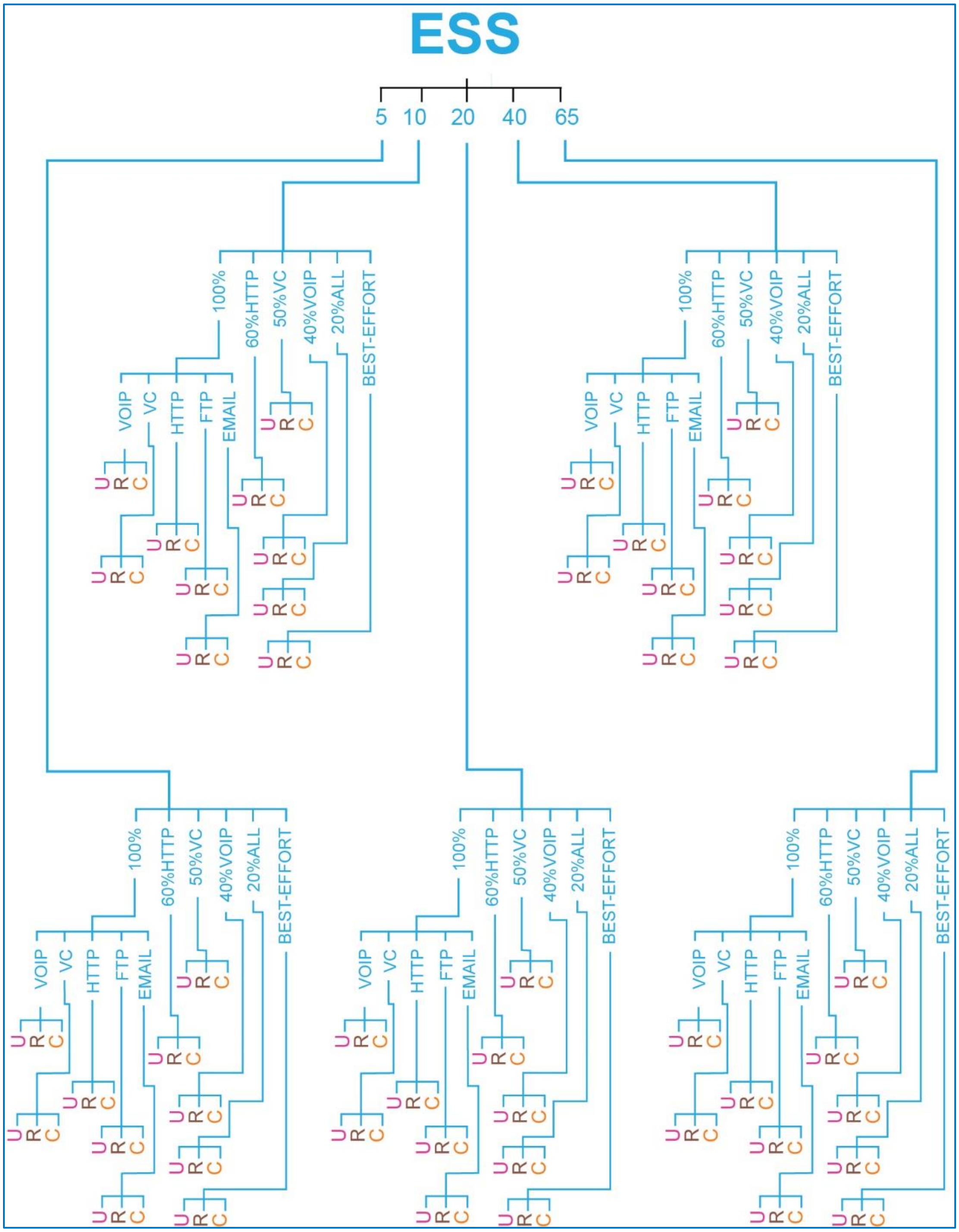


Figure 3. 26 Diagrammatic representation of ESS

The graphical representations of ESS network configuration across all three spatial distributions are illustrated as follow:

A) ESS network configuration in a uniform distribution is shown in Figure 3.27:

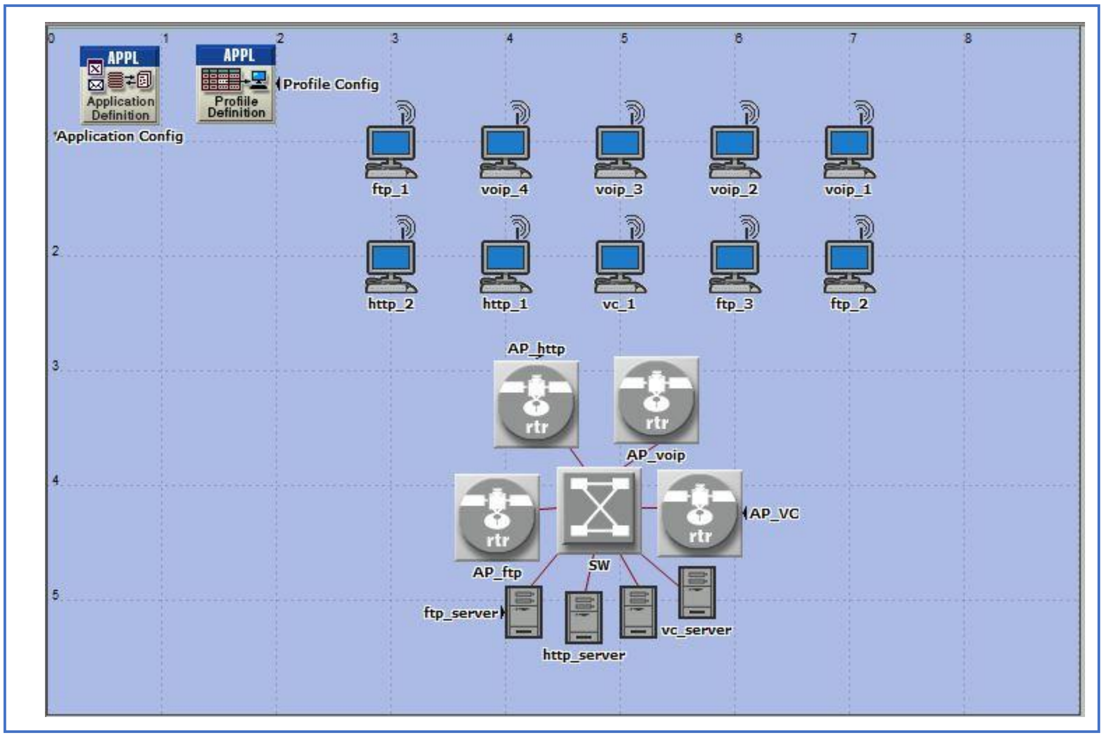


Figure 3. 27 ESS in a uniform distribution

B) ESS network configuration in a random distribution is shown in Figure 3.28:

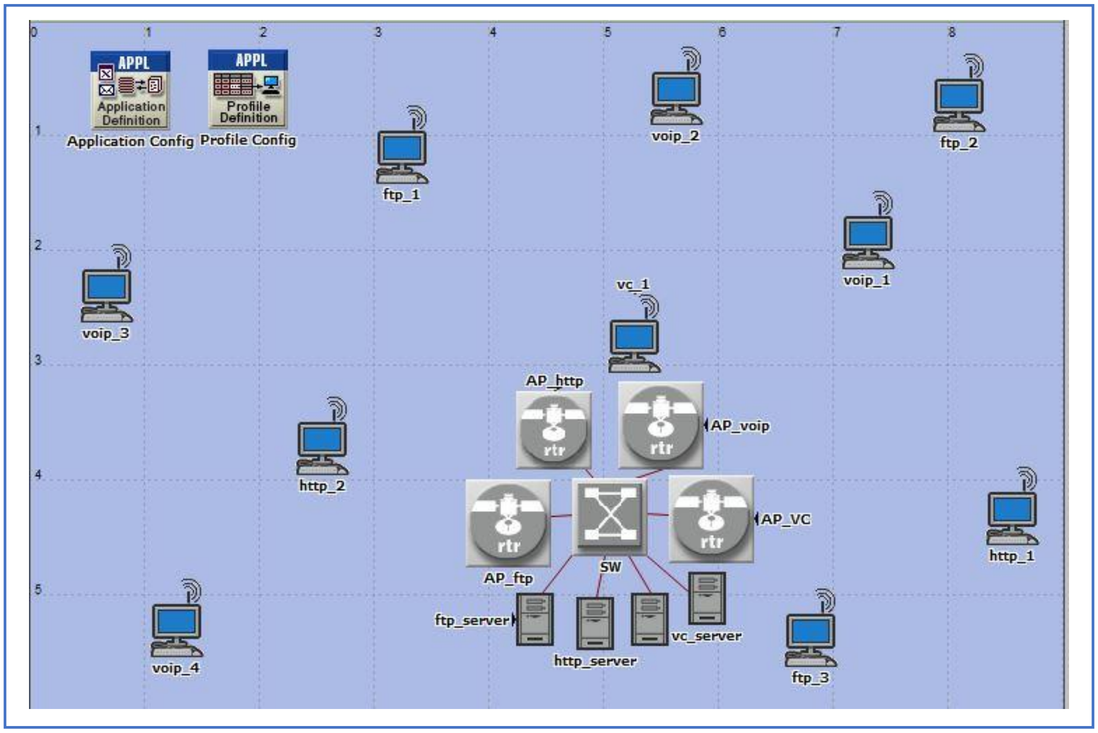


Figure 3. 28 ESS in a random distribution

C) ESS network configuration in a circular distribution is shown in Figure 3.29:

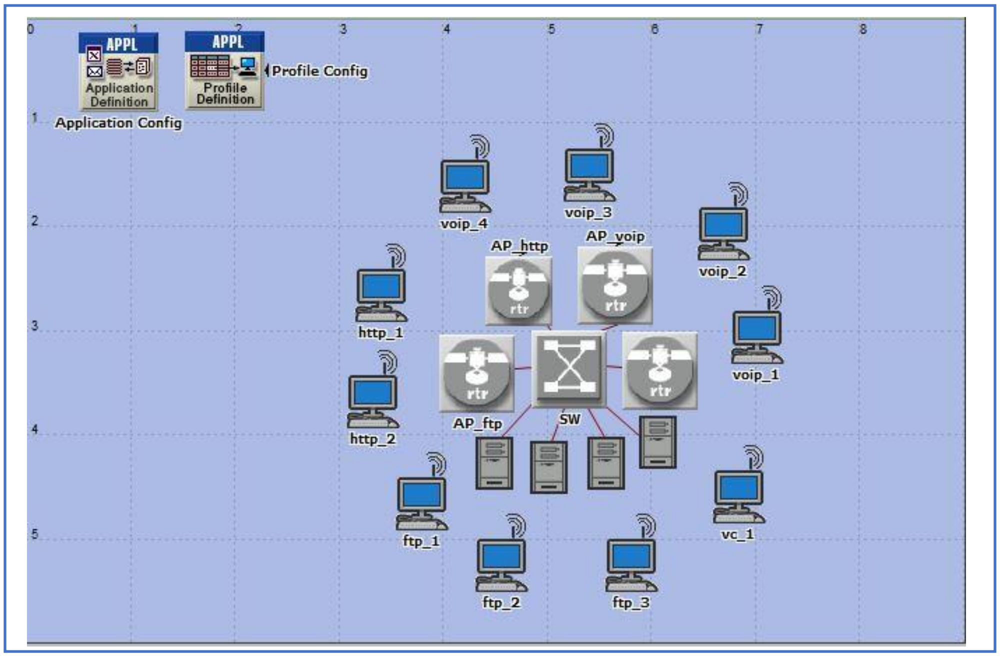


Figure 3. 29 ESS in a circular distribution

3.6 Scenario's Naming Convention

The scenario naming convention is mapped directly to the Scenario Architecture to organize building and tracking of the scenarios. The scenarios in all three case studies are organized based on the network configuration (architecture), the number of nodes being used, and the number of applications used in the configuration and network set up.

The names format is: [Network Configuration], [Number of Nodes], [Percentages of Applications running], [Spatial Distribution].

The following is the way that this naming convention is applied to specific network configuration scenarios:

- First (Network Configuration, Number of Nodes, 100% Application, Spatial Distribution): all scenarios run only one application. Number of Nodes indicates which nodes-group is being configured in the scenario. 100% Application indicates that all nodes in the scenario are configured with a specific application. Spatial Distribution indicates the way that nodes are going to be distributed.
- Second (Network Configuration, Number of Nodes, 60HTTP, spatial Distribution): the proportion of applications in each scenario is 60% of nodes running HTTP application,

20% of nodes running VoIP and 20% of nodes running VC application. Here the [Percentages of Applications running] element, “60HTTP”, is shortened for the purposes of readability.

- Third (Network Configuration, Number of Nodes, 50VC, Spatial distribution): in these scenarios, just the two applications VC and VoIP are used in the network set up. Here the [Percentages of Applications running] element, “50VC”, is shortened for the purposes of readability.
- Fourth (Network Configuration, Number of Nodes, 40VoIP, Spatial Distribution): these scenarios include four applications and their proportions are 40% of nodes running VoIP, 30% of nodes running FTP, 20% of nodes running HTTP, and 10% of nodes run VC. Here the [Percentages of Applications running] element, “40VoIP”, is shortened for the purposes of readability.
- Fifth (Network Configuration, Number of Nodes, 20All, Spatial Distribution): these scenarios include the highest number of applications and their proportions are 20% of nodes running VoIP, 20% of nodes running VC, 20% of nodes running FTP, 20% of nodes running HTTP, and 20% of nodes run Email. Here the [Percentages of Applications running] element, “20All”, is shortened for the purposes of readability.
- Sixth (Network Configuration, Number of Nodes, Best-effort, Spatial Distribution): these scenarios include the best-effort applications and their proportions are 40% of nodes running HTTP, 30% of nodes running FTP, and 30% of nodes run Email. Here the [Percentages of Applications running] element, “Best-effort”, is shortened for the purposes of readability.

To take one example from the Scenario Architecture in Figure 3.30:

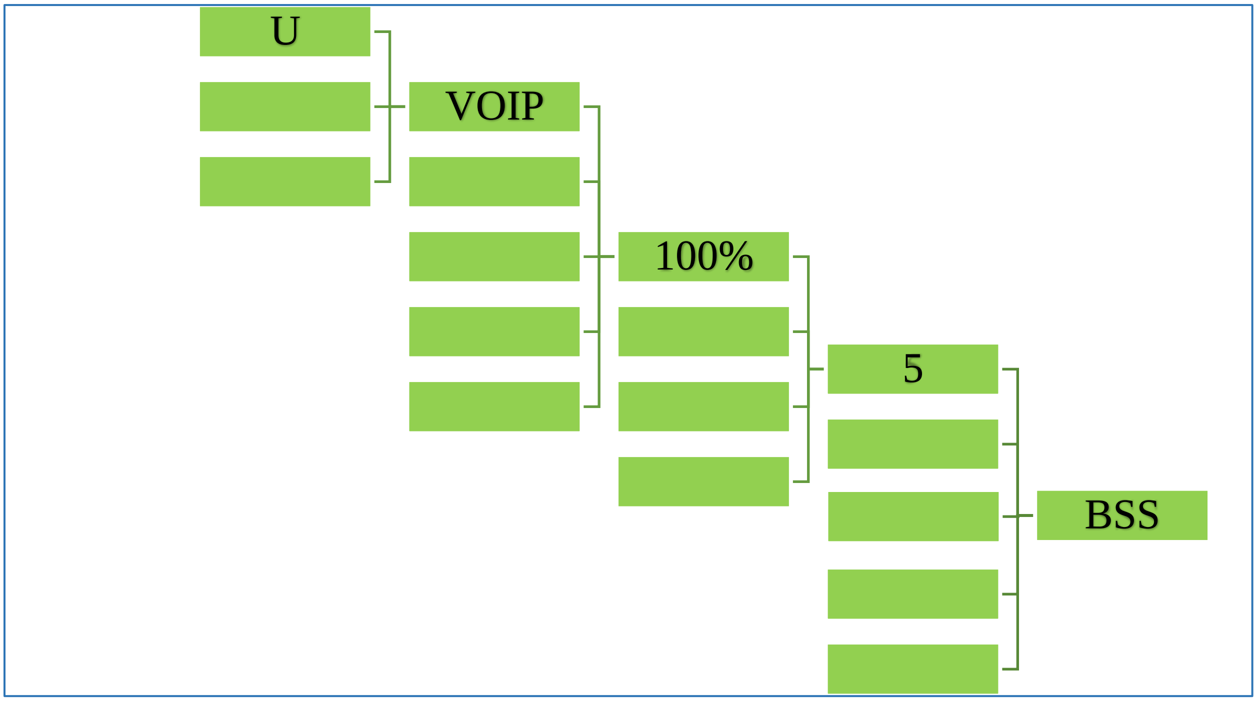


Figure 3. 30 BSS1$_{ST}$ Example of Scenario Architecture

The name convention of this scenario:

BSS_5_100VOIP_U, which is:

– Basic Service Set

– Number of Nodes (5)

– Percentage of Applications running (100%)

– Application configured (VOIP)

– Spatial Distribution (Uniform)

To take the second example from the Scenario Architecture in Figure 3.31:

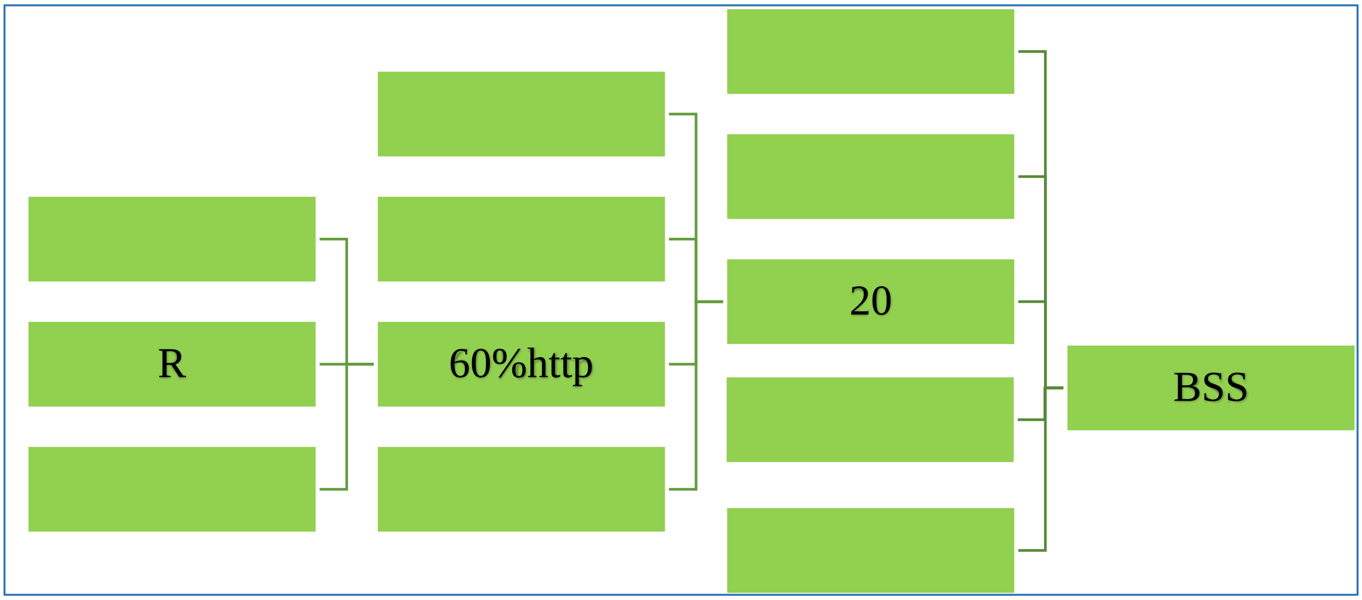


Figure 3. 31 BSS2ND Example of Scenario Architecture

The name convention of this scenario:

BSS_20_60http_R, which is:

– Basic Service Set

– Number of Nodes (20)

– Percentage of Applications running (60%http, 20%voip, 20%vc)

– Spatial distribution (Random)

As you can see the name does not include the full mix. This is because the name would become too long. Thus, as mentioned above, the third part of the name (60http) is modified according to the following: 60% HTTP, 20%VoIP, and 20% VC.

To take a third example of Scenario Architecture for IBSS naming convention in Figure 3.32:

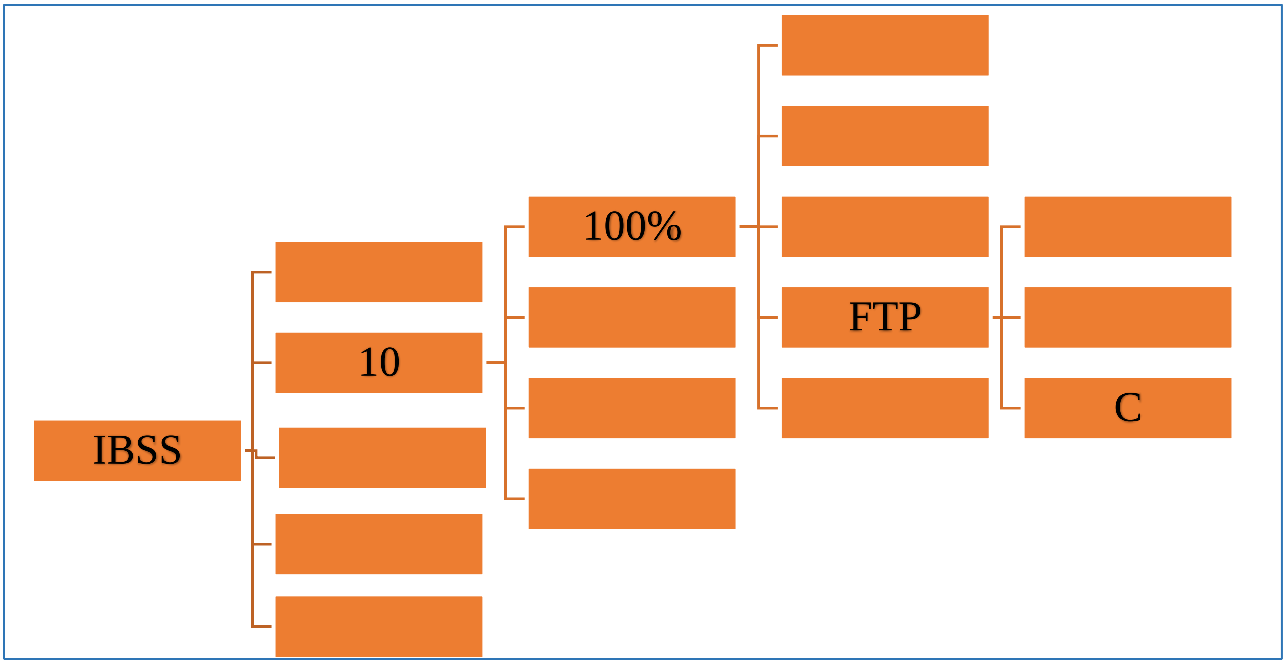


Figure 3. 32 IBSS Example of Scenario Architecture

The name convention of this scenario:

IBSS_10_100FTP_C, which is:

– Independent Basic Service Set

– Number of Nodes (10)

– Percentage of Applications running (100%)

– Application configured (FTP)

– Spatial Distribution (Circle)

To take a fourth example of Scenario Architecture for IBSS naming convention in Figure 3.33:

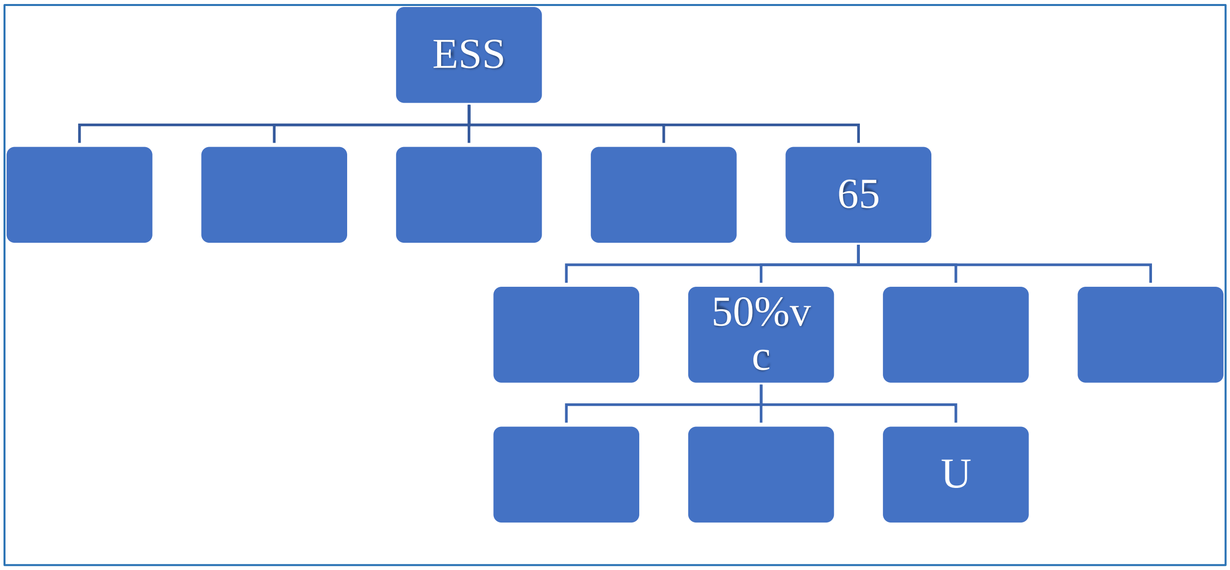


Figure 3. 33 ESS Example of Scenario Architecture

The name convention of this scenario:

ESS_65_50vc_U, which is:

– Extended Service Set

– Number of Nodes (65)

– Percentage of Applications running (50%vc & 50%voip)

– Spatial distribution (Uniform)

As can be seen, the name does not include the full mix. This is because the name would become too long. Thus, as mentioned above, the third part of the name (50vc) is modified according to the following: 50%VC and 50% VOIP.

3.7 System Settings and Parameters

Once the scenarios are built in the OPNET Modeler, the number of settings and parameters should be configured regarding the application (or mix of applications) used in the scenario as appears in Table 3.2. Settings 1–4 are common in all projects and scenarios. The other settings from 5–10 are related to the application being used and configured.

Table 3. 2 Typical simulation settings and parameters used

System Settings			
1	Profile start time (sec)	60	
2	Simulation time (min)	20	
3	Value Per Statistic	200	
4	IP Routing	EIGRP Enable	
5	**VC**	**Parameters**	**Values**
		Frame Interarrival Time Information	10-15 frames/sec
		Symbolic Destination Name	Video Destination
		Frame Size Information (bytes)	128×120/128×240 pixels
		Type of service (TOS)	Interactive multimedia
6	**VoIP**	**Parameters**	**Values**
		Voice frame per packet	1
		Application	Voice
		Codec	G.711
		Compression and Decompression delay	0.02 sec
		Types of service (TOS)	Interactive voice
7	**HTTP**	**Parameters**	**Values**
		HTTP Specification	HTTP 1.1
		Page Interval Time (sec)	Exponential (60)
		Types of service (TOS)	Best Effort
8	**FTP**	**Parameters**	**Values**
		Command Mix (Get/Total)	50%
		Inter-Request Time (sec)	Exponential (360)
		File Size (bytes)	50000
		Types of service (TOS)	Best Effort
9	**Email**	**Parameters**	**Values**
		Send Interarrival Time (sec)	Exponential (360)
		Receive Interarrival Time (sec)	Exponential (360)
		E-Mail Size (bytes)	20000
		Symbolic Server Name	Email Server
		Types of service (TOS)	Best Effort

The performances of different scenarios for all applications have been investigated via an OPNET simulator. Scalable Video Coding, or SVC, has had a huge influence on the VC industry and on video communications as a whole. SVC has identified four scalable profiles: Scalable Base, Scalable High, Scalable Constrained Base, and Scalable Constrained High. The profiles configured for VC applications are mainly "Scalable Baseline" and "Scalable Constrained Baseline," while "High" profiles are commonly used in HD resolution software implementations. The video considered in this work is 128×120 pixels for the first four nodes groups and 128×240 pixels for the fifth one, where these video formats are taken from the literature (Eleftheriadis, 2016) and match the VC profiles’ applications requirements.

The maximum data rate is nominal and often does not reflect actual delivered rates so would not be of much help to a potential client. Therefore, why use the maximum theoretical data rate, whereby standard 802.11e is capable of 54 Mbps when in the real world no one gets close to theoretical speed (Kelly, 2014). Therefore, minimum data rates, as shown in Table 3.3, are more likely to assist users and are more realistic, since the system is handling uplink and downlink applications activities where the maximum for uplink performance is almost equal to the minimum data rate given by the standard technology (Aagela, Holmes, Dhimish, & Wilson, 2017).

Table 3. 3 IEEE technologies’ data rates

Parameters	**Data rate (Mbps)**
IEEE 802.11	2
IEEE 802.11a	6
IEEE 802.11b	2
IEEE 802.11g	6
IEEE 802.11e	11
IEEE 802.11n	6.5 (base) / 60 (max)

The next step of the OPNET workflow after creating a network model as appears in Figure 3.11, is to choose the statistics (parameters) according to the implemented application. To achieve this aim, this work defined a number of statics (QoS parameters) for each application to be evaluated and analysed as described in Table 3.4.

Table 3. 4 QoS Application parameters

QoS \ Application	**Email**	**FTP**	**HTTP**	**VC**	**VoIP**
Download Response time (sec)	X	X			
Page Response time (sec)			X		
Jitter/Delay Variation (sec)				X	X
Delay (sec)				X	X
Throughput(kbps)	X	X	X	X	X
Packet loss (%)	X	X	X	X	X

The quality of Internet-based applications is significantly affected by the following QoS metrics (Zaidi & Nand Dwivedi, 2018); (Mohd Ali, Dhimish, & Glover, 2020); (Mohd Ali, Dhimish, & Glover, 2020):

- Packet End-to-End delay (sec): Data/voice time is taken to move from node A to node B over the network.
- Jitter (sec): The delay variation induced by the queuing.

- Throughput (bit/sec): The defined cumulative rate at which the packets are transmitted from the source to the destination.

- Traffic Sent (packet/sec) and Traffic Received (packet/sec): It is used to measure the rate of packet loss, i.e., the proportion of packets lost along the transmission path after the user has sent the packet over the network.

3.8 QoS performance metrics and Importance coefficient for Internet-based applications

The QoS metric parameters for applications are identified with performance metrics. The satisfaction criterion (acceptable threshold) for each QoS metric parameter shall be specified for each application (Zawia, Hassan, & Dahnil, 2018); (Al-Shaikhli, Esmailpour, & Nasser, 2016); (Mohd Ali, Dhimish, & Glover, 2020); (Mohd Ali, Dhimish, & Glover, 2020) as shown in Table 3.5, reflecting main QoS criteria and recommendations for each application (bearer traffic).

Table 3. 5 QoS Application Importance (threshold value)

QoS / Application	**Delay/Response (sec)**	**Jitter/Delay Variation (sec)**	**Throughput (kbps)**	**Packet Loss Rate (%)**
E-mail	1[1]	0	30	10
File Transfer (FTP)	1[1]	0	45	5
Web Browsing (HTTP)	1[2]	0	30	10
VoIP	0.17	0.04	45	5
Video Conferencing	0.15	0.03	250	1

[1] Download response time.

[2] Page response time.

It should be noted that, in view of the impact on the quality of the service, an important coefficient is allocated for each application parameter (ICP). Table 3.6 indicates the QoS qualitative importance for every QoS metric (Mohd Ali, Dhimish, Alsmadi, & Mather, 2020). When these qualitative variables are to be taken into account in a simulation, they must be interpreted into numbers (H=1, M=0.5, L=0.1, and VL=0) (Mohd Ali, Dhimish, & Glover, 2020); (Mohd Ali, Dhimish, & Glover, 2020).

Table 3. 6 QoS Qualitative importance for each applications' parameters

QoS / Application	**Delay/Response**	**Jitter/Delay Variation**	**Throughput**	**Packet Loss Rate**
E-mail	L[1]	VL	L	L
File Transfer (FTP)	L[1]	VL	M	H
Web Browsing (HTTP)	M[2]	VL	L	L
VoIP	H	H	M	L
Video Conferencing	H	H	H	M

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

3.9 Scenarios Calculations

After running scenarios for both stand-alone applications and application mixes, calculations will be made to assess how well different scenarios have achieved those performance criteria for each application. For the algorithm, we considered two key source inputs with OPNET simulation: User settings and Technical specifications (standards), as mentioned above. These factors are identified in the top portion of Figure 3.34.

- User configurations: depending on what the user (client) actually requires, these include:
  - ➢ The number of nodes needed in the network.
  - ➢ Application mixes that define the percentages required for each application in the environment.
  - ➢ The spatial distribution that defines the topology to be applied for these nodes: circular (ring), uniform (gird) or random.

- Technical specifications
  - ➢ Physical layer framework used for several design scenarios.
  - ➢ Network configurations, which indicate the communication of different wireless components in one of two ways: the absence of the access point (Ad-hoc) or the presence of the access point (BSS and ESS).

The size of the network chosen, up to 65, is consistent with Mehmood & Alturki (2011), Orfanou, Tselios, & Katsanos (2015) and Anouari & Haqiq (2013). On the other hand, all the observed findings from these five groups of nodes have been described as appropriate to preserve the consistency of network performance; that is, an increase in the number of nodes in the network means that, given limited bandwidth capacity, a small amount of traffic will lead to a network performance loss.

This was validated on 2×3 m to 10×14 m room size only since a part of this scope is the standard size of the room of the normal school/college/university laboratory. In the bottom part of Figure 3.34, Phase II displays system calculations and mathematical models. QoS Threshold values of every application and Cumulative Distribution Function (CDF) are the inputs for the mathematical calculations of the algorithm. QoS Threshold values (criterion of compliance) are derived from literature for applications. After running the simulation scenarios, CDF distribution is generated from OPNET for all the QoS metric parameters.

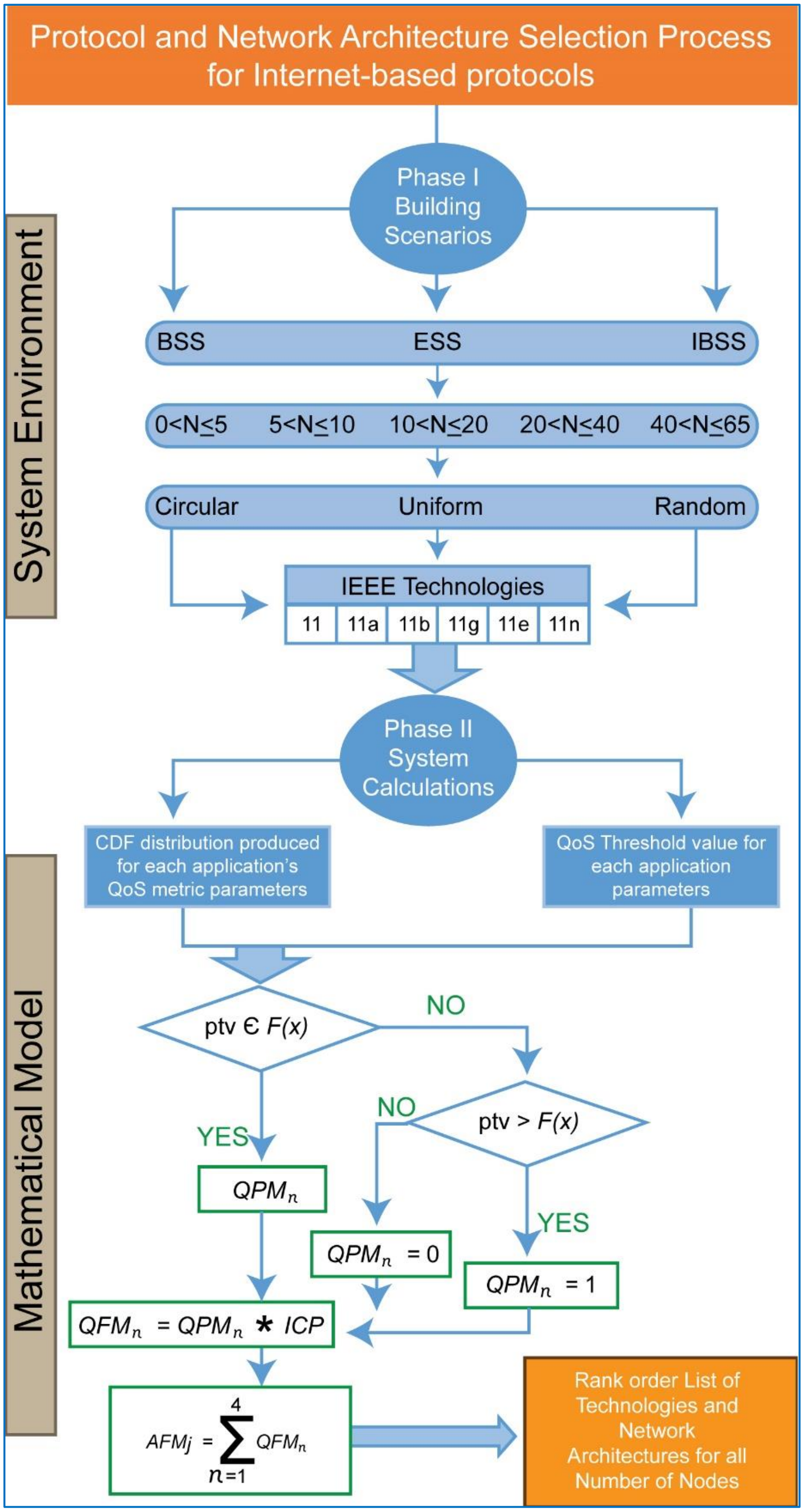


Figure 3. 34 Flow chart of Research Algorithm Process

Mathematical calculations would be made to assess whether many success metrics for each application have been achieved by a specific scenario. To clarify the calculations of this algorithm and to calculate the results of each of the above projects, the following steps will be taken (Mohd Ali, Dhimish, Alsmadi, & Mather, 2020); (Mohd Ali, Dhimish, & Glover, 2020); (Mohd Ali, Dhimish, & Glover, 2020):

- QoS Performance Metric (QPM): as shown in Figure 3.35, for each QoS performance criterion *n*, the value generated by implementing the application QoS metric Parameter Threshold Value (PTV) when it is defined in the CDF distribution *F(n)* given by Eq. (3.2):

$$QPM_n = F(ptv) \tag{3.2}$$

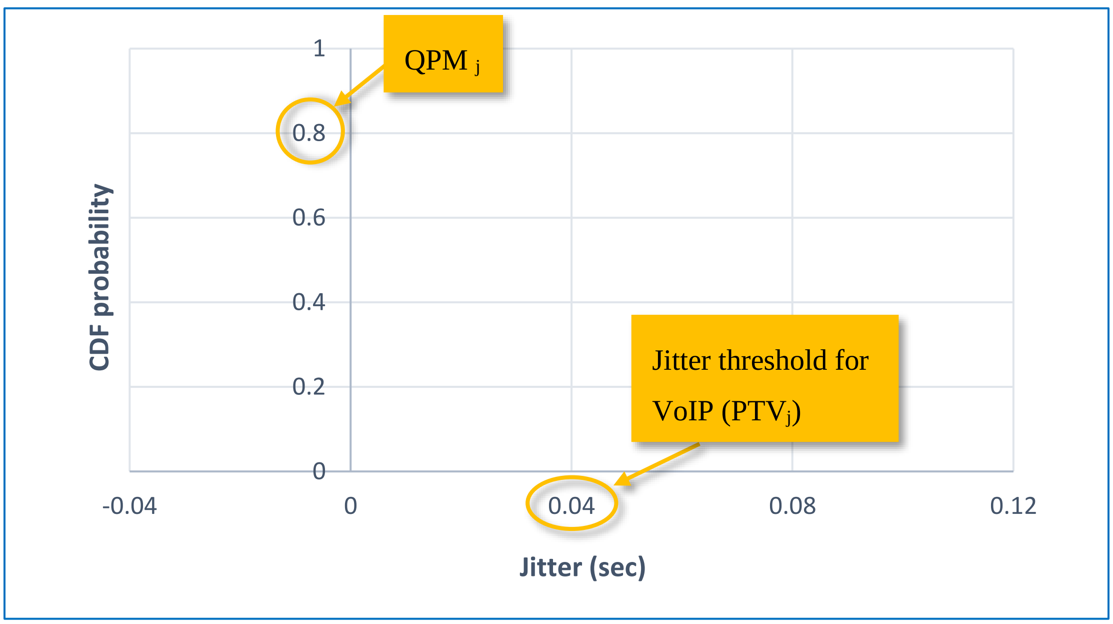


Figure 3. 35 QPM for Jitter

The acceptable jitter parameter limit for VoIP applications is 0.04 sec, as defined in Figure 3.35 and Table 3.5. Therefore, 80% of packets are late for this QoS parameter by less than 0.04 sec, which symbolizes the QPM. The QPM therefore, informs us how likely each metric VoIP parameter is to be sufficient.

- QoS Fitness Metric (QFM): In every QoS metric parameter (H=1, M=0.5, L=0.1, and VL=0), the value generated by implementing a weighting to the QPM (allocated by importance) is defined by Eq. (3.3) (Mohd Ali, Dhimish, & Glover, 2020); (Mohd Ali, Dhimish, & Glover, 2020):

$$QFM_n = QPM_n \times ICP \tag{3.3}$$

  For the same QoS parameter, the coefficient of importance is High (H=1); the QFM is equal to 0.8 and weighted by 1; this produces 0.8. for jitter that is the performance metric. Thus, 80 per cent of adequacy is multiplied by the coefficient of importance (H=1).

- In the last step, the Application Fitness Metric (AFM) is calculated to add all QFMs for *n* application QoS metric (delay, jitter, throughput and packet loss) parameters for each IEEE 802.11 technology g, and let *M* be the actual machines percentages in the mixed services scenarios as demonstrated by Eq. (3.4) (Mohd Ali, Dhimish, & Glover, 2020); (Mohd Ali, Dhimish, & Glover, 2020).

$$AFM_g = \sum_{n=1}^{4} QFM_n \times M \tag{3.4}$$

- The ranking of all these six/five technologies will be created for each of the three network architectures designed, on the basis of IEEE 802.11 technology's AFMs. For all node groups, then the best performance of network architecture is defined.

Figure 3.34 shows these mathematical measures, which give each IEEE MAC technology the AFM value. As explained above, all QoS metric parameters from the OPNET Modeler simulation will be given, with the CDF distribution *F(n)* (Yates & Goodman, 2014), and evaluated versus PTV as follows (Mohd Ali, Dhimish, Alsmadi, & Mather, 2020); (Mohd Ali, Dhimish, & Glover, 2020); (Mohd Ali, Dhimish, & Glover, 2020):

1. If $PTV \in F(n)$: This means that the PTV has a specific value for this metric parameter on its CDF distribution equal to QPM. QPM is weighted by ICP for the output of QFM. Then the aggregation of all QFMs creates AFMs that are used to identify IEEE technologies.

2. If $PTV > F(n)$: This implies that the QPM value is equal to 1 and the QFM value is raised.

3. If $PTV < F(n)$: This implies that the QPM value is equal to 0 and the QFM value is raised.

QoS metric parameters' value (jitter, late, performer, and packet loss) produced for the applications, can help to fill in Table 3.7, which contributes to the classification of IEEE technologies for each network architecture.

Table 3. 7 IEEE technologies calculation and rank order list for one project

Technology	**Application (VoIP, VC, HTTP, FTP, Email)**				**AFM**	**Technology Rank order**
	Jitter	**Delay**	**Throughput**	**Packet Loss**		
802.11	QFM_J	QFM_D	QFM_{TH}	QFM_{PL}	$\boldsymbol{AFM_{11}}$	Technology1
802.11a	QFM_J	QFM_D	QFM_{TH}	QFM_{PL}	$\boldsymbol{AFM_{11a}}$	Technology2
802.11b	QFM_J	QFM_D	QFM_{TH}	QFM_{PL}	$\boldsymbol{AFM_{11b}}$	Technology3
802.11g	QFM_J	QFM_D	QFM_{TH}	QFM_{PL}	$\boldsymbol{AFM_{11g}}$	Technology4
802.11e	QFM_J	QFM_D	QFM_{TH}	QFM_{PL}	$\boldsymbol{AFM_{11e}}$	Technology5

The scenarios' calculations for different application mixes will be done as explained in Table 3.8. The aggregation of all AFMs for each technology gives a Scenario Fitness Metric (SFM) for that technology. SFM will be used for ranking IEEE technologies and will later contribute to the definition of the optimum network architecture.

Technology / Application		802.11		802.11b		802.11a		802.11g		802.11e		802.11n	
Application 1	**QoS P1**	QFM		QFM		QFM		QFM		QFM		QFM	
	QoS P2	QFM	QFM	QFM	QFM	QFM	QFM	QFM	QFM	QFM	QFM	QFM	QFM
	QoS P3	QFM		QFM		QFM		QFM		QFM		QFM	
	QoS P4	AFM		AFM		AFM		AFM		AFM		AFM	
Application 2	**QoS P1**	QFM		QFM		QFM		QFM		QFM		QFM	
	QoS P2	QFM		QFM		QFM		QFM		QFM		QFM	
	QoS P3	QFM	QFM	QFM	QFM	QFM	QFM	QFM	QFM	QFM	QFM	QFM	QFM
	QoS P4	AFM		AFM		AFM		AFM		AFM		AFM	
Application 3	**QoS P1**	QFM		QFM		QFM		QFM		QFM		QFM	
	QoS P2	QFM		QFM		QFM		QFM		QFM		QFM	
	QoS P3	QFM	QFM	QFM	QFM	QFM	QFM	QFM	QFM	QFM	QFM	QFM	QFM
	QoS P4	AFM		AFM		AFM		AFM		AFM		AFM	
SFM		**SFM**		**SFM**		**SFM**		**SFM**		**SFM**		**SFM**	
Rank		Technology1		Technology2		Technology3		Technology4		Technology5		Technology6	

Table 3. 8 Scenario Calculations for Application Mixes

Apart from a packet loss parameter, all QoS parameters are computed in the same way in all applications as stated above. A Boolean value (0.0 or 1.0) corresponding to acceptance or rejection of the parameter packet loss is used to generate the performance of the OPNET Modeler. This study, however, involves the packet loss' value as a numerical aspect. Application packet loss rate ω_i of a node i is the ratio of dropped voice packet ki to total voice packets ρ_i multiplied by 100%, as demonstrated by Eq. (3.5) (Mohd Ali, Dhimish, & Glover, 2020); (Mohd Ali, Dhimish, & Glover, 2020):

$$\omega_i = (ki/\rho_i) \times 100\% \tag{3.5}$$

In the present analysis, two methods are developed to measure each application's percentage of packet loss: one with Excel Office software and the other with MATLAB to program it. Either method can be related to the OPNET Modeler directly for a given application to produce a particular packet loss percentage. More information will be given on the MATLAB code and algorithm (see section 4.2).

Both methods are based on getting the traffic received/sent rate from the OPNET Modeler to produce the CDF distribution for packet loss QoS parameter. Figure 3.36 explains the CDF distribution of the packet loss parameter for project BSS_20_40VOIP_R after applying the MATLAB code. In Table 3.5, as the acceptable packet loss parameter threshold is 5% for the VoIP application, the QPM for this QoS parameter will be 1. Over the same QoS parameter, as indicated in Table 3.6, the coefficient of importance is Low (L=0.1), so that QFM equals 1 weighted by 0.1, which gives 0.1.

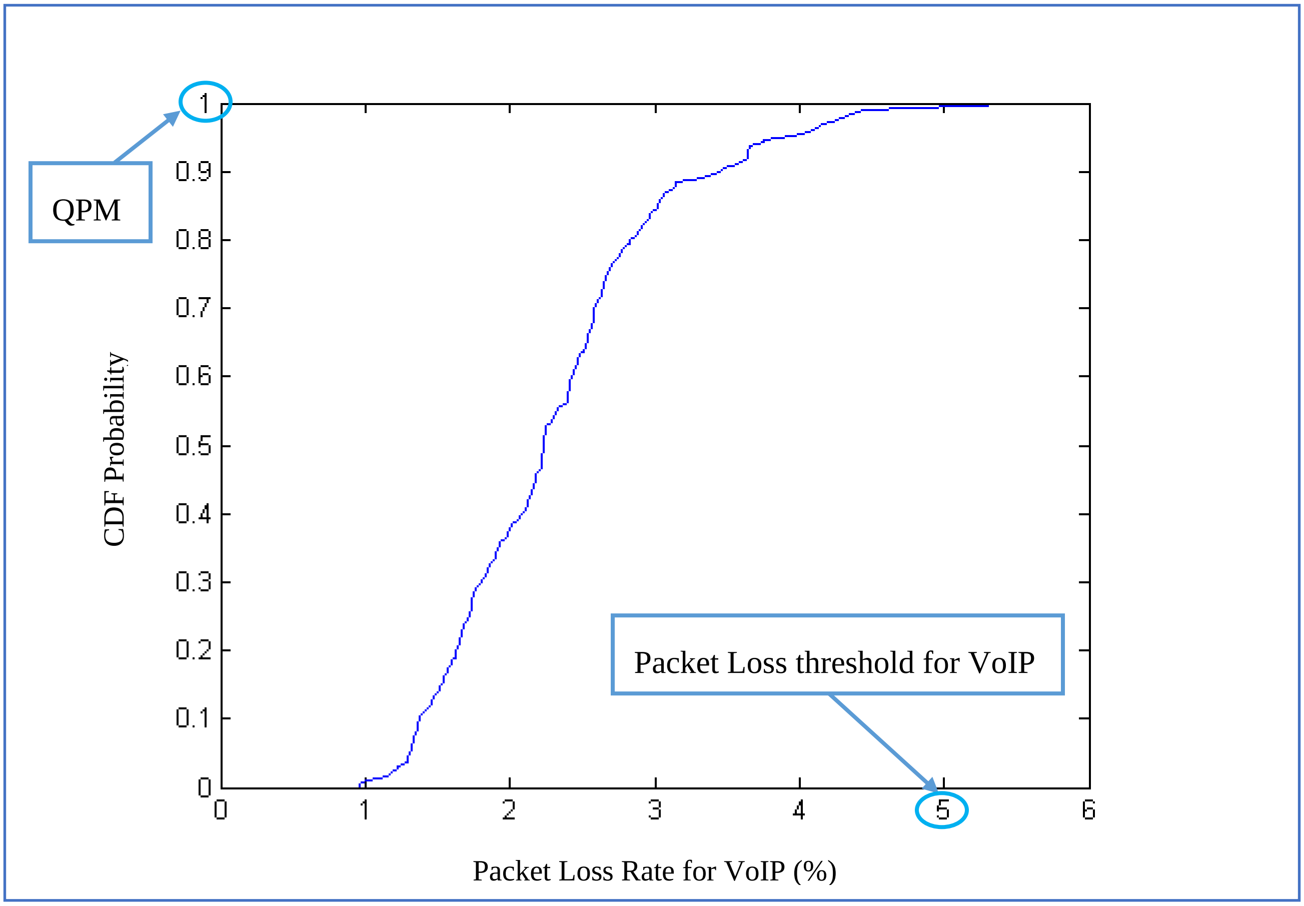


Figure 3. 36 CDF distribution of Packet Loss

All QFM values are defined at this point to make the calculation of the AFM clear. For the scenarios that are configured with one application (stand-alone application), all the calculations are done and Table 3.7 is completed. The scenarios that are configured with different application mixes for the aggregation of all AFMs for each application for each WLAN technology will be done as explained in Table 3.8. Once all the values of AFMs and SFM are done, the rank order of all technologies should be implemented and go directly to discussing and analysing these results.

3.10 Summary

This chapter describes the methodology used for ranking the existing WLAN 802.11 specifications for both stand-alone and mixed network applications. For each application, the coefficient of importance shall be defined for each statistic. The algorithmic approach provides the ability to decide the IBSS (Ad-hoc), BSS, or ESS network topology provides the best overall performance to be applied in real practice. The following aspects will be covered and clarified in this chapter:

network setup, parameters and simulation scenarios, performance metrics and flow charts. To independently select an appropriate wireless protocol based on user requirements, we built a comprehensive set of system simulations. Invent a coefficient of significance for each of the parameters of QoS for each application. In addition, there have been more than 8000 scenarios, including five applications (VoIP, VC, HTTP, FTP, E-mail) configured as stand-alone and mixed services, as well as six IEEE (11, 11a, 11b, 11g, 11e, 11n) supported by OPNET academic licenses, three network configurations (BSS, ESS, IBSS), in the meantime, all scenarios run in all possible spatial distributions (circular, random, IBSS). All of these scenarios have been applied to five groups of nodes.

The three main approaches are modelling, simulation, and experimentation in WLAN performance assessment. When selecting the appropriate methodology for a particular issue, it is very evident that there are essential settlements that are truly crucial to each of them. The main objective, as well as the strategic objectives that need to be achieved, is to improve the main performance method. Therefore, we address the three trade-offs of every approach instead of examining the methods separately.

CHAPTER 4 IMPLEMENTATION

4.1 Introduction

The purpose of this study is to create several scenarios to rank the current IEEE 802.11 standards for stand-alone and mixed applications by inventing a coefficient of importance for each application statistics (ICP). The objective here is to explore which standard leads to better overall results for both types of application, stand-alone and mixed applications, with specific environmental circumstances, such as number of nodes, physical layer technologies, network applications and network configurations.

At the same time, the aim is to establish a structured approach that gives the opportunity to determine the Ad-hoc, BSS or ESS network configuration that provides the best overall performance and should be applied.

4.1.1 The Key Features of Choice for Both Best-Effort and Real-Time Applications

Application definition attribute includes a number of predetermined applications that will be configured according to user requirements. Among those predefined applications like VoIP, VC, FTP, Email and HTTP. Here, we considered three best-effort services (FTP, Email, HTTP) and two real-time services (VoIP and VC). The key attributes that explain the importance of these services and its feature definitions that explains their use in the simulation model scenarios.

- Exchange electronic mail to just about every Internet user anywhere around the world. A service that is much older than the World Wide Web and has captured clients' interest is a digitalized way of transmitting information (text, data, or pictures) over the internet from one person to another or from many people simultaneously. In 1996, more E-mails were sent than postal mail mainly thanks to the rapid growth of the number of web users and the rising speed of communication.

Some of the essential email attributes are:

i. Immediate communications.
ii. Affordable and widely available, internet connections are only needed.
iii. Gmail, Microsoft Outlook, and AOL mail are some of the most common email providers that are freely accessible to any internet user.

- One of the oldest internet usages was to transfer files between computers, long before browsing the web emerged back into the picture. FTP allows remote computer documents to be accessed and allows types of files to be transmitted between local and remote computers. FTP runs over TCP, which delivers connection-oriented transmission. The advantage of TCP is that the transmission is much more reliable as it uses recognition packets to ensure delivery. FTP comes in the form of a client-server network infrastructure that utilizes various client-server controls and commands. You need an FTP client if you want to upload a file from your computer to a remote server.

FTP's purpose:

i. It allows data files, folders (directories), and applications to be exchanged.
ii. It allows us to efficiently and effectively share information.
iii. It is quicker than other protocols such as HTTP or POP, so it would be a favoured file sharing technique. With ease, it can send out big documents.

- The World Wide Web (WWW) is one of the most popular services on the internet. World Wide means widespread distribution, and the Web means network computing. The scope of material on WWW servers is increasingly rising. The language used to write web pages is HTML (Hypertext Markup Language). HTTP is the protocol that web browsers and web servers are using to interact over the Internet with each other. It is an application-level protocol since it resides in the protocol stack at the top of the TCP layer.

In addition, internet web services, such as internet banking and online shopping, are continuously growing. There is an increasing number of seats provided by internet services through web shopping so that anything can be purchased using online shopping and specialized banking services to pay so that ordered products came to the house without the consumer having to visit the stores. Each of these demonstrates the essence and importance of this web application services in today's world modern activities.

On the other hand, a growing number of newspapers and television stations have recently posted their content on their websites. Increased communication speed and the growth of Internet web services have made it possible for end-users to increase access and use these services. This leads society to rely effectively on the reliability of its Internet network and on a variety of online services that can be provided.

- Real-time applications (VoIP and VC) provide its services through online audio communication or video conferencing between a number of people using purpose-built computer programs and equipment that will enable them to participate in a live conversation. Such a service is based on free software support that makes free calls to anybody anywhere in the world who has program support installed on their computers. There is an exponentially increased quality of connectivity due to high-speed Internet access. It should be noted that this doesn't include contact between traditional landline phones but between the two user accounts registered with the application service, such as Skype or Zoom. In their accounts, the user can later change the details as necessary.

  VoIP reduces costs for companies and businesses because compared to the traditional telephone system, phone calls over the internet are much lower in price. Many businesses tend to use more than one tool on a regular basis when it comes to handling company communications: a landline phone and a phone or video conferencing services. Although this strategy works for certain companies, there is obviously a much better approach that costs less and provides more features and facilities: VoIP and VC application services.

4.2 Stand-alone Scenarios Description

This is a description of how to use the system's algorithms with two stand-alone scenarios examples:

Receiving a request from an organization for installing two networking labs, each one has its own specifications as follow:

First Lab:

1. Ten workstations with minimum specifications that can work with hardware and software installation.
2. A central server that will handle resource sharing to client workstations.
3. Networking devices that will allow users to install, connect, configure and test the network to any other end device.
4. Printing capability for report generating purposes.
5. Deploying VoIP application in all workstations.

Second Lab:

1. Five workstations with minimum specifications that can work with hardware and software installation.
2. Servers that will handle resource sharing to client workstations.
3. Networking devices that will allow users to install, connect, configure and test the network to any other end device.
4. Printing capability for report generating purposes.
5. Deploying Video Conferencing application in all workstations.

The task is to design a network plan that contains:

A. A specified Network Configuration (IBSS, BSS, ESS) that provides the best performance usage.
B. A floor plan that includes the location for proposed access points for physical and mobile connectivity.
C. Spatial distribution of workstations (Uniform, Random, Circle).
D. All hardware components required, e.g., NICs, routers, hubs, wireless routers, wireless access points, and PCs/Laptops.
E. Identified IEEE technology (802.11, 11a, 11b, 11g, and 11e) and data rate that should be used.

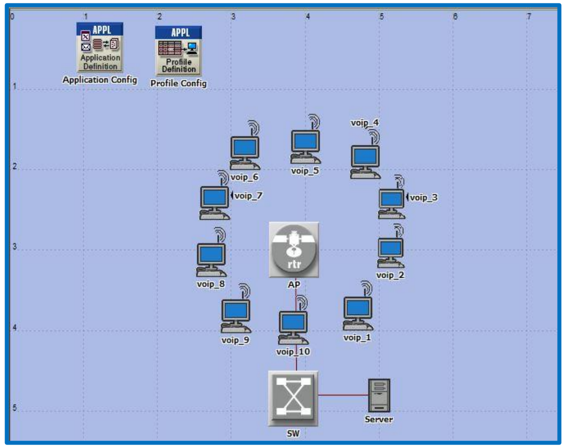
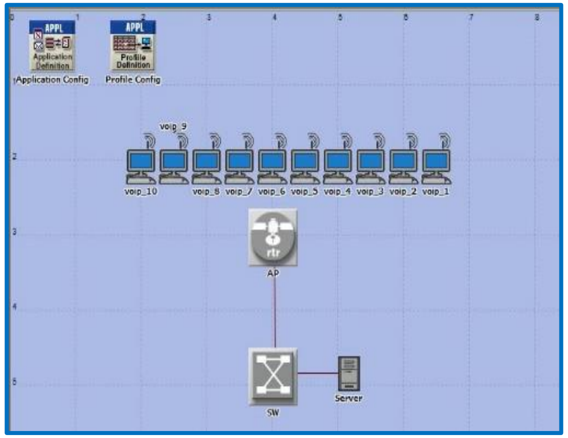
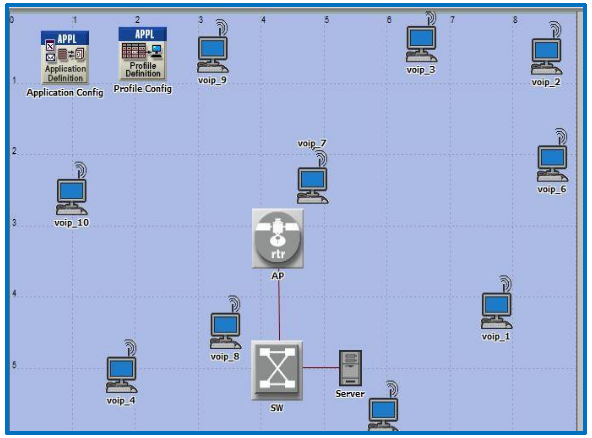
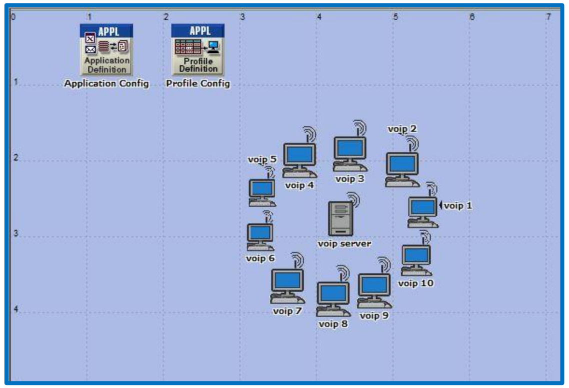
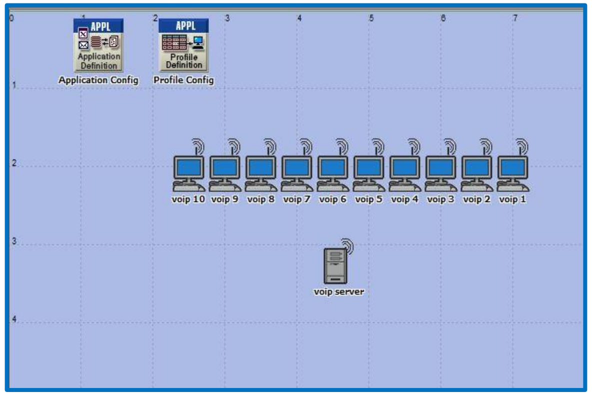
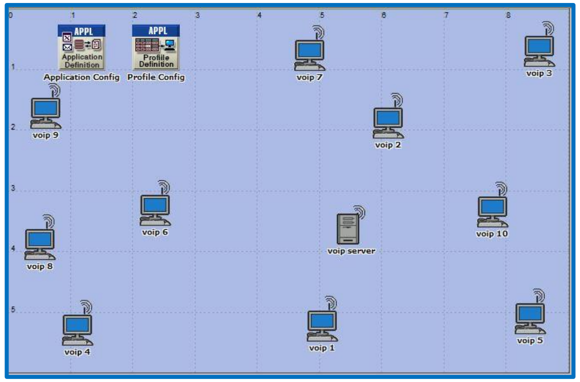
4.2.1 VoIP Example

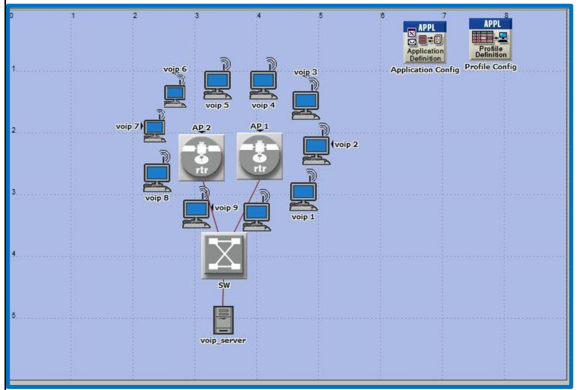
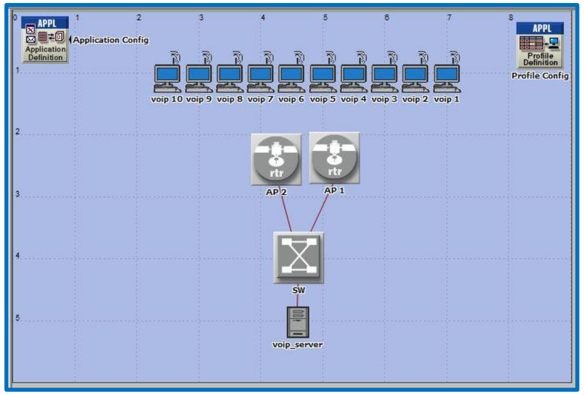
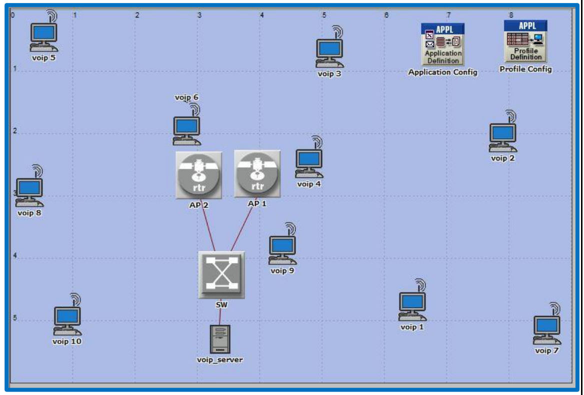
This research work and its system's algorithm should be able to satisfy all the organization's requirements for installing and implementing those two labs. Using OPNET Modeler all the scenarios have been built, configured, run, and analysed.

For the first lab, the scenarios are built as follows:

1. Design the network with 10 workstations.
2. Deploy VoIP application in all 10 workstations.
3. Choose the QoS statistics, VoIP statistics (Mohd Ali, Dhimish, & Mather, 2019); (Mohd Ali, Dhimish, Alsmadi, & Mather, 2020):
    A. Packet End-to-End delay (sec).
    B. Jitter (sec).
    C. Throughput (bit/sec).
    D. Traffic Sent (packet/sec) and Traffic Received (packet/sec).
4. Configure these 10 workstations in three main network configurations (IBSS, BSS, ESS) across three spatial distributions (Circular, Uniform, Random) as shown in Table 4.1.
5. The 10 workstations across three spatial distributions will be configured with the five IEEE technologies (802.11, 11a, 11b, 11g, and 11e).

Table 4. 1 Design of the three Network Configurations (BSS, IBSS, ESS) across three Spatial Distributions (C, U, R) for VoIP

SD / NC	Circular	Uniform	Random
BSS			
IBSS			

ESS			

6. Run the scenarios and view the results.
7. Cumulative Distribution (CDF) distribution should be produced for the following QoS statistics (Mohd Ali, Dhimish, & Mather, 2019); (Mohd Ali, Dhimish, Alsmadi, & Mather, 2020):
   - Packet End-to-End delay (sec).
   - Jitter (sec).
   - Throughput (bit/sec).
   - Packet Loss (%).
8. The system algorithms and calculations will be applied using Tables 4.2 and 4.3.

Table 4. 2 QoS Application Importance

QoS / Application	**Delay (sec)**	**Jitter (sec)**	**Throughput (kbps)**	**Packet Loss Rate (%)**
VoIP	H	H	M	L

Table 4. 3 Threshold for each Application

QoS / Application	**Delay (sec)**	**Jitter (sec)**	**Throughput (kbps)**	**Packet Loss Rate (%)**
VoIP	0.17	0.04	45	5

First of all, it is important to define the QPM which is the value generated in the CDF for VoIP, implementing per each performance criterion the required threshold (QoS parameter).

The QFM value generated using QPM weighting (as defined by the importance) for each QoS parameter (H=1, M=0.5, L=0.1, and VL=0), will then be considered (Mohd Ali, Dhimish, & Mather, 2019); (Mohd Ali, Dhimish, Alsmadi, & Mather, 2020). The final step will be to measure the AFM for each WLAN technology, which is the sum of all VoIP QFMs. The following example explains the algorithm and its calculations. At the beginning three different projects should be built for each of the three main network configurations regarding the workstations' spatial distributions (circular, uniform, random) as follow:

A. BSS projects: (BSS_10_100VOIP_C, BSS_10_100VOIP_U, BSS_10_100VOIP_R).
B. IBSS projects: (IBSS_10_100VOIP_C, IBSS_10_100VOIP_U, IBSS_10_100VOIP_R).
C. ESS projects: (ESS_10_100VOIP_C, ESS_10_100VOIP_U, ESS_10_100VOIP_R).

Furthermore, five scenarios are going to be built in each project regarding the five WLAN physical layer technologies (802.11, 11a, 11b, 11g, and 11e).

Starting with the first case study; BSS network configuration. Five scenarios are going to be built for the five WLAN technologies, across three spatial distributions. So, in each spatial distribution, there are five different scenarios, each of which sets up with 10 workstations configured with each of the WLAN technologies. As a result, in this network configuration there are three main projects BSS_10_100VOIP_C, BSS_10_100VOIP_U, and BSS_10_100VOIP_R, each project is configured with five scenarios regarding the five WLAN standards.

The system of this work and its algorithms are going to be explained by discussing one of these projects. Taking the circular one that is configured with the scenario of the 802.11e technology. The project name is: **BSS_10_100VOIP_C**, the physical layer technology is: 802.11e, and the network configuration is: Basic Service Set. All the 10 workstations configured with 802.11e technology are organized in a circular way and include one access point as appears in Figure 4.1.

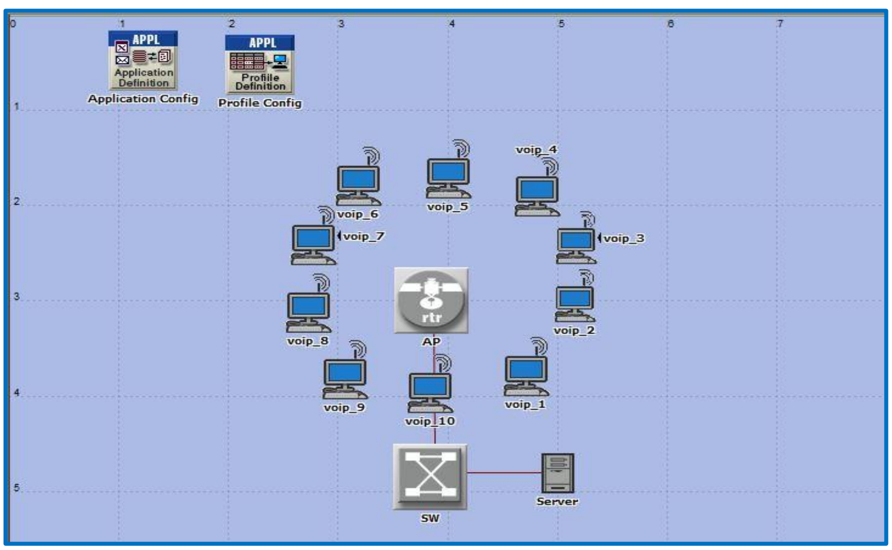


Figure 4. 1 Circular Distribution of 10 workstations and one AP

The effects of each QoS parameter will be assessed in the same way after running the five scenarios for 20 minutes each. The following calculations will be on the scenario 802.11e:

A. Jitter:

The VoIP threshold value for Jitter is 0.04 sec and QoS Application Importance is High as is shown in both Tables 4.2 and 4.3. According to the result in Figure 4.2, QPM is 1. The importance coefficient for Jitter is High (H=1), so the QFM is equal to 1 weighted by 1; that produces 1.

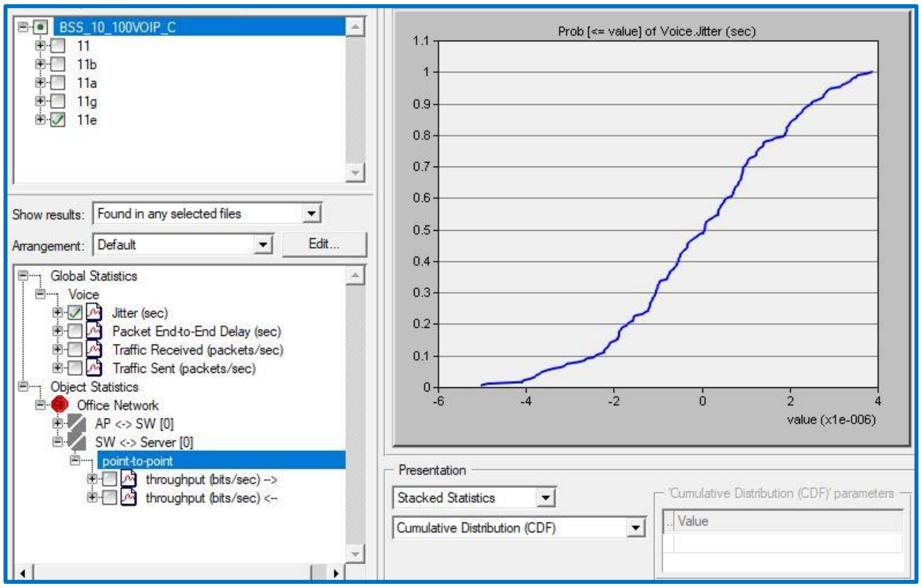


Figure 4. 2 Jitter result of BSS_10_100VOIP_C

B. Delay:

The VoIP threshold value for the delay is 0.17 sec and QoS Application Importance is High as is shown in both Tables 4.2 and 4.3. According to the result in Figure 4.3, QPM is 1. The importance coefficient for the delay is High (H=1), so the QFM is equal to 1 weighted by 1; that produces 1.

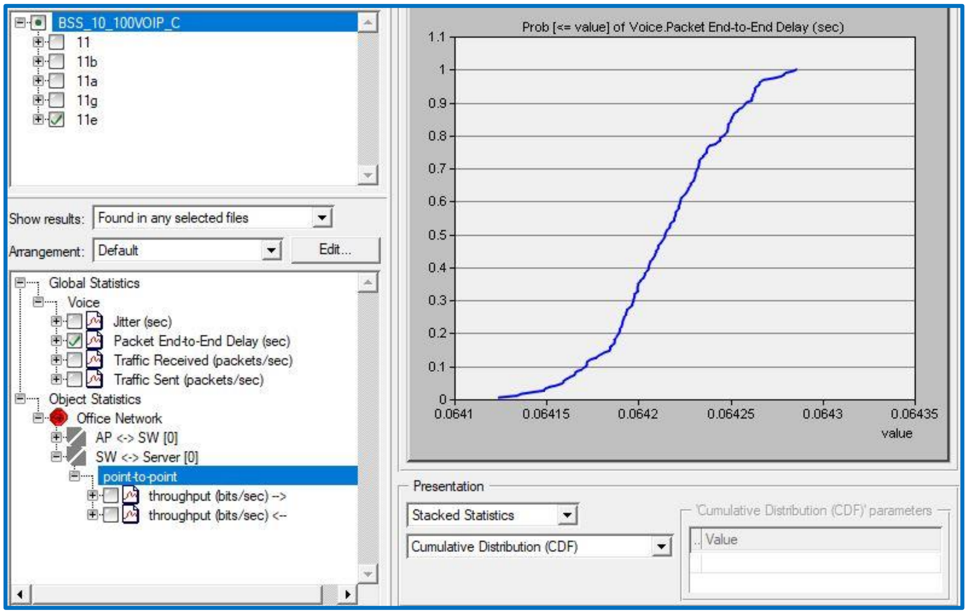


Figure 4. 3 Delay result of BSS_10_100VOIP_C

C. Inbound Throughput:

The VoIP threshold value for throughput is 45 kbps and QoS Application Importance is Medium as is shown in both Tables 4.2 and 4.3. According to the result in Figure 4.4, QPM is 0.052. The importance coefficient for throughput is Medium (M=0.5), so the QFM is equal to 0.052 weighted by 0.5; that produces 0.0026.

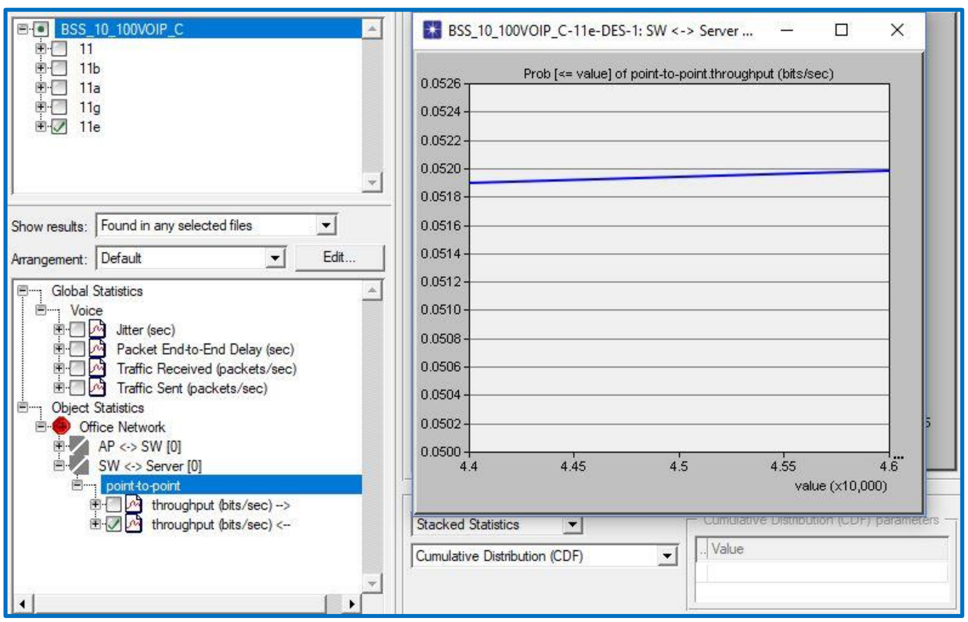


Figure 4. 4 Inbound results of BSS_10_100VOIP_C

D. Outbound Throughput:

The VoIP threshold value for throughput is 45 kbps and QoS Application Importance is Medium as is shown in both Tables 4.2 and 4.3. According to the result in Figure 4.5, QPM is 0.052. The importance coefficient for throughput is Medium (M=0.5), so the QFM is equal to 0.052 weighted by 0.5; that produces 0.0026.

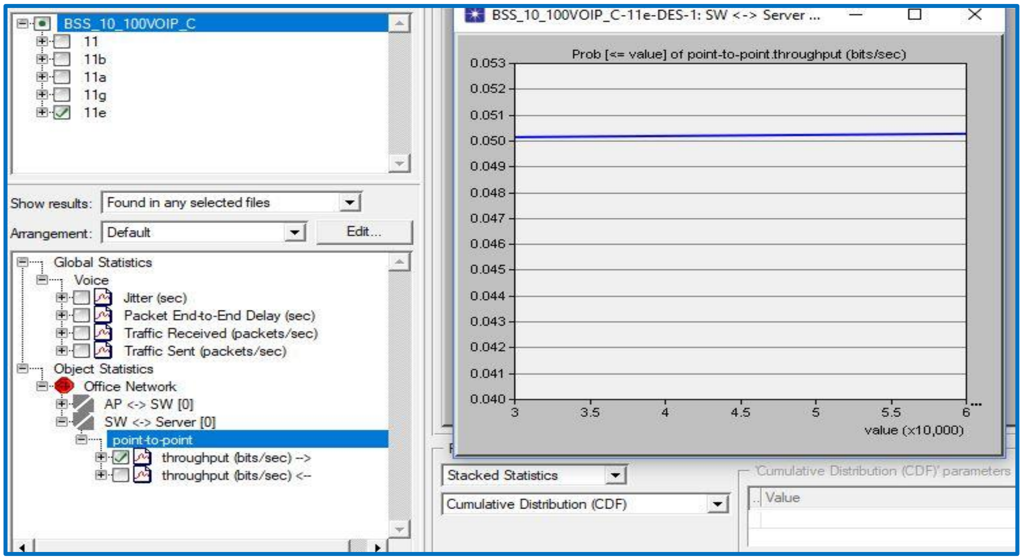


Figure 4. 5 Outbound result of BSS_10_100VOIP_C

QoS statistics calculations for other WLAN technologies (11, 11a, 11b, and 11g) will be produced using the same method. The results of all QoS parameters except packet loss for all technologies are shown in Table 4.4.

Table 4. 4 Jitter, Delay and Throughput Calculation for BSS_10_100VOIP_C

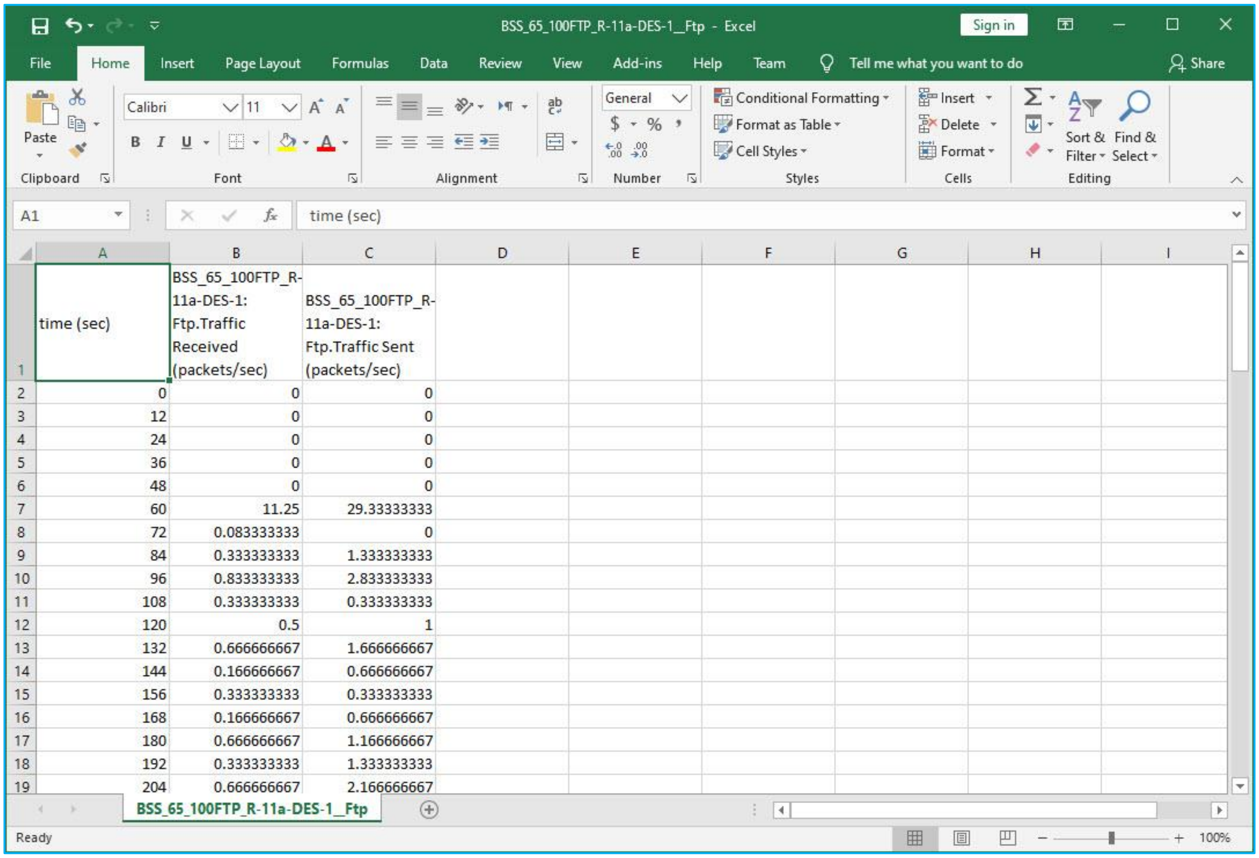
Application / Technology	VOIP							The rank order for this scenario
	J	**D**	**TH →**	**TH ←**	**PL**	**AFM**		
802.11	1	0	0.0026	0.0026				
802.11b	1	0	0.0026	0.0026				
802.11a	1	1	0.0026	0.0026				
802.11g	1	1	0.0026	0.0026				
802.11e	1	1	0.0026	0.0026				

To complete this table, as indicated in the previous chapter (see section 3.9), two methods are used to calculate the percentage of packet loss for each application: one using Excel Office software and the other using MATLAB software to program the code. The MATLAB code, used to measure a percentage of packet loss, is shown in Figure 4.6.

```
filename='C:\Users\Germany\Desktop\U\BSS_10_100VOIP_C-11e-DES-1__Voice.xlsx';

A = xlsread(filename,'A:A');

B = xlsread(filename,'B:B');

C = xlsread(filename,'C:C');

for i=1:1:199;

nr(i)=(B(i+1)+B(i))./2. X (A(i+1)-A(i));

ns(i)=(C(i+1)+C(i))./2. X (A(i+1)-A(i));

pl(i)=(ns(i)-nr(i))./(ns(i)) X 100;

end

[f,x1] = ecdf(pl)

plot(x1,f)
```

Figure 4. 6 MATLAB Code for Packet Loss Calculations

Before using this code, OPNET produces the result of traffic sent/received rate and provides the ability to export and save them as a spreadsheet file as is shown in Figure 4.7.



time (sec)	BSS_65_100FTP_R-11a-DES-1: Ftp.Traffic Received (packets/sec)	BSS_65_100FTP_R-11a-DES-1: Ftp.Traffic Sent (packets/sec)
0	0	0
12	0	0
24	0	0
36	0	0
48	0	0
60	11.25	29.33333333
72	0.083333333	0
84	0.333333333	1.333333333
96	0.833333333	2.833333333
108	0.333333333	0.333333333
120	0.5	1
132	0.666666667	1.666666667
144	0.166666667	0.666666667
156	0.333333333	0.333333333
168	0.166666667	0.666666667
180	0.666666667	1.166666667
192	0.333333333	1.333333333
204	0.666666667	2.166666667

Figure 4. 7 OPNET's Spreadsheet for Traffic Sent/Received Rate

After saving the spreadsheet file, the MATLAB code will be applied. In the beginning, the name of the spreadsheet including its location is given to the code. The code reads all the values in all three columns; column A which represents simulation time in seconds, column B which represents traffic received rate in packets/sec, and column C which represents the traffic sent rate in packets/sec. Two-line codes, below, reflect the packet loss principle, which the overall number of transmitted packets minus numbers of arrived packets at the destination divided by the whole transmitted packets, then multiplying the quantity by 100 per cent, thus allowing the values in both columns B and C to be integrated to generate the total number of packets sent and received (Mohd Ali, Dhimish, & Mather, 2019); (Mohd Ali, Dhimish, Alsmadi, & Mather, 2020).

$$nr(i) = \left(\frac{B(i+1)+B(i)}{2} \times (A(i+1) - A(i))\right) \tag{4.1}$$

$$ns(i) = \left(\frac{C(i+1)+C(i)}{2} \times (A(i+1) - A(i))\right) \quad (4.2)$$

then, the exact packet loss ratio is produced using the following code line equation:

$$pl(i) = \left(\frac{ns(i)-nr(i)}{ns(i)} \times 100\right) \quad (4.3)$$

This packet ratio value should be presented as a CDF diagram as is shown in Figure 4.8, to give the ability to identify the values of QPM, QFM, AFM and SFM.

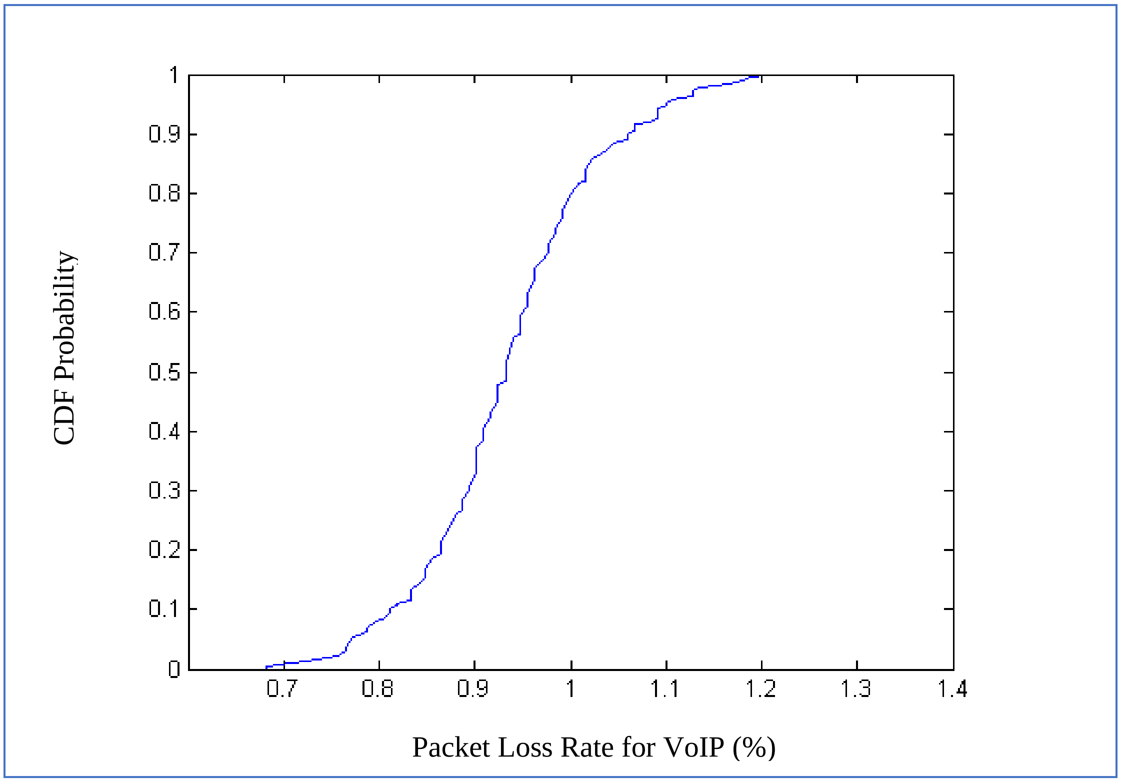


Figure 4. 8 CDF distribution of Packet loss

The VoIP threshold value for packet loss is 5% and QoS Application Importance is Low as is shown in both Tables 4.2 and 4.3. According to the result in Figure 4.8, QPM is 1. The importance coefficient for packet loss is Low (L=1), so the QFM is equal to 1 weighted by 0.1; that produces 0.1. Using the same method, the packet loss values for other WLAN technologies (11, 11a, 11b, and 11g) will be calculated. Table 4.5 represents the results of all QoS parameters (QFMs) including packet loss.

Table 4. 5 QFMs for Project BSS_10_100VOIP_C

Application / Technology	VOIP							The rank order for this scenario
	J	D	TH →	TH ←	PL	AFM		
802.11	1	0	0.0026	0.0026	0	**AFM**		
802.11b	1	0	0.0026	0.0026	0	**AFM**		
802.11a	1	1	0.0026	0.0026	0.1	**AFM**		
802.11g	1	1	0.0026	0.0026	0.1	**AFM**		
802.11e	1	1	0.0026	0.0026	0.1	**AFM**		

The AFMs for all technologies will be calculated through aggregates of the values of QFMs for each WLAN standard technology, which produces Table 4.6 as follows:

Table 4. 6 AFMs and Rank order list for Project BSS_10_100VOIP_C

Application / Technology	VOIP							The rank order for this scenario
	J	D	TH →	TH ←	PL	AFM		
802.11	1	0	0.0026	0.0026	0	**1.005**		**802.11a**
802.11b	1	0	0.0026	0.0026	0	**1.005**		**802.11g**
802.11a	1	1	0.0026	0.0026	0.1	**2.105**		**802.11e**
802.11g	1	1	0.0026	0.0026	0.1	**2.105**		**802.11**
802.11e	1	1	0.0026	0.0026	0.1	**2.105**		**802.11b**

The ranking list of these five technologies will be provided on the basis of WLAN AFM technologies, as shown in Table 4.6. The technologies 11a, 11g, and 11e produce the highest AFMs of 2.105 and then are highly recommended to be used in this project BSS_10_100VOIP_C.

The same procedure will be followed for the uniform and random distributions to rank order the five WLAN technologies. Table 4.7 shows the rank order list of all WLAN technologies in uniform distribution. While Table 4.8 shows the rank order list of all WLAN technologies in random distribution.

Table 4. 7 AFMs and Rank order list for Project BSS_10_100VOIP_U

Application / Technology	VOIP							The rank order for this scenario
	J	D	TH (→)	TH (←)	PL	AFM		
802.11	1	0	0.0026	0.0026	0	**1.005**		**802.11a**
802.11b	1	0	0.0026	0.0026	0	**1.005**		**802.11g**
802.11a	1	1	0.0026	0.0026	0.1	**2.105**		**802.11e**
802.11g	1	1	0.0026	0.0026	0.1	**2.105**		**802.11**
802.11e	1	1	0.0026	0.0026	0.1	**2.105**		**802.11b**

Table 4. 8 AFMs and Rank order list for Project BSS_10_100VOIP_R

Application / Technology	VOIP							The rank order for this scenario
	J	D	TH (→)	TH (←)	PL	AFM		
802.11	1	0	0.0026	0.0026	0	**1.005**		**802.11a**
802.11b	1	0	0.0026	0.0026	0	**1.005**		**802.11g**
802.11a	1	1	0.0026	0.0026	0.1	**2.105**		**802.11e**
802.11g	1	1	0.0026	0.0026	0.1	**2.105**		**802.11**
802.11e	1	1	0.0026	0.0026	0.1	**2.105**		**802.11b**

System algorithms and calculations will be applied for the other two network configurations (BSS and ESS), to determine the best performing WLAN technology (or technologies) across these two network configurations; and also, to produce all the values of QPMs, QFMs, and AFMs for all

QoS parameters for all five technologies regarding VoIP application in IBSS and ESS across the three spatial distributions.

Second case study: IBSS network configuration. Three main projects IBSS_10_100VOIP_C, IBSS_10_100VOIP_U, and IBSS_10_100VOIP_R are going to be established across three spatial distributions. Each one of them will be configured with five scenarios regarding the five WLAN standards.

The same calculation procedure that was applied in the first case study (BSS network configuration) to determine all the values of QPMs, QFMs and AFMs for all five WLAN standards will be applied in this case also. Table 4.9 shows the rank order of WLAN technologies for the three spatial distributions.

Table 4. 9 AFMs and Rank order List for Project IBSS_10_100VOIP_C, U, R

Application / Technology	VOIP						The rank order for this scenario
	J	**D**	**TH**	**PL**	**AFM**		
802.11	1	0	0.0026	0	**1.002**		**802.11a**
802.11b	1	0	0.0026	0	**1.002**		**802.11g**
802.11a	1	1	0.0026	0.1	**2.102**		**802.11e**
802.11g	1	1	0.0026	0.1	**2.102**		**802.11**
802.11e	1	1	0.0026	0.1	**2.102**		**802.11b**

Third case study (ESS network configuration). Three main projects ESS_10_100VOIP_C, ESS_10_100VOIP_U, and ESS_10_100VOIP_R are going to be established across three spatial distributions. Each one of them will be configured with five scenarios regarding the five WLAN standards.

The same calculation procedure that has been applied in the above two case studies (BSS and IBSS network configurations) to determine all the values of QPMs, QFMs and AFMs for all five WLAN standards will be applied in this case also.

Table 4.10 shows the rank order of WLAN technologies for both the circular and random spatial distributions.

Table 4. 10 AFMs and Rank order list for both Projects ESS_10_100VOIP_C, R

Application / Technolog	VOIP							The rank order for this scenario
	J	**D**	**TH** (→)	**TH** (←)	**PL**	**AFM**		
802.11	1	0	0.0026	0.0026	0	**1.005**		**802.11a**
802.11b	1	0	0.0026	0.0026	0.08	**1.085**		**802.11g**
802.11a	1	1	0.0026	0.0026	0.10	**2.105**		**802.11e**
802.11g	1	1	0.0026	0.0026	0.10	**2.105**		**802.11b**
802.11e	1	1	0.0026	0.0026	0.10	**2.105**		**802.11**

The rank order of the WLAN technologies for uniform distribution is explained in Table 4.11.

Table 4. 11 AFMs and Rank order List for Project ESS_10_100VOIP_U

Technology \ Application	VOIP							The rank order for this scenario
	J	D	TH (→)	TH (←)	PL	AFM		
802.11	1	0	0.0026	0.0026	0	**1.002**		**802.11a**
802.11b	1	0	0.0026	0.0026	0	**1.002**		**802.11g**
802.11a	1	1	0.0026	0.0026	0.10	**2.105**		**802.11e**
802.11g	1	1	0.0026	0.0026	0.10	**2.105**		**802.11**
802.11e	1	1	0.0026	0.0026	0.10	**2.105**		**802.11b**

The system now will be able to provide the organization with all the details that are required for installing the first networking lab. Table 4.12, summarizes the results of this example and provides the answers to the organization query:

Table 4. 12 Results for BSS, IBSS, and ESS with 100% VoIP for 10 workstations

Technology \ Application	BSS			IBSS			ESS		
	C	**U**	**R**	**C**	**U**	**R**	**C**	**U**	**R**
802.11	**1.005**	**1.005**	**1.005**	**1.002**	**1.002**	**1.002**	**1.005**	**1.005**	**1.005**
802.11b	**1.005**	**1.005**	**1.005**	**1.002**	**1.002**	**1.002**	**1.085**	**1.005**	**1.085**
802.11a	**2.105**	**2.105**	**2.105**	**2.102**	**2.102**	**2.102**	**2.105**	**2.105**	**2.105**
802.11g	**2.105**	**2.105**	**2.105**	**2.102**	**2.102**	**2.102**	**2.105**	**2.105**	**2.105**
802.11e	**2.105**	**2.105**	**2.105**	**2.102**	**2.102**	**2.102**	**2.105**	**2.105**	**2.105**

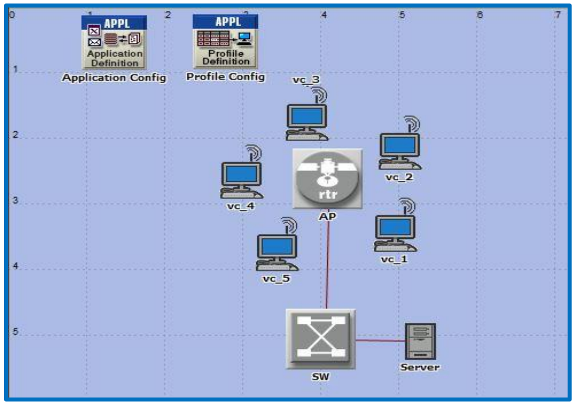
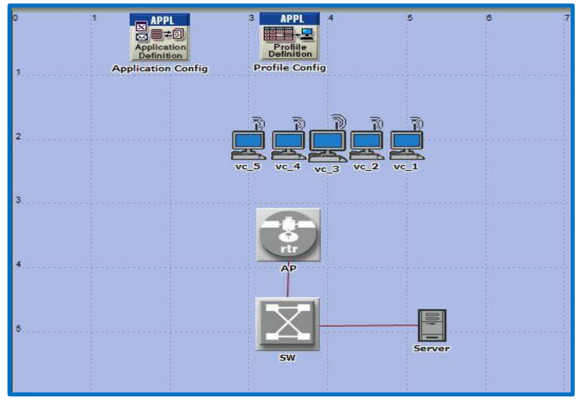
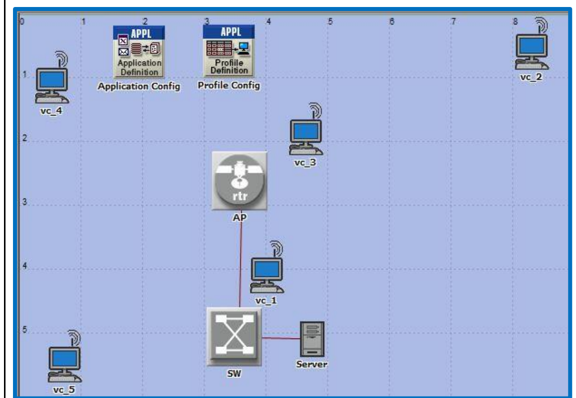
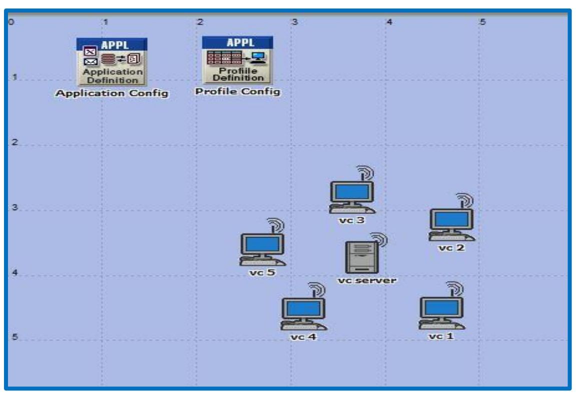
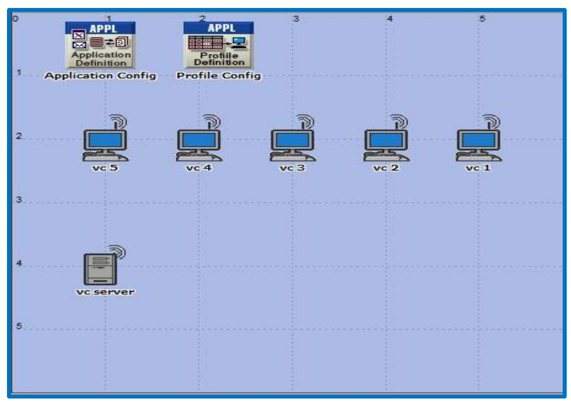
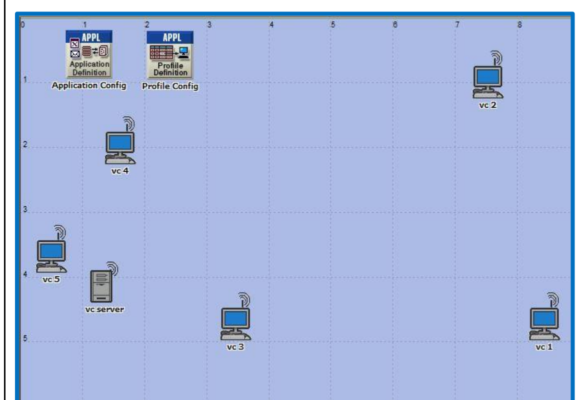
From Table 4.12, the organization has a number of options because there are three technologies (802.11a, 11g, and 11e) all performing, as long as they configure in both BSS and ESS network configuration across all three spatial distributions. Those technologies have the highest AFM results of 2.105. On the other hand, the ESS network configuration produces the best overall performance regarding all five technologies compared with the other two BSS and IBSS.

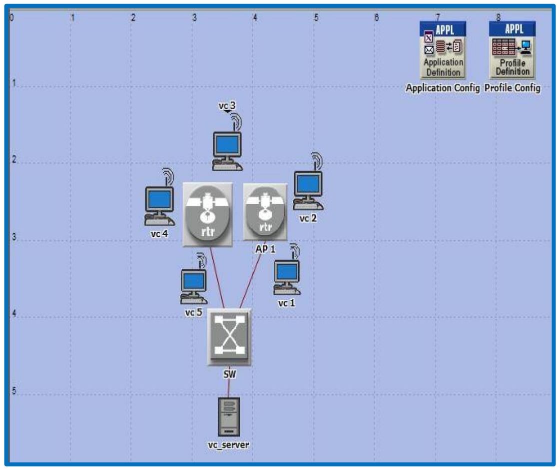
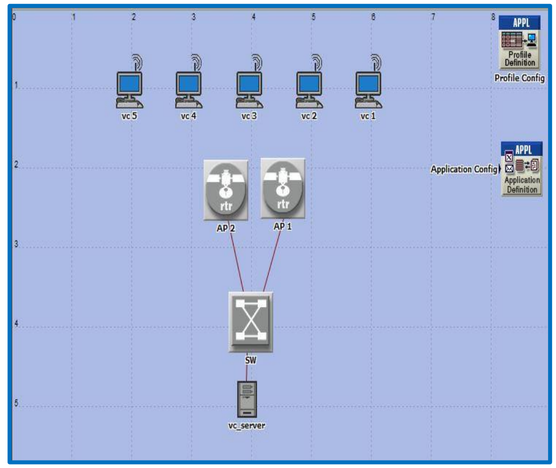
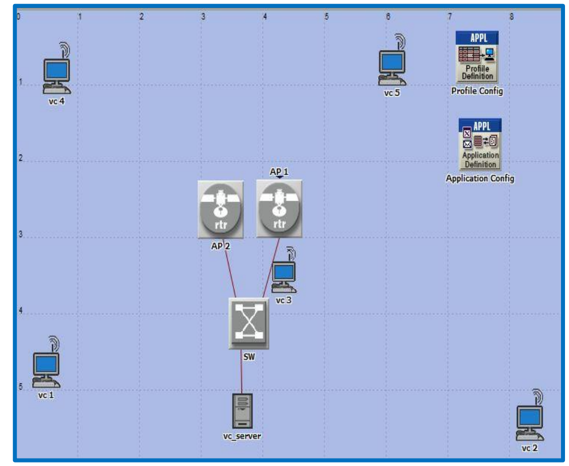
4.2.2 VC Example

For the second lab, the projects and scenarios are built as follow:

1. Design the network with 5 workstations.
2. Deploy Video Conferencing (VC) application in all 5 workstations.
3. Choose the QoS statistics, VC statistics (Mohd Ali, Dhimish, & Mather, 2019); (Mohd Ali, Dhimish, Alsmadi, & Mather, 2020):
   A. Packet End-to-End delay (sec).
   B. Packet Delay Variation (sec).
   C. Throughput (bit/sec).
   D. Traffic Sent (packet/sec) and Traffic Received (packet/sec).
4. Configure these 5 workstations in three main network configurations (IBSS, BSS, ESS) across three spatial distributions (Circular, Uniform, Random) as shown in Table 4.13.
5. The 5 workstations across three spatial distributions will be configured with the five Physical layer standard technologies (802.11, 11a, 11b, 11g, and 11e).

Table 4. 13 Design of the three Network Configurations (BSS, IBSS, ESS) across three Spatial Distributions (C, U, R) for VC

SD / NC	**Circular**	**Uniform**	**Random**
BSS			
IBSS			

ESS	Application Config Profile Config vc 3 vc 2 vc 4 AP 1 vc 5 vc 1 SW vc_server	Profile Config vc 5 vc 4 vc 3 vc 2 vc 1 Application Config AP 2 AP 1 SW vc_server	vc 4 vc 5 Profile Config Application Config AP 1 AP 2 vc 3 SW vc 1 vc_server vc 2

6. Run the scenarios and view the results.
7. Cumulative Distribution (CDF) distribution should be produced for the following QoS statistics (Mohd Ali, Dhimish, & Mather, 2019); (Mohd Ali, Dhimish, Alsmadi, & Mather, 2020):
   - Packet End-to-End delay(sec).
   - Packet Delay Variation (sec).
   - Throughput (bit/sec).
   - Packet Loss (%).
8. The system algorithms and calculations will be applied using Tables 4.14 and 4.15.

Table 4. 14 QoS Application Importance

QoS / Application	**Delay (sec)**	**Delay Variation (sec)**	**Throughput (kbps)**	**Packet Loss Rate (%)**
VC	H	H	H	M

Table 4. 15 Threshold for each Application

QoS / Application	**Delay (sec)**	**Delay Variation (sec)**	**Throughput (kbps)**	**Packet Loss Rate (%)**
VC	0.15	0.03	250	1

First of all, it is important to define the QPM, which is the value generated in the CDF for VC, applying the appropriate threshold for each performance criterion (QoS parameter).

The QFM value generated using QPM weighting (as defined by the importance) for each QoS parameter (H=1, M=0.5, L=0.1, and VL=0), will then be considered. The final step will be to measure the AFM for each WLAN technology, which is the sum of all VC QFMs. The following example explains the algorithm and its calculations. At the beginning three different projects should be built for each three main network configurations regarding the workstations' spatial distributions (circular, uniform, random) as follow:

A. BSS projects: (BSS_5_100VC_C, BSS_5_100VC_U, BSS_5_100VC_R).
B. IBSS projects: (IBSS_5_100VC_C, IBSS_5_100VC_U, IBSS_5_100VOC_R).
C. ESS projects: (ESS_5_100VC_C, ESS_5_100VC_U, ESS_5_100VC_R).

Furthermore, five scenarios need to be built in each project regarding the five WLAN physical layer technologies (802.11, 11a, 11b, 11g, and 11e). Starting with the first case study; IBSS network configuration. Five scenarios are to be built for the five WLAN technologies, across three spatial distributions. So, in each spatial distribution, there are five different scenarios each of which sets up with five workstations configured with each one of the WLAN technologies. As a result, in this network configuration, there are three main projects, IBSS_5_100VC_C, IBSS_5_100VC_U, and IBSS_5_100VCOIP_R; each project is configured with five scenarios regarding the five WLAN standards.

The system of this work and its algorithms are explained by discussing one of these projects. Taking the circular one that is configured with the scenario of the 802.11e technology, the project name is: **IBSS_5_100VC_R**, the physical layer technology is: 802.11e, and the network configuration is: Independent Basic Service Set. All five workstations are configured with 802.11e technology, organized in a circular way as appears in Figure 4.9.

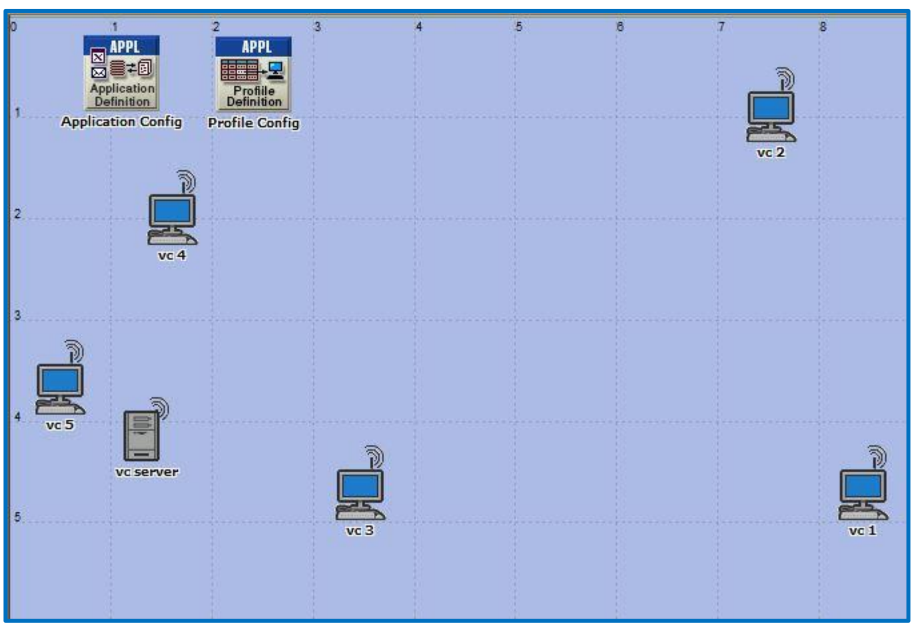


Figure 4. 9 Five Workstations Randomly distributed in IBSS Configuration

After a 20-minute run of every five scenarios, the effects of the QoS parameters will be examined. The following calculations will be made in scenario 802.11e:

A. Packet Delay Variation:

VC threshold value for delay variation is 0.03 sec and QoS Application Importance is High as is shown in both Tables 4.14 and 4.15. According to the result in Figure 4.10, QPM is 0.014. The importance coefficient for delay variation is High (H=1), so the QFM is equal to 0.014 weighted by 1; that produces 0.014.

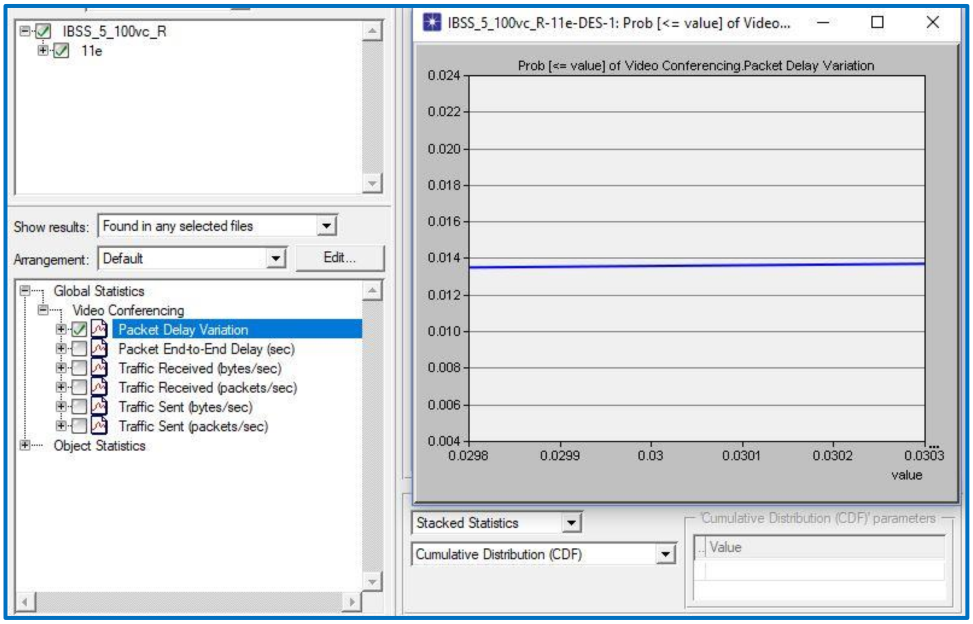


Figure 4. 10 Packet Delay Variation result of IBSS_5_100VC_R

A. Delay:

VC threshold value for the delay is 0.15 sec and QoS Application Importance is High as is shown in both Tables 4.14 and 4.15. According to the result in Figure 4.11, QPM is 0. The importance coefficient for the delay is High (H=1), so the QFM is equal to 0 weighted by 1; that produces 0.

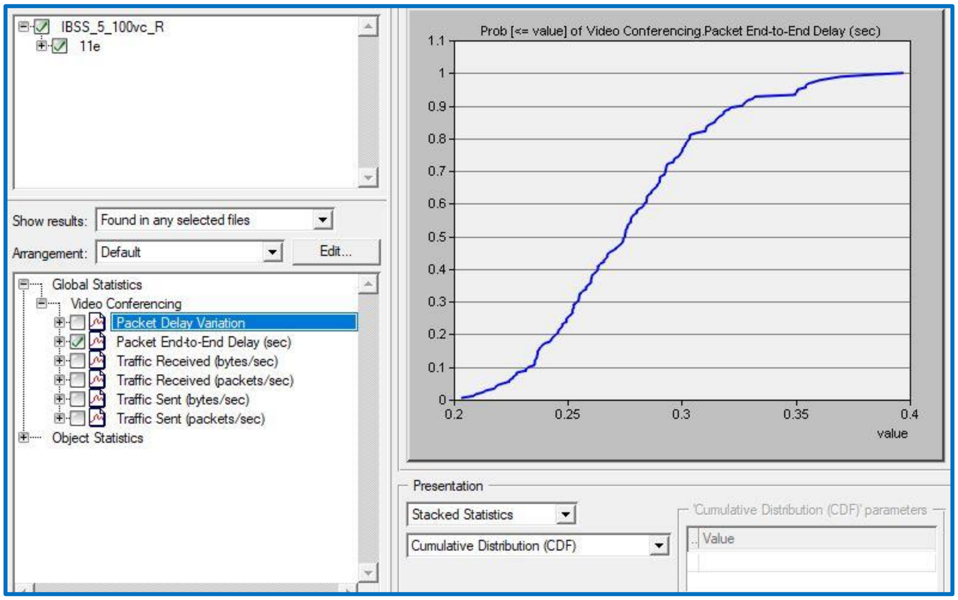


Figure 4. 11 Delay result of IBSS_5_100VC_R

B. Throughput:

VC threshold value for throughput is 250 kbps and QoS Application Importance is High as is shown in both Tables 4.14 and 4.15. According to the result in Figure 4.12, QPM is 0.1. The importance coefficient for throughput is High (H=1), so the QFM is equal to 0.1 weighted by 1; that produces 0.1.

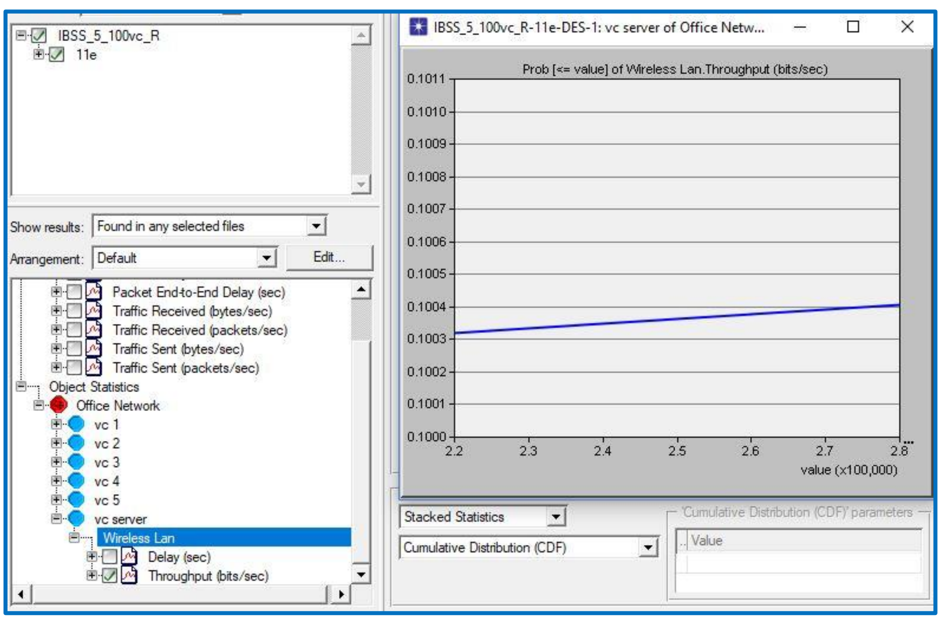


Figure 4. 12 Throughput result of IBSS_5_100VC_R

C. Packet Loss:

VC threshold value for packet loss is 1% and QoS application importance is Medium as is shown in both Tables 4.14 and 4.15. After applying the MATLAB code and drawing the result as shown in Figure 4.13, QPM is 0. The importance coefficient for packet loss is Medium (L=0.5), so the QFM is equal to 0 weighted by 0.5; that produces 0.5.

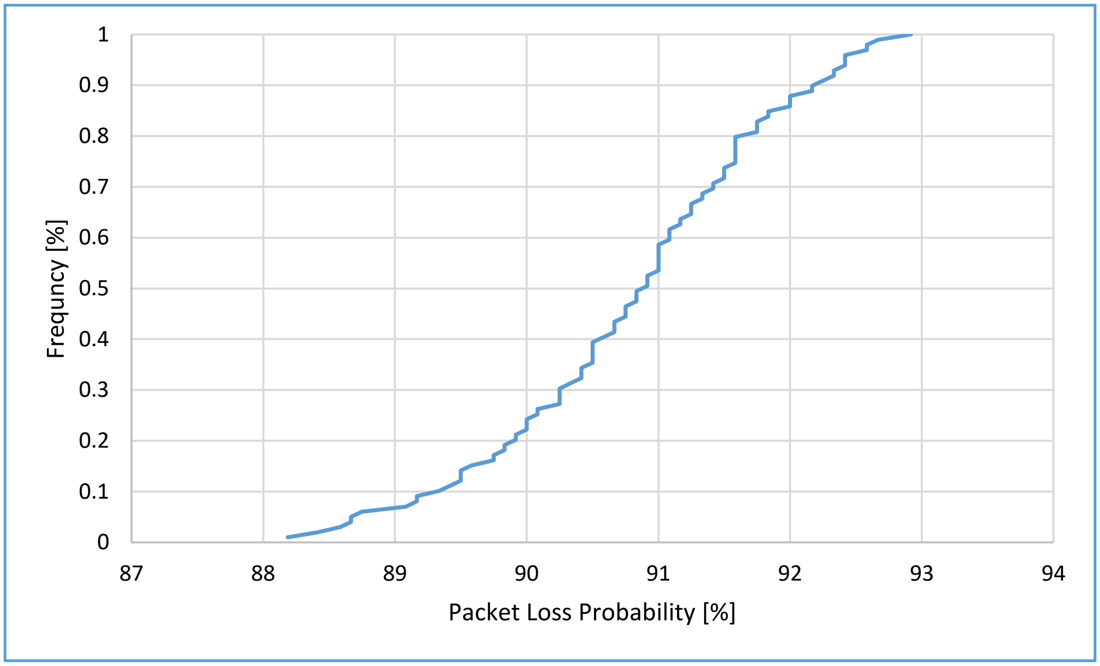


Figure 4. 13 Packet Loss result of IBSS_5_100VC_R

All other WLAN scenarios (11, 11a, 11b, and 11g) will be analysed in the same way. That yields values of QPMs, QFMs, and AFMs for the project IBSS_5_100VC_R as shown in Table 4.16.

Table 4. 16 AFMs and Rank order List for Project IBSS_5_100VC_ R

Application / Technology	VC						The rank order for this scenario
	DV	**D**	**TH**	**PL**	**AFM**		
802.11	0	0	0.102	0	**0.102**		**802.11g**
802.11b	0	0	0.102	0	**0.102**		**802.11e**
802.11a	0	0	0.100	0	**0.100**		**802.11**
802.11g	0.018	0	0.100	0	**0.118**		**802.11b**
802.11e	0.014	0	0.100	0	**0.114**		**802.11a**

Based on AFMs, the ranking list of these five technologies will be drawn up as shown in Table 4.16. The technology 11g produces the highest AFMs of 0.118 and thus are highly recommended to be used in this project IBSS_5_100VC_R. To produce the rank order list of WLAN technologies in the other two distributions (circular and uniform) the same procedure is followed. Table 4.17, shows the rank order list of all WLAN technologies in circular distribution.

Table 4. 17 AFMs and Rank order List for Project IBSS_5_100VC_ C

Application / Technology	VC						The rank order for this scenario
	DV	**D**	**TH**	**PL**	**AFM**		
802.11	0	0	0.102	0	**0.102**		**802.11**
802.11b	0	0	0.102	0	**0.102**		**802.11b**
802.11a	0	0	0.100	0	**0.100**		**802.11a**
802.11g	0	0	0.100	0	**0.100**		**802.11g**
802.11e	0	0	0.100	0	**0.100**		**802.11e**

The circular distribution of the project IBSS_5_100VC shows that the technologies 11 and 11b produce the highest AFMs of 0.102. Table 4.18 shows the AFMs and the rank order for all technologies in uniform distributions. The uniform distribution of the project IBSS_5_100VC shows that the technology 802.11e produces the highest AFM of 0.116.

Table 4. 18 AFMs and Rank order List for Project IBSS_5_100VC_ U

Application / Technology	VC						The rank order for this scenario
	DV	D	TH	PL	AFM		
802.11	0	0	0.102	0	**0.102**		**802.11e**
802.11b	0	0	0.102	0	**0.102**		**802.11g**
802.11a	0	0	0.100	0	**0.100**		**802.11**
802.11g	0.010	0	0.100	0	**0.110**		**802.11b**
802.11e	0.016	0	0.100	0	**0.116**		**802.11a**

System's algorithms and calculations will be applied for the other two network configurations (BSS and ESS), to determine the best performing WLAN technology (or technologies) across these two network configurations; and also, to produce all the values of QPMs, QFMs, and AFMs for all QoS parameters for all five technologies regarding VoIP application in IBSS and ESS across the three spatial distributions.

Second case study; BSS network configuration. Three main projects, BSS_5_100VC_C, BSS_5_100VC_U, and BSS_5_100VC_R are going to be established across three spatial distributions. Each one of them will be configured with five scenarios regarding the five WLAN standards.

The same calculation procedure that has applied in the first case study (IBSS network configuration) to determine all the values of QPMs, QFMs and AFMs for all five WLAN standards will be applied in this case also. Table 4.19, shows the rank order of WLAN technologies for the circular spatial distribution.

Table 4. 19 AFMs and Rank order List for Project BSS_5_100VC_ C

Application / Technology	VC							The rank order for this scenario
	DV	D	TH →	TH ←	PL	AFM		
802.11	0	0	0.103	0.10	0	**0.203**		**802.11b**
802.11b	0	0	0.103	0.13	0	**0.233**		**802.11a**
802.11a	0	0	0.101	0.13	0	**0.231**		**802.11g**
802.11g	0	0	0.101	0.13	0	**0.231**		**802.11e**
802.11e	0	0	0.101	0.13	0	**0.231**		**802.11**

The circular distribution of the project BSS_5_100VC shows that the technology 802.11b produces the highest AFMs of 0.233. Table 4.20, shows the rank order of WLAN technologies for the uniform spatial distribution.

Table 4. 20 AFMs and Rank order List for Project BSS_5_100VC_ U

Application / Technology	VC							The rank order for this scenario
	DV	D	TH →	TH ←	PL	AFM		
802.11	1	0	0.103	0.13	0	**1.233**		**802.11**
802.11b	0	0	0.103	0.13	0	**0.233**		**802.11g**
802.11a	0.46	0	0.101	0.13	0	**0.691**		**802.11a**
802.11g	0.73	0	0.101	0.13	0	**0.961**		**802.11b**
802.11e	0	0	0.101	0.13	0	**0.231**		**802.11e**

The uniform distribution of the project BSS_5_100VC shows that the technology 802.11 produces the highest AFM of 1.233. Table 4.21, shows the rank order of WLAN technologies for the random spatial distribution.

Table 4. 21 AFMs and Rank order List for Project BSS_5_100VC_ R

Application / Technology	VC							The rank order for this scenario
	DV	D	TH (→)	TH (←)	PL	AFM		
802.11	1	0	0.103	0.10	0	**1.203**		**802.11b**
802.11b	1	0	0.103	0.13	0	**1.233**		**802.11**
802.11a	0.90	0	0.101	0.13	0	**1.131**		**802.11g**
802.11g	0.92	0	0.101	0.13	0	**1.151**		**802.11a**
802.11e	0	0	0.101	0.13	0	**0.231**		**802.11e**

The random distribution of the project BSS_5_100VC shows that the technology 802.11b produces the highest AFM of 1.233.

The third case study (ESS network configuration). Three main projects ESS_5_100VC_C, ESS_5_100VC_U, and ESS_5_100VC_R are going to be established across three spatial distributions. Each one of them will be configured with five scenarios regarding the five WLAN standards.

The same calculation procedure that has been applied in the above two case studies (IBSS and BSS network configurations) to determine all the values of QPMs, QFMs and AFMs for all five WLAN standards will be applied in this case also. Table 4.22, shows the rank order of WLAN technologies across three spatial distributions.

Table 4. 22 AFMs and Rank order List for Project ESS_5_100VC_ C, U, R

Application / Technology	VC							The rank order for this scenario
	DV	**D**	**TH (→)**	**TH (←)**	**PL**	**AFM**		
802.11	0	0	0.102	0.13	0	**0.232**		**802.11**
802.11b	0	0	0.101	0.13	0	**0.231**		**802.11b**
802.11a	0	0	0.100	0.13	0	**0.230**		**802.11a**
802.11g	0	0	0.100	0.13	0	**0.230**		**802.11g**
802.11e	0	0	0.100	0.13	0	**0.230**		**802.11e**

Table 4.22 shows that the technology 802.11 provides the highest AFM of 0.232 for the project ESS_5_100VC across all three spatial distributions.

The system will now be able to provide the organization with all the details that are required for installing the second networking lab. Table 4.23, summarizes the results of this example and provides the answers to the organization query:

Table 4. 23 Results for BSS, IBSS, and ESS with 100% VC for 5 workstations

Technology \ Application	BSS			IBSS			ESS		
	C	**U**	**R**	**C**	**U**	**R**	**C**	**U**	**R**
802.11	**0.203**	**1.233**	**1.203**	**0.102**	**0.102**	**0.102**	**0.232**	**0.232**	**0.232**
802.11b	**0.233**	**0.233**	**1.233**	**0.102**	**0.102**	**0.102**	**0.231**	**0.231**	**0.231**
802.11a	**0.231**	**0.691**	**1.131**	**0.100**	**0.100**	**0.100**	**0.230**	**0.230**	**0.230**
802.11g	**0.231**	**0.961**	**1.151**	**0.100**	**0.110**	**0.118**	**0.230**	**0.230**	**0.230**
802.11e	**0.231**	**0.231**	**0.231**	**0.100**	**0.116**	**0.114**	**0.230**	**0.230**	**0.230**

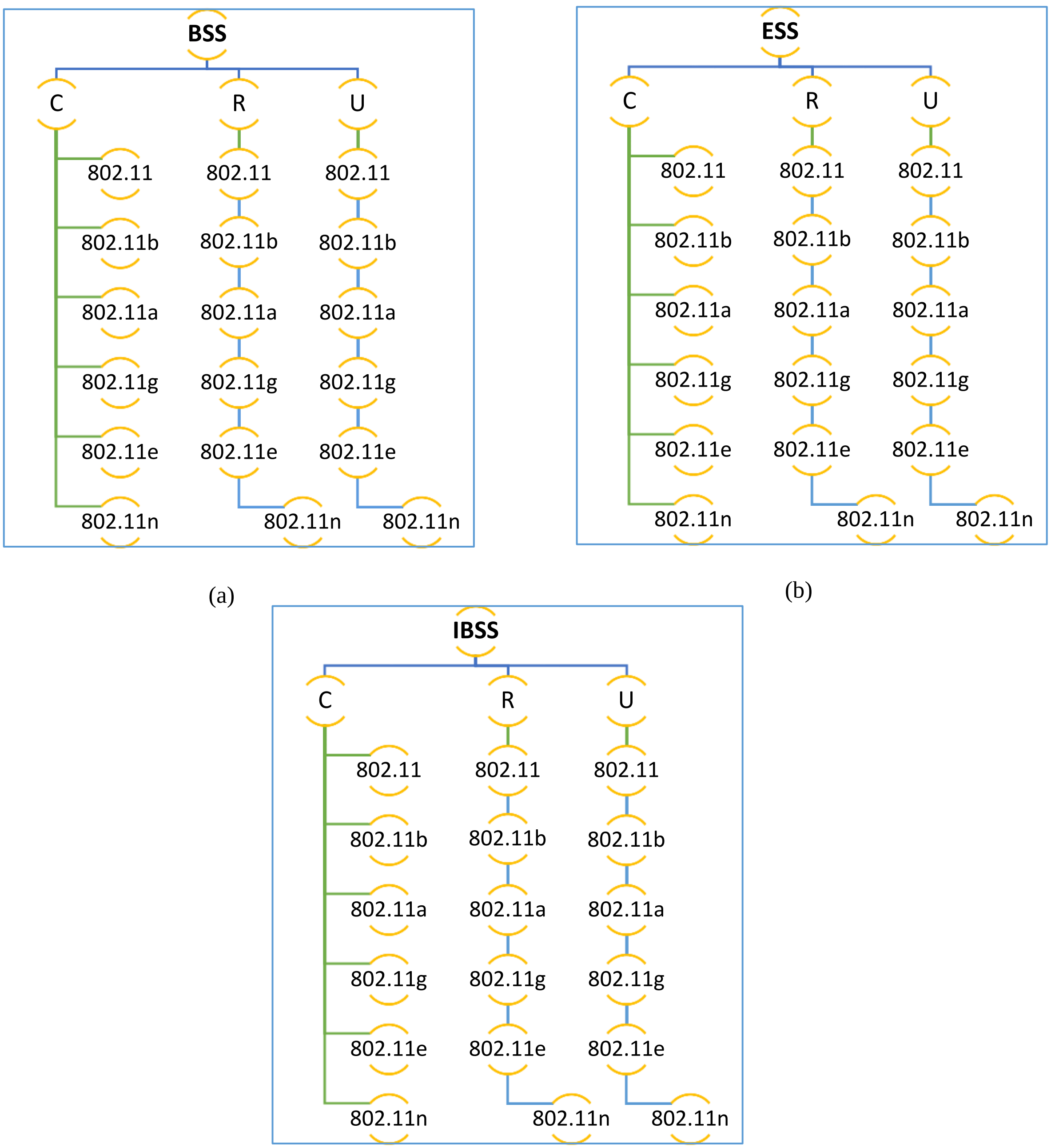
From Table 4.23, both technologies 802.11 and 802.11b in BSS configuration that configured in a uniform and random ways, respectively, yields the best overall performance result of 1.233.

4.3 Mixed Services Scenarios Description

This is an explanation of how to use system algorithms and their mathematical model (equations) and justify them for examples of mixed services scenarios:

Receiving a request from a university to set up a networking lab, that they have 40 machines in it because they have 40 students, they are going to work on it. The university's best estimate is that at any time, traffic will be divided equally between real-time and best-effort services where 40 per cent of the machine will be used for VoIP services, 20 per cent will be used for HTTP browsing, 10 per cent will be used for VC applications such as Zoom, 30 per cent will be used for file sharing and transfer. The university decides that because they know how much browsing they are going to use, VoIP, VC and file transfer, so they specify that. In addition, our algorithm and mathematical equations should tell them the best IEEE technology and network architecture to use, as well as the best spatial distribution for these 40 machines.

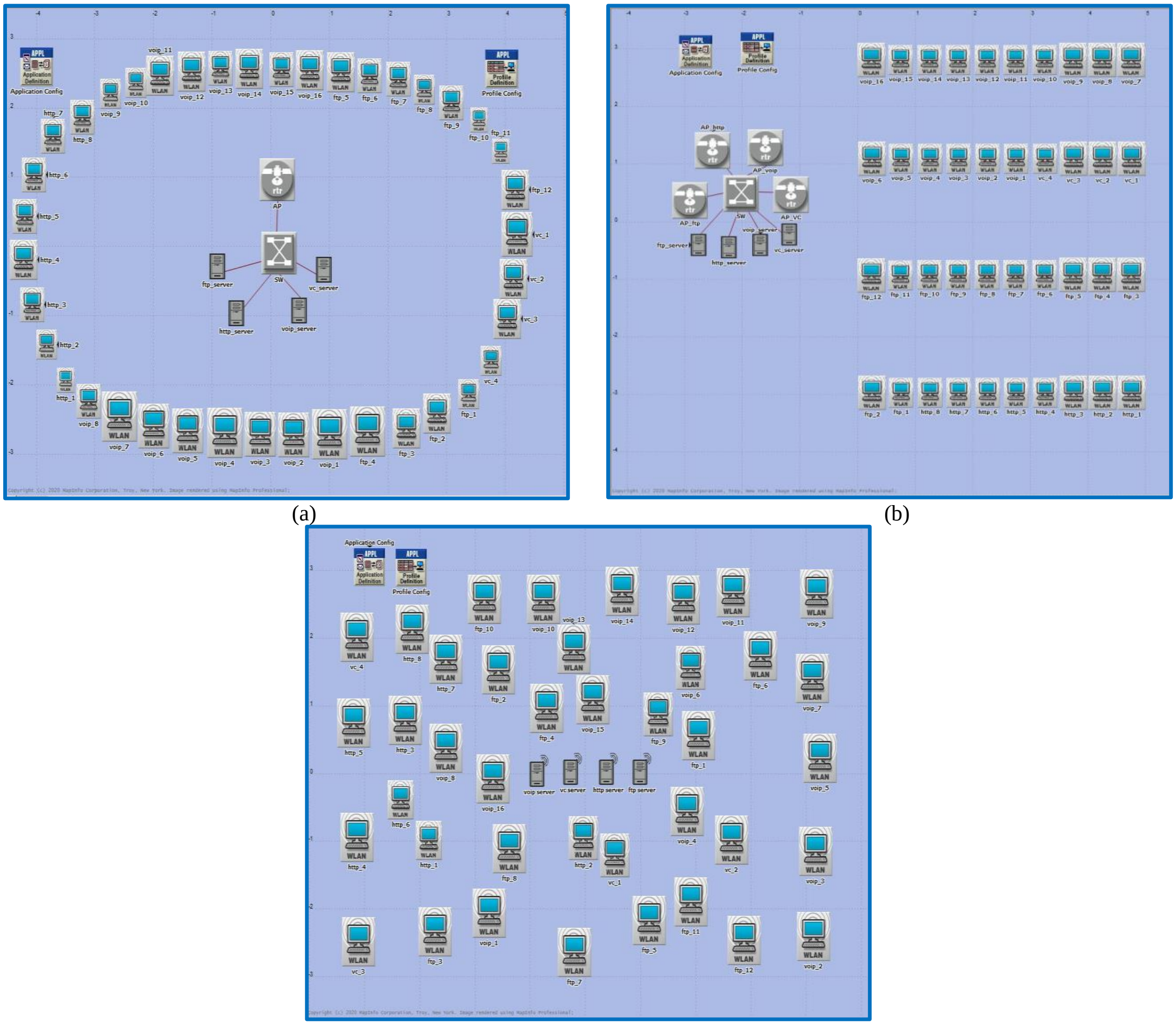
At the beginning for forty machines, 54 scenarios will be configured as there are three major projects to be built for each of the three main network configurations (BSS, ESS, IBSS) each of which should also consider the spatial distributions of the workstations (circular, uniform, random). Moreover, six scenarios will be created for each spatial distribution of the six WLAN technologies (802.11, 11a, 11b, 11g, 11e and 11n). Furthermore, these scenarios include four applications and their proportions are 40% of nodes running VoIP (16 machines), 30% of nodes running FTP (12 machines), 20% of nodes running HTTP (8 machines), and 10% of nodes run VC (4 machines). Here is a diagrammatic representation of BSS, ESS and IBSS scenarios' projects in Figure 4.14:



(c)

Figure 4. 14 Scenario's projects for all three network configurations. (a) BSS, (b) ESS, (c) IBSS

The performances of different scenarios for the three network configuration projects have been investigated via an OPNET simulator, Figure 4. 15 shows some of the implemented scenarios.



(a) (b) (c)

Figure 4. 15 Design of the three Network Architectures across three Spatial Distributions for 40 VoIP Service Mix Scenarios (a) BSS, (b) ESS, (c) IBSS

The system calculations and the mathematical model are shown in phase II at the bottom part of Figure. 3.34. The inputs for the algorithm's mathematical calculations are QoS Threshold values for each application and CDF distribution produced for each application's QoS metric. Tables 3.5 and 3.6 show the QoS qualitative importance of each QoS parameter and their related threshold values for each mixed application. CDF distribution is produced for these QoS metric parameters from OPNET after running the simulation scenarios.

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

As Table 4.24 shows, there are four mixed services which are FTP 30%, HTTP 20%, VC 10% and VoIP 40%. The calculation will be done for each QoS parameters *n* for each mixed service. It starts with the QoS parameters of the first service VoIP 40%, let *J* be jitter and *D* be the delay, the mathematical Eq. (4.4) will be applied to find QPM for both metric parameters for all six IEEE technologies *g*, then QFM will be calculated using Eq. (4.5) for all technologies. If throughput is taken as *TH*, then those two equations are going to be applied also for it, the implementation of these equations and how to find QPM and QFM is explained in details in sections 4.2.1 and 4.2.2. Application packet loss rate ω_i of a node *i* is the ratio of dropped data packet ki to total data packets ρ_i multiplied by 100%, as demonstrated by Eq. (4.6), a code has been programmed using MATLAB software as shown in Figure 4.16, to develop a method to calculate its percentage for all four mixed applications. This method is linked directly with the OPNET Modeler to produce a specific packet loss percentage for each mixed application and IEEE technology. Moreover, the Eq. (4.7) and the Eq. (4.8) will be used to calculate the AFM for stand-alone services and SFM for mixed services, respectively.

$$QPM_n = F(ptv) \tag{4.4}$$

$$QFM_n = QPM_n \times ICP \tag{4.5}$$

$$\omega_i = (\, ki/\rho_i) \times 100\% \tag{4.6}$$

$$AFM_g = \sum_{n=1}^{4} QFM_n \times M \tag{4.7}$$

$$SFM_g = \sum_{n=1}^{4} AFM_n \tag{4.8}$$

Table 4. 24 Service Mix (40% VoIP, 30% FTP, 20% HTTP and 10%VC) BSS_40_40VOIP_C

Application	Technology	802.11	802.11b	802.11a	802.11g	802.11e	802.11n
VOIP 40%	***J***	QFM_J	QFM_J	QFM_J	QFM_J	QFM_J	QFM_J
	D	QFM_D	QFM_D	QFM_D	QFM_D	QFM_D	QFM_D
	TH	QFM_{TH} QFM_{TH}	QFM_{TH} QFM_{TH}	QFM_{TH} QFM_{TH}	QFM_{TH} QFM_{TH}	QFM_{TH} QFM_{TH}	QFM_{TH} QFM_{TH}
	PL	QFM_{PL}	QFM_{PL}	QFM_{PL}	QFM_{PL}	QFM_{PL}	QFM_{PL}
	1	Sum (QFM_J + QFM_D + QFM_{TH} + QFM_{PL}) × 40%	$\boldsymbol{AFM_{11b}}$	$\boldsymbol{AFM_{11a}}$	$\boldsymbol{AFM_{11g}}$	$\boldsymbol{AFM_{11e}}$	$\boldsymbol{AFM_{11n}}$
VC 10%	***DV***	QFM_{DV}	QFM_{DV}	QFM_{DV}	QFM_{DV}	QFM_{DV}	QFM_{DV}
	D	QFM_D	QFM_D	QFM_D	QFM_D	QFM_D	QFM_D
	TH	QFM_{TH} QFM_{TH}	QFM_{TH} QFM_{TH}	QFM_{TH} QFM_{TH}	QFM_{TH} QFM_{TH}	QFM_{TH} QFM_{TH}	QFM_{TH} QFM_{TH}
	PL	QFM_{PL}	QFM_{PL}	QFM_{PL}	QFM_{PL}	QFM_{PL}	QFM_{PL}
	2	Sum (QFM_{DV} + QFM_D + QFM_{TH} + QFM_{PL}) × 10%	$\boldsymbol{AFM_{11b}}$	$\boldsymbol{AFM_{11a}}$	$\boldsymbol{AFM_{11g}}$	$\boldsymbol{AFM_{11e}}$	$\boldsymbol{AFM_{11n}}$
HTTP 20%	***PR***	QFM_{PR}	QFM_{PR}	QFM_{PR}	QFM_{PR}	QFM_{PR}	QFM_{PR}
	TH	QFM_{TH} QFM_{TH}	QFM_{TH} QFM_{TH}	QFM_{TH} QFM_{TH}	QFM_{TH} QFM_{TH}	QFM_{TH} QFM_{TH}	QFM_{TH} QFM_{TH}
	PL	QFM_{PL}	QFM_{PL}	QFM_{PL}	QFM_{PL}	QFM_{PL}	QFM_{PL}
	3	Sum (QFM_{PR} + QFM_{TH} + QFM_{PL}) × 20%	$\boldsymbol{AFM_{11b}}$	$\boldsymbol{AFM_{11a}}$	$\boldsymbol{AFM_{11g}}$	$\boldsymbol{AFM_{11e}}$	$\boldsymbol{AFM_{11n}}$
FTP 30%	***DR***	QFM_{DR}	QFM_{DR}	QFM_{DR}	QFM_{DR}	QFM_{DR}	QFM_{DR}
	TH	QFM_{TH} QFM_{TH}	QFM_{TH} QFM_{TH}	QFM_{TH} QFM_{TH}	QFM_{TH} QFM_{TH}	QFM_{TH} QFM_{TH}	QFM_{TH} QFM_{TH}
	PL	QFM_{PL}	QFM_{PL}	QFM_{PL}	QFM_{PL}	QFM_{PL}	QFM_{PL}
	4	Sum (QFM_{DR} + QFM_{TH} + QFM_{PL}) × 30%	$\boldsymbol{AFM_{11b}}$	$\boldsymbol{AFM_{11a}}$	$\boldsymbol{AFM_{11g}}$	$\boldsymbol{AFM_{11e}}$	$\boldsymbol{AFM_{11n}}$
SFM		**1+2+3+4**	$\boldsymbol{SFM_{11b}}$	$\boldsymbol{SFM_{11a}}$	$\boldsymbol{SFM_{11g}}$	$\boldsymbol{SFM_{11e}}$	$\boldsymbol{SFM_{11n}}$
Rank		**802.11e**	**802.11a**	**802.11g**	**802.11**	**802.11n**	**802.11b**

```
filename='C:\Users\Germany\Desktop\U\BSS_40_40VOIP_C-11n-DES-1__VoIP.xlsx';

A = xlsread(filename,'A:A');

B = xlsread(filename,'B:B');

C = xlsread(filename,'C:C');

for i=1:1:199;

nr(i)=(B(i+1)+B(i))./2. X (A(i+1)-A(i));

ns(i)=(C(i+1)+C(i))./2. X  (A(i+1)-A(i));

pl(i)=(ns(i)-nr(i))./(ns(i)) X  100;

end

[f,x1] = ecdf(pl)

plot(x1,f)
```

Figure 4. 16 MATLAB Code for Packet Loss Calculations for the mixed services 40 VoIP (VoIP 40%, VC 10%, FTP 30%, and HTTP 20%).

Before using this code, OPNET produces the result of traffic sent/received rate and provides the ability to export and save them as a spreadsheet file. The code reads all the values in all three columns; column A which represents simulation time in seconds, column B which represents traffic received rate in packets/sec, and column C which represents the traffic sent rate in packets/sec. Two-line codes (4.9) and (4.10), reflect the packet loss principle, which is the total number of packets sent minus the total number of received packets divided by the total number of packets sent and multiplied by 100%, thus allowing the values in both columns B and C to be integrated to generate the total number of packets sent and received.

$$nr(i) = \left(\frac{B(i+1)+B(i)}{2} \times (A(i+1) - A(i))\right) \tag{4.9}$$

$$ns(i) = \left(\frac{C(i+1)+C(i)}{2} \times (A(i+1) - A(i))\right) \tag{4.10}$$

then, the exact packet loss ratio is produced using the following code line equation:

$$pl(i) = \left(\frac{ns(i)-nr(i)}{ns(i)} \times 100\right) \tag{4.11}$$

This packet ratio value should be presented as a CDF diagram as is shown in Figure 4.8. However, at this point, the QFM values for all QoS metric parameters for VoIP 40% have been identified. On this basis of calculation, its AFM is estimated using Eq. (4.7) with taking into our consideration that this AFM for VoIP service should be multiplied by *M* the actual machines' percentages in the mixed services scenario, which is 40%. This calculation will be done for all six IEEE technologies to find the AFM values for each one of them.

Finding the AFM's values for the other three mixed services in this project scenario (VC 10%, HTTP 20%, FTP 30%) will follow the same mathematical procedure. Should be clear that the AFM for VC should be multiplied by its machine's percentage weights in the scenarios which are 10%, AFM for HTTP will be multiplied by the weight of its machines 20%, and AFM for FTP will be multiplied by 30% which reflects its machines percentages in all scenarios.

The aggregation of all AFMs for each technology gives an SFM for that technology, which is presented using Eq. (4.8). SFM will be used for ranking IEEE technologies and will later contribute to the definition of the optimum network architecture.

The ranking list of these six technologies for the circular distribution of the 40VoIP mixed services for BSS scenarios will be provided on the basis of WLAN SFM values. The same procedure will be followed for the uniform and random distributions to rank order the six WLAN technologies for both distributions.

System algorithms and calculations will be applied for the other two network configurations (ESS and IBSS), to determine the best performing WLAN technology (or technologies) across these two network configurations; and also, to produce all the values of QPMs, QFMs, AFMs and SFM for all QoS parameters for all six technologies regarding each mixed service in 40VoIP scenarios projects across the three spatial distributions. Table 4.25 shows the rank order list of all WLAN technologies for the 40 VoIP mixed services across three spatial distributions.

Table 4. 25 Results for BSS, IBSS, and ESS with 40VOIP for 40 workstations

Application / Technology	BSS			IBSS			ESS		
	C	**U**	**R**	**C**	**U**	**R**	**C**	**U**	**R**
802.11	SFM_{11}	SFM_{11}	SFM_{11}	SFM_{11}	SFM_{11}	SFM_{11}	SFM_{11}	SFM_{11}	SFM_{11}
802.11a	SFM_{11a}	SFM_{11a}	SFM_{11a}	SFM_{11a}	SFM_{11a}	SFM_{11a}	SFM_{11a}	SFM_{11a}	SFM_{11a}
802.11b	SFM_{11b}	SFM_{11b}	SFM_{11b}	SFM_{11b}	SFM_{11b}	SFM_{11b}	SFM_{11b}	SFM_{11b}	SFM_{11b}
802.11g	SFM_{11g}	SFM_{11g}	SFM_{11g}	SFM_{11g}	SFM_{11g}	SFM_{11g}	SFM_{11g}	SFM_{11g}	SFM_{11g}
802.11e	SFM_{11e}	SFM_{11e}	SFM_{11e}	SFM_{11e}	SFM_{11e}	SFM_{11e}	SFM_{11e}	SFM_{11e}	SFM_{11e}
802.11n	SFM_{11n}	SFM_{11n}	SFM_{11n}	SFM_{11n}	SFM_{11n}	SFM_{11n}	SFM_{11n}	SFM_{11n}	SFM_{11n}

From Table 4.25, the university has a number of options because all the six technologies will be ranked order based on their SFM, so the university will be able to choose the best performing technology/technologies and network architecture that suits their specific requirements as well as it will be able to decide the optimal spatial distributions for their lab machines.

4.4 Summary

A framework for implementing the proposed algorithm and its mathematical model (equations) to achieve the most efficient network setup based on the current technologies available for both stand-alone and mixed services was presented in this chapter. Two stand-alone examples were studied and constructed, the first to implement an organization request to set up a lab for 10 workstations, all of which were configured with a VoIP service. The second example of a request to set up a VC lab for 5 workstations. In addition, there is a third example of a university's requirement for the establishment of a networking lab for mixed services based on one particular service percentage for each service that meets the criteria and uses of the university.

The purpose of this chapter is to implement several scenario projects to demonstrate how this algorithm and related mathematical calculation work to rank current IEEE 802.11 standards for stand-alone and mixed applications by applying mathematical equations and MATLAB software code that helped to develop a method for calculating packet loss percentage for both stand-alone and mixed applications. The objective here is to explore which IEEE standard leads to better overall results for all application types, stand-alone and mixed applications, with particular environmental circumstances, such as a number of nodes, physical layer technologies, network applications and network configurations. At the same time, the idea is to produce a standard procedure that offers the opportunity to identify IEEE technology/technologies and network architecture for internet applications and technologies. 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.

CHAPTER 5 RESULTS OF STAND-ALONE APPLICATION

5.1 Introduction

The options available to the client will be identified while reviewing the results. Best performing technologies are recommended in all three networking architectures (IBSS, BSS and ESS). The results are divided into two main case studies related to the type of traffic being implemented: Real-time applications (VoIP and VC) and Best-effort applications (HTTP, FTP, Email). The results format has a flowchart for every group of nodes for a specific application. The flowchart has identified the number of nodes, network architectures, spatial distributions, and WLAN technologies used. In stand-alone applications the results are known as AFM.

In the following journal articles, the algorithm, analysis and findings have been published (Mohd Ali, Dhimish, Alsmadi, & Mather, 2020) and (Mohd Ali, Dhimish, & Mather, 2019).

The beginning of each application presents an overall picture of the network architecture including all groups of nodes (5, 10, 20, 40, and 65) with their AFM results. The results are shown on the basis of the presence of the access point; consequently, the results tables are interpreted (translated) in two flowcharts of the results: the generic flowchart and the IBSS chart, as will be shown later for each application (Mohd Ali, Dhimish, Alsmadi, & Mather, 2020).

The final step is to highlight the best performing technology per case study (network configuration) and per each group of nodes for that application.

- In the event that the network includes at least one access point, the algorithm suggested in Figure 3.34 is implemented and results are shown in Figures 5.1, 5.3, 5.5, 5.7 or 5.9. This case refers to the two categories of infrastructure architecture (ESS and BSS). All of these scenarios work in five technologies of IEEE 802.11 and three ways of distributions: circular, uniform and random (Mohd Ali, Dhimish, Alsmadi, & Mather, 2020).

- The proposed algorithm in Figure 3.34 and the flowchart of the IBSS results listed in Figures 5.2, 5.4, 5.6, 5.8 and 5.10 will be used, if the network is configured without any access points. Every scenario is operating in all five IEEE 802.11 technologies and in three space distributions (circular, regular and random) (Mohd Ali, Dhimish, Alsmadi, & Mather, 2020) and (Mohd Ali, Dhimish, & Mather, 2019).

5.2 Real-time applications

5.2.1 VOIP

In both Figures 5.1 and 5.2, both results' algorithms can be seen for all the nodes (5, 10, 20, 40 and 65) running the VoIP application and using all five WLAN standard technologies (802.11, 802.11a, 802.11b, 802.11g, and 802.11e) in three spatial distributions (C, U, R). The results of both algorithms classify five key groups of nodes, presented as follows (Mohd Ali, Dhimish, Alsmadi, & Mather, 2020) and (Mohd Ali, Dhimish, & Mather, 2019):

1. If the client generates a small network, when $5 \geq N > 0$, (five nodes or less) in the general flowchart, as shown in Figure 5.1, then ESS is the better network architecture for all three space distributions. In addition, all five technologies of IEEE 802.11 behave the same way. In the case of the IBSS flow chart, however, according to Figure 5.2, all three technologies 802.11a, 11 g and 11e deliver optimum results across all space distributions.
2. In the case of $10 \geq N > 5$, where the client implements a network with a number of nodes from 5 to 10, ESS or BSS performs properly in all three spatial distributions while only using three technologies, including 802.11a, 11 g and 11e. This can be seen in Figure 5.1. The 802.11a, 11 g and 11e technologies continue the ideal solution in all space distributions in the case of the flowchart for IBSS results.

3. In the third category, where $20 \geq N > 10$ is established, BSS and ESS offer a number of options if a client is to build the medium-size network with the number of nodes 10 to 20. IEEE 802.11a technology is the optimal technology in all three space distributions for BSS architecture. The preferred solutions for ESS architecture are IEEE 802.11a, 11g and 11e. The IEEE 802.11a and 11e are the best technology, however, according to the IBSS flow chart.
4. In the fourth category, $40 \geq N > 20$, ESS is the optimum network architecture. Therefore, according to the data given in Figure 5.1, the user has a set of choices. First, if the network is only configured in circular and random configurations, both the 802.11a and 11g technologies can be optimally employed; while the second-best approach is to use uniformly configured IEEE 802.11a technology. On the other hand, all three 802.11a, 11g and 11e technologies work equally well in the IBSS flowchart.
5. In the fifth category where $65 > 40$, both ESS and BSS have the best performance for all three spatial distributions using only three technologies, including 802.11a, 11g, and 11e. Figure 5.1, demonstrates the generic flowchart. In the IBSS flowchart, the 802.11a, 11g and 11e technologies provide users with the most effective output for all space distributions, as shown in Figure 5.2.

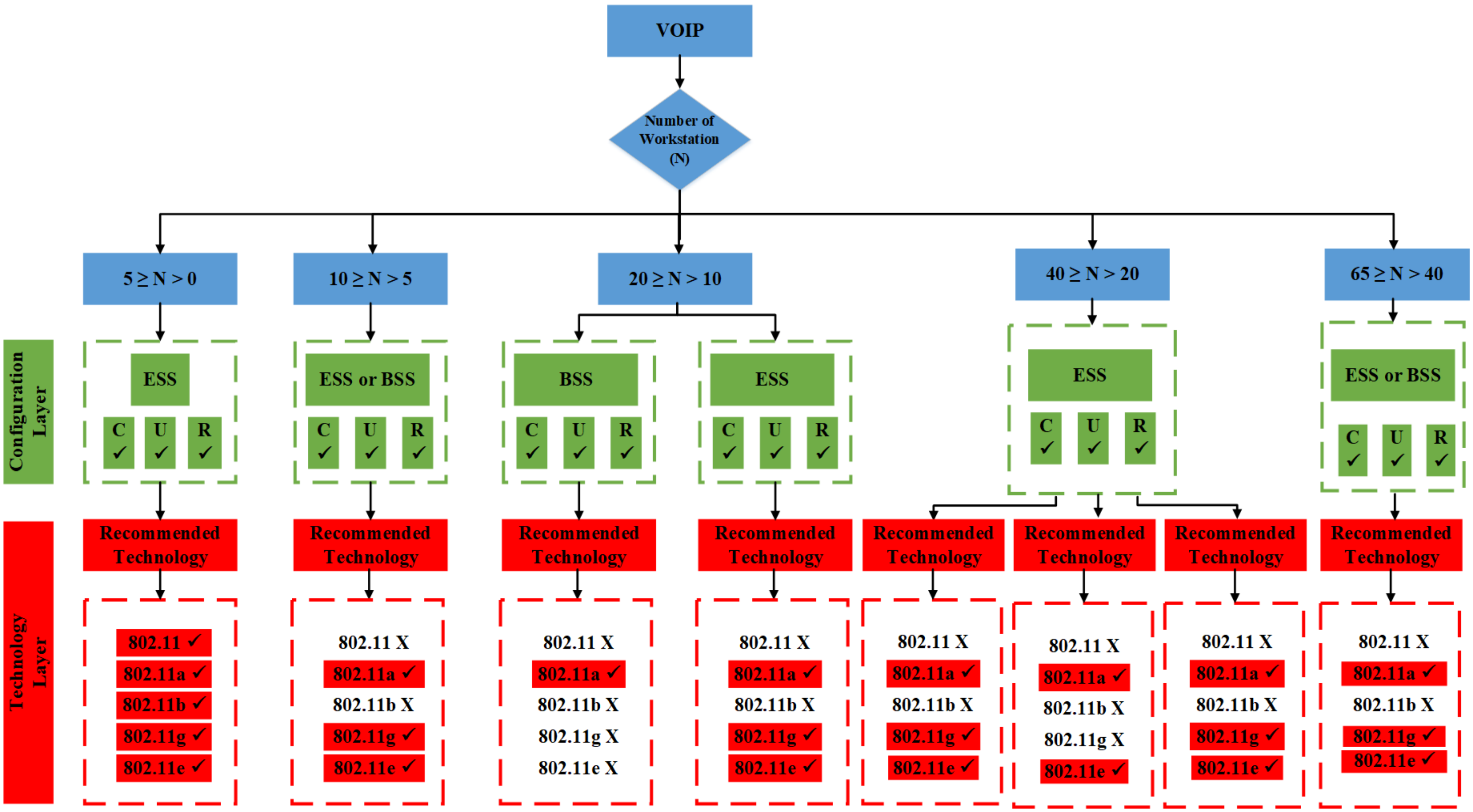


Figure 5. 1 Generic flowchart of the proposed algorithm for VoIP

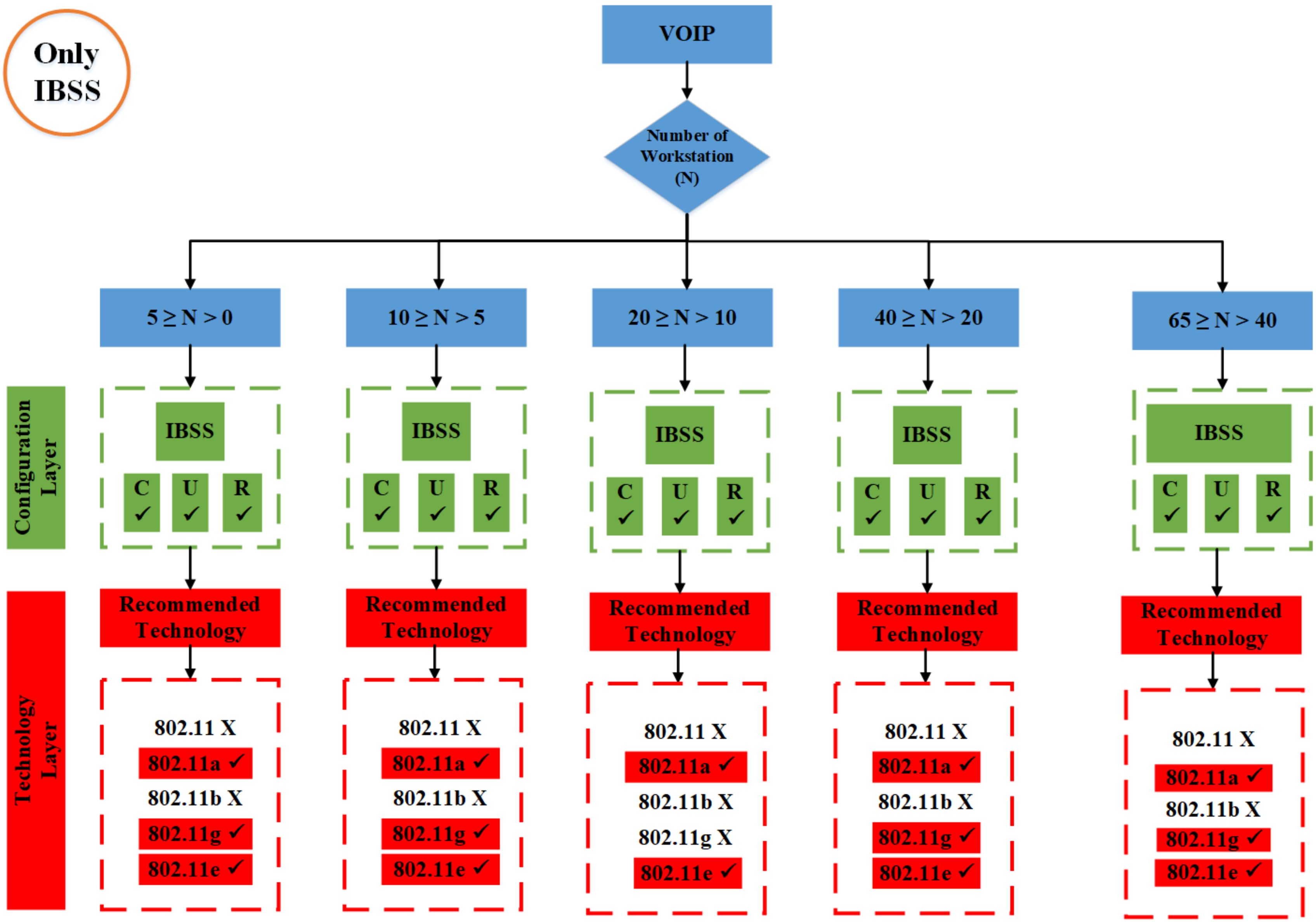


Figure 5. 2 Flowchart of only IBSS's results for VoIP

5.2.2 VC

As can be seen from both Figures 5.3 and 5.4, both results' algorithms for all the nodes (5, 10, 20, 40 and 65) are running the VC application and using all five WLAN standard technologies (802.11, 802.11a, 802.11b, 802.11g, and 802.11e) in three spatial distributions (C, U, R). The results of the two algorithms classify the following five key node groups:

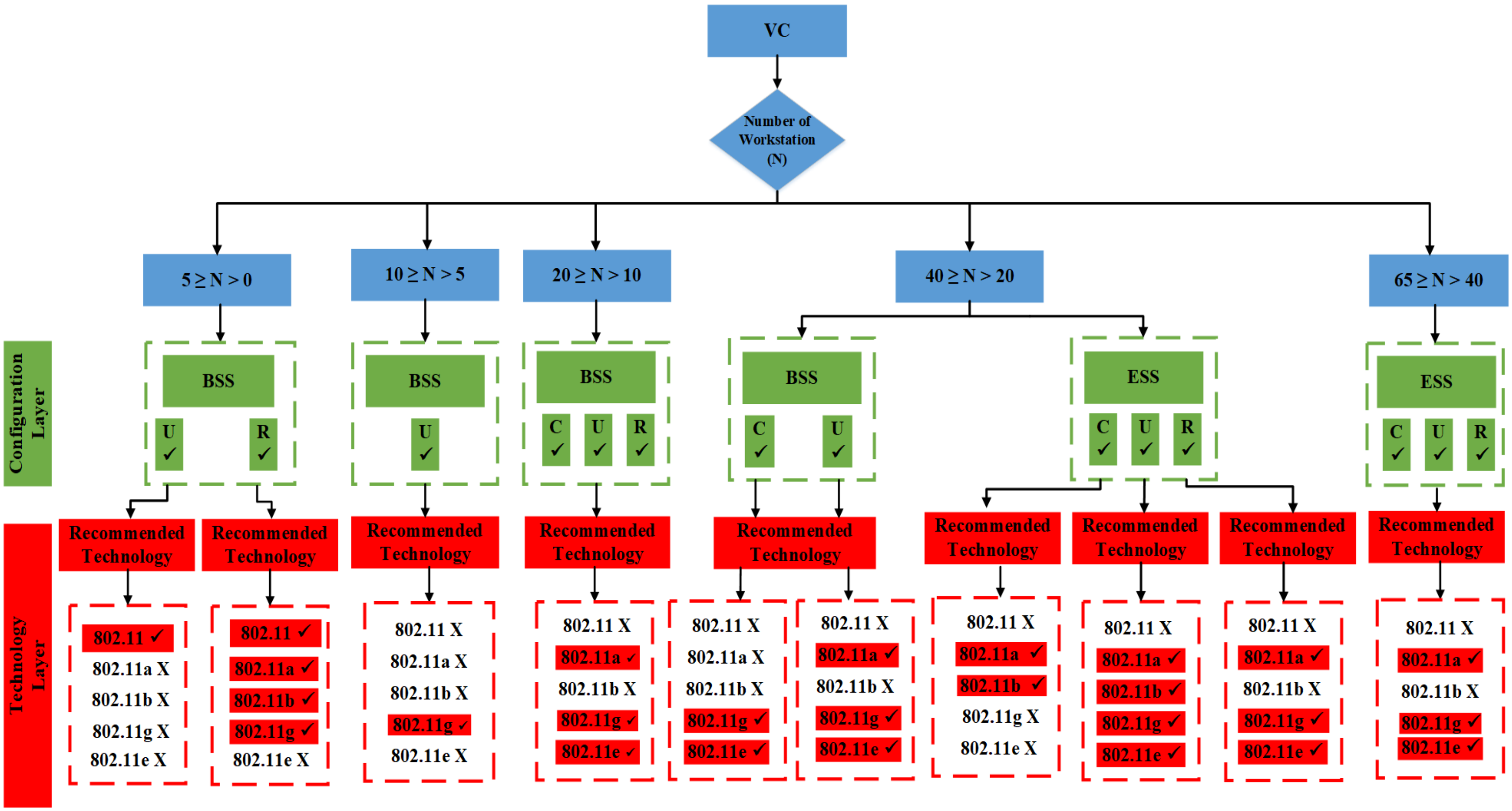


Figure 5. 3 Generic flowchart of the proposed algorithm for VC

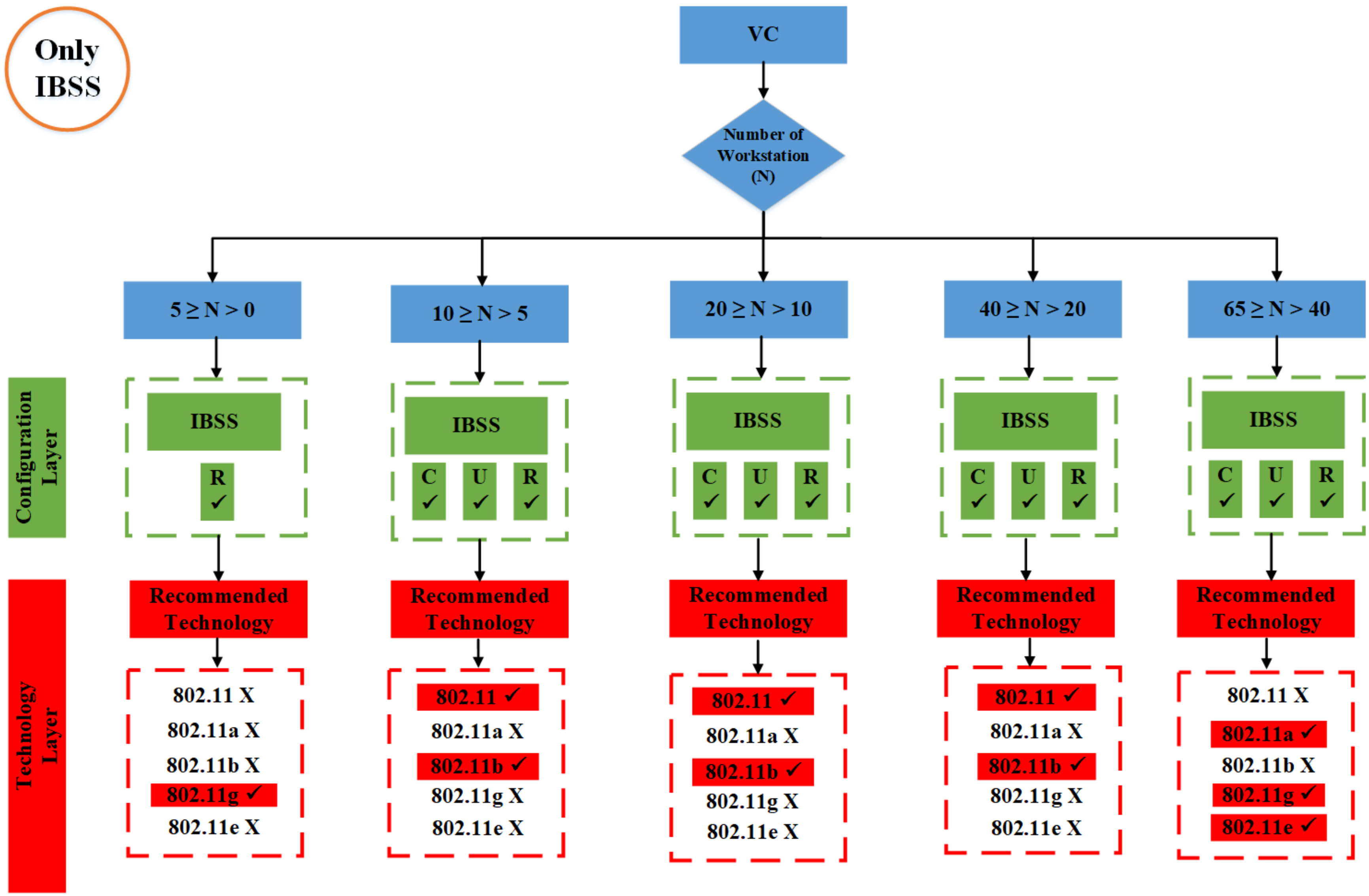


Figure 5. 4 Flowchart of only IBSS's results for VC

1. In the first group, where 5 > N > 0, shown in Figure 5.3, BSS is the best network architecture if the client is going to establish a small network. First, 802.11, if the setup is only on a uniform network, is the best technology to be used. The second-best approach is to use randomly designed 802.11b technology. That is because the performance metric of the packet delay is 100% adequate for both selected technologies. However, for IBSS, the best performance of 802.11g technology is set up randomly as illustrated in Figure 5.4 (Mohd Ali, Dhimish, Alsmadi, & Mather, 2020).

2. If the client configures a network using a number of nodes between 5 and 10, BSS offers optimum performance which has been uniformly configured and 802.11g implemented, as illustrated in Figure 5.3. This is because the packet delay performance metric provides 80% adequacy. However, both 802.11 and 11b technologies offer the client the best performance in all space distributions, as shown in Figure 5.4, in the case of IBSS (Mohd Ali, Dhimish, Alsmadi, & Mather, 2020).

3. If the client builds a medium-sized network with the number of nodes from 10 to 20, in the third category, when 20 > N > 10, then you can use BSS as the best choice. Moreover, according to the information provided in Figure 5.3, the client has several choices. As they have greater throughput sufficiency for both transmitting and receiving than other technologies, IEEE 802.11a, 11g and 11e are known as the suitable solutions across different geometric allocations. While IEEE 802.11 and 11b both work in all IBSS space distributions (Mohd Ali, Dhimish, Alsmadi, & Mather, 2020).

4. BSS and ESS offer a range of options in the fourth group, where $40 \geq N > 20$. IEEE 802.11g and 11e technologies are only effective in BSS architecture if the network is circularly and uniformly designed. In addition, IEEE 802.11a only operates if it is uniformly set up. On the other hand, ESS offers a number of possibilities. The preferred solutions are only acknowledged as IEEE 802.11a, 11g, and 11e, where the network is set up in a uniform and random distribution. Furthermore, as shown in Figure 5.3, both IEEE 802.11a and 11b technologies provide optimum performance in circular or uniform configuration, due to a slightly higher difference in their throughput performance metric, which stands at around

0.006. The results of IBSS provide users with the best performance in both 802.11 and 11b technology for all space distributions (Mohd Ali, Dhimish, Alsmadi, & Mather, 2020).

5. ESS is the optimal network architecture performance in the fifth group, where $65 \geq N > 40$, in the generic flowchart. The client also has a range of options if this wide network is to be built. The best user output for all space distributions is provided by 802.11a, 11g, and 11e technologies. In the IBSS flowchart, 802.11a, 11g and 11e technologies provide the user with the best efficiency for all space distributions, due to higher throughput adequacy that makes a difference (Mohd Ali, Dhimish, Alsmadi, & Mather, 2020).

5.3 Best-effort applications

5.3.1 HTTP

The results of both algorithms for all the nodes (5, 10, 20, 40 and 65) running the HTTP application and using all five WLAN standard technologies (802.11, 802.11a, 802.11b, 802.11g, and 802.11e) in three spatial distributions (C, U, R) can be seen from Figures 5.5 and 5.6. The results of both algorithms classify five key groups of nodes, presented as follows (Mohd Ali, Dhimish, Alsmadi, & Mather, 2020) and (Mohd Ali, Dhimish, & Mather, 2019):

1. As can be seen in Figure 5.5, both BSS and ESS architectures have the most efficient output overall spatial distributions for all five technologies in the first, second, and fifth categories, where $5 \geq N > 0$, $10 \geq N > 5$ and $40 \geq N > 20$, respectively, in the generic flow chart. For the IBSS, the client has a certain number of choices in accordance with the information provided in Figure 5.6 for the first group of nodes. First, 802.11 is the best possible technology to be used if only in circular distribution it is configured. Moreover, 802.11b technology is configured at random because its packet loss performance metric is a slightly higher difference, approximately 0.098. IBSS provides a variety of options for the second group of nodes. Firstly, 802.11 is the perfect system for all space distributions. Secondly, both 802.11b and 11g technologies are ideal for use if the network is only configured for random and circular distributions, respectively.

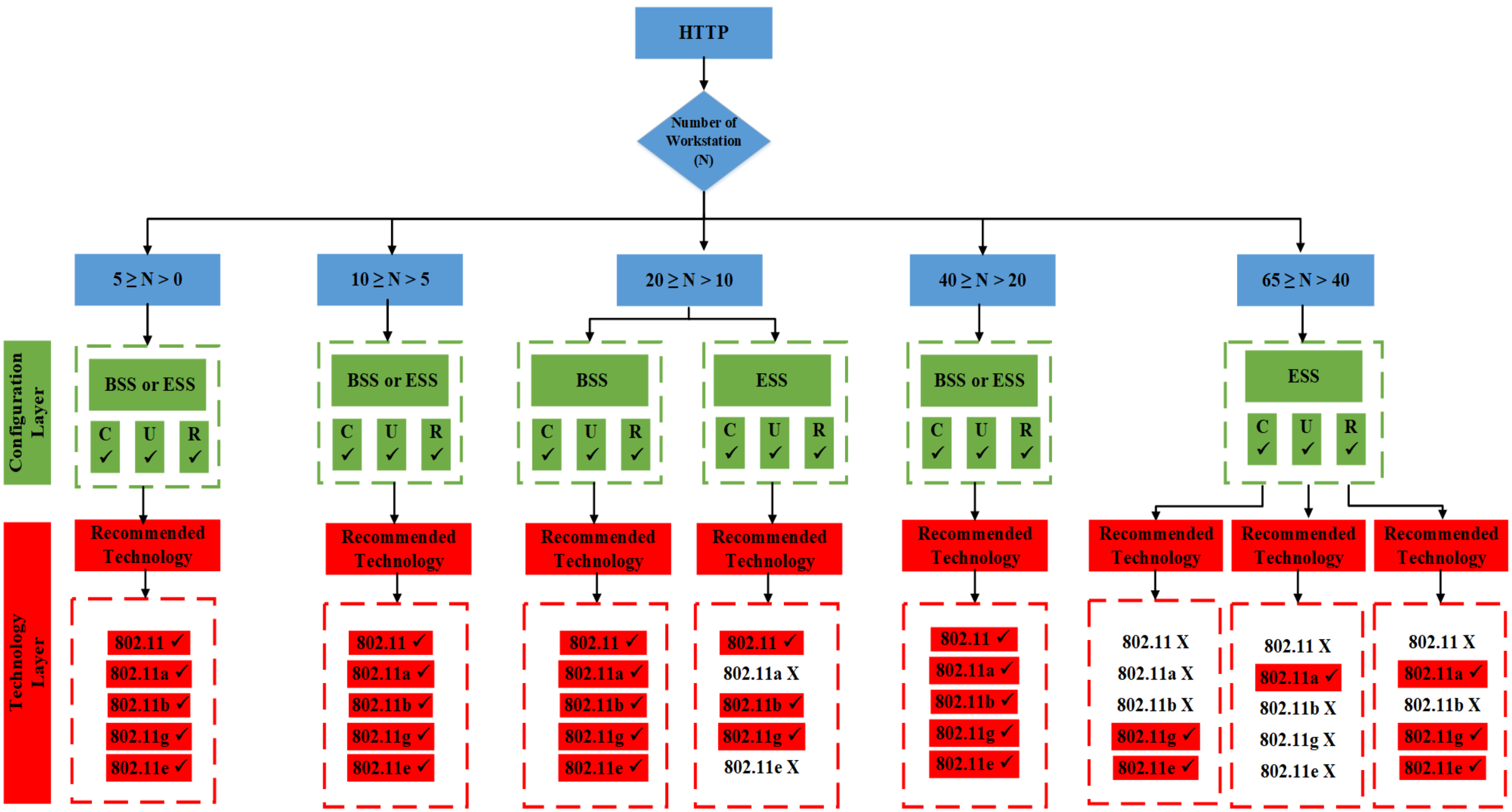


Figure 5. 5 Generic flowchart of the proposed algorithm for HTTP

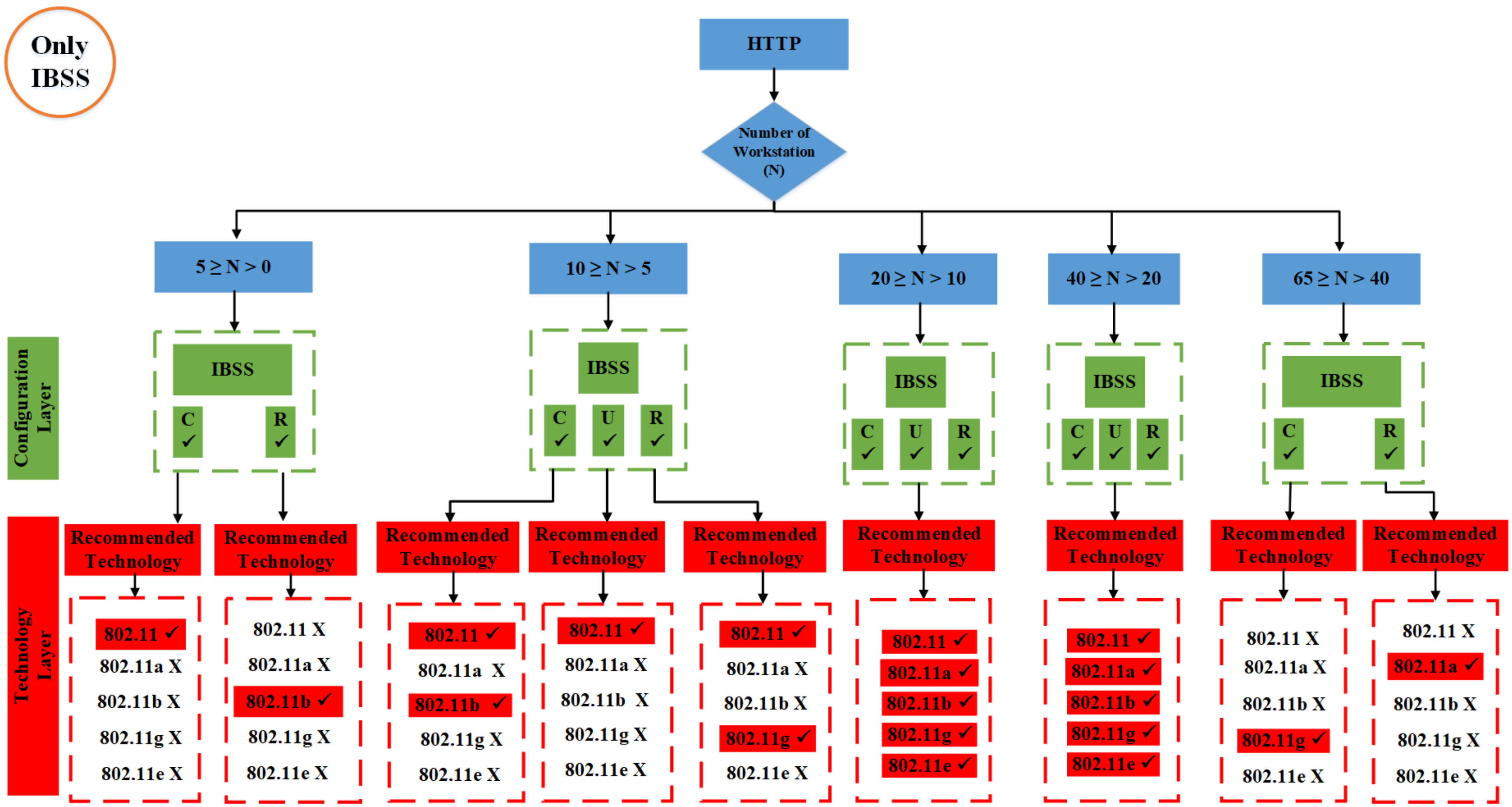


Figure 5. 6 Flowchart of only IBSS's results for HTTP

2. In the third category, where $20 \geq N > 10$, both BSS and ESS offer several options in the general flow chart. For BSS architecture, all three spatial distributions have five technologies that perform well. Nevertheless, IEEE technologies 802.11, 11b and 11 g are recognized as the preferred ESS solutions. On the other hand, all IEEE technologies work well for all spatial distributions, as shown in Figure 5.6, according to the IBSS flowchart, for the 3rd and 4th groups.
3. For the large network (fifth group), where $65 \geq N > 40$, the best architecture, in the generic flowchart, is ESS. There are then a number of options for the client to choose from. Firstly, if a network is only set up in circular and random distributions, all 802.11g and 11e technologies can be optimally implemented, whereas second-best choices include using a uniformly and randomly configured IEEE 802.11a technology. On the other side, the user has many options to choose in the IBSS flowchart. First, the best technology can be used when 802.11 g is configured only in circular distribution. As shown in Figure 5.6, the second-best choice is the randomly configured 802.11 technology.

5.3.2 FTP

1. BSS is the best network architecture in the first category, where $5 \geq N > 0$, as demonstrated in Figure 5.7, in the generic flowchart. Both 802.11a and 11e technologies are optimal for use in every spatial distribution because their performance metric is slightly greater than other technologies. However, both 802.11b and 11 g technologies are considered superior solutions only if they are circularly and uniformly configured, as is shown in Figure 5.8, according to the IBSS flowchart.
2. The BSS and ESS offer a set of options in the second group, in which $10 \geq N > 5$. If the network is set up in a circular and uniform way, BSS and ESS provide optimum efficiency for all five technologies. All technology, however, works well across all space distributions, according to the IBSS flowchart.

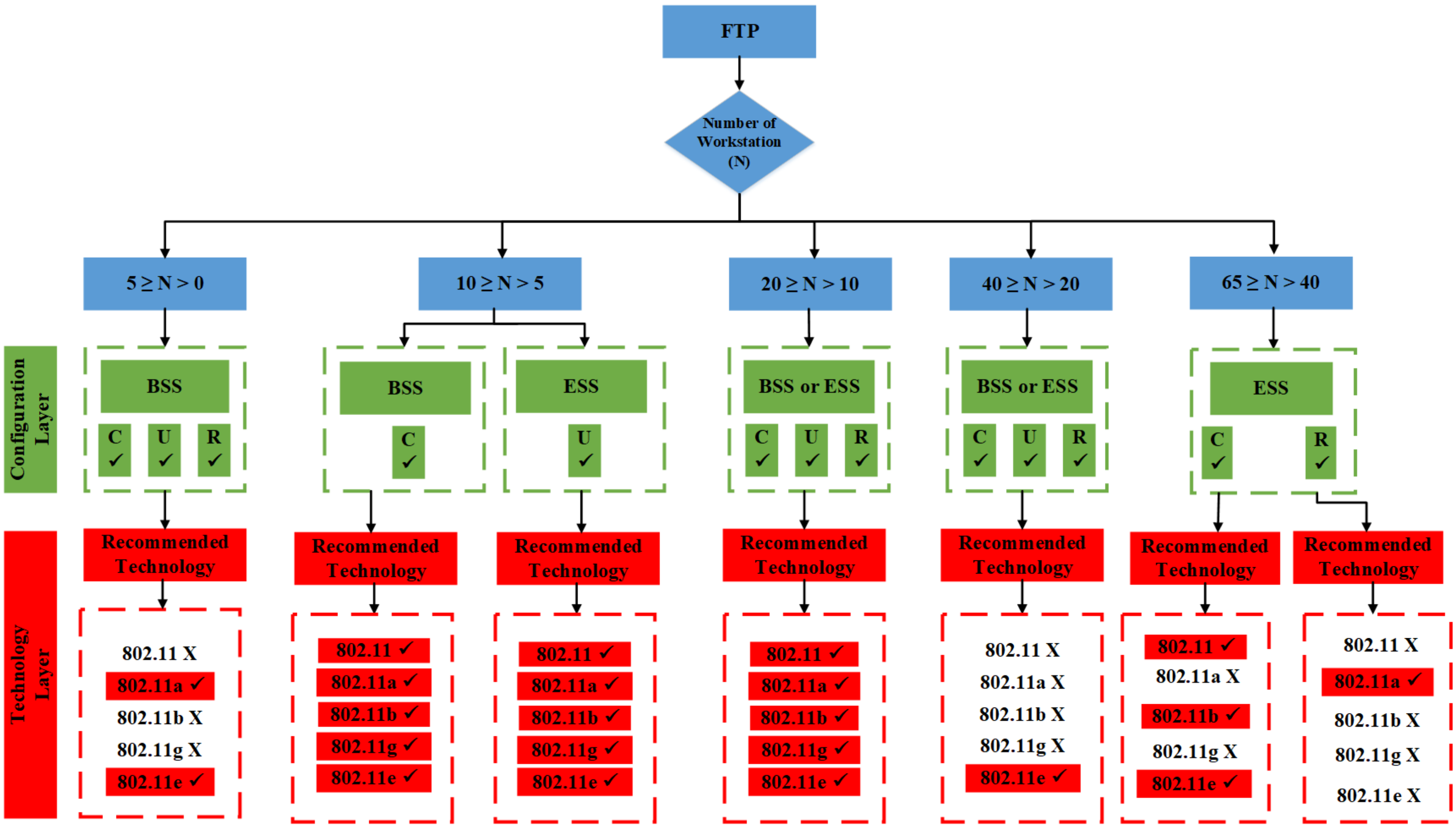


Figure 5. 7 Generic flowchart of the proposed algorithm for FTP

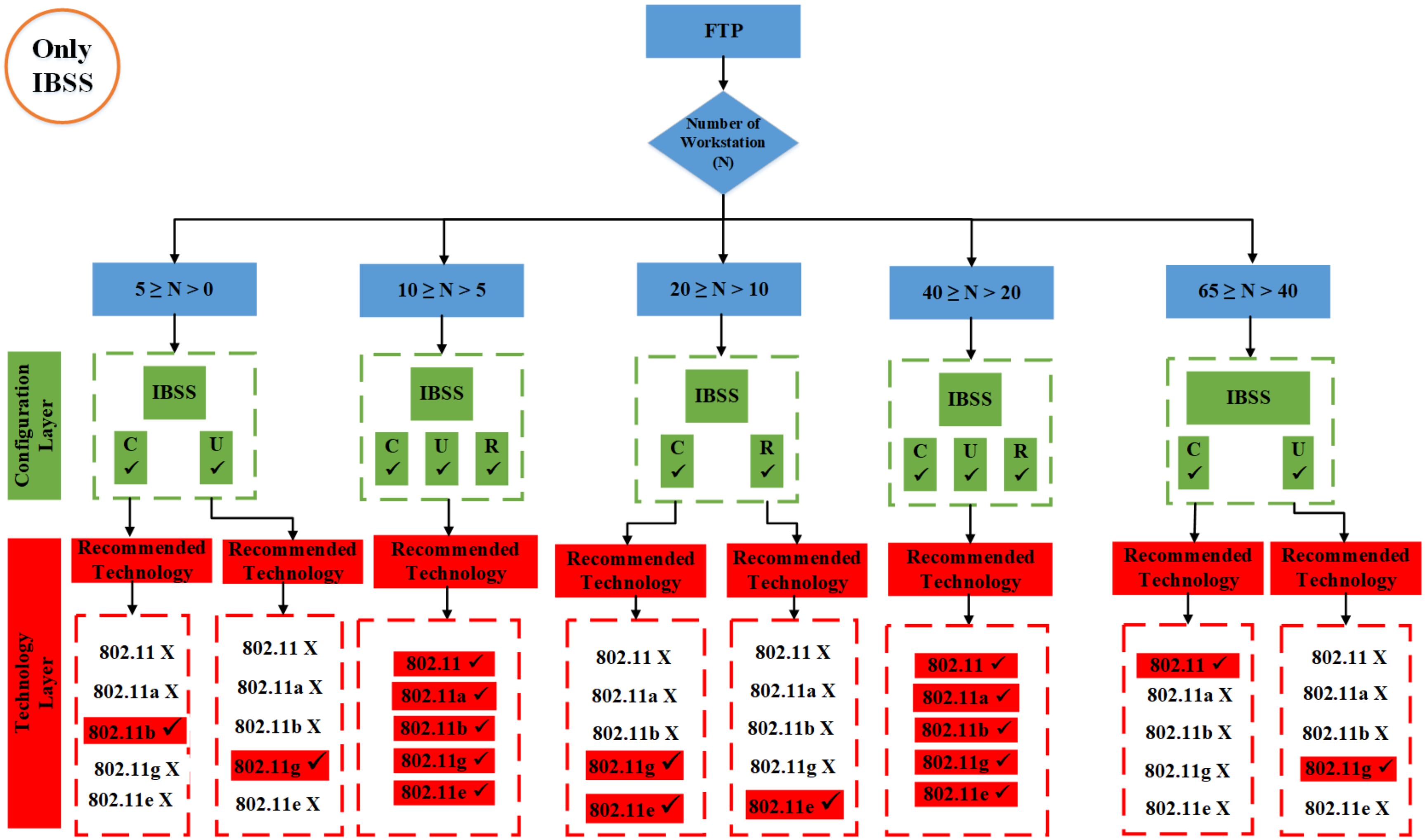


Figure 5. 8 Flowchart of only IBSS's results for FTP

3. For the third category, in which 20 ≥ N > 10, BSS and ESS architectures provide the best performance for all five technologies among all space distributions. In the case of IBSS, however, the client has the option of many choices. First, the optimal technologies for use are 802.11 g and 11e only if configured in circular distribution. Secondly, if configured randomly, 802.11e technology is used because of a somewhat higher difference in its packet loss metric adequacy (Mohd Ali, Dhimish, Alsmadi, & Mather, 2020).
4. While ESS and BSS give the best performance in all three space distributions for the fourth group, where 40 ≥ N > 20, if the technology is used with only IEEE 802.11e. However, all technologies operate across all spatial distributions according to the IBSS flowchart, as shown in Figure 5.8.
5. The most suitable architecture for the large-scale network in the fifth group, where 65 ≥ N > 40, is ESS as is shown in Figure 5.7. There are then a number of options for the client to choose from. First of all, all 802.11, 11b and 11e technologies can be used optimally when the network is configured in circular distribution only; the second-best choice is to use randomly configured IEEE 802.11a technologies. The client has a range of choices to pick from the IBSS flowchart, on the other hand. First, 802.11 is the optimum technology to be used if in circular distribution it is set up. The second-best choice, as shown in Figure 5.8, is to use 802.11g uniformly configured technology (Mohd Ali, Dhimish, Alsmadi, & Mather, 2020).

5.3.3 Email

1. For categories 1 and 2 and 3, where 5 ≥ N > 0, 10 ≥ N > 5 and 20 ≥ N > 10, respectively, in the generic flowcharts, the BSS and ESS architectures have the best output for all spatial distributions if only three technology systems are applied, including 802.11a, 11g and 11e, as shown in Figure 5.9 (Mohd Ali, Dhimish, Alsmadi, & Mather, 2020).
2. In the fourth and fifth categories, where 40 ≥ N > 20 and 65 ≥ N > 40, respectively, for these major networks, the best architecture is the ESS. The client then has two options to choose from (802.11a and 802.11g) in the fourth category and has three options to select (802.11a, 11g 11e) in the fifth category according to the information provided in Figure 5.9. Both options are optimal to use across all spatial distributions.

3. In Figure 5.10, 802.11a shows the best performance in the first four categories for all spatial distributions in the IBSS flowchart; whilst all technologies are performing in the fifth category (Mohd Ali, Dhimish, Alsmadi, & Mather, 2020).

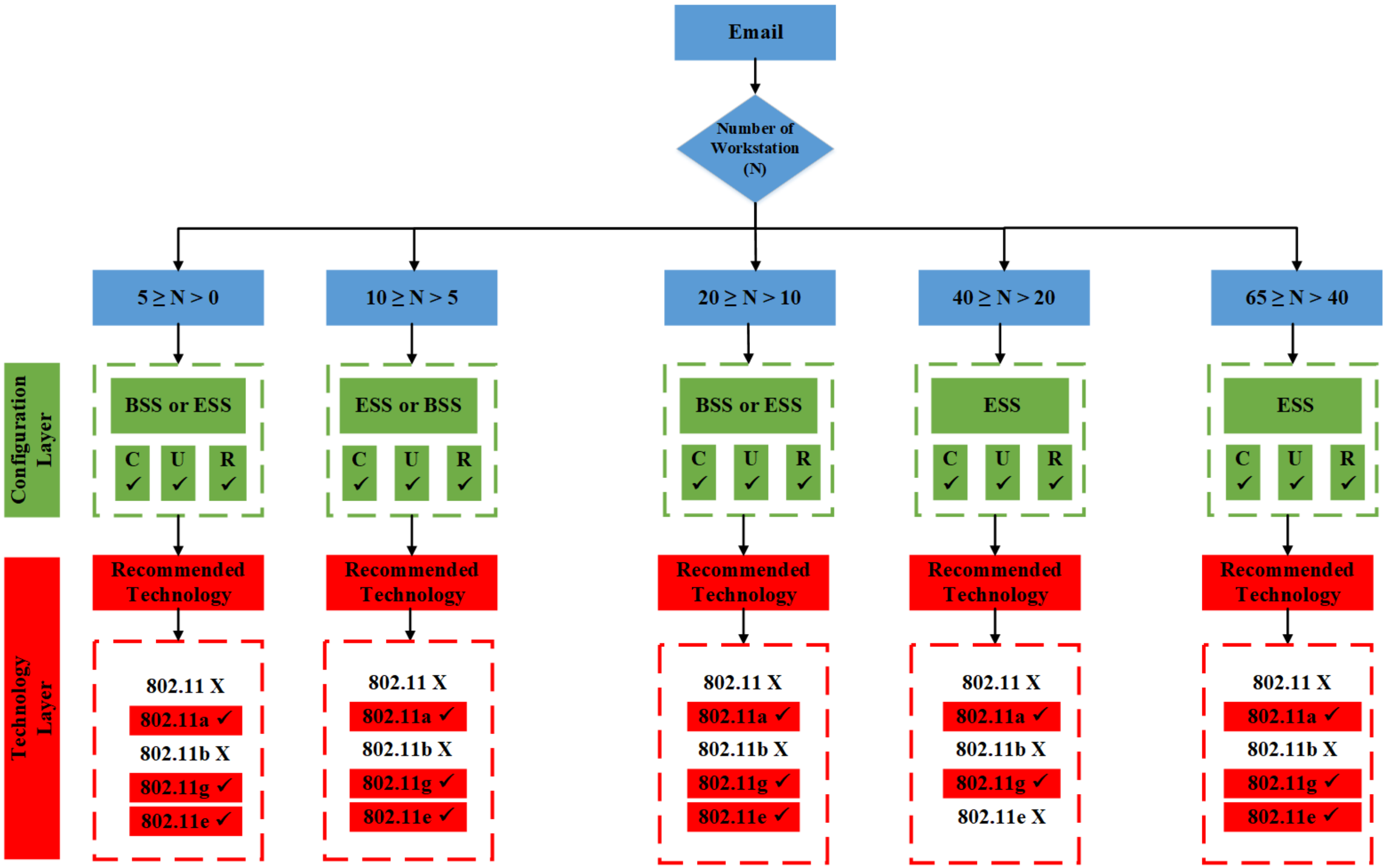


Figure 5. 9 Generic flowcharts of the proposed algorithm for Email

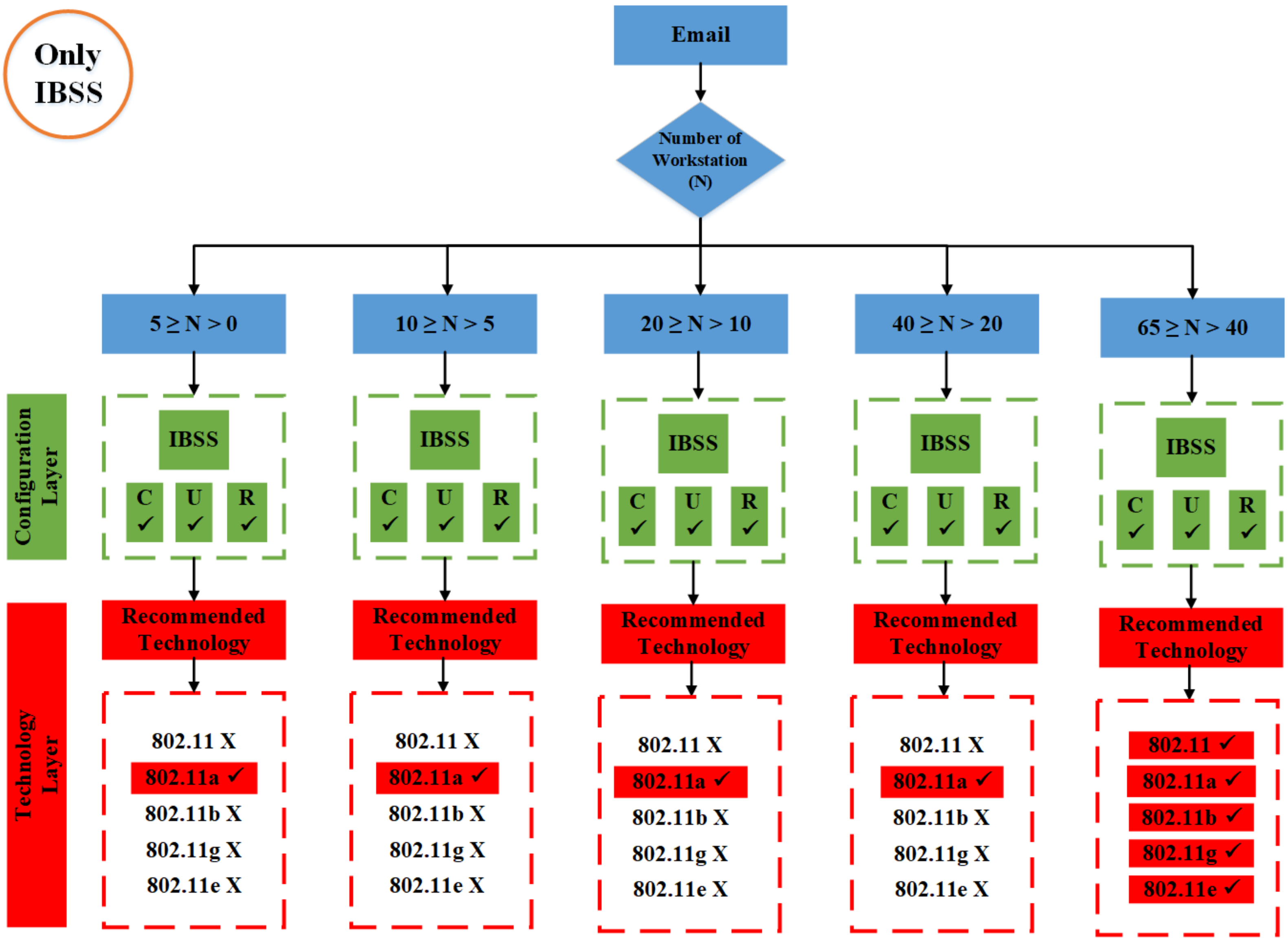


Figure 5. 10 Flowchart of only IBSS's results for Email

5.4 Comparative Study

In this section, a brief comparison between our proposed method with multiple algorithms presented will be offered. The following features have been compared and summarized in Table 5.1, including QoS metric parameters, number of nodes, network architecture, IEEE technology, and the simulation model.

Analysis of the impact of node's Spatial Distribution (i.e., Circular, Random, Uniform) on the network performance for all five IEEE 802.11 technologies was carried out. The recent studies did not demonstrate this particular area of research such as the analysis made in Al-Maqri, Mansoor, Sabri, Ravana, & Yaseein (2020), Sammour & Chalhoub (2020), Khiat, Bahnasse, EL-Khail, & Bakkoury (2017) and Wei, Hong, & Shi (2016) and considered only one distributed pattern.

Recent works Nosheen & Khan (2020), Khiat, Bahnasse, EL-Khail, & Bakkoury (2017) and Sammour & Chalhoub (2020) illustrate and implement their models with different nodes of two and (5-50), respectively, in the calculations of the optimized network configuration with metrical parameters such as end-to-end delays and throughput. However, only BSS and IBSS network architectures were used to validate their proposed approaches.

On the other hand, other studies such as Hassan, Idrus, King, Ahmed, & Faulkner (2020), So & Lee (2019) and Eliab, Kim, Lee, Lee, & So (2019) are only considered IEEE 802.11a technology for its assessment framework. Likewise, Miraz, Ganie, Molvi, Ali, & Hussein (2017) and Schmitt, Redi, Cesar, & Bulterman (2016), assessed IEEE technologies using a fixed number of nodes (24) and (9), respectively. Whereas Rattal, Badri, & Moughit (2016) and Sllame (2017) evaluated the network on the basis of (15) and (30) nodes, taking into account only one network architecture BSS and IBSS, respectively. However, the proposed approaches have only been validated with IEE 802.11 and 11g as the only WLAN technology, respectively.

In addition, methods such as Lawal & Mu'azu (2020), Sllame, Raey, Mohamed, & Alagel (2015), Orfanou, Tselios, & Katsanos (2015), Krupanek & Bogacz (2016) and Wei, Hong, & Shi (2016) assess network based on the fixed number of nodes where the measurements of the optimum network configuration have metric parameters as the delay. Furthermore, an evaluation of various

IEEE technologies was assessed with regard to a fixed number of nodes, with only one network architecture of IBSS and BSS in view.

Despite some studies using different nodes, which vary from 5 to 49, their model has been integrated; though, only IBSS and BSS network architectures have been validated for their proposed approaches. Another drawback associated with Sllame, Raey, Mohamed, & Alagel (2015) and Orfanou, Tselios, & Katsanos (2015) approaches, is that it only takes into account the algorithm evaluation using the single IEEE 802.11 standard, IEEE 802.11 g, 11b and 11e in particular.

By contrast with the above limitations, in this work, we present the development of a novel evaluation parametric approach that is capable of identifying the optimum network configuration using three different network architectures: BSS, ESS and IBSS. The proposed approach has been evaluated for five stand-alone applications using different node size (1 to 65) with respect to five different IEEE technology standards including 802.11, 802.11a, 802.11b, 802.11g and 802.11e.

Table 5. 1 Comparative results between the proposed approach and stand-alone methods available in the literature

Reference	Approach	QoS metric parameters	Number of nodes	Network Architecture	IEEE Technology	Simulation model
(Al-Maqri, Mansoor, Sabri, Ravana, & Yaseein, 2020)	In order to improve the scheduling of multimedia traffic in terms of channel use, a framework was implemented to maximize the use of extra bandwidth to achieve optimal transmission efficiency of multimedia applications.	End-to-end delay Bandwidth	10	BSS	802.11g 802.11e	NS2
(Schmitt, Redi, Bulterman, & Cesar, 2017)	Offer an empirical approach to network readiness and evaluation of desktop video conferencing.	Packet Loss Queue Delay	9	BSS	NA	OPNET
(Hassan, Idrus, King, Ahmed, & Faulkner, 2020)	In multiple BSS scenarios, using the idle sense (IS)-based MAC system, a series of schemes were proposed to boost the efficiency of the WLAN, which resembles the wireless side of the fibre-wireless (FiWi) networks.	Fairness	4-120	BSS	802.11a	OPNET
(Sammour & Chalhoub, 2020)	Several of the common rate adaptation systems are presented and their features summarized. As regards the methods used to approximate channel conditions and selection, they	Throughput MCS values selected by the nodes Frame Loss Rate (FLR) based on MPDUs	5-50	IBSS BSS	802.11ac	NS3

	are also categorized into different classifications according to their design and functionality.	FLR based on A-MPDUs				
(Sllame, 2017)	VoIP QoS performance metrics were studied using different routing protocols to evaluate QoS.	Jitter WLAN delay Throughput	30	IBSS	802.11g	OPNET
(Lawal & Mu'azu, 2020)	In an attempt to optimise the effectivity of QoS for VoIP in terms of delay in the WiMAX and WLAN networks, a distributed client-server model was built in this work to achieve greater efficiency provided to users. Incorporating Server BSs and applying the OFDM technique increased QoS performance in terms of delay.	Delay	30, 55 and 77	BSS WiMAX	802.11 802.16	OPNET
(Sllame, Raey, Mohamed, & Alagel, 2015)	VoIP QoS performance metrics were studied using different routing protocols.	Jitter (DSR(FIFO) has the least value of jitter, which is nearly zero). LAN delay (AODV(FIFO) case has the best WLAN delay which is 0.8 s). Packets size (500 calls/h).	15	IBSS	802.11b	OPNET

(Khiat, Bahnasse, EL-Khail, & Bakkoury, 2017)	Review and explore the impact of QoS mechanisms on web-based services incorporating 802.16e (Best Effort, nRTPS) and IEEE802.11e (DCF, PCF, HCCA, EDCA) networks.	TCP delay TCP retransmission count HTTP Response and Database Page Response Time.	2	BSS	802.11e 802.16	OPNET
(Orfanou, Tselios, & Katsanos, 2015)	Assess the terms of EDCA 802.11e QOS support protocol in the scenario 802.11a of 36 Mbps.	Average delay (of voice grows to 46 ms, and the video reaches the 130 ms for 45 stations). Queue size (for voice and video traffic remain below 0.4 packets for 35 stations).	5-45	BSS	802.11e	Möbius™
(Miraz, Ganie, Molvi, Ali, & Hussein, 2017)	The OPNET simulation tool is used to classify certain conditions and specifications that influence the QoS of VoIP across heterogeneous networks such as WLAN, WiMAX and between them. It addresses network optimization for both intra- and inter-system traffic to minimize the deterioration of QoS.	Delay Jitter	24	BSS	802.11 802.16	OPNET
(Wei, Hong, & Shi, 2016)	Different clients have been examining the performance of HTTP and FTP protocols in the	Average queuing delay TCP delay	5-30	IBSS	NA	OPNET

	same network environment.					
(Krupanek & Bogacz, 2016)	The study compares the performance of DCF and PCF channel access schemes in terms of support for real-time traffic.	Delay Throughput	50	BSS	802.11	OPNET
(So & Lee, 2019)	A basic structure that allows the use of multiple channels is proposed in this article. By supporting several radios as well as using advanced hardware such as SDR to split a single channel into multiple channels, multiple channels could be used. Channels allocated to nodes are dependent on their approximate distance from the AP.	Throughput	100	ESS	802.11a	NS3
(Eliab, Kim, Lee, Lee, & So, 2019)	This article suggests G-DCF, a wireless LAN MAC protocol that increases device throughput over 802.11 DCF by enabling exposed devices to simultaneously transmit. The key concept is to create network groups and have all nodes	Fairness Packet loss Throughput	20	ESS	802.11a	NS3

	broadcast together in the same group.					
(Rattal, Badri, & Moughit, 2016)	Presented the deployment of the H.323 signalling method developed as part of three gatekeepers in the same VoIP ad hoc network configuration where nodes receive their contact details and instantly measure the distances between the three gatekeepers that are accessible; the minimum distance would be the essential criteria for determining the selected gatekeeper.	End-to-end delay Jitter Packet loss rate	15	BSS	802.11	OPNET
(Nosheen & Khan, 2020)	This work has developed innovative network resource allocation strategies to provide high QoE for video streams on the IEEE 802.11ac network for all traffic load conditions. High throughput and low delay, along with high throughput and delay fair value are provided by the algorithms that	Throughput Delay	2	BSS	802.11ac	NS3

	have been developed.					
Present study	To define the best network architecture, analyse stand-alone software metrics of different IEEE 802.11 technologies.	Delay Jitter Throughput Packet loss	1-65	BSS ESS IBSS	802.11 802.11a 802.11b 802.11g 802.11e	OPNET

5.5 Summary

In this chapter, a way of analysing the network performance to achieve the most optimized network setup based on the currently available technologies for stand-alone services was conducted. In addition, it identifies which IEEE technology/technologies and network architecture can be implemented for future internet applications and technologies.

While analysing the findings, the options accessible to the client will be listed. Highest rated technologies in all three networking architectures are proposed (IBSS, BSS and ESS). The results of the study are split into two major case studies on the form of traffic being carried out: real-time applications (VoIP and VC) and best-effort applications (HTTP, FTP, Email). For each group of nodes for a particular application, the results format has a flowchart. The number of nodes, network structures, spatial distributions, and WLAN technologies used has been defined by the flowchart. The results of the study are known as AFM for stand-alone applications.

CHAPTER 6 RESULTS OF MIXED APPLICATIONS

6.1 Introduction

The results of mixed applications will be introduced in this chapter. This work presents the analysis of each best-effort application (HTTP, FTP, Email) and real-time application (VoIP and Video Conferencing) for three spatial distribution (Circular, Random, Uniform) of different IEEE 802.11 technologies in order to identify the optimum network architecture for five different mixed applications case studies.

The proposed algorithm would also have the best overall network efficiency and high-quality services, which is in line with the six rankings of the IEEE 802.11 technologies (802.11, 11a, 11b, 11 g, 11e and 11n), for a specified mix of applications in the specific context.

Five different mixed applications cases have been evaluated and analysed under different factors such as Spatial distribution, number of nodes and network architectures.

1. 50% VoIP and 50% VC (Real-time applications): All scenarios in this case study are specialized in examining and analysing the mixes of real-time applications only. “50VC”, is shortened for the purposes of readability.
2. 40% HTTP, 30% FTP, 30% Email (Best-effort applications): All configurations that have been implemented in this case study mainly concern the mixes of best-effort applications evaluated in this scenario. “Best-effort” is shortened for the purposes of readability.
3. 20% VoIP, 20% VC, 20% HTTP, 20% FTP, 20% Email: where 20% is the percentage of nodes in each considered application in this case study. “20ALL”, is shortened for the purposes of readability.
4. Majority of the traffic as Best-effort (60% HTTP, 20% VoIP and 20% VC): the mixes of real-time and best-effort applications have been implemented here but the majority and concentration of the traffic used are best-effort. “60HTTP”, is shortened for the purposes of readability.

5. Divide the traffic similarly – 50% Real-time and 50% Best-effort (40% VoIP, 10% VC and 30% FTP, 20% HTTP): This case study has been configured based on the similarity of traffic's percentages between real-time and best-effort services. "40VoIP", is shortened for the purposes of readability.

The format of results has a flowchart and bar chart for each group of nodes for each mixed application. The flowchart has identified the number of nodes, network architectures, spatial distributions, and WLAN technologies used. In mixed-applications, the results are known as SFM.

The results are indicated by the existence of the access point; hence, the result tables are represented (translated), as shown later for each application in two flowcharts: the generic flowcharts and the IBSS chart. The final step is to highlight the best performing technology per case study (network configuration) and per each group of nodes for that application.

- If at least one access point is available, the proposed algorithm will be implemented as shown in Figure 3.34 and the results in Figures 6.1, 6.8, 6.17, 6.21 and 6.27. The case applies to both the ESS and BSS architecture layers. The six IEEE 802.11 technologies and three space distributions all operate on all scenarios.

- The algorithm proposed in Figure 3.34 and Figures 6.2, 6.9, 6.18, 6.22 and 6.28 of the IBSS results can be used if the network is configured without an access point. The six IEEE 802.11 technologies and three space distributions all operate on all scenarios.

6.2 Mixed of Real-Time Applications (50% VoIP and 50% VC)

Figures 6.1 and 6.2 show both results' algorithms for all the nodes (5, 10, 20, 40 and 65) running the 50% VoIP and 50% VC case study and using all six WLAN standard technologies (802.11, 802.11a, 802.11b, 802.11g, 11e, and 802.11n) in three spatial distributions (C, U, R). The results of both algorithms identify five main node groups, as follows:

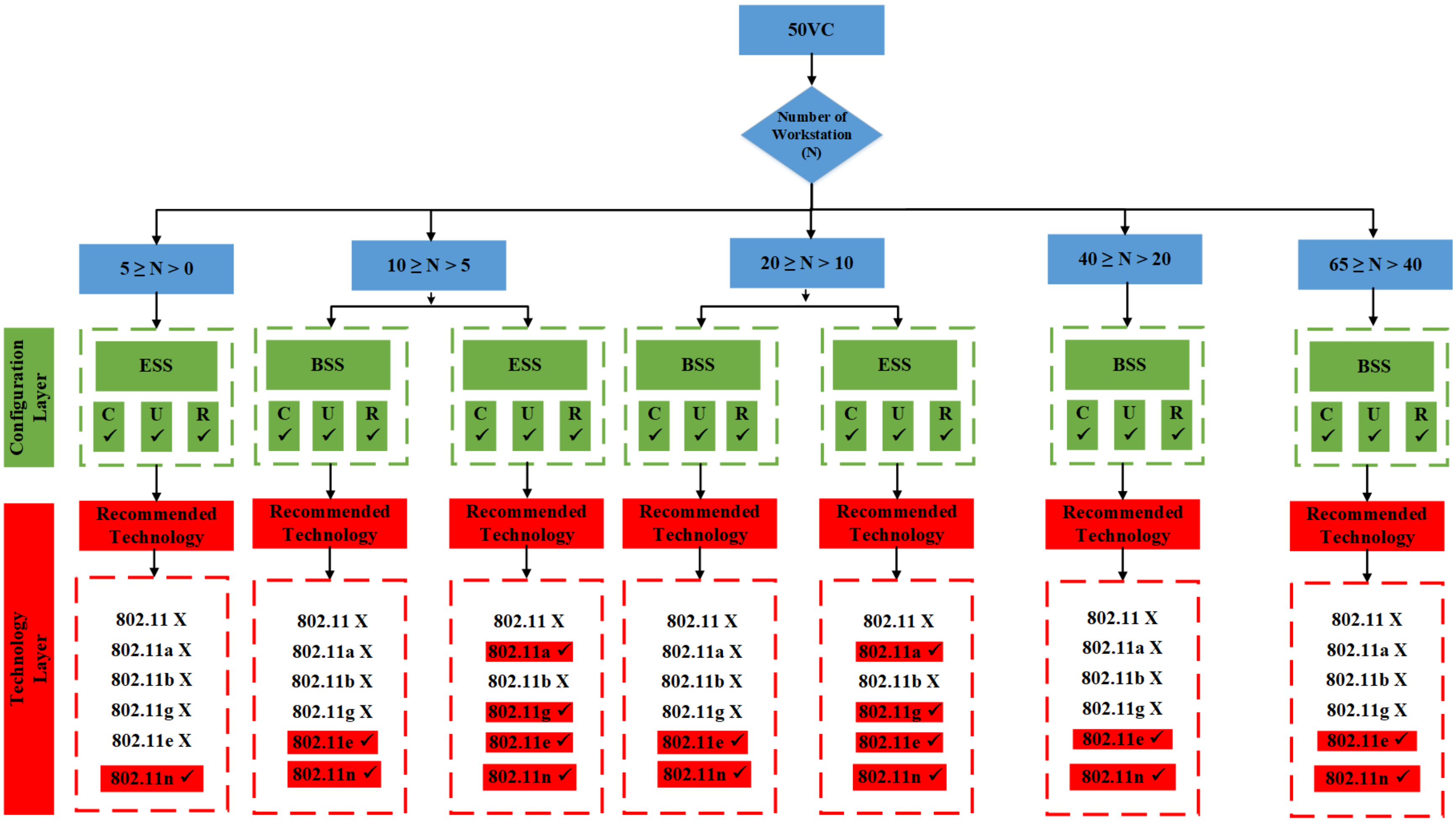


Figure 6. 1 Generic flowchart of the proposed algorithm for 50%VC

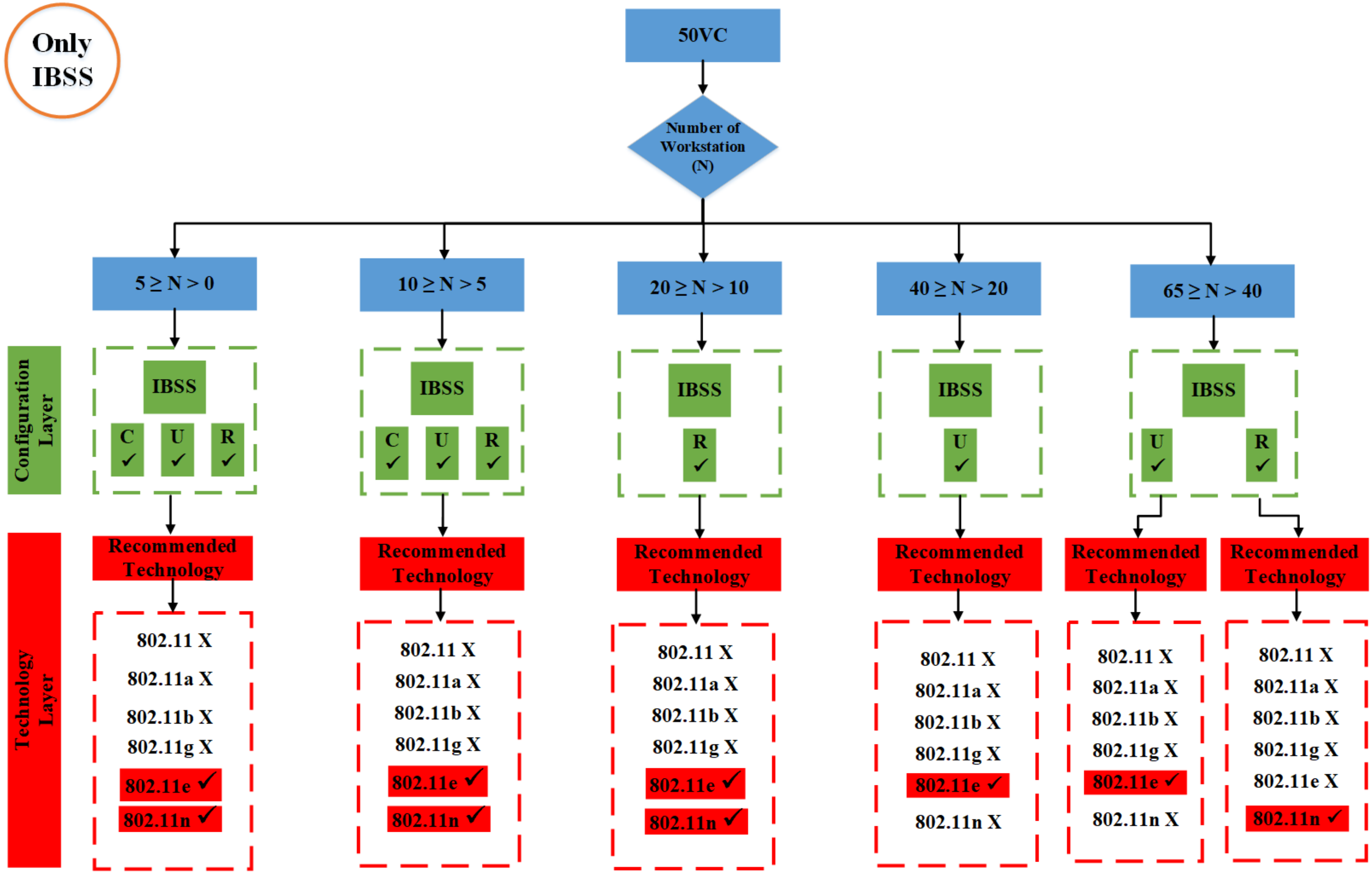
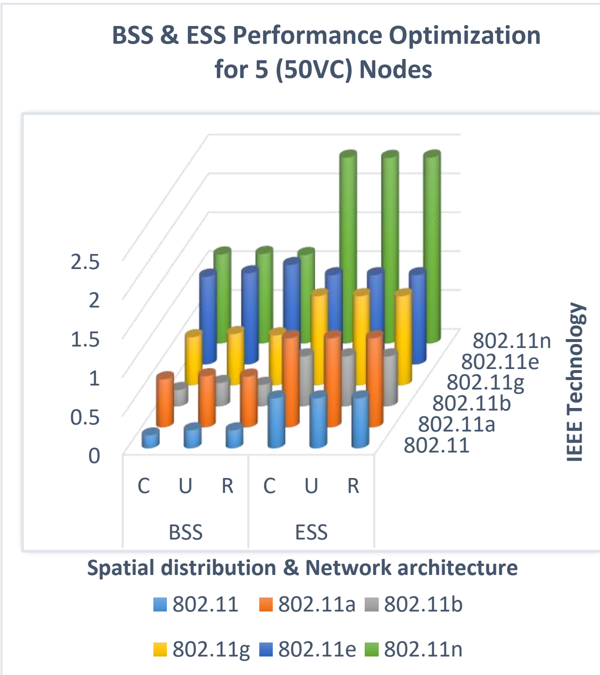
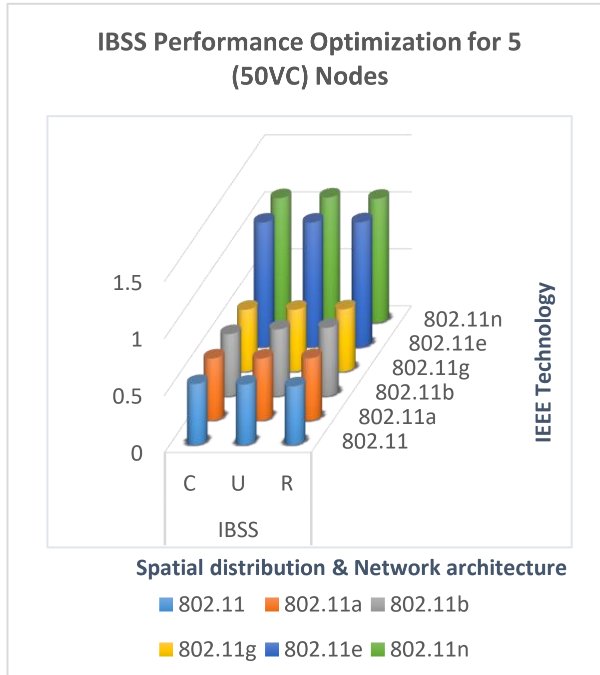


Figure 6. 2 Flowchart of only IBSS's results for 50VC

1. When a client builds a network with a limited number of nodes, ESS is the ideal network system in the first group, where 5 ≥ N > 0, as can be seen in Figure 6.3(a); IEEE 802.11n is, moreover, the best technology for all special distributors. However, in the case of IBSS, both 802.11e and 11n technologies provide the best performance as shown in Figure 6.3 (b) (Mohd Ali, Dhimish, Alsmadi, & Mather, 2020).



(a)



(b)

Figure 6. 3 Performance Optimization for 5 (50%VC) nodes.
(a) BSS & ESS, (b) only IBSS

2. In the second and third categories, where 10 ≥ N > 5 and 20 ≥ N > 10, respectively, both BSS and ESS architectures have the best performance in the generic flowchart as shown in Figures 6.4 (a) and 6.5 (a). Both 802.11e and 11n technologies are fine for all three space distributions for BSS architecture. The ESS solutions are thus recognized as preferable for IEEE 802.11a, 11 g, 11e, and 11n systems. In contrast, only IEEE 802.11e and 11n technologies are performing well with all space distribution in the second and third categories according to the IBSS flowchart, as illustrated in Figures 6.4(b) and 6.5(b) (Mohd Ali, Dhimish, Alsmadi, & Mather, 2020).

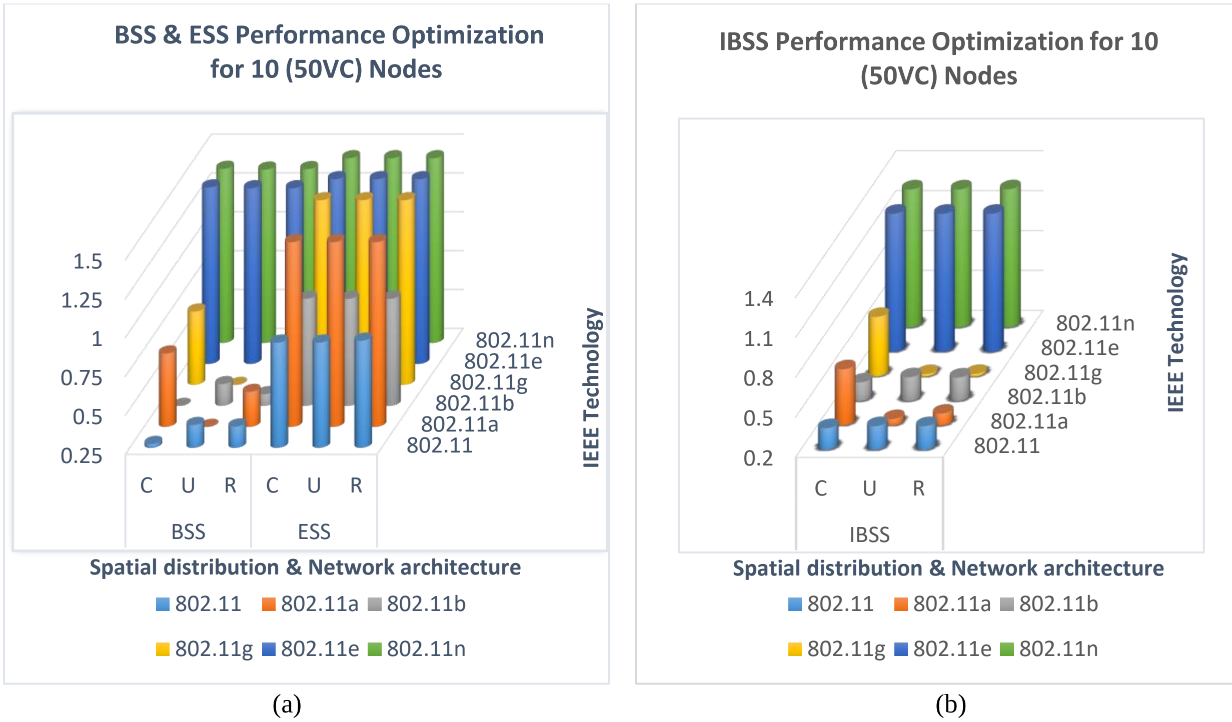


Figure 6. 4 Performance Optimization for 10 (50%VC nodes). (a) BSS & ESS, (b) only IBSS

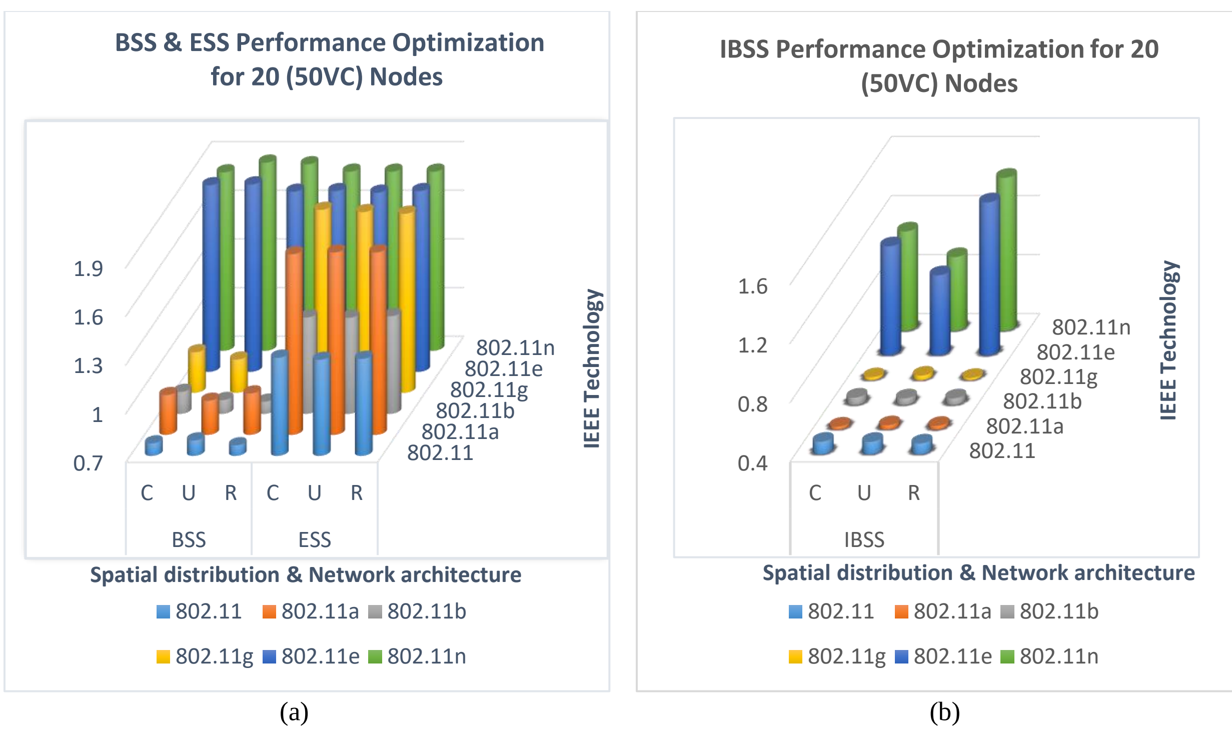
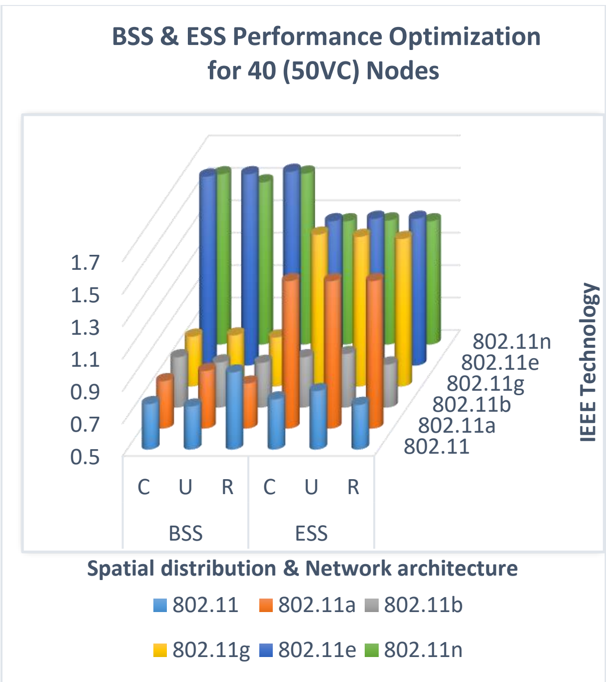


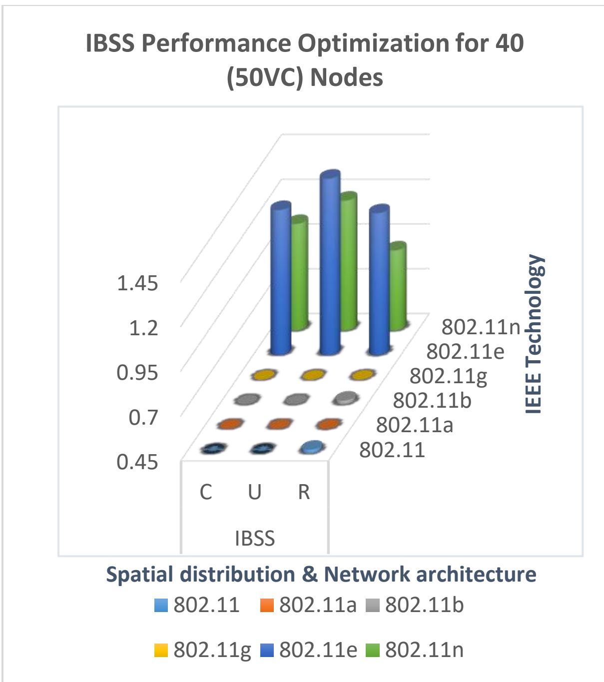
Figure 6. 5 Performance Optimization for 20 (50%VC nodes). (a) BSS & ESS, (b) only IBSS

3. In the fourth and fifth categories, where 40 ≥ N > 20 and 65 ≥ N > 40, respectively, in the generic flowchart, as can be seen in Figures 6.6 (a) and 6.7 (a), BSS provides the best performance.

   All three spatial distribution systems perform well with 802.11e and 11n technologies. While, in the IBSS results, 802.11e technology offers the user the best possible performance if they are configured uniformly in the fourth and fifth categories; however, 802.11n will be optimum in the fifth category if configured randomly as shown in Figures 6.6 (b) and 6.7 (b).



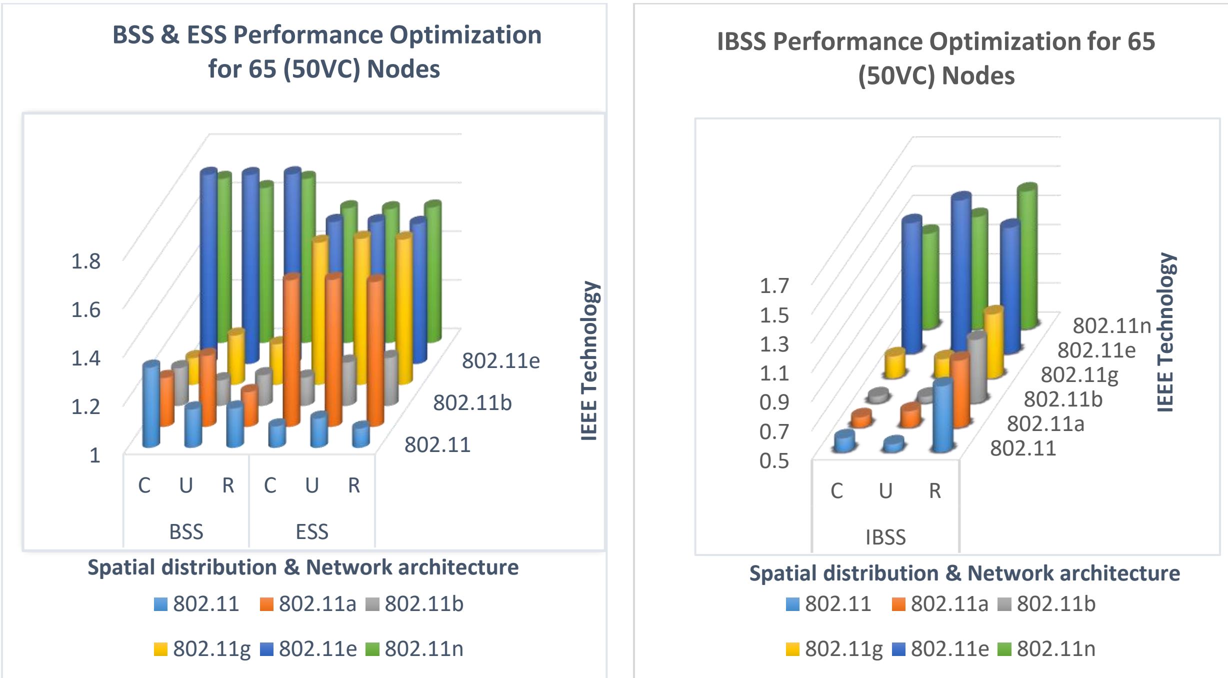
(a)



(b)

Figure 6. 6 Performance Optimization for 40 (50%VC nodes).

(a) BSS & ESS, (b) only IBSS



(a) (b)

Figure 6. 7 Performance Optimization for 65 (50%VC nodes).
(a) BSS & ESS, (b) only IBSS

6.3 Mixed of Best-effort Applications (40% HTTP, 30% E-mail, and 30% FTP)

Both Figures 6.8 and 6.9 illustrate the results of both algorithms for all the nodes (5, 10, 20, 40 and 65) running the Best-effort case study and using all six WLAN standard technologies (802.11, 802.11a, 802.11b, 802.11g, 11e, and 802.11n), presented as follows:

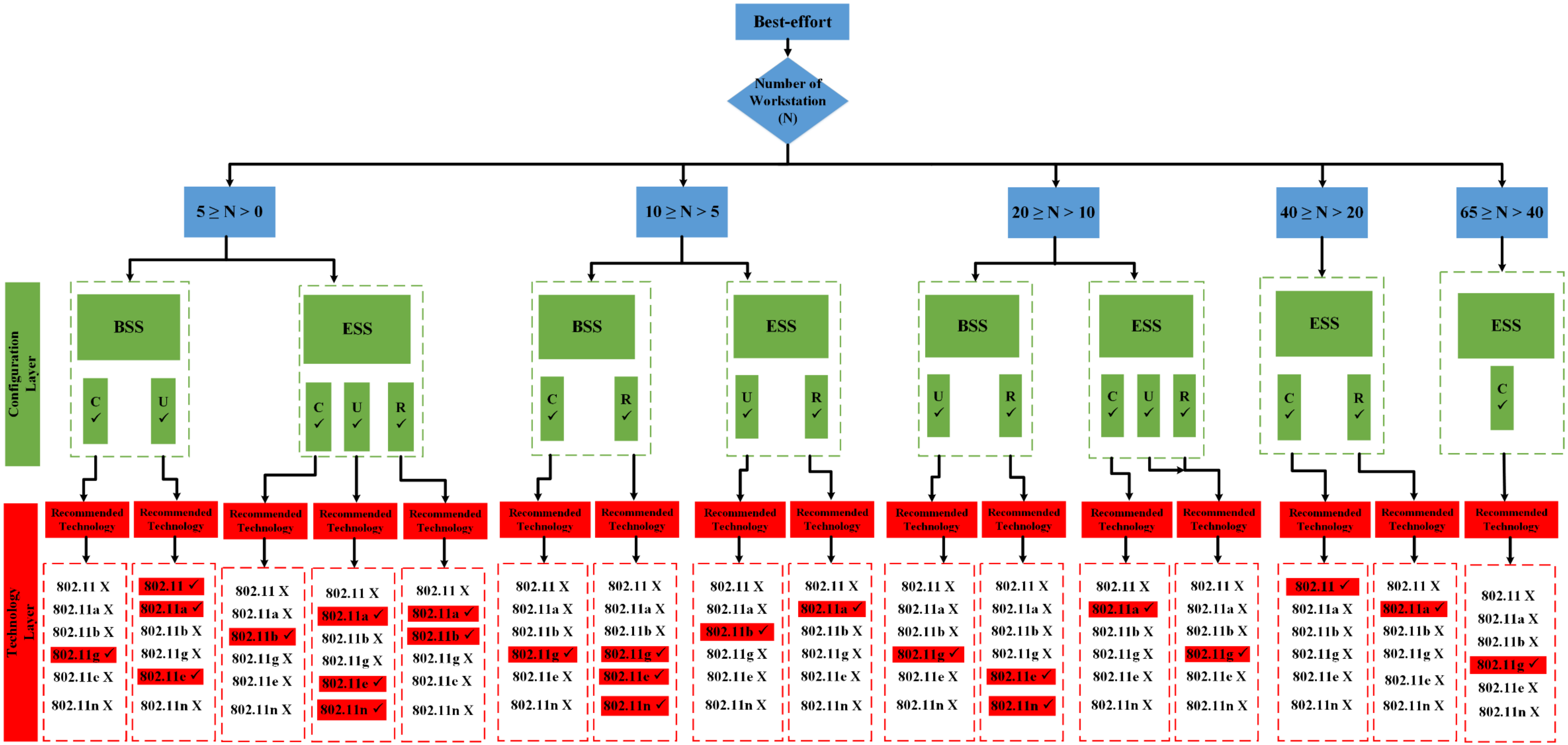


Figure 6. 8 Generic flowcharts of the proposed algorithm for Best-effort

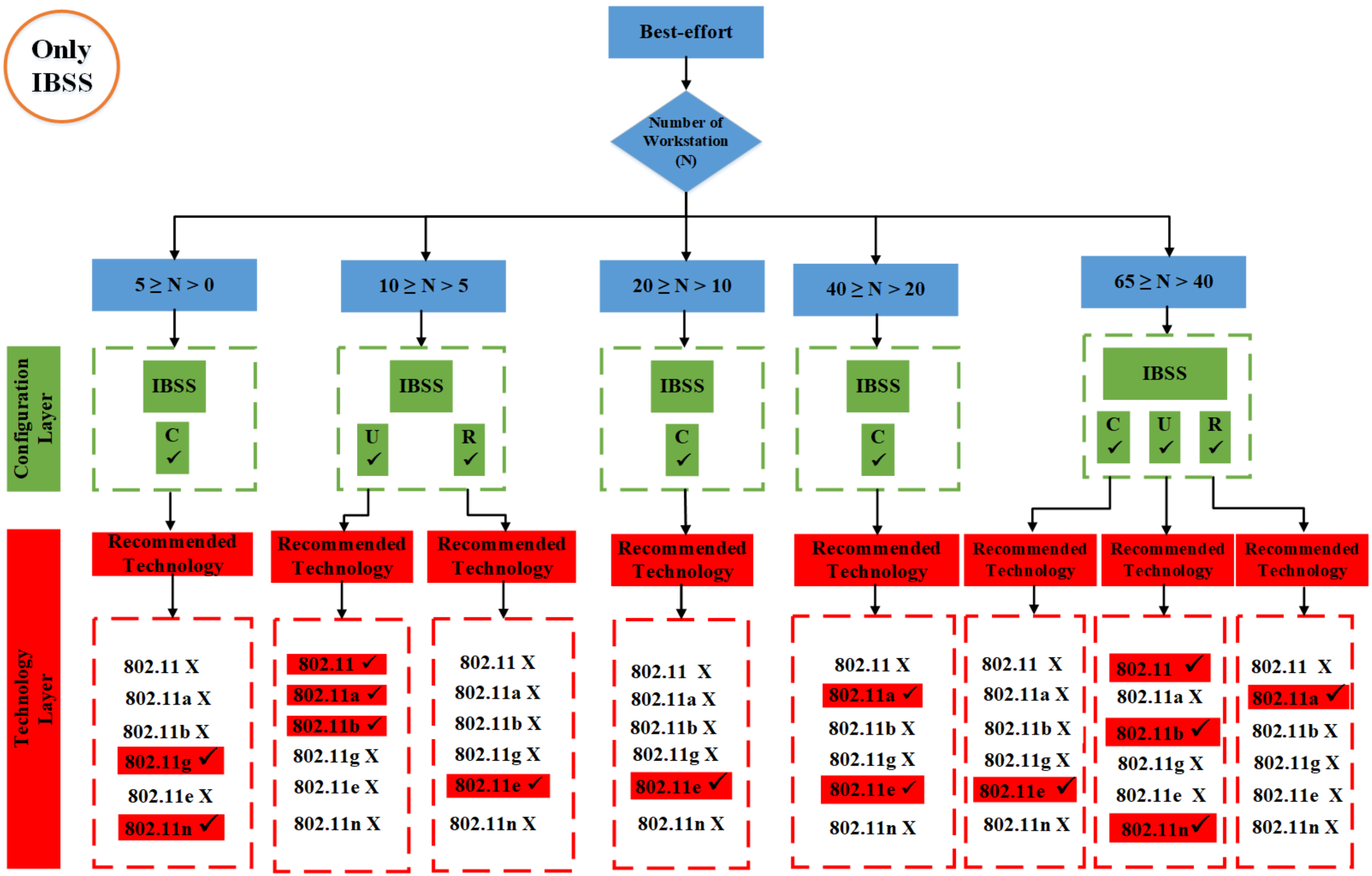
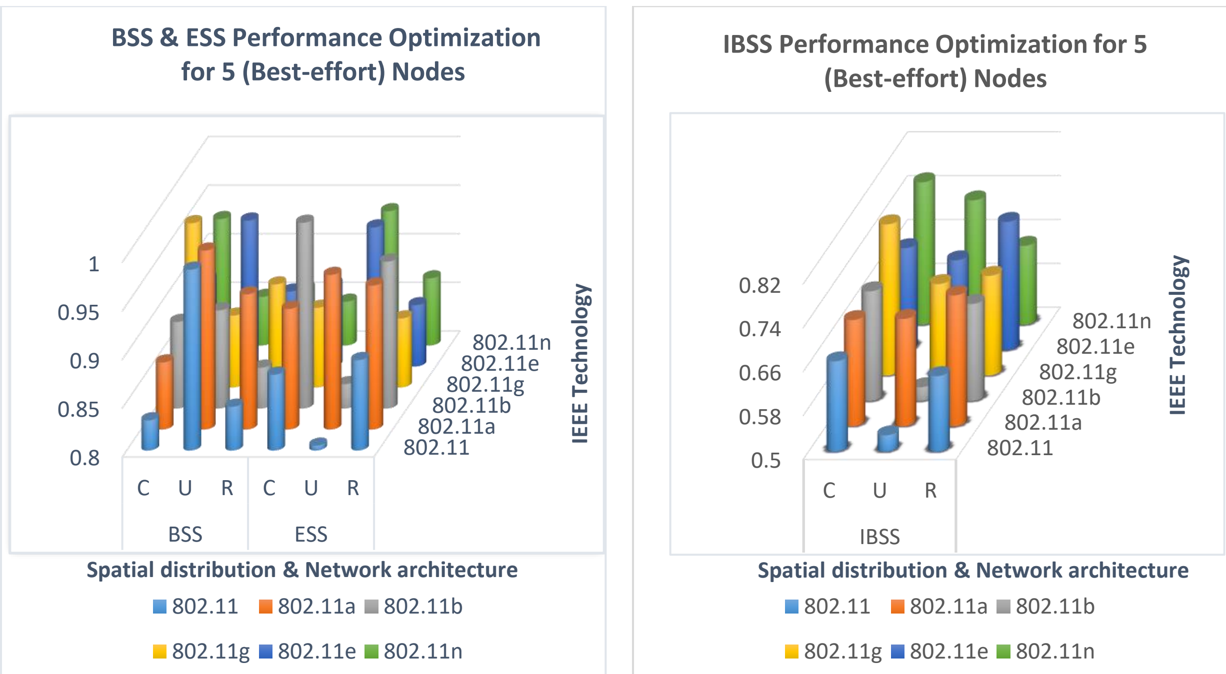


Figure 6. 9 Flowchart of only IBSS's results for Best-effort

1. BSS and ESS give a range of options in the first category, where $5 \geq N > 0$. IEEE 802.11 g technologies work well for BSS architecture only with a circular layout of the network. In addition, the technologies IEEE 802.11, 11a and 11e are good only if uniformly configured. ESS offers several options on the other hand. IEEE802.11b is only recognized in circular and random distributions as the preferable solutions. Moreover, IEEE 802.11a provides the optimum performance if it is configured uniformly or randomly, where both 11e and 11n technologies are performing in a uniform distribution, as shown in Figure 6.10 (a); whereas the findings from the IBSS provide the best user output for circular distribution, both the 802.11 g and the 11n technologies, which appear in Figure 6.10 (b).



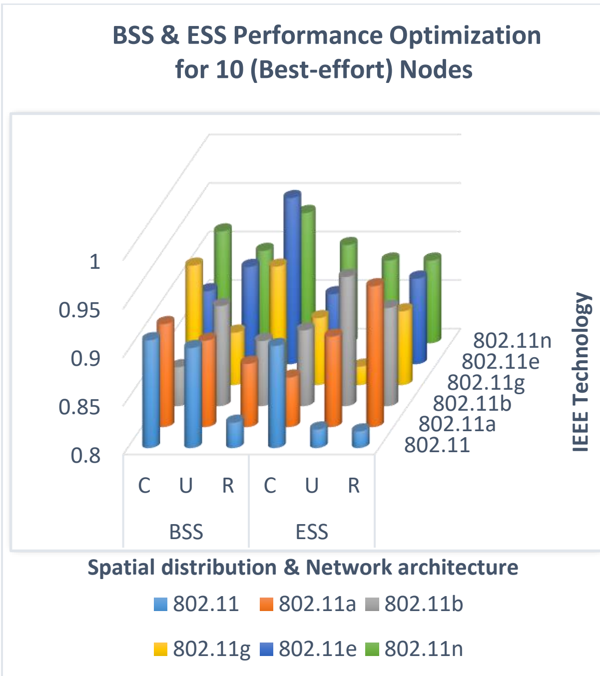
(a) (b)

Figure 6. 10 Performance Optimization for 5 (Best-effort) nodes.

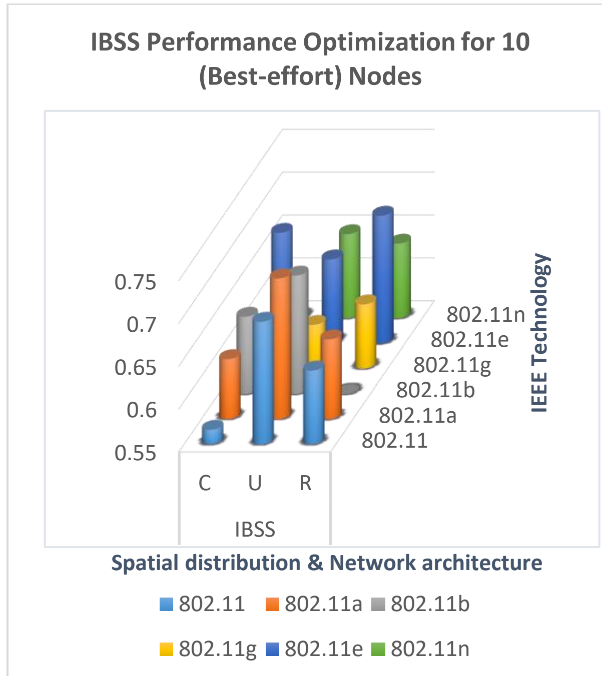
(a) BSS & ESS, (b) only IBSS

2. BSS and ESS have many choices in the second range, where $10 \geq N > 5$, are available. IEEE 802.11g technology works well for BSS architecture only with a circular layout of the network. Moreover, even when configured at a random pace, IEEE 802.11g, 11e and 11n technologies work well. ESS provides a variety of alternatives, on the other hand. IEEE802.11b is only known as the best option if the network is uniformly configured. In

addition, IEEE 802.11a provides the optimum performance if it is configured randomly, as shown in Figure 6.11 (a). The IBSS findings provide the client with the best results in the circular deployment, as shown in Figure 6.11(b), using 802.11g and 11n technologies.



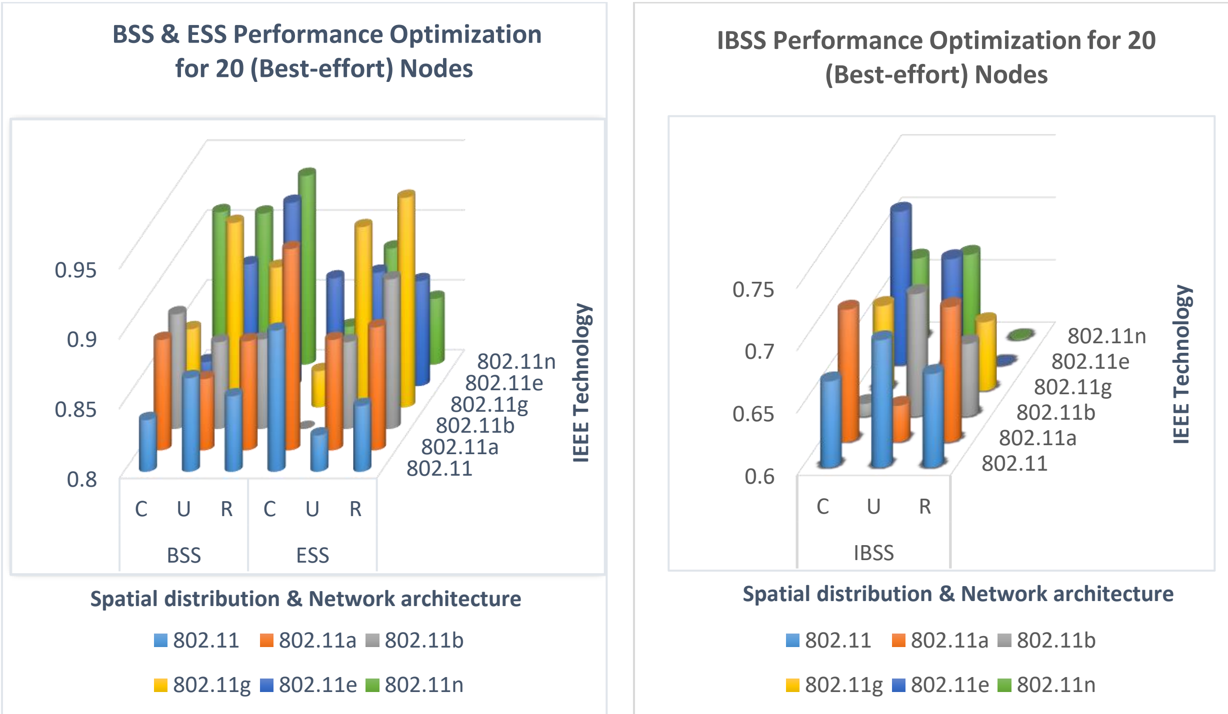
(a)



(b)

Figure 6. 11 Performance Optimization for 10 (Best-effort) nodes.
(a) BSS & ESS, (b) only IBSS

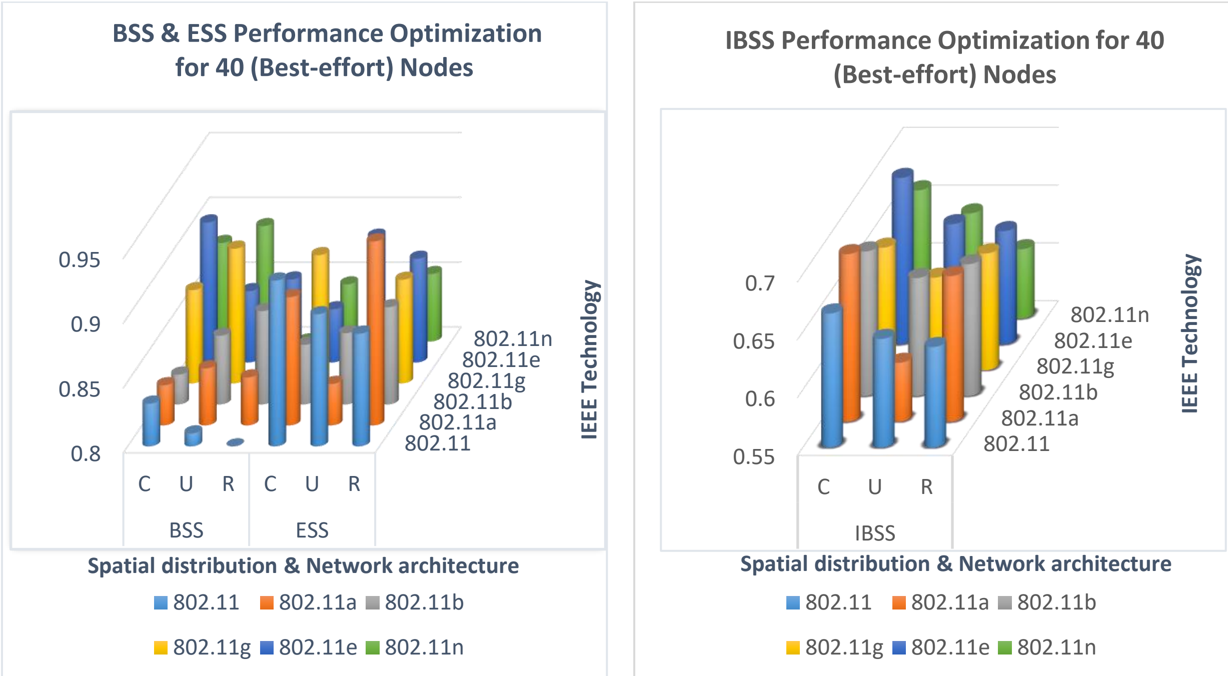
3. BSS and ESS give a range of options in the third group, where $20 \geq N > 10$. IEEE 802.11 g technologies only perform well for BSS architectures when the network is uniformly built. Further, IEEE 802.11e and 11n technologies perform well only if configured randomly. On the other hand, a variety of options are offered by ESS. IEEE 802.11a which is only recognized as the optimal solution if the network is circularly designed. In addition, IEEE 802.11g provides the optimum performance if it is configured uniformly or randomly, as shown in Figure 6.12 (a). While, in the IBSS results, the best performance for circular distributions is given by IEEE 802.11e., as shown in Figure 6.12 (b).



(a) (b)

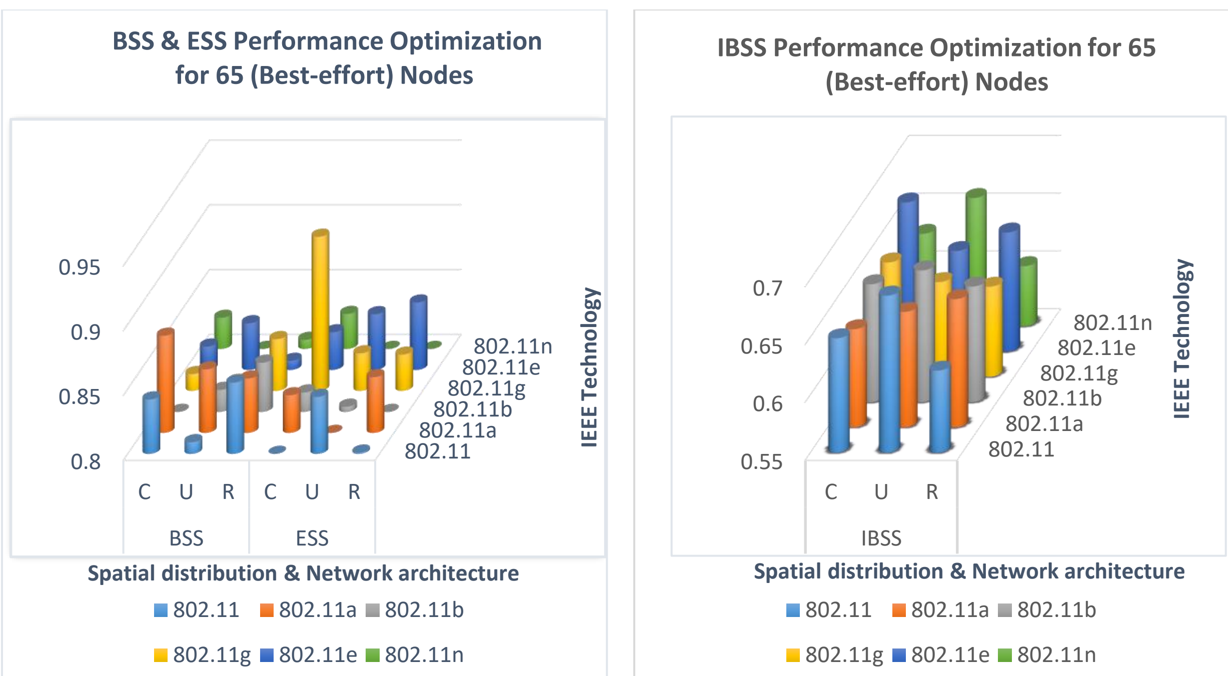
Figure 6. 12 Performance Optimization for 20 (Best-effort) nodes.
(a) BSS & ESS, (b) only IBSS

4. In the fourth and fifth categories, where 40 ≥ N > 20 and 65 ≥ N > 40, respectively, in the generic flowchart, as can be seen in Figures 6.13 (a) and 6.14 (a), ESS provides the best performance. The client has two choices for the fourth group of nodes to choose from, based on the information given in Figure 6.13 (a). First, 802.11 is the best technology to use when configured only in circular distribution. The second choice is to use randomly configured 802.11a technology. For the fifth group of nodes, 802.11g technology is optimum to use if it is configured circularly, as shown in Figure 6.14 (a). However, in the case of IBSS, for the fourth category, both 802.11a and 11e technologies are the best technologies to use if only the circular network is designed, as shown in Figure 6.13 (b). For the fifth category, 802.11e technology is considered the best option if it is configured circularly, whereas technologies 802.11, 11b or 11n are suitable to be used if the network is only uniformly configured. However, 802.11a provides the best option if it is configured randomly, as shown in Figure 6.14 (b).



(a) (b)

Figure 6. 13 Performance Optimization for 40 (Best-effort) nodes.
(a) BSS & ESS, (b) only IBSS



(a) (b)

Figure 6. 14 Performance Optimization for 65 (Best-effort) nodes.
(a) BSS & ESS, (b) only IBSS

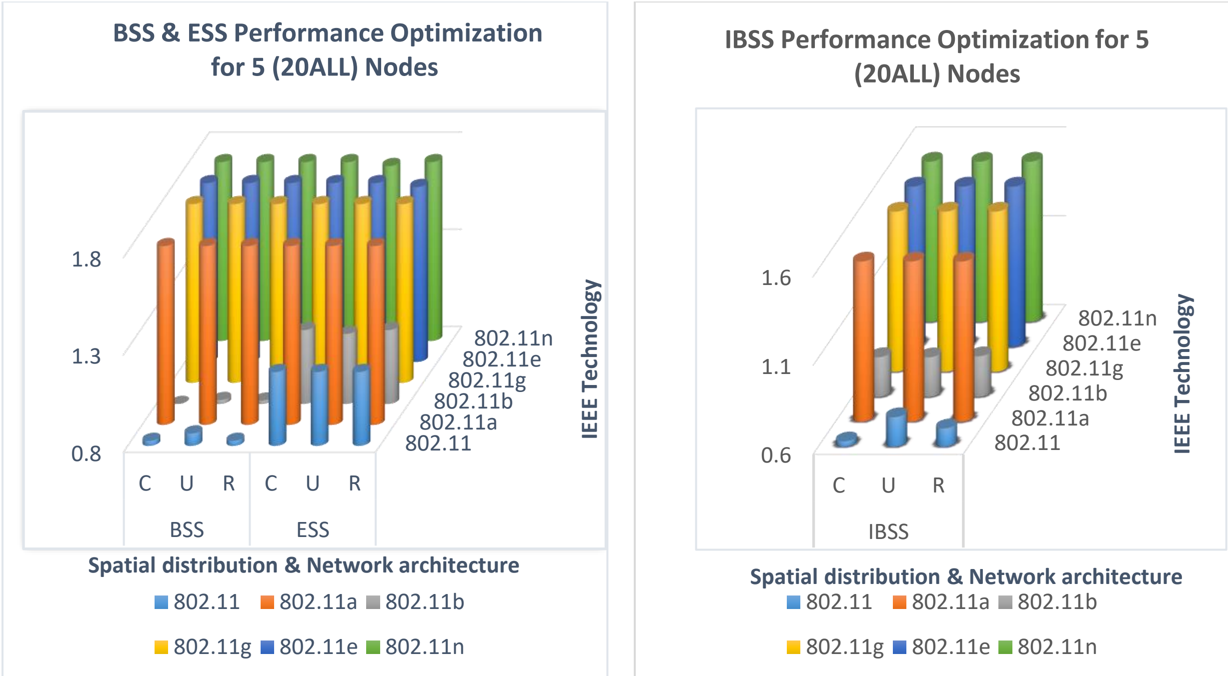
6.4 Mixed of Real-time and Best-effort applications

Three different mixed applications cases between real-time and best-effort services have been evaluated and analysed under different factors such as Spatial distribution, number of nodes and network architectures.

- 20% VoIP, 20% VC, 20% HTTP, 20% FTP, 20% Email: where 20% is the percentage of nodes in each considered application in this case study. “20ALL”, is shortened for the purposes of readability.
- Majority of the traffic as Best-effort (60% HTTP, 20% VoIP and 20% VC): the mixes of real-time and best-effort applications have been implemented here but the majority and concentration of the traffic used are best-effort. “60HTTP”, is shortened for the purposes of readability.
- Divide the traffic similarly – 50% Real-time and 50% Best-effort (40% VoIP, 10% VC and 30% FTP, 20% HTTP): This case study been configured based on the similarity of traffic’s percentages between real-time and best-effort services. “40VoIP”, is shortened for the purposes of readability.

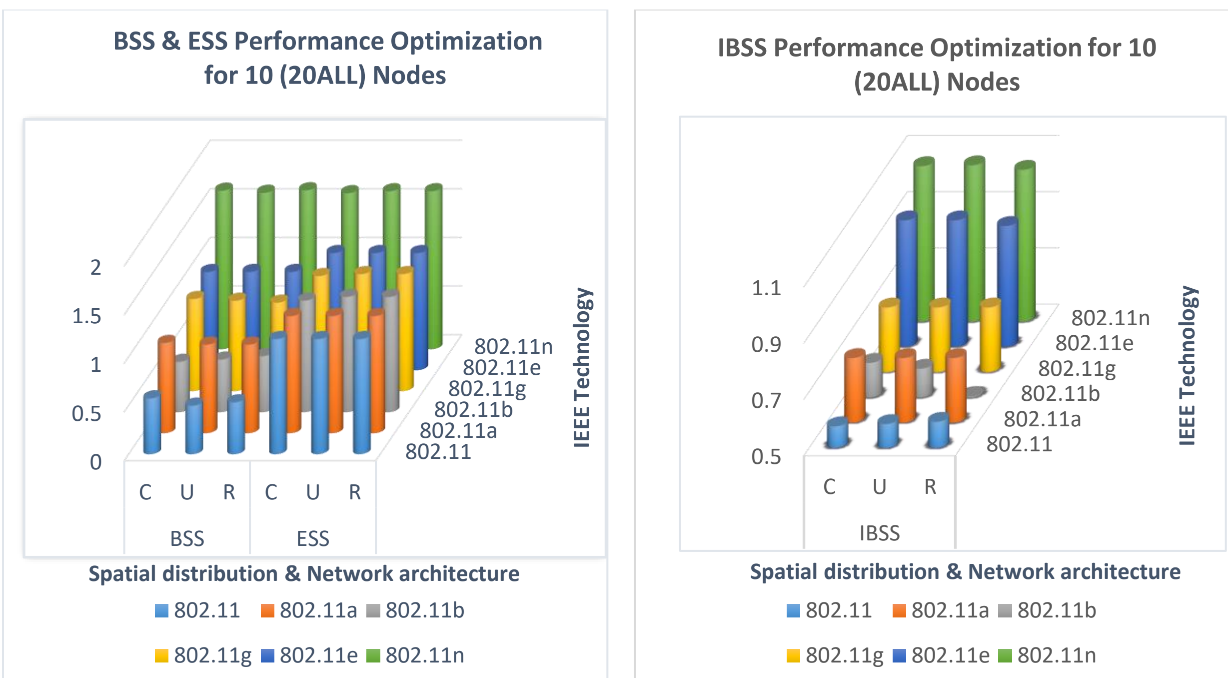
6.4.1 20ALL (20% VoIP, 20% VC, 20% HTTP, 20% FTP, and 20% E-mail)

1. In the first and second categories, where $5 \geq N > 0$ and $10 \geq N > 5$, respectively, in the generic flowchart, as can be realized in Figures 6.15 (a), 6.16 (a) and 6.17, both architectures BSS and ESS provide the best performance. In all three spatial distributions, IEEE 802.11a, 11 g, 11e and 11n are well-performing in the first group. But for the second category, IEEE 802.11n is recognized as the preferred solution. In the case of IBSS flowchart, both categories perform the same as the generic algorithm with one exception that 802.11e technology is also performing with 802.11n technology for the second category for all spatial distributions, as can be seen in Figures 6.15 (b), 6.16 (b) and 6.18.



(a) (b)

Figure 6. 15 Performance Optimization for 5 (20ALL) nodes.
(a) BSS & ESS, (b) only IBSS



(a) (b)

Figure 6. 16 Performance Optimization for 10 (20 ALL) nodes.
(a) BSS & ESS, (b) only IBSS

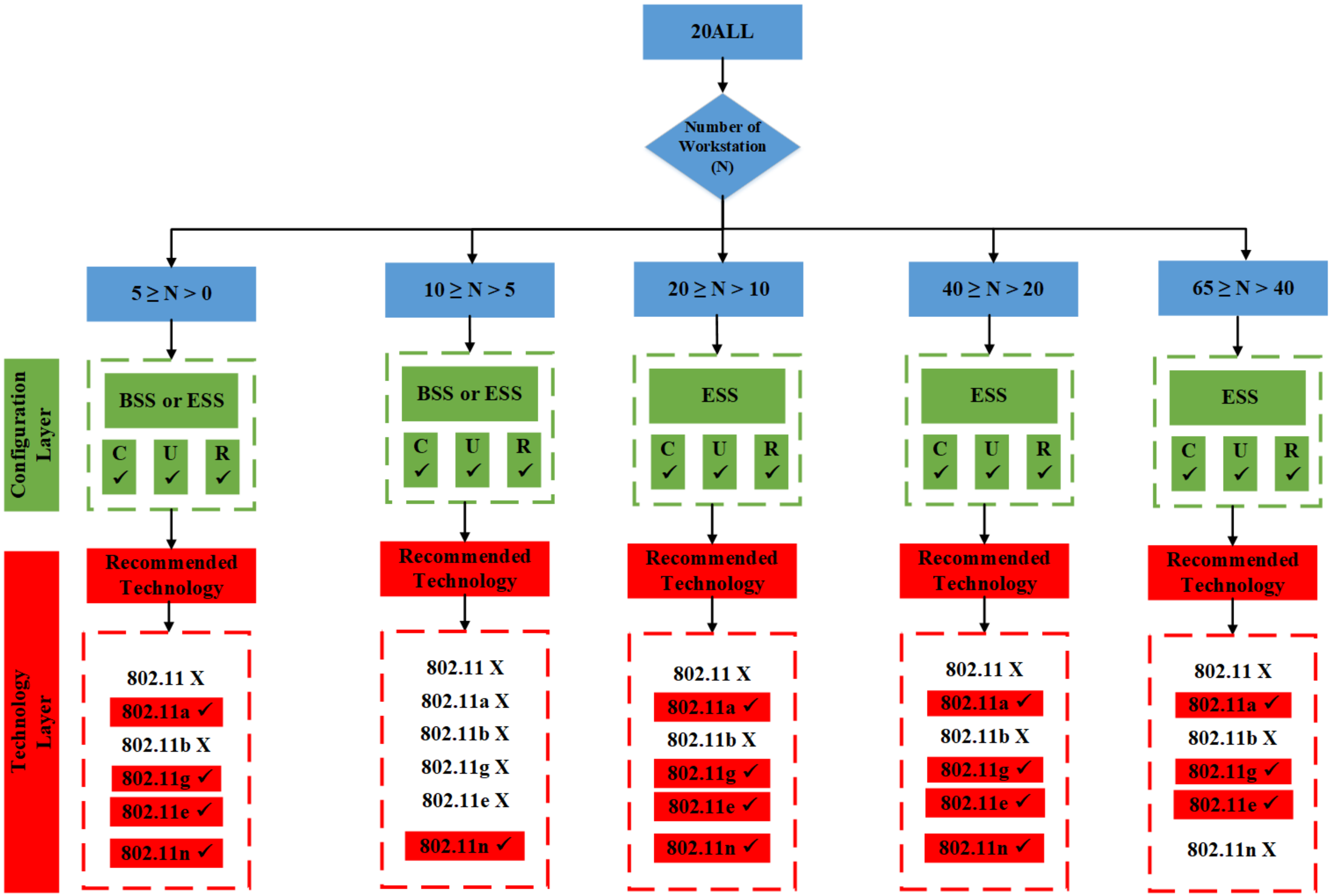


Figure 6. 17 Generic flowchart of the proposed algorithm for 20ALL

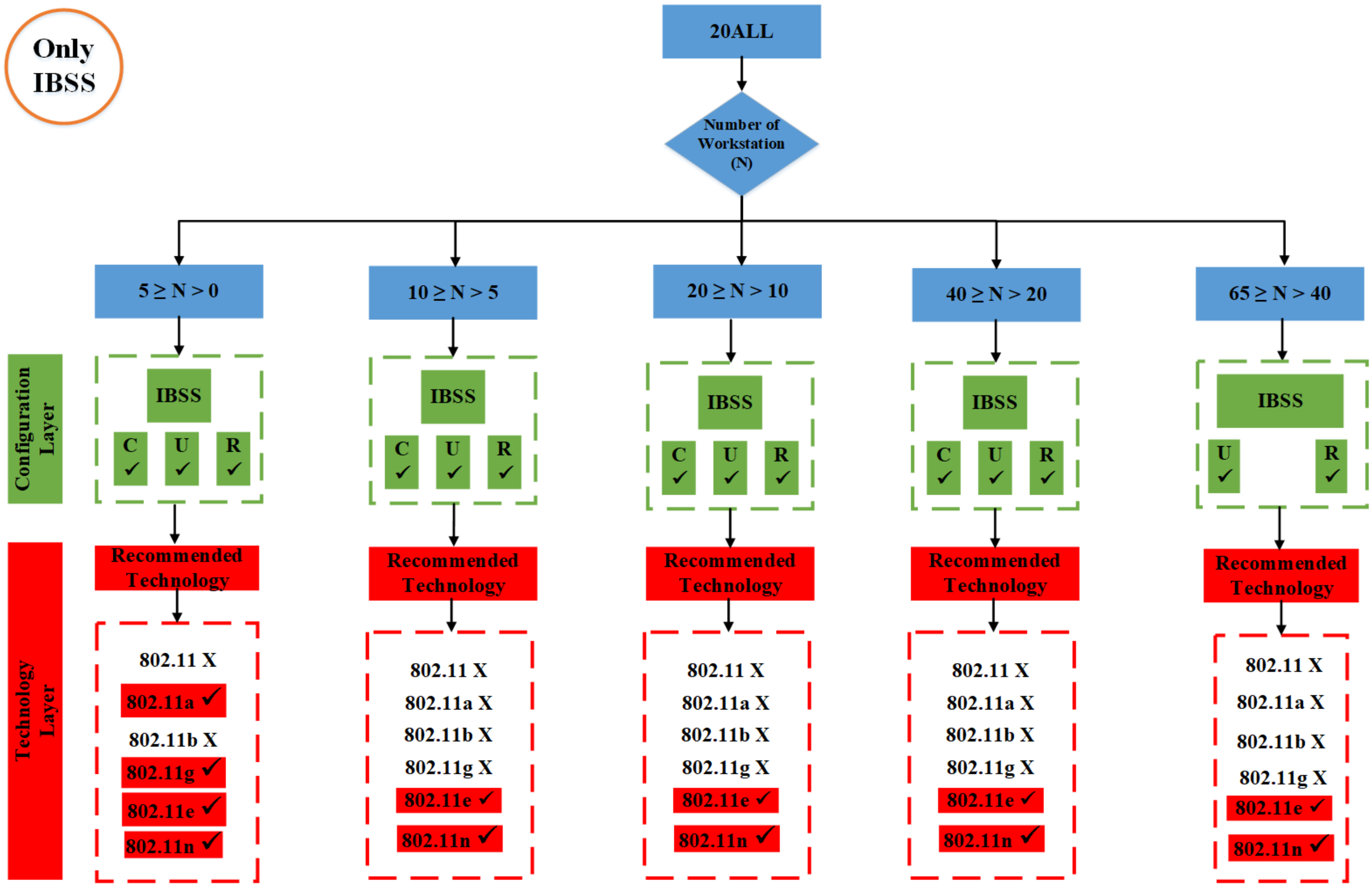
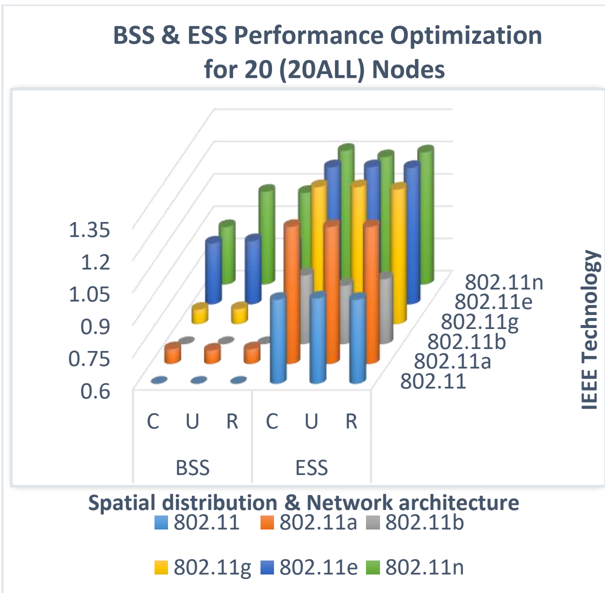
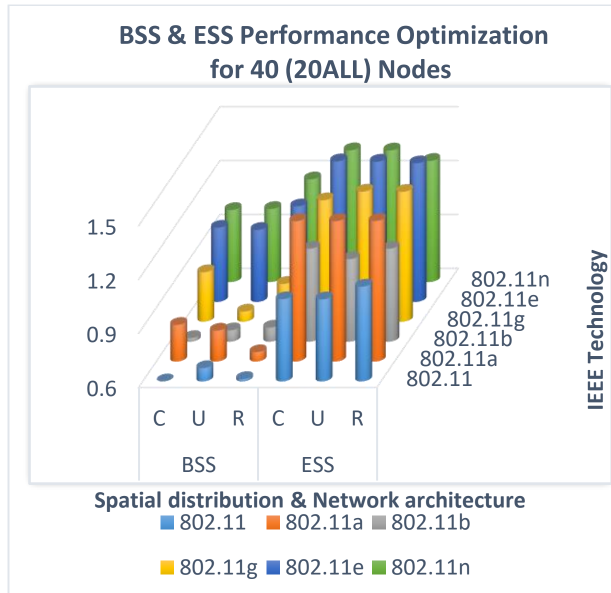


Figure 6. 18 Flowchart of only IBSS's results for 20ALL

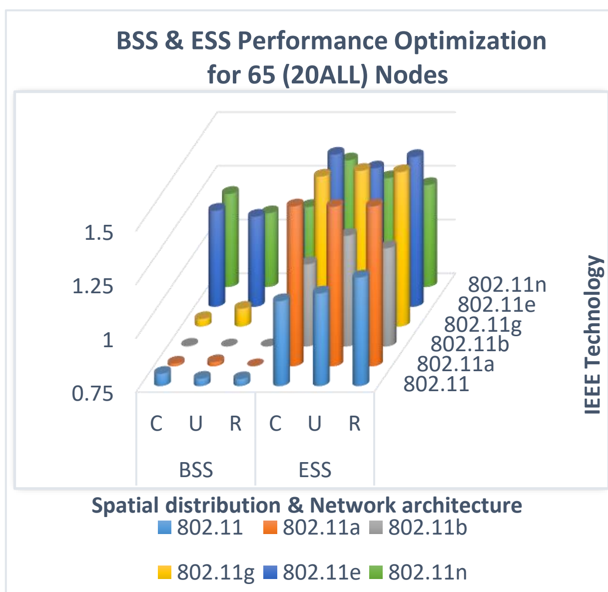
2. In the third, fourth and fifth categories, where $20 \geq N > 10$, $40 \geq N > 20$ and $65 \geq N > 40$, respectively, in the generic flowchart, ESS provides the best performance. Moreover, the technologies IEEE 802.11a, 11g, 11e and 11n work well, as seen in Figures 6.19 (a) and (b), for the third and fourth groups. Whereas only three 802.11a, 11 g and 11e technologies deliver maximum efficiency in the fifth group, as shown in Figure 6.19 (c).



(a)



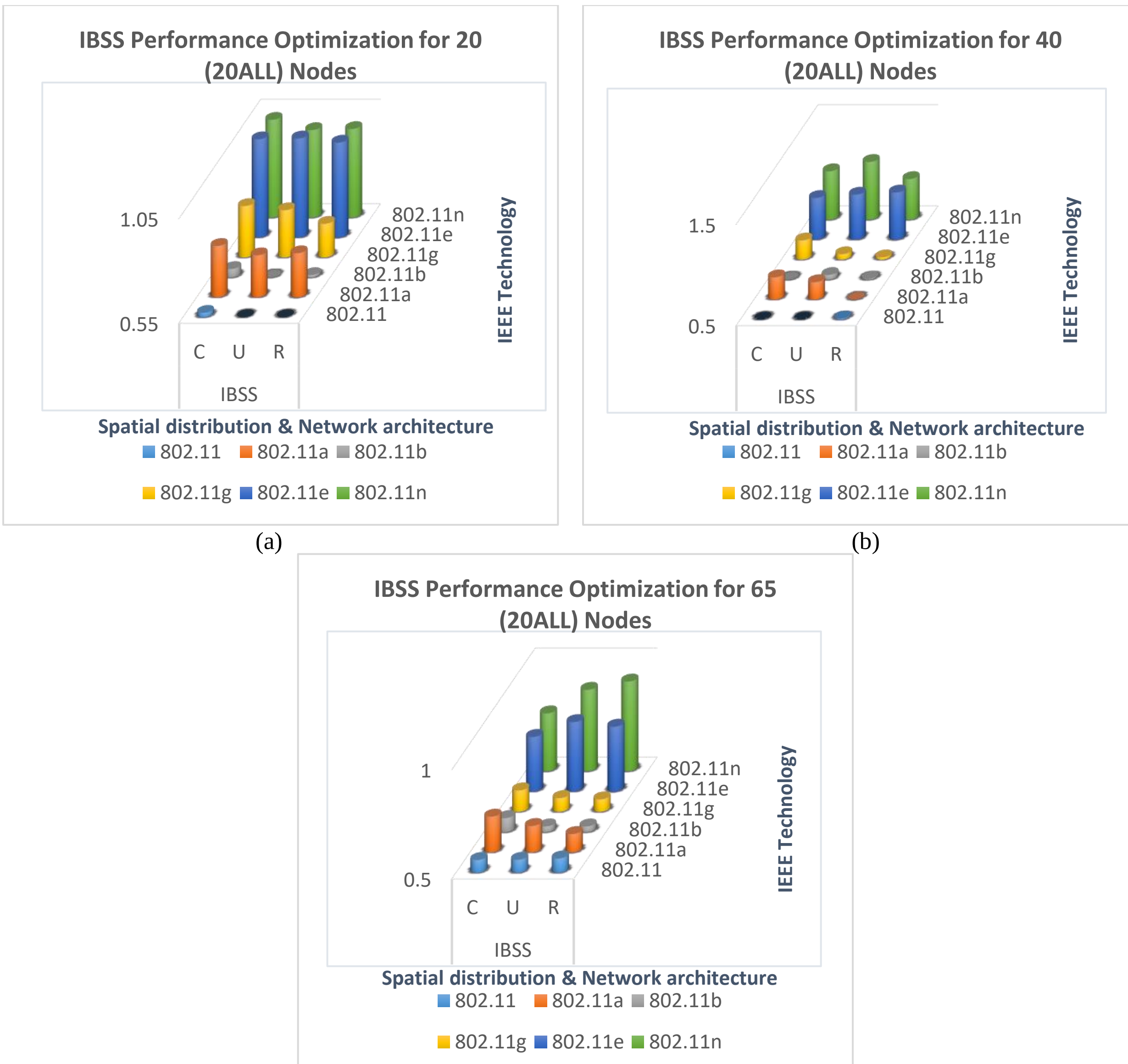
(b)



(c)

Figure 6. 19 20ALL's BSS & ESS Performance Optimization for various nodes.
(a) 20 nodes, (b) 40 nodes, (c) 65 nodes

IEEE 802.11e and 11n perform well in the third and fourth groups of all spatial distributions, however, in compliance with the IBSS flowchart. For the fifth category, both technologies only perform in uniform and random ways, as can be seen in Figure 6.20.



(c)

Figure 6. 20 20ALL's IBSS Performance Optimization for various nodes.
(a) 20 nodes, (b) 40 nodes, (c) 65 nodes

6.4.2 60HTTP (60% HTTP, 20% VoIP and 20% VC)

Figures 6.21 and 6.22 show both results' algorithms for all the nodes (5, 10, 20, 40 and 65) running the 60% HTTP, 20% VoIP and 20% VC case study.

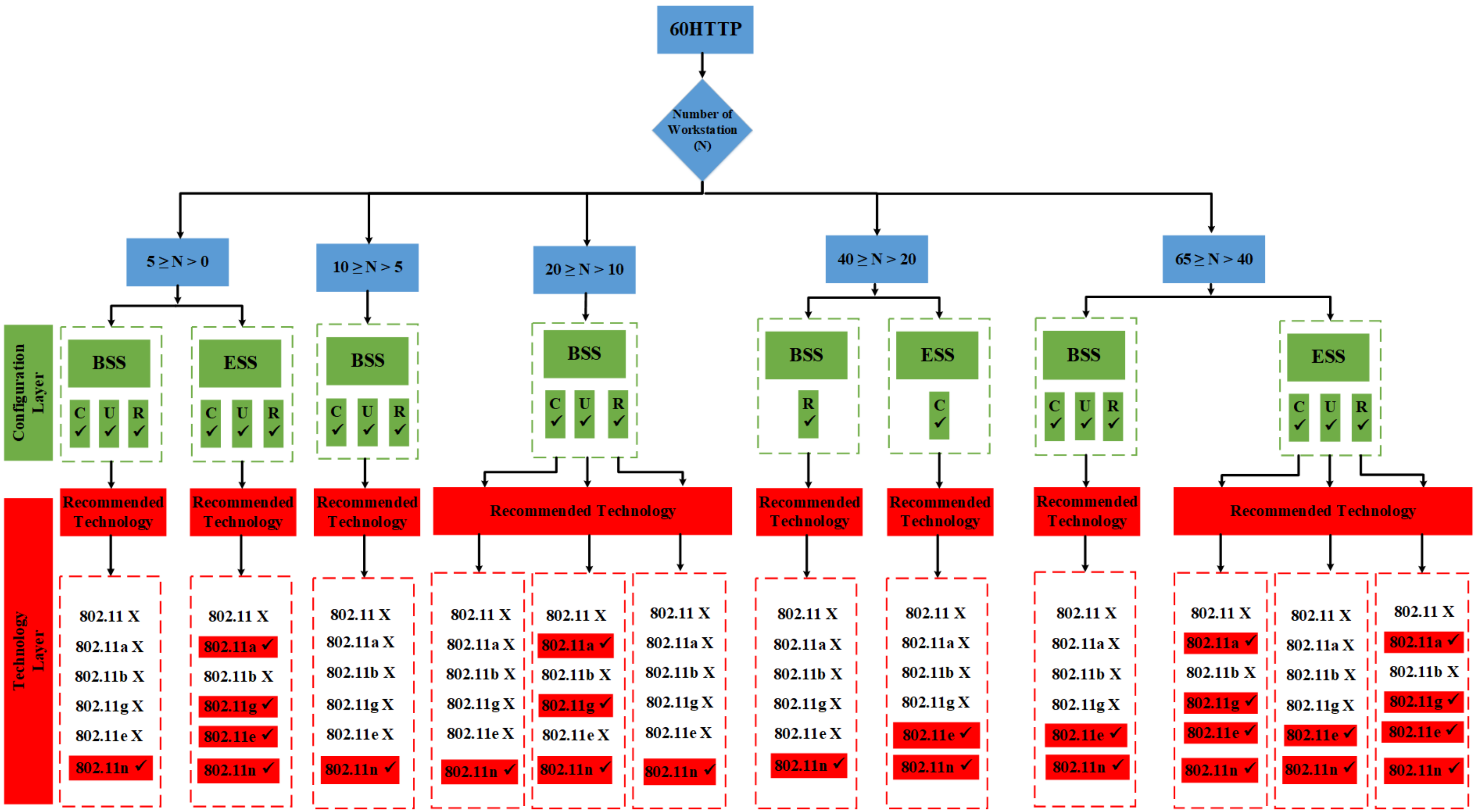


Figure 6. 21 Generic flowchart of the proposed algorithm for 60HTTP

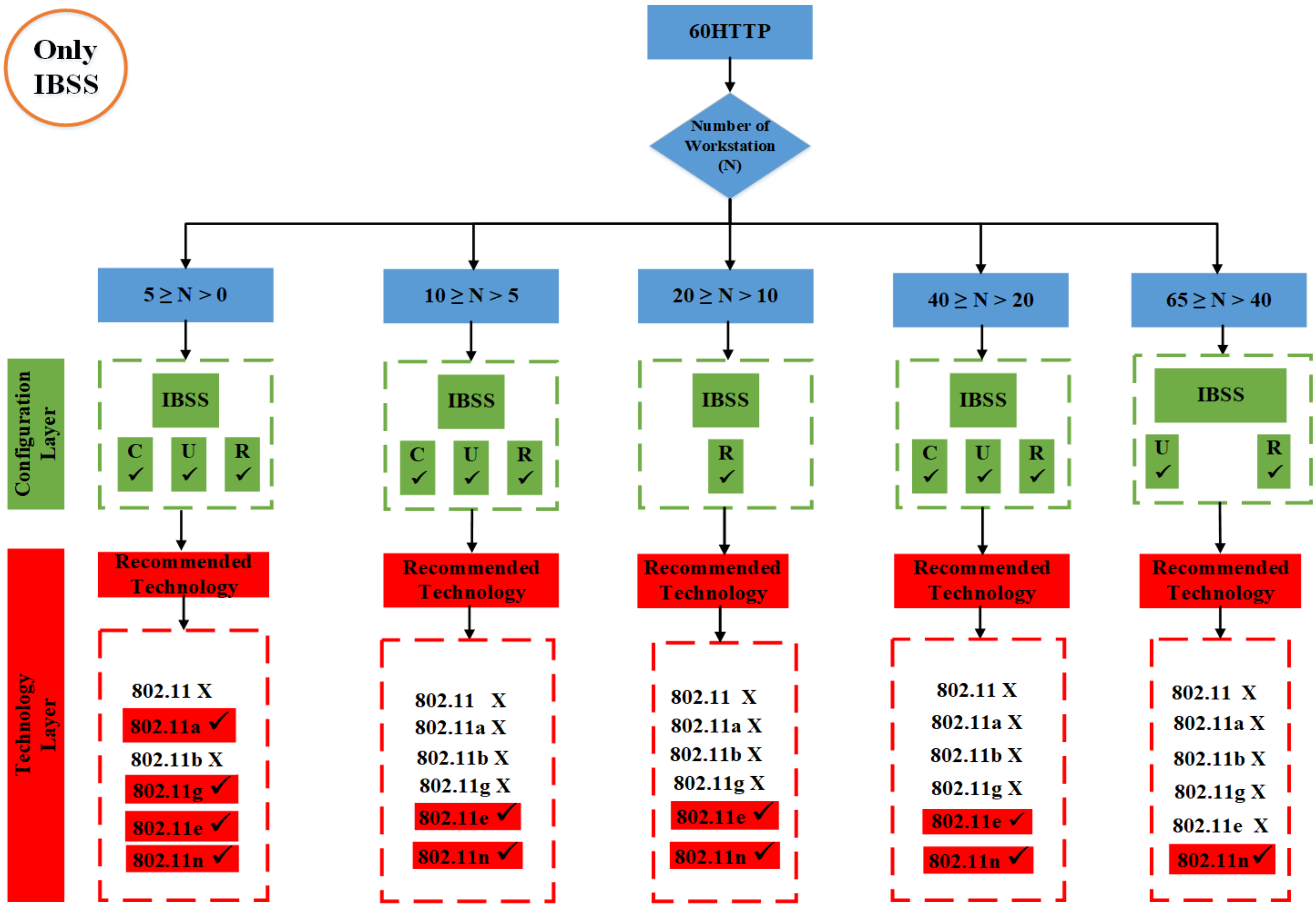
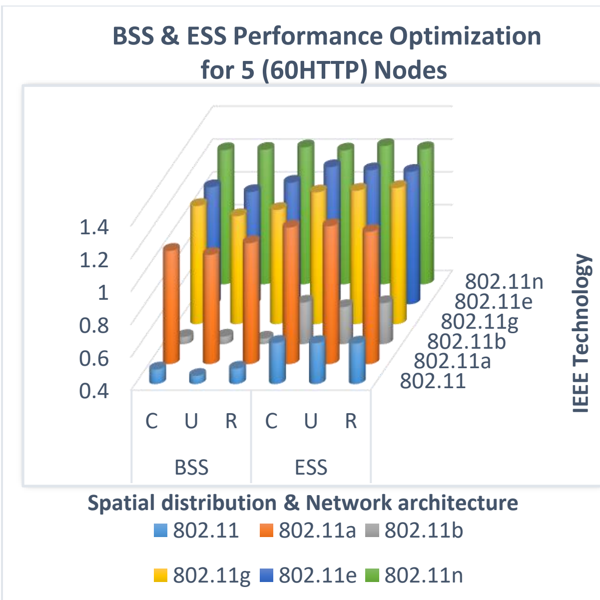
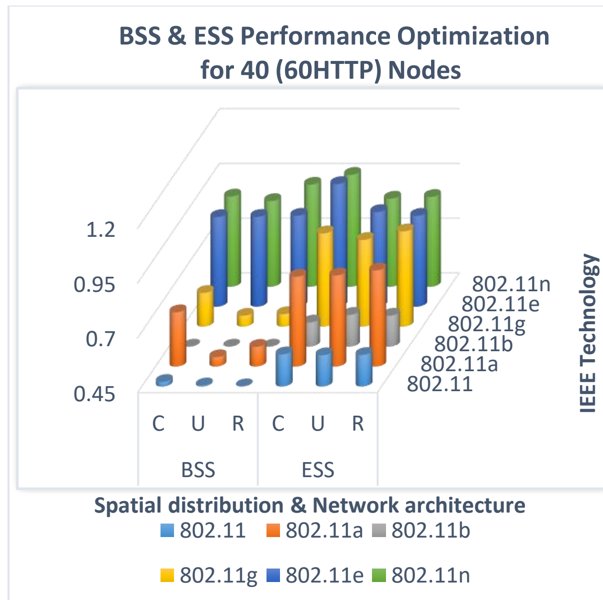


Figure 6. 22 Flowchart of only IBSS's results for 60HTTP

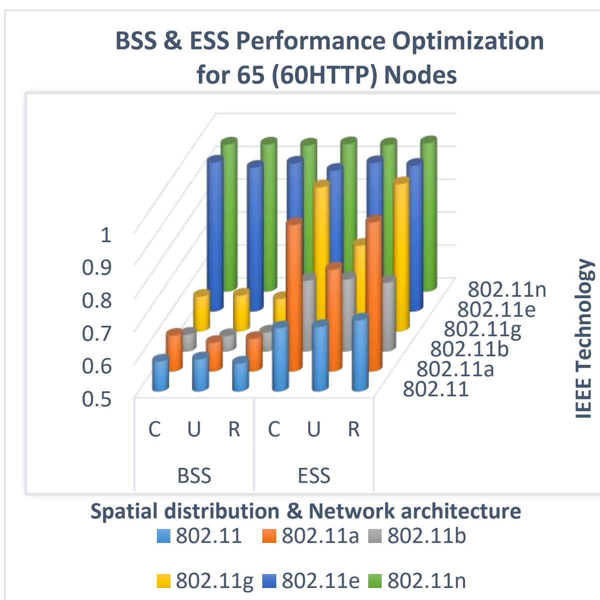
1. In the first, fourth and fifth categories, where 5 ≥ N > 0, 40 ≥ N > 20 and 65 ≥ N > 40, respectively, both BSS and ESS architectures give optimum efficiency in the generic flowchart, as shown in Figures 6.21 and 6.23. For the first category, 802.11a technology performs well across all three spatial distributions in the BSS network. In the case of ESS, four technologies 802.11a, 11g, 11e and 11n are acknowledged as preferable solutions across three spatial distributions. In three space distributions four technologies 802.11a, 11 g, 11e and 11n are known as the preferred solutions. 802.11n provides optimal efficiency



(a)



(b)



(c)

Figure 6. 23 60HTTP's BSS & ESS Performance Optimization for various nodes.
(a) 5 nodes, (b) 40 nodes, (c) 65 nodes

in the fourth group if only randomly installed in the BSS network and circularly along with 11e in the ESS network. For the fifth category, both technologies 802.11e and 11n perform well in both architectures for all spatial distributions. Besides that, both 802.11a and 11g perform well if they are only configured in a circular and random way. On the other hand, according to the IBSS flowchart, as shown in Figures 6.22 and 6.24, IEEE 802.11a, 11g, 11e and 11n perform well for the first category for all spatial distributions, while only

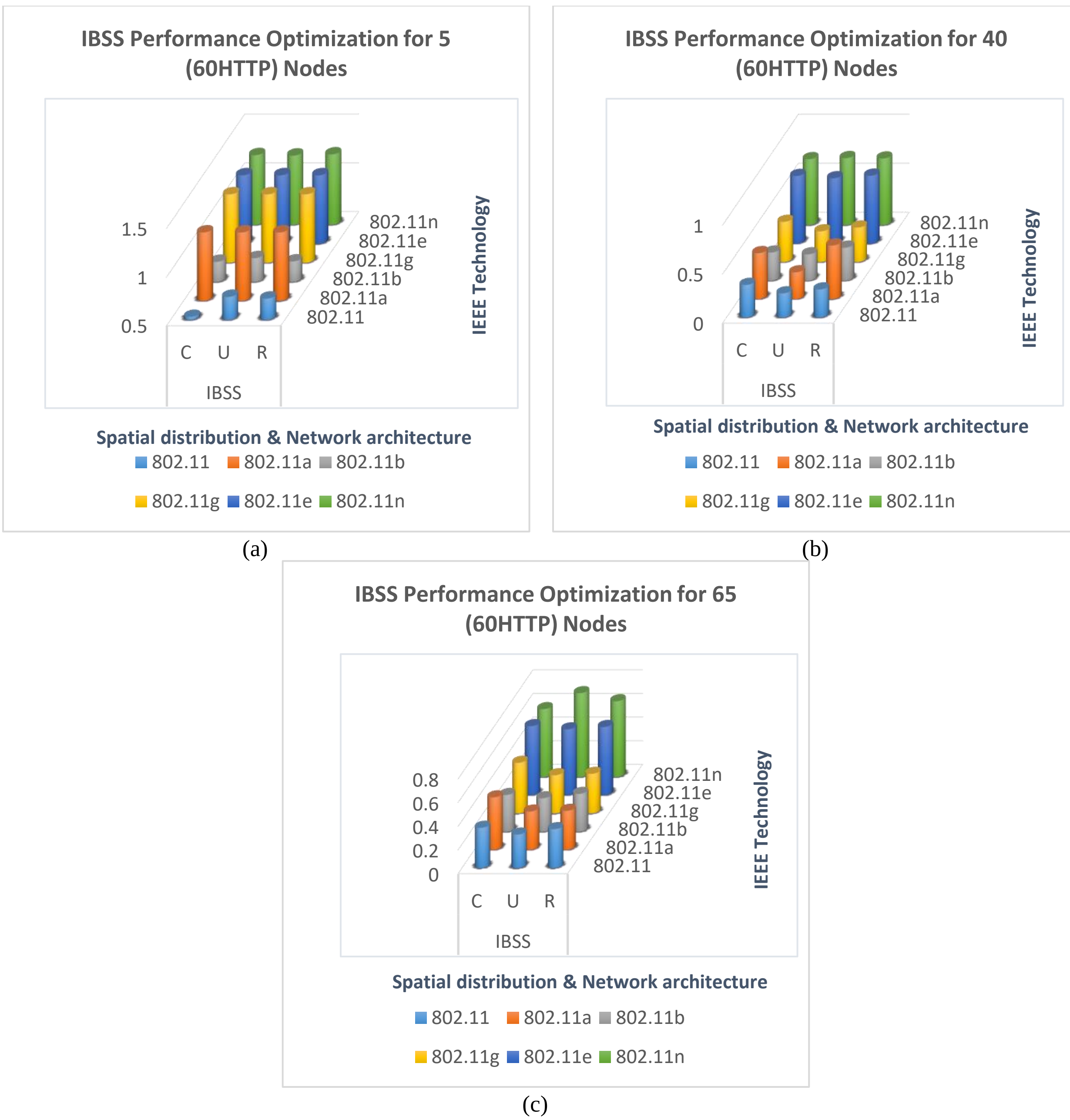


Figure 6. 24 60HTTP's IBSS Performance Optimization for various nodes. (a) 5 nodes, (b) 40 nodes, (c) 65 nodes

technologies 11e and 11n perform well for the fourth category. In the fifth category, only 11n provides the best performance if it is configured in a uniform and random way.

2. In the second and third categories, where 10 ≥ N > 5 and 20 ≥ N >10, respectively, in the generic flowchart, as shown in Figures 6.21 and 6.25, BSS provides the best performance. IEEE 802.11n technology for both groups and all three space distributions is known as the preferred solution. At the same time, in the case of the second category, both technologies 802.11a and 11g also perform only if they are configured in a circular way.

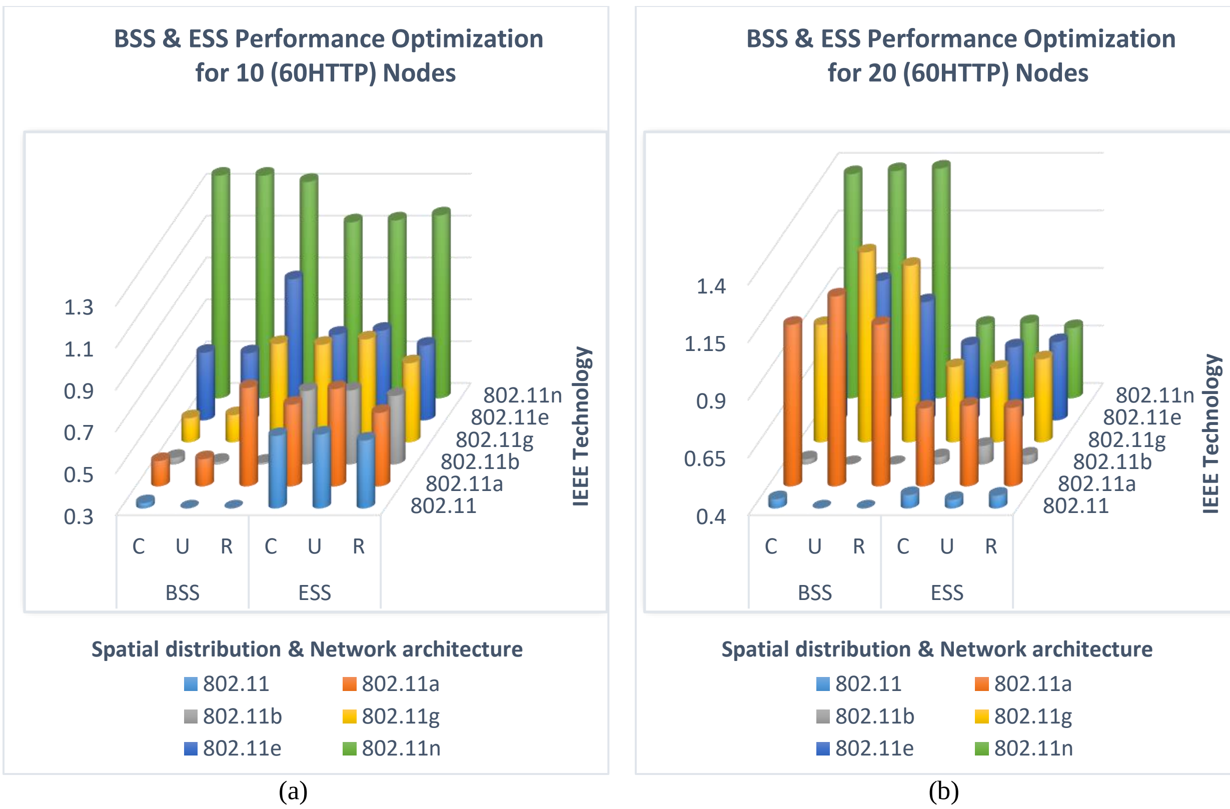
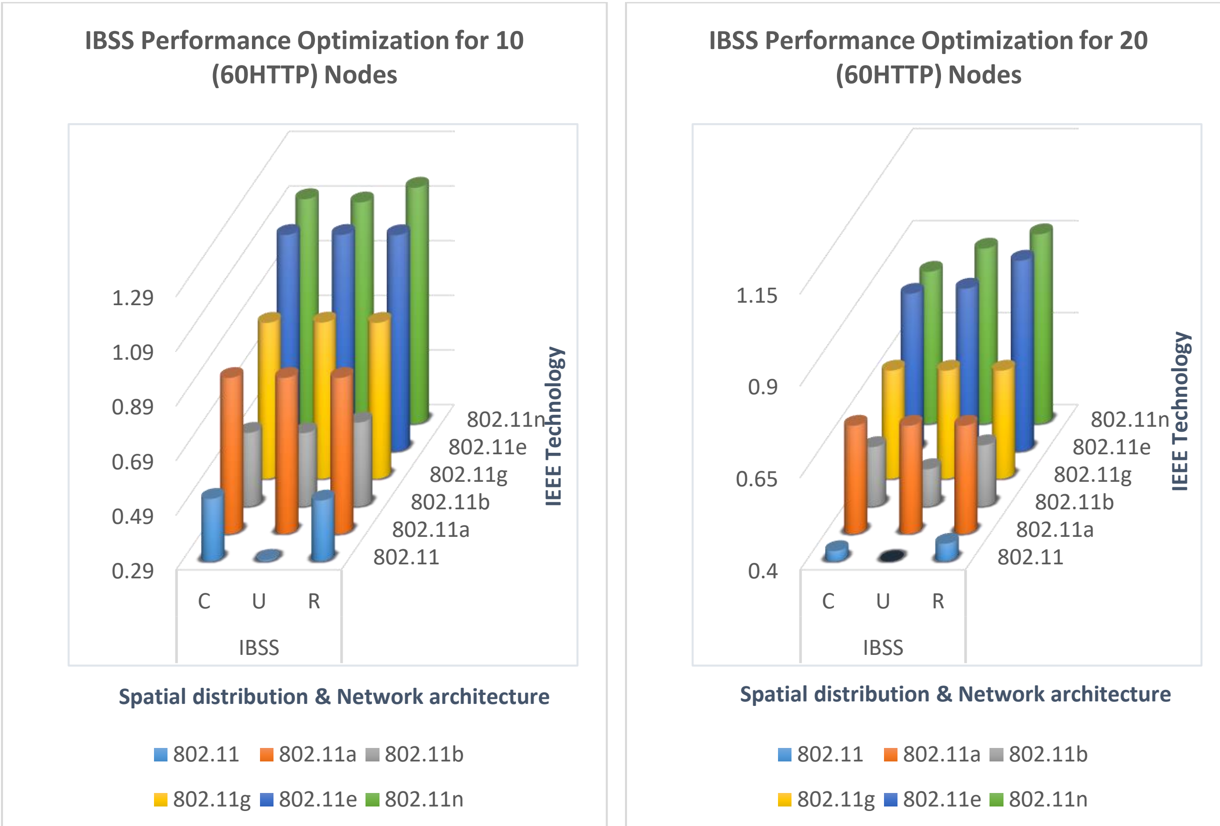


Figure 6. 25 60HTTP's BSS & ESS Performance Optimization for various nodes. (a) 10 nodes, (b) 20 nodes

On the other hand, the IEEE 802.11e and 11n work well for the second category for all space distributions according to the IBSS Flowchart, while the third category only offers optimal output when configured in the random distribution for both technologies, as can be seen in Figures 6.21 and 6.26.



(a) (b)

Figure 6. 26 60HTTP's IBSS Performance Optimization for various nodes.
(a) 10 nodes, (b) 20 nodes

6.4.3 40VOIP (40% VoIP, 10% VC and 30% FTP, 20% HTTP)

As can be seen from both Figures 6.27 and 6.28, both results' algorithms for all the nodes (5, 10, 20, 40 and 65) are running the 40% VoIP, 10% VC and 30% FTP, 20% HTTP case study.

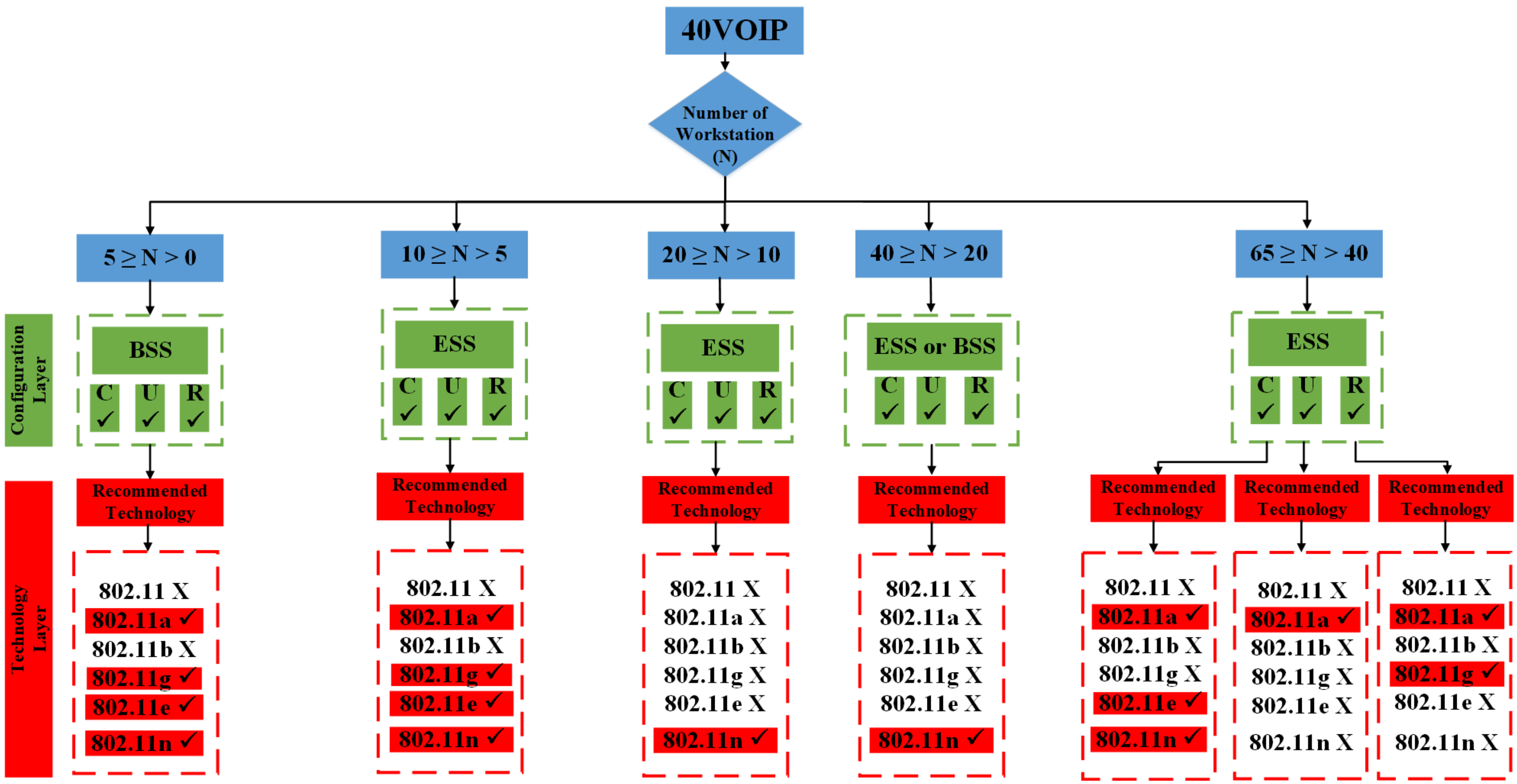


Figure 6. 27 Generic flowchart of the proposed algorithm for 40VOIP

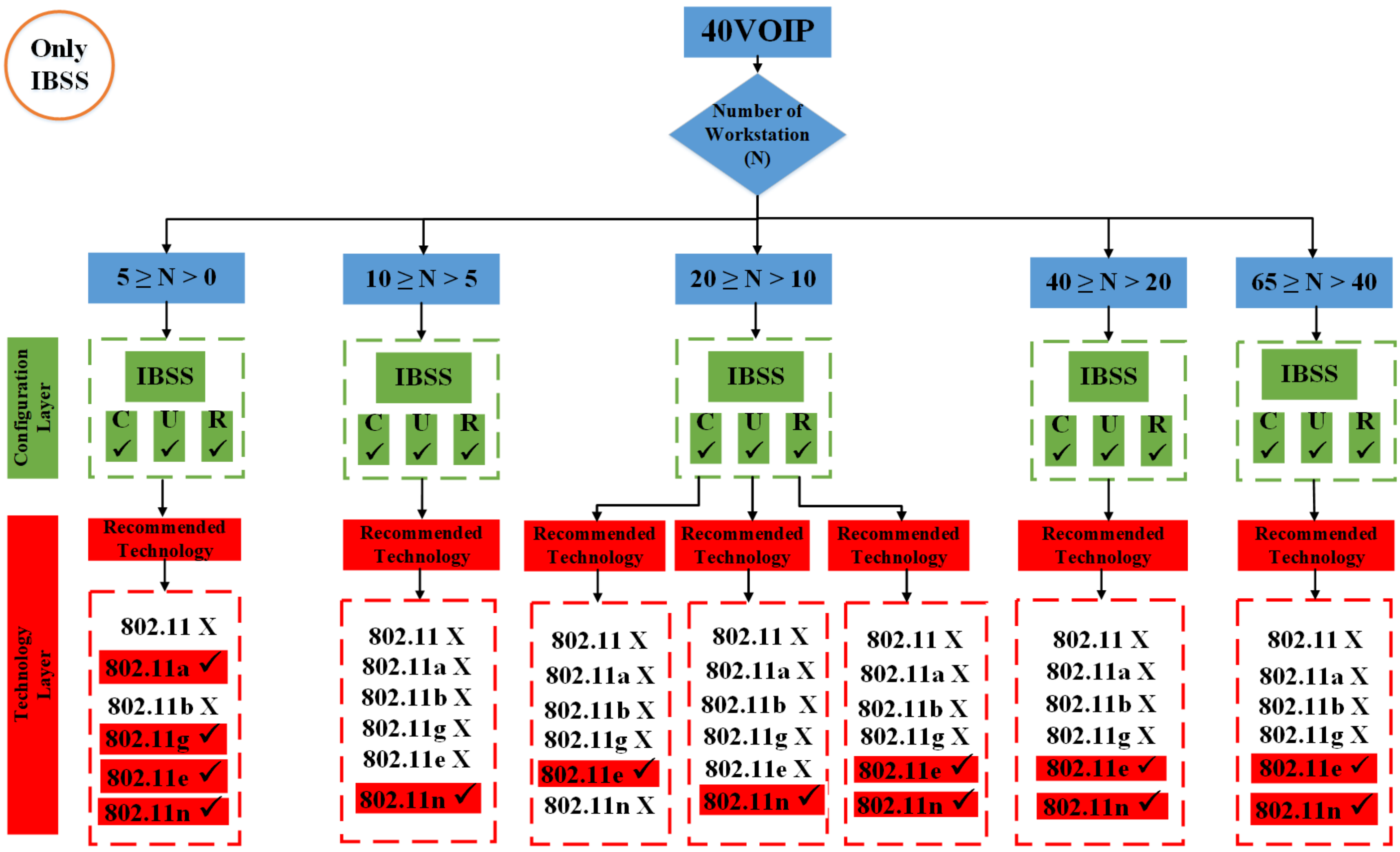
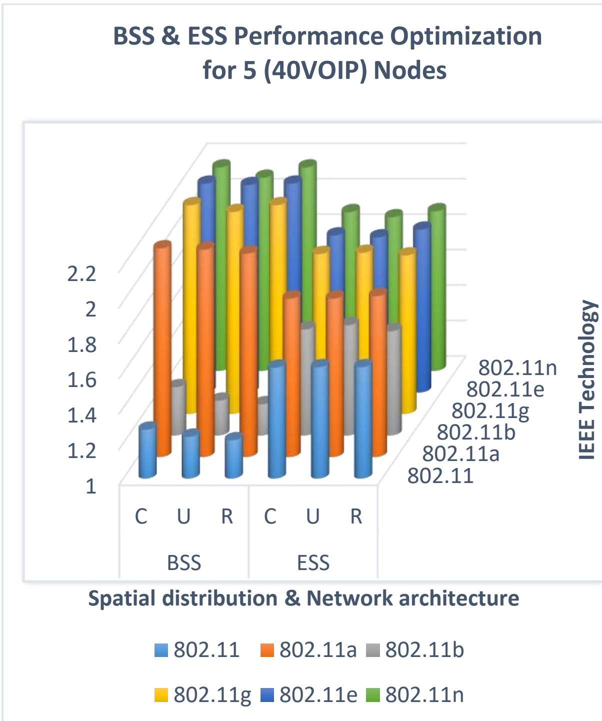
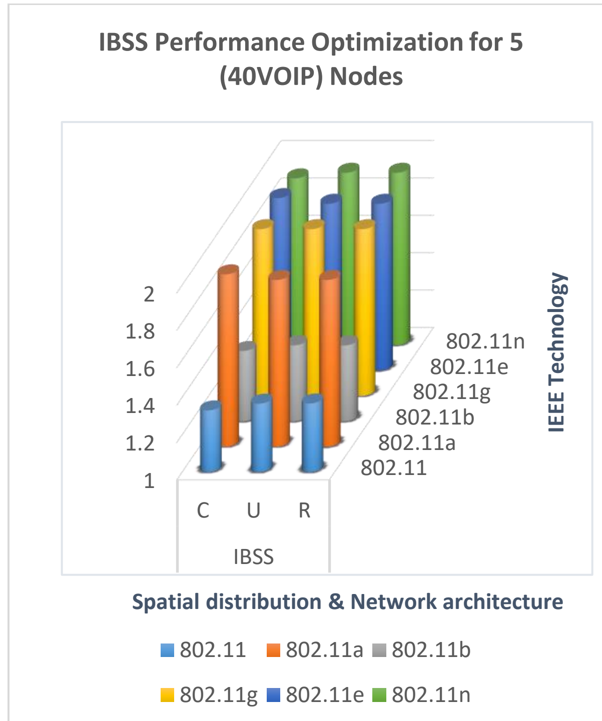


Figure 6. 28 Flowchart of only IBSS's results for 40VOIP

1. BSS and IBSS have a range of choices for the first group, where 5 ≥ N > 0. For all space distributions for both network architectures, IEEE 802.11a, 11 g, 11e and 11n technologies work well, as shown in Figures 6.27, 6.28 and 6.29.



(a)



(b)

Figure 6. 29 Performance Optimization for 5 (40VOIP) nodes.
(a) BSS & ESS, (b) only IBSS

2. If the client configures a network through a set of nodes, when 10 ≥ N > 5, then, according to Figure 6.30 (a), ESS provides optimal performance for all spatial distributions and the client implements 802.11a, 11g, 11e, and 11n. For IBSS, however, the user performs better in all spatial distributions only using 802.11n, as shown in Figure 6.30 (b).

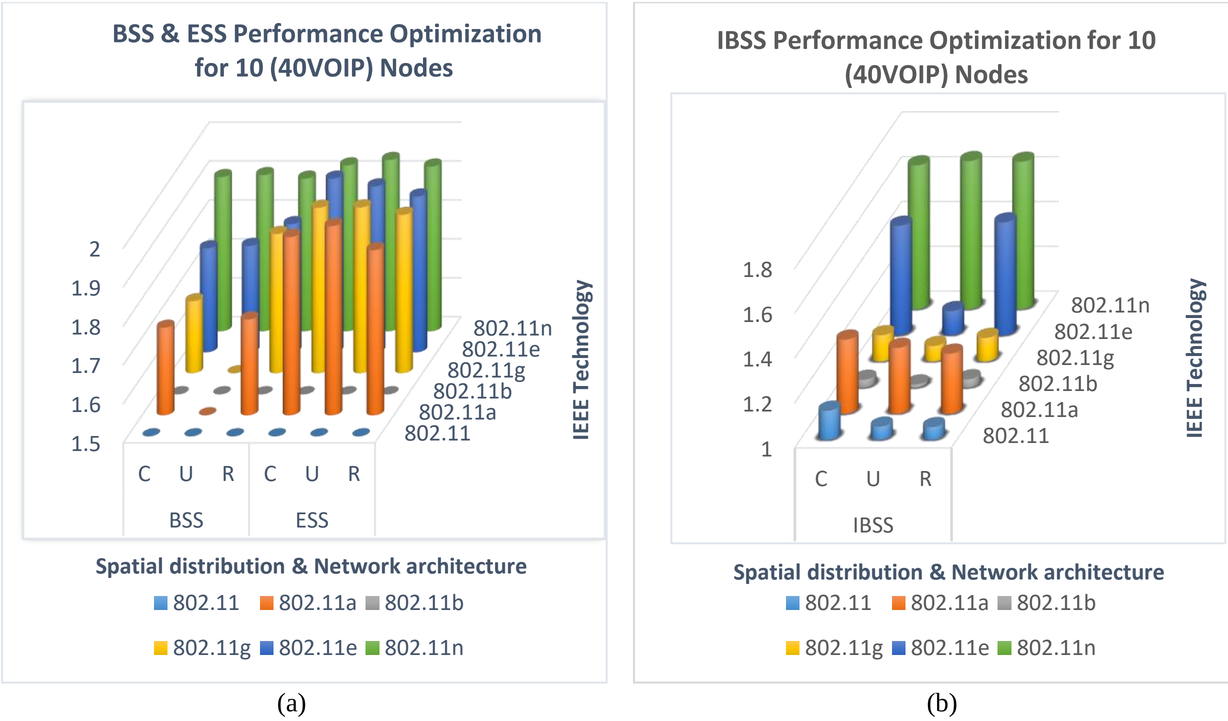
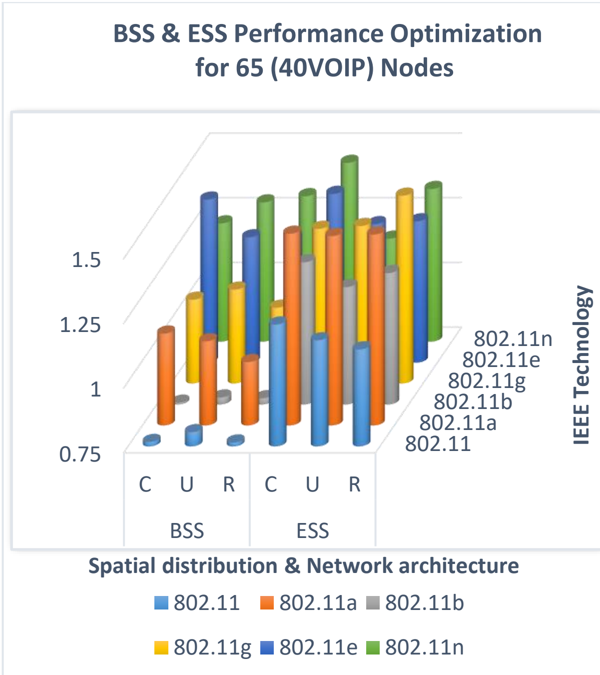
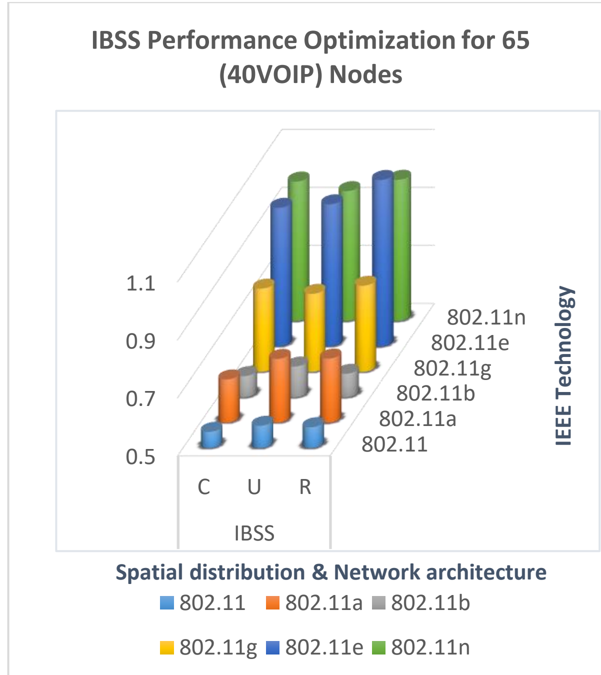


Figure 6. 30 Performance Optimization for 10 (40VOIP) nodes.
(a) BSS & ESS, (b) only IBSS

3. In the third range, where 20 ≥ N > 10, ESS provides the best choice if the client creates a medium-sized network with nodes from 10 to 20. In addition, IEEE 802.11n is recognized as the preferred solution in three spatial distributions, according to the details given in Figure 6.31 (a). In IBSS, however, a range of options are available for clients in both the technology IEEE 802.11e and 11n. 11e performs well only if it is configured in circular and random ways; 11n, however, offers optimum performance only, as shown in Figure 6.31 (b), if it configures uniformly and randomly.



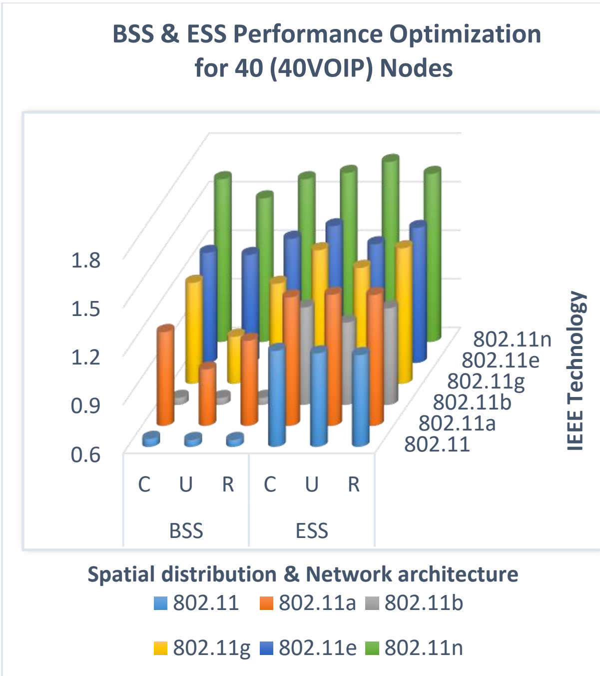
(a)



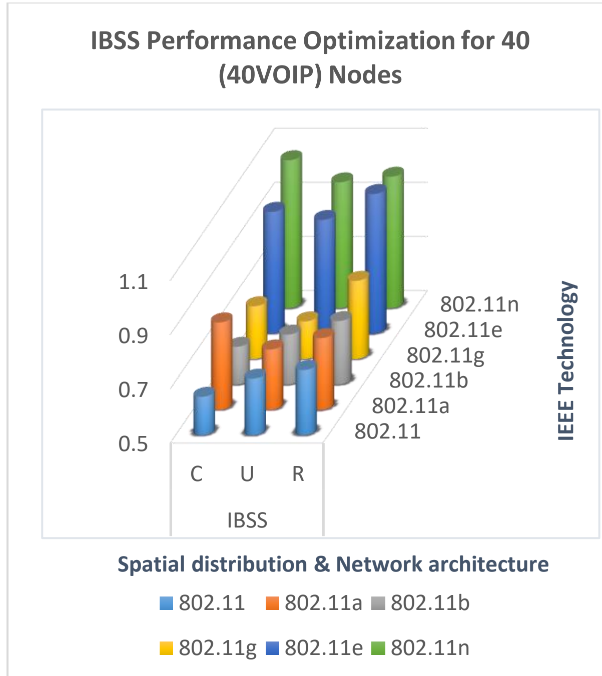
(b)

Figure 6. 32 Performance Optimization for 65 (40VOIP) nodes.
(a) BSS & ESS, (b) only IBSS

4. The fourth group, which includes $40 \geq N > 20$, should have the optimum output for all three spatial distributions, as can be seen from Figures 6.27 and 6.32 (a), if only 802.11n are used; whereas, the IBSS flowchart indicates the users' best performance in both 802.11e and 11n technologies thanks to their throughput adequacy which is substantially different in all the space distributions, as shown in Figures 6.28 and 6.32 (b).



(a)



(b)

Figure 6. 33 Performance Optimization for 40 (40VOIP) nodes.
(a) BSS & ESS, (b) only IBSS

5. ESS is the best performance for the large network in the fifth category, where 65 ≥ N > 40, in the general flowchart. In addition, once the large network is set up, the client has many options, as it shows in Figures 6.27 and 6.33 (a). First choice, 802.11a technology offers the client the best efficiency for all space distributions. Second option, both technologies 802.11e and 11n provide optimum performance that is only configured circularly. Third choice, 802.11g is the optimum technology that can only be used if it is randomly configured. IEEE 802.11e and IEEE 11n technologies, both work well in all the spatial distributions, as shown in Figures 6.28 and 6.33 (b).

6.5 Comparative Study

In this section, a brief comparison between our proposed method with multiple algorithms presented will be offered. The following features have been compared and summarized in Table 6.1, including QoS metric parameters, number of nodes, network architecture, IEEE technology, and the simulation model.

In the calculations of the optimized network configuration with metric parameters such as end-to-end delays, jitter and throughput, recent approaches Farej & Jasim (2020), Genc & Del Carpio (2019) and Khiat, Bahnasse, EL Khail, & Bakkoury (2017) have demonstrated and implemented their models with different nodes of (3, 9 and 18), (20) and (2), respectively. To validate their proposed approaches, however, only BSS network architectures have been used.

The effect of node spatial distribution (i.e., circular, random, uniform) on the efficiency of the network for all six IEEE 802.11 technologies have been examined. This unique area of study has not been shown in recent studies, such as the review done in Refaet, Ahmed, Aish, & Jasim (2020), Cao, Zuo, & Zhang (2018) and Bhatt, Kotwal, & Chaubey (2019).

Other studies, on the other hand, such as Vivekananda & Chenna Reddy (2018), Mohammadani, et al. (2020) and Farej & Jasim (2018), are only considered to assess approaches to IEEE802.11, 11ac and 11n technologies, respectively. additionally, Kaur, et al. (2020) and Refaet, Amed, Abed, & Aish (2020) evaluated IEEE technologies using a fixed number of nodes, (16) and (10), respectively.

Although Farej & Jasim (2018) and Mohammadani, et al. (2020) evaluated the network on the basis of (3, 9 and18) and (8) nodes, only one BSS network architecture was taken into account. However, the approaches proposed were only validated as the only WLAN technologies with IEE 802.11n and 11ac, respectively.

However, the network evaluation was carried out using methods such as AlAlawi & Al-Aqrabi (2015), Vivekananda & Chenna Reddy (2018) and Jabbar *et al*. (2014) based on a fixed number of nodes and an evaluation of different IEEE technologies. However, the assessment of algorithms takes into account only one IEEE standard, in particular, IEEE 802.11b and 802.11 in Jabbar *et al*.

(2014) and Vivekananda & Chenna Reddy (2018), respectively, and two IEEE standards (11g and 11e) used in AlAlawi & Al-Aqrabi (2015).

While two QoS VoIP parameters, jitter and throughput were examined for WiMAX 802.16 Anouari & Haqiq (2013), three VoIP parameters (end-to-end delay, jitter, throughput) were studies for both 802.11g and 11e technologies AlAlawi & Al-Aqrabi (2015). Furthermore, none of these approaches investigated the performance of networks in the case of mixed applications.

In contrast to the limitations mentioned above, this work presents the development of a novel parametric evaluation approach capable of identifying optimum network configuration using three different network architectures: BSS, ESS and IBSS. The proposed approach has been evaluated for five mixed based applications using different node size (1 to 65) with respect to six different IEEE technology standards including 802.11, 802.11a, 802.11b, 802.11g, 802.11e and 802.11n.

Table 6. 1 Comparative results between the proposed approach and mixed algorithms available in the literature

Reference	**Approach**	**QoS metric parameters**	**Number of nodes**	**Network Architecture**	**IEEE Technology**	**Simulation model**
(Vivekananda & Chenna Reddy, 2018)	The impact of the varying performance assessment protocols on ad hoc networks was addressed in this article. This article presents a comparative study of TCP, UDP and SCTP for different performance measures using ns2.	End-to-end delay Jitter Packet loss Throughput	10	IBSS	802.11	NS2
(Mohammadani, et al., 2020)	This study evaluated the characteristics of a wireless fibre architecture that integrates a 10-Gigabit passive optical network (XGPON) and a fifth-generation WLAN (IEEE 802.11ac). Both technologies are mutually beneficial and have benefits and drawbacks to subscribers' QoS demands.	End-to-End Delay Fairness Bandwidth	8	BSS	802.11ac	OMNET++

(AlAlawi & Al-Aqrabi, 2015)	Evaluate VoIP efficiency for wireless networks using both 802.11e and 11 g technologies.	End-to-end delay (has been reduced significantly over 802.11e). Jitter (appears to be within ITU-T tolerance in all cases). Throughput using 5 frames per packet in G729.	3-15	ESS	802.11g 802.11e	OPNET
(Farej & Jasim, 2018)	The typical EDCA efficient service differentiation framework is activated and evaluated aim of providing high QoS for various customer-needed multimedia (video, voice and FTP) services (particularly critical or time-sensitive services).	Throughput Delay	3, 9 and 18	BSS	802.11n	OPNET

(Refaet, Ahmed, Aish, & Jasim, 2020)	The impact of various QoS techniques on VoIP performance and capacity implementation via OPNET simulation is investigated in this work. The highest VoIP capability to deliver approved quality will also be explored.	Throughput Delay Jitter	5	ESS	802.11	OPNET
(Anouari & Haqiq, 2013)	Assess the output of different VoIP codecs in multiple service classes.	Jitter (The rtPS service class comes out to be better than BE service). Throughput and Average delay (UGS service class has the best performance parameters serving VoIP).	2, 4, 6, 8 and 10	WiMAX	802.16	NS-2
(Khiat, Bahnasse, EL Khail, & Bakkoury, 2017)	This study measures and evaluates the behaviour of Web-based applications in a vertical handover context between 802.16e and 802.11e technologies, taking into account all possible QoS	TCP delay HTTP load page delay DB query delay Mail download and upload delay	2	BSS WiMAX	802.16e 802.11e	OPNET

	mechanisms. The evaluation scenarios were performed using OPNET Modeler. The applications used are: Dynamic web (HTTP + database) and mail flow					
(Refaet, Amed, Abed, & Aish, 2020)	The fragmentation threshold and the RTS threshold are analyzed to assess its impact on the performance of the network. The performance assessment of voice and FTP traffic in IEEE 802.11g/e WLAN was also provided and the performance of the network was tested against various MAC access protocols and different MAC specifications.	End-to-end delay Throughput Jitter	10	IBSS	802.11e 802.11g	OPNET
(Jabbar *et al*. 2014)	Assess three types of internet traffic that are readily accessible in smart city applications: VoIP, HTTP and FTP.	Throughput End-to-end delay Jitter Average time in FIFO Queue	25, 36, 49, 64, 81, and 100	IBSS	802.11b	EXata 3.1

(Kaur, et al., 2020)	Research the efficiency of the optimized network architecture that combines XG-PON and EDCA with bursty real-time traffic generated from the current distribution of global IP traffic.	Throughput End-to-end delay Jitter Fairness	16	BSS	802.11n	NS3
(Cao, Zuo, & Zhang, 2018)	The robust performance of the OPNET-based communication IP network simulation model offers a versatile, graphical environment and design of network communication, recognizes the modelling of actual network scenarios, can incorporate performance specifications for the operation of existing equipment.	Delay Throughput Link data rate	NA	ESS	802.11	OPNET
(Mehmood & Alturki, 2011)	Present an architecture for delivering and routing Ad hoc networks to study over 802.11g technology using a combination of HTTP, voice and video	End-to-end delay Throughput Delay variation	9, 25 and 49	IBSS	802.11g	OPNET

	streaming applications.					
(Bhatt, Kotwal, & Chaubey, 2019)	A range of simulations of different standardized smart meter networks was built in this article with evaluation metrics that were derived from different wired and wireless communication in a computing database query, file transfer to the server about the time when usual data transmission and DDoS attack to the network were performed.	HTTP request received in the server FTP request response in server	20	BSS	802.11	OPNET
(Genc & Del Carpio, 2019)	This work approach focuses on enhancing Wi-Fi downlink quality of service to MAC layer improvement while evaluating network jitter and delay efficiency. The results of the simulation show that the new time-critical traffic access classification improves efficiency and opens the way to	Jitter Delay	20	BSS	802.11ac	Monte Carlo simulation

	the use of time-sensitive networking and Wi-Fi technologies for multiple uses in industrial applications.					
(Farej & Jasim, 2020)	This study discusses the review and performance assessment of IEEE 802.11n random topology WLAN multimedia services. The optimized structure with the required physical layer spatial stream of the standard MAC layer features explained the effect of the standard on the output of the network.	Throughput Delay Data drop and retransmission attempts	3, 9 and 18	BSS	802.11n	OPNET
Present study	Assess mixed application metrics of different IEEE 802.11 technologies for optimal protocol and network architecture.	Delay Jitter Throughput Packet loss	1-65	BSS ESS IBSS	802.11 802.11a 802.11b 802.11g 802.11e 802.11n	OPNET

6.6 Summary

In this chapter, a way of analysing the network performance to achieve the most optimized network setup based on the currently available technologies for mixed services was presented. In addition, it identifies which IEEE technology/technologies and network architecture can be implemented for future internet applications and technologies. Moreover, it shows that the best efficiency of the IEEE technology in the real-time industry is not always guaranteed by the latest technologies but by a variety of factors, such as QoS metrics, network architecture, and spatial distributions.

This section gives an overview of five different mixed services, which are distributed in three patterns (circular, random, uniform) for the different IEEE 802.11 technologies, in order to find the ideal network architecture. The proposed algorithm, which is consistent with the six rankings of IEEE 802.11 technologies (IEEE 802.11, 11a, 11b, 11 g, 11e and 11n), would also have the best overall network efficiency and quality services for a specific mix of applications in a particular circumstance.

Mixed applications are studied as follows: (where % is the percentage of nodes in each considered application).

1) 20% VoIP, 20% VC, 20% HTTP, 20% FTP, 20% Email.
2) 50% VoIP and 50% VC (Real-time applications).
3) 40% HTTP, 30% FTP, 30% Email (Best-effort applications).
4) Majority of the traffic as Best-effort (60% HTTP, 20% VoIP and 20% VC).
5) Divide the traffic similarly – 50% Real time and 50%best-effort (40% VoIP, 10% VC and 30% FTP, 20% HTTP).

CHAPTER 7 DEVELOPMENT OF A PRACTICAL APPLICATION (END-USER APPLICABILITY)

7.1 Introduction

This chapter will present a web-based tool, and it is well known that new software developments make the world a better place. This is why we really aim to identify the proper IEEE technologies/protocols and optimum network configurations autonomously using a web-based application generated by an extensive collection of system simulations. Our website provides users, businesses and universities with all the choices for what type of WLAN technology, network configuration and spatial distribution they need, and we provide free advice and guidance for them to find the best way based on their personal configuration input.

The web-based information and guidance system introduced herein is meant to overcome a considerable number of technical and non-technical barriers experienced by network engineers and other personnel that prevent the efficient use of network resources and the random allocation of IEEE technologies and network architectures.

Furthermore, the efficient use of web-based tools maintains financial resources (cost-effective) and provides network optimization for infrastructure projects. It also provides a vital opportunity to evaluate the network requirement on the basis of the application's bandwidth needs and other QoS metrics. Figure 7.1 shows the steps of web-tool execution. The title of the WLAN Protocol and Network Architecture Selection (WPNAS) website is derived from the objectives of this research.

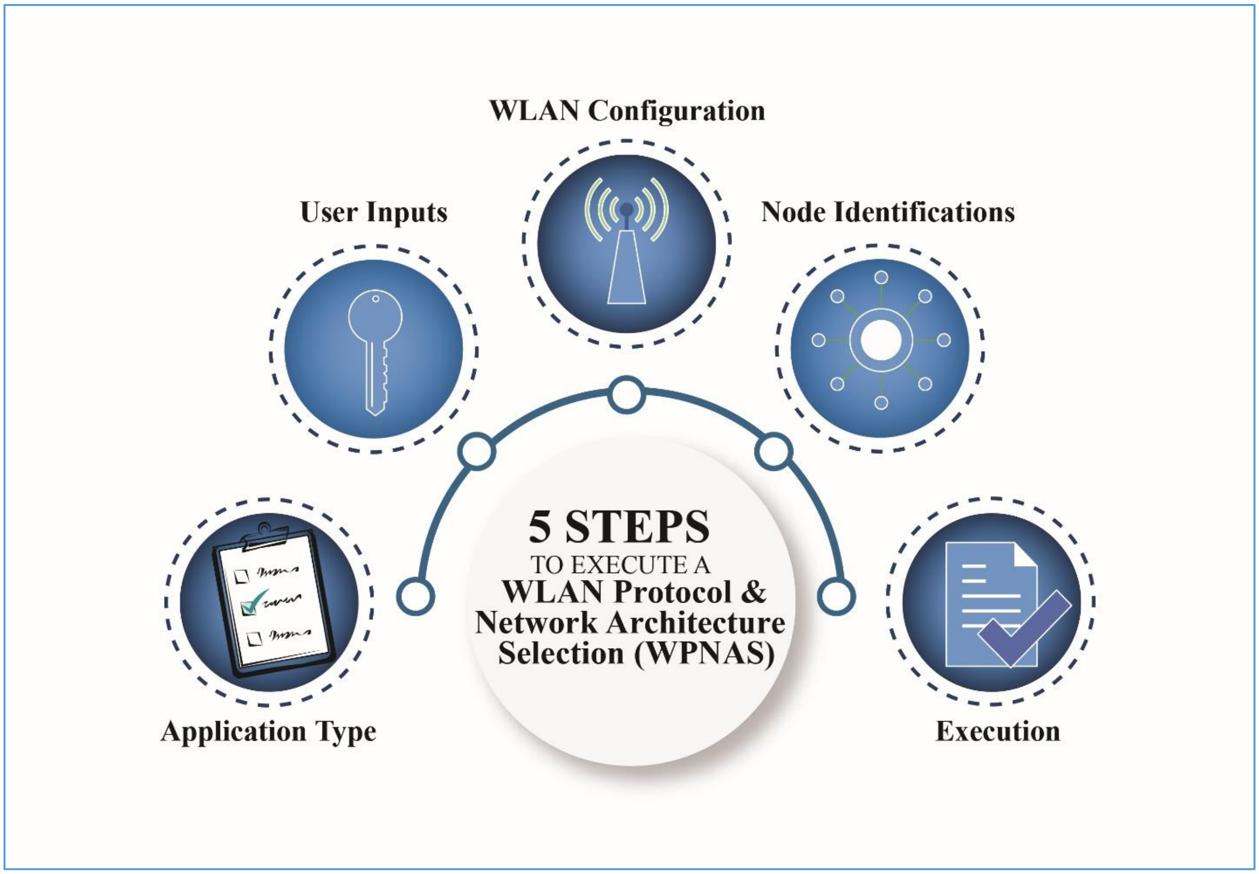


Figure 7. 1 Web-based tool's execution steps

The target audience of the WLAN Protocol and Network Architecture Selection (WPNAS) is public companies, university and personnel at specialized and non-specialized wireless network levels. Other users will include universities, colleges, architect/engineer groups, and academics/students. The website allows immediate and automated access to the results of the research project.

7.2 Application Type

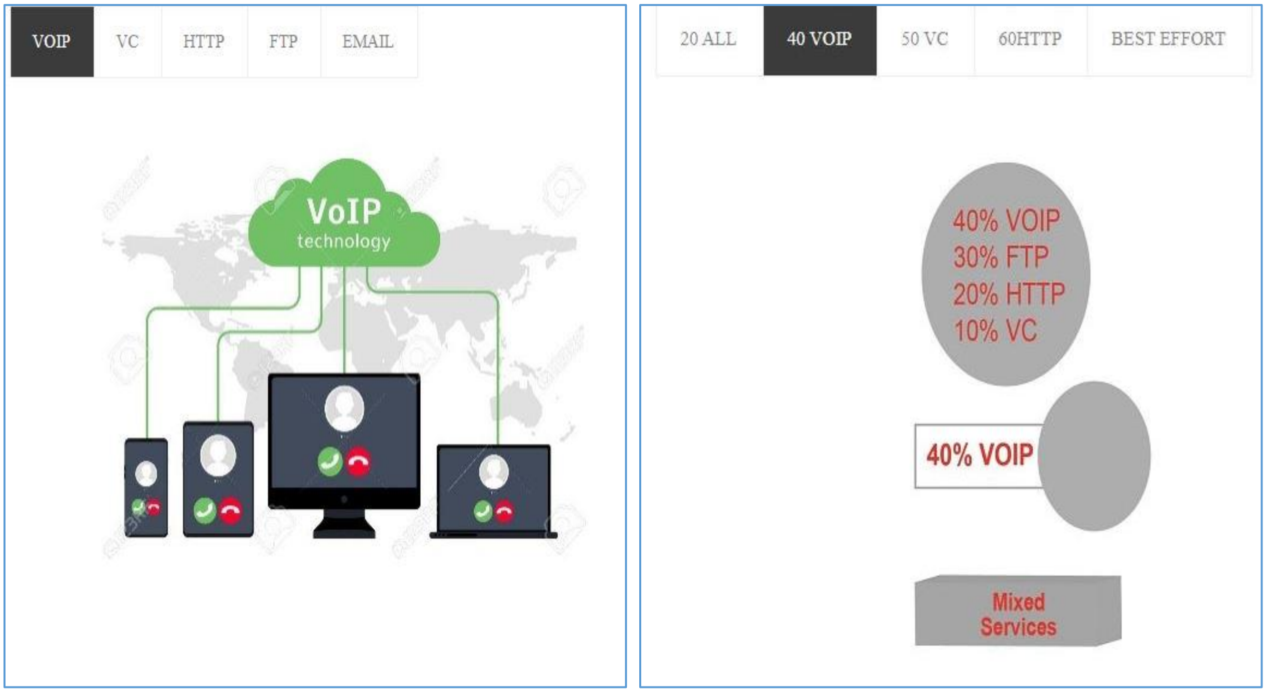
The WLAN Protocol and Network Architecture Selection (WPNAS) website are currently housed in a server at this URL address (www.wpnas.net). The first step, as shown in Figure 7.2, is to decide the type of application/service that fits the business activities.

Figure 7. 2 Web-tool Application/Service Type

- Mix services give the user the ability to set-up a network that consists of more than one application/service running at the same time.
- Stand-alone offers the user the choices to build the network with one application/service running at a time.

7.3 User Inputs

There are two main sources' inputs at this stage: user configurations and application/service percentages. User configurations based on what the user (client) actually requires, define the required service, either real-time (VoIP, VC) or best-effort (HTTP, FTP, E-mail), as shown in Figure 7.3 (a). Application/service's percentages, in case of mixed applications, the clients should define the purpose of their business. They should know the type of services that will be implemented (real-time or best-effort) and their percentages, such as 40 VoIP, as shown in Figure 7.3 (b).



(a) (b)

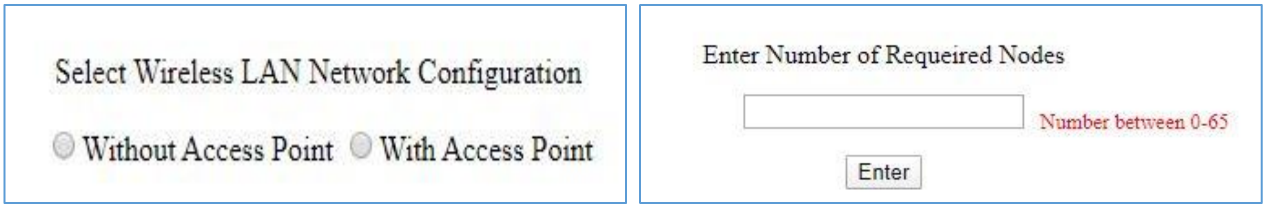
Figure 7. 3 User inputs. (a) User configuration, (b) Applications' percentages

7.4 WLAN Configuration

Defining the architectural network configurations, which describe how different wireless modes communicate in one of two ways: absence of access points (IBSS), or access point mode (BSS and ESS), as described in Figure 7.4 (a).

7.5 Node Identifications

Defining the size of the required network, i.e., the number of nodes. The number of selected workstations/nodes categorized into five main groups: 0 to 5, 6 to 10, 11 to 20, 21 to 40 and last, 41 to 65 workstations/nodes, as explained in Figure 7.4 (b).



(a) (b)

Figure 7. 4 User inputs. (a) WLAN Configuration, (b) Node Identifications

7.6 Execution

An Execution web page was developed to capture the results for all user inputs and requirements as shown in Figure 7.5.

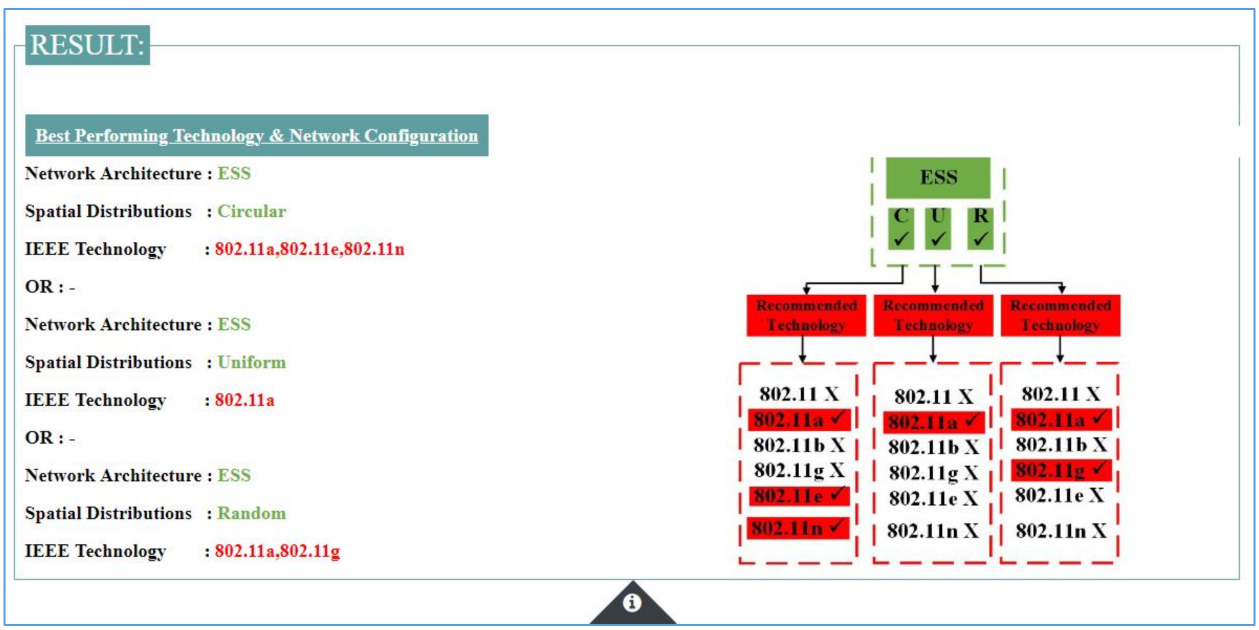


Figure 7. 5 Web-based results

7.7 Evaluation of the system

The aim of this evaluation study is to examine the effectiveness of the developed web-based tool (www.wpnas.net) on technical experts, users and specialized WLAN designers. As well as, their reasoning for doing so and the obstacles they face in managing the framework. To measure usability and attainment, survey strategies will be used. To assess usability in a significant manner, an accepted approach must be used to perform the survey.

A questionnaire is a technique structured for respondents to collect information. The elements in a questionnaire may be open-ended questions, but with users accessing from a collection of options, they are more usually multiple choices. A structured questionnaire is a repeat-use questionnaire, usually with a particular collection of questions submitted using a specified format in a particular sequence, with defined standards for generating metrics based on participants' responses. As part of the creation of a structured questionnaire, it is common for the designer to provide statistics of its reliability, validity, and sensitivity (Sauro & Lewis, 2016).

An accepted view of usability is the way a system is "easy to use". Therefore, usability does not always take into account a product's features or technological capabilities, but the understanding of the clients when achieving the desired objectives. Table 7.1, displays the most commonly utilized structured usability questionnaires that used at the end of a study for assessing the understanding of usability (Once a number of test scenarios are performed). Those questionnaires are as follow:

- The Questionnaire for User Interaction Satisfaction (QUIS)
- The Software Usability Measurement Inventory (SUMI)
- The Post-Study System Usability Questionnaire (PSSUQ)
- The System Usability Scale (SUS)
- Usability Metric for User Experience (UMUX)

Table 7. 1 shows the usability testing techniques (Sauro & Lewis, 2016)

Questionnaire	**Requires License Fee**	**Number of Items**	**Global Reliability**	**Validity Notes**
QUIS	Yes	27	0.94	Generate validity; prove sensitivity
SUMI	Yes	50	0.92	Generate validity; prove sensitivity; Standards availability
PSSUQ	No	16	0.94	Generate validity; synchronized validity; sensitivity evidence; some standard knowledge
SUS	No	10	> 0.89	Generate validity; prove sensitivity; emerging knowledge on standardized criteria
UMUX	No	4	> 0.80	Generate validity; synchronized validity; sensitivity evidence
UMUX-LITE	No	2	> 0.82	Generate validity; synchronized validity; sensitivity evidence; possibilities of implementing SUS criteria

An assessment technique is needed to evaluate the ease with which the system can be taught, the satisfaction and the user's attitudes towards the system (Brooke, 2013). The System Usability Scale, which is a subjective indicator of usability, has been considered to quantify these factors.

A questionnaire, the System Usability Scale (SUS), was developed that could be used to easily assess how society views the usability of the computer systems they operated on. This has demonstrated to be an incredibly easy and accurate instrument for use in usability assessments. SUS is a cost-effective but efficient tool to evaluate a product's usability, covering websites, mobile phones, videoconferencing systems, and also much more (Brooke, 2013).

ISO9241-11, a standard comprising of detailed measures on how well a user achieves specific objectives, defines one of the quantitative approaches to assess usability. ISO 9241-11 explains in detail how a product can be dealt with by clients, using hands-on approaches to demonstrate its general usability. The monitoring of users as they execute specific tasks during interactions is such a basic approach. The product can be defined to have attained appropriate usability if the specified measurements of effectiveness, efficiency and satisfaction are adequately accomplished (Georgsson & Staggers, 2016). The definitions of these terms are presented in Table 7.2.

Table 7. 2 Attributes for usability according to ISO 9241–11 (Georgsson & Staggers, 2016)

Attribute	**Definition**
Effectiveness	How accurately and completely the user can accomplish a goal.
Efficiency	The degree of effort and use of resources needed by the user to accomplish the adequacy and completeness of the goal.
Satisfaction	The optimistic connections and the lack of discontent encountered by the user during the task.

SUS score calculation

- For odd questions: deduct one from the respondent's answer.
- For even: deduct the answer of the participant from 5.
- This scales all values from 0 to 4, with the most positive answer is 4.
- For each participant, add the converted answers and multiply the number by 2.5. Instead of 0 to 40, this transforms the number of potential values from 0 to 100.
- It is important to note that, as shown in Table 7.3, raw scores are not depicted as percentages and translated into grades, this analysis was carried out by researchers Bangor, Kortum, & Miller (2009).

Table 7. 3 Translation of SUS scores into letter grades (Bangor, Kortum, & Miller, 2009)

<table>
<tr><th>SUS Score</th><th>Letter Grade</th><th>Accessibility</th><th>Adjective Rating</th></tr>
<tr><td>90-100</td><td>A</td><td rowspan="3">Acceptable</td><td>Best Imaginable</td></tr>
<tr><td>80-90</td><td>B</td><td>Excellent</td></tr>
<tr><td>70-80</td><td>C</td><td>Good</td></tr>
<tr><td>60-70</td><td>D</td><td rowspan="2">Marginal</td><td rowspan="2">OK</td></tr>
<tr><td>50-60</td><td rowspan="6">F</td></tr>
<tr><td>40-50</td><td rowspan="5">Not Acceptable</td><td rowspan="2">Poor</td></tr>
<tr><td>30-40</td></tr>
<tr><td>20-30</td><td rowspan="3">Worst Imaginable</td></tr>
<tr><td>10-20</td></tr>
<tr><td>0-10</td></tr>
</table>

In order to achieve a fair and equitable rating process, Sauro (2011) created percentiles, such as those computed in Table 7.4, to establish a curved grading scale for mean SUS scores measured for a sample from a group of independent SUS scores, as shown in Table 7.5 (Sauro & Lewis, 2016).

Table 7. 4 Percentile Ranks for Raw SUS Scores (Sauro & Lewis, 2016)

Raw SUS Score	**Percentile Rank (%)**	**Raw SUS Score**	**Percentile Rank (%)**
5	0.3	**69**	53
10	0.4	**70**	56

15	0.7	**71**	60
20	1	**72**	63
25	1.5	**73**	67
30	2	**74**	70
35	4	**75**	73
40	6	**76**	77
45	8	**77**	80
50	13	**78**	83
55	19	**79**	86
60	29	**80**	88
65	41	**85**	97
66	44	**90**	99.8
67	47	**95**	99.9999
68	50	**100**	100

Table 7. 5 Curved Grading Scale Interpretation of SUS Scores (Sauro & Lewis, 2016)

SUS Score Range	**Grade**
84.1–100	A+
80.8–84.0	A
78.9–80.7	A−
77.2–78.8	B+
74.1–77.1	B
72.6–74.0	B−
71.1–72.5	C+
65.0 –71.0	C
62.7–64.9	C−
51.7–62.6	D
0.0–51.6	F

Usability & Learnability Measurements of SUS

Although SUS was only meant to calculate user satisfaction (a particular component), it demonstrates that it offers a global metric of system satisfaction and usability and learning sub-scales. The learning aspect is given by adding items 4 and 10 multiply the result by 12.5. (This scales the results from 0 to 100), while adding the other 8 items and multiply the result by 3.125. (This scales the results from 0 to 100.) provide the usability aspect. This implies that on both subscales and the global SUS rating, you can measure and review (Borsci, Federici, Malizia, & De Filippis, 2019).

Reliability of SUS

Reliability is a measure of how users respond consistently to the elements. It has been shown that SUS is more accurate and measures variations in smaller sample sizes than other commercially available questionnaires. Using an internal reliability coefficient named Cronbach alpha or alpha coefficient (Lewis & Sauro, 2017)

Alpha coefficient, according to Sauro & Lewis (2016), is a statistical reliability/consistency coefficient varying from 0 to 1. The nearer the coefficient is to 1, the more accurate and consistent the components are. Moreover, the lowest limit of satisfactory internal reliability deemed to be 0.7 (Estrada, Dawson, & Cárdenas-Haro, 2019).

Let us assume the measure of a quantity that is the sum of the elements of K (K-items): $X = Y_1 + Y_2 + \ldots + Y_K$. Cronbach's α is presented using Eq. (7.1):

$$\alpha = \frac{K}{K-1}\left(1 - \frac{\sum_{i=1}^{K}\sigma_{Y_i}^2}{\sigma_X^2}\right) \tag{7.1}$$

where σ_X^2 is the variance of the aggregate of the measured study scores, and $\sigma_{Y_i}^2$ the variance of component i for the current study (Cho, 2016).

Validity of SUS

Validity correlates to how well something can evaluate what it is supposed to assess. That is perceived usability in this context. As effective as or better than standardized questionnaires, SUS has been shown to efficiently differentiate between useless and useful systems. SUS also corresponds strongly with other usability measurements dependent on questionnaires (referred to as the concurrent validity) (Borsci, Federici, Malizia, & De Filippis, 2019).

In order to test the usability of the www.wpnas.net web-based tool in a variety of user settings and application/service proportions, SUS surveys are considered suitable techniques, shown in Appendix. As it is easy to manage, the SUS is therefore chosen so that the possibility of respondent fatigue is mitigated owing to the many questionnaires being filled out. Moreover, given the advancements made in technology since its beginnings, the SUS continues to be a conventional and convenient approach of technology to differentiate between usable and unusable programs (Orfanou, Tselios, & Katsanos, 2015).

The survey consists of ten questions with answers rated on a scale from one to five, indicating clear disagreement and agreement. Similarly, without having a large number of participants, it is distinguished by high internal efficiency, but it can only identify that a problem occurs within the system rather than diagnosing a particular area of usability that is problematic. The SUS has, however, been used to offer analysis into two variables (Sauro & Lewis, 2016).

The questionnaires could be carried out in a variety of ways: through a web-based survey, such as Google Forms and SurveyMonkey. As well as electronically through e-mail. SUS results were extracted from different forms of technology platforms, such as social media websites, user-specific software and smartphone devices.

7.7.1 Findings and discussion

A quantitative standardized questionnaire (SUS) was deemed to be completed by the participant separately and anonymously, structured to provide responses to a series of questions that would allow us to check for correlations and relationships between different variables.

However, supported by a massive database of more than five thousand SUS findings gathered from different types of programs, such as platforms, commercial enterprise and user applications, and intelligent personal applications, Sauro (2011) reported that the overall mean score of the SUS is 68 with a standard deviation of 12.5. This SUS benchmark was used in this evaluation study.

The detailed SUS score statistics from the assessment analysis are presented in Table 7.6. In total, there were 154 respondents to the WPNAS usability survey. In the responses from the SUS surveys, as expected, there is high internal reliability: 0.74, suggesting the internal consistency of the questionnaire for 154 participants in this study and the standard deviation of 18.2. The mean SUS score of 82.2, which indicates that this website tool is acceptable. The overall average on the basis of the SUS standard is 68 (Sauro & Lewis, 2016). The usability impact of the WPNAS web tool is therefore Excellent. Furthermore, the Usability and Learning obtained from this evaluation are 84.9 and 73.3, respectively. Details of the raw form answers of the respondents are provided in the Appendix.

Table 7. 6 SUS Descriptive Statistics for WPNAS website

Mean SUS score 82.2 **Std Dev** 18.2 **(N)** 154		
Cronbach alpha (α) 0.74 *Internal Reliability:* Good		
Scales		
SUS	**Usability**	**Learnability**
82.2	84.9	73.3

Table 7.7, shows the raw SUS score as interpreted in the percentile rank by the test method. The raw SUS score of 82.2 reveals that the WPNAS website tool used for this analysis has a greater SUS score than 92 % of all products tested. The usability grading scale is calculated as A and B by both Sauro & Lewis (2016) and Bangor (2009), respectively.

Table 7. 7 Grade and Percentile Rank for a Raw SUS score for WPNAS website

Input	Raw SUS score **82.2**			
Results				
Percentile Rank	Adjective	Grade (Bangor)	Grade (Sauro & Lewis)	Acceptability
92nd	Excellent	B	A	Acceptable

Furthermore, the analysis of the second part of the WPNAS survey (questions11-14) revealed the following information from the participants, as shown in Figure 7.6.

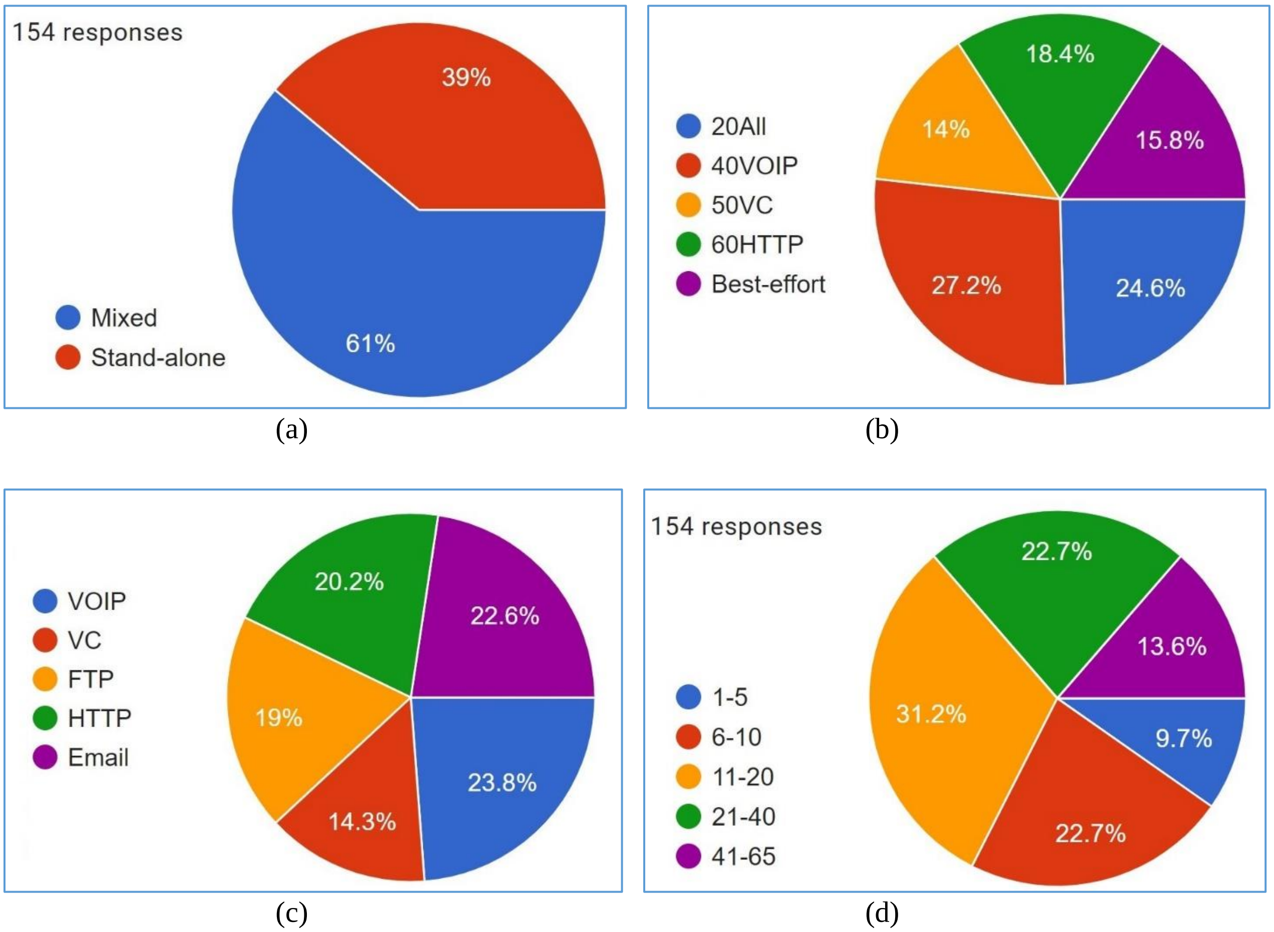


Figure 7. 6 WPNAS Participants responses.
a) Service type, (b) Mixed, (c) Stand-alone, (d) Number of nodes

61% of respondents choose mixed services as appropriate for their use, Figure 7.6 (a). Most of these, 27.2% preferred 40 VOIP services, as shown in Figure 7.6 (b). While 39% of respondents used stand-alone services and VOIP services, as shown in Figure 7.6 (c), had the highest implementation rate of 23.8%. In addition, the third group of nodes (11-21) is the most popularly used since this category was implemented by participants at a rate of 31.2%, as shown in Figure 7.6 (d).

7.8 Summary

This chapter will present a web-based tool to identify appropriate IEEE technologies/protocols and optimal network configurations autonomously using a web-based application created by a comprehensive set of system simulations. The aim of this website is to address a significant number of technical and non-technical challenges affecting network engineers, architects and personnel that restrict the efficient use of network resources and the random allocation of network architecture and IEEE technologies.

The WLAN Protocol and Network Architecture Selection (WPNAS) intended audience are public companies, universities and wireless network specialist and non-specialized staff. Other users will include researchers, colleges, and architect/engineering groups. The website offers instant and automated access to research findings. It also provides users with all the options required for the type of WLAN technology, network configuration and space distribution, as well as free consultation and guidance to achieve their personal configuration inputs.

The developed web tool was evaluated in order to analyse its impact among technical experts, users and specialized WLAN designers. As well as, exploring their motivations and difficulties they have faced in implementing the method. Survey methods would be used to assess usability and achievement. To assess usability in a sensible manner, an accepted approach must be used to carry out the survey.

Usability has been assessed using the SUS. The mean SUS score for the WPNAS web tool is 82.2, which is higher than the average usability (68). In addition, the internal reliability of the questionnaire for this analysis is 0.74, demonstrating respectable internal consistency. Furthermore, the usability and learning obtained from this evaluation are 84.9 and 73.3, respectively.

CHAPTER 8 CONCLUSION AND FUTURE WORK

8.1 Conclusion

The management of stand-alone and mixed applications with QoS in both real-time and best-effort systems is already a major challenge in the media industry. Particularly, the most appropriate network configuration/architecture is to be recognized based on traffic parameters such as delay, jitter, throughput, and packet loss. However, a logical assessment is essential for the analysis of IEEE 802.11 technologies that are preferable to practical scenarios.

Nevertheless, the application development process will never take place without limitations: the literature does not sufficiently discuss the performance consequences for all six IEEE 802.11 technologies of implementing in-same network real-time and best-effort services, nor the effect of node spatial distribution analysis on network performance.

In addition, a thorough analysis of existing methods found that the optimum performance of IEEE technology used in industrial communication systems in real-time is not always safeguarded in contrast to the older technology, for this exact reason, our study offers an analysis that proposes optimum technology and network configuration to the user/client without wasting resources or addressing random choices of different technologies and then redesigning the complete configuration.

Analysis of the impact of node's Spatial Distribution (i.e., Circular, Random, Uniform) on the network performance for all six IEEE 802.11 technologies was carried out. The literature did not demonstrate this particular area of research such as the analysis made in Al-Maqri, Mansoor, Sabri, Ravana, & Yaseein (2020), Jabbar, Ismail, & Nordin (2014) and Pal & Vanijja (2017).

Table 8.1 shows that a brief comparison between our proposed method with multiple algorithms presented in Schmitt, Redi, Bulterman, & Cesar (2017), Al-Maqri, Mansoor, Sabri, Ravana, & Yaseein (2020), Sllame (2017) and Kaur, et al. (2020) and highlighted their drawbacks. The following features have been compared and summarized, including QoS metric parameters, number of nodes, network architecture, IEEE technology, and the simulation model.

Previous works Al-Maqri, Mansoor, Sabri, Ravana, & Yaseein (2020) and Kaur, et al. (2020), have been illustrating and implementing their models with different nodes of (10) and (16), respectively, in the calculations of the optimized network configuration with metric parameters such as end-to-end delays and throughput. However, only BSS network architectures have been used to validate their proposed approaches. The additional downside associated with Al-Maqri, Mansoor, Sabri, Ravana, & Yaseein (2020) and Kaur, et al. (2020) methods is that only IEEE (802.11g, 11e) and (802.11n), evaluations are considered, respectively. Likewise, Schmitt, Redi, Cesar, & Bulterman (2016), assessed IEEE technologies using a fixed number of nodes (9), while Sllame (2017) evaluated the network on the basis of (30) nodes and only took into account one network architecture (IBSS). However, the approaches proposed have only been validated with BSS and IBSS as the only network architecture, respectively.

The algorithm has two main input parameters, namely, the number of nodes and the service applications, whereas the output scenarios include:

- The number of workstations/nodes grouped into five major classes: 0 to 5, 6 to 10, 11 to 20, 21 to 40 and last, 41 to 65 workstations/nodes.
- The algorithm determines the best configuration layer on the basis of the selected number of nodes. In practice, all network configurations, including ESS, BSS, and IBSS, are visualized. Three spatial distribution structures, including circular, uniform and random, are also included in the research process.
- Finally, the technology layer addresses the best possible IEEE 802.11 technology (802.11, 11a, 11b, 11g, 11e and 11n) that would perfectly suit the selected network configuration.

This work takes several variables and produces a list of options for the client. There is likely to be a trade-off between speed and cost. So, it is not the case that the clients will always choose the fastest data rate as this may be too expensive for them. What they want to see is the cost-performance data so they can choose the service at speeds they are willing to tolerate at a price they are willing to pay.

Table 8. 1 Brief comparison between the proposed method with multiple algorithms

Reference	Approach	QoS metrics	Number of nodes	Network Architecture	IEEE Technology	Simulation model
(Schmitt, Redi, Bulterman , & Cesar, 2017)	Offer an empirical approach to network readiness and evaluation of desktop video conferencing.	Packet Loss Queue Delay	9	BSS	NA	OPNET
(Al-Maqri, Mansoor, Sabri, Ravana, & Yaseein, 2020)	In order to improve the scheduling of multimedia traffic in terms of channel use, a framework was implemented to maximize the use of extra bandwidth to achieve optimal transmission efficiency of multimedia applications.	End-to-end delay Bandwidth	10	BSS	802.11g 802.11e	NS2
(Sllame, 2017)	VoIP QoS performance metrics were studied using different routing protocols to evaluate QoS.	Jitter WLAN delay Throughput	30	IBSS	802.11g	OPNET
(Kaur, et al., 2020)	Research the efficiency of the optimized network architecture that combines XG-PON and EDCA with bursty real-time traffic generated from	Throughput End-to-end delay Jitter Fairness	16	BSS	802.11n	NS3

	the current distribution of global IP traffic.					
Thesis study	To define the best network architecture, evaluate VOIP, VC, HTTP, FTP and Email metrics for different IEEE 802.11 technologies	Delay Jitter Throughput Packet loss	1-65	BSS ESS IBSS	802.11 802.11a 802.11b 802.11g 802.11e 802.11n	OPNET

This study aims to develop a new algorithm to identify optimal network topologies among BSS, IBSS or ESS, which offers the best overall performance for a mixed and standalone application (VoIP, VC, HTTP, FTP, Email) in accordance with predetermined network arrangements.

Hence, the algorithm has two main input parameters, namely, the number of nodes and the service applications, whereas the output scenarios include:

- The number of workstations/nodes grouped into five major classes: 0 to 5, 6 to 10, 11 to 20, 21 to 40 and last, 41 to 65 workstations/nodes.
- The algorithm determines the best configuration layer on the basis of the selected number of nodes. In practice, all network configurations, including ESS, BSS, and IBSS, are visualized. Three spatial distribution structures, including circular, uniform and random, are also included in the research process.
- Finally, the technology layer addresses the best possible IEEE 802.11 technology (802.11, 11a, 11b, 11g, 11e and 11n) that would perfectly suit the selected network configuration.

The following is a brief description of the objectives and specific achievements of this research work:

Objective One: To build different representative scenarios with different user applications such as VoIP, File Transfer Protocol (FTP), Web Browsing (HTTP), VC, and E-mail aiming to evaluate QoS parameters such as throughput, packet loss, jitter and different types of delay.

Achievement: Under various factors such as spatial distribution, number of nodes and network architectures, five different services (applications) were evaluated and analysed; whereas, in literature, the evaluation was conducted only on a single technology at a time. In addition, there is a lack of research that involves the assessment and study of mixed applications, including the best-effort and real-time services. To evaluate best-effort services such as HTTP, FTP, E-mail and real-time services such as VoIP and VC throughout different IEEE 802.11 technologies, a novel algorithm was developed, whereas various QoS metrics were used and studied in the development of this algorithm. Namely; delay, jitter, throughput, packet loss, download response time, and page response time. The algorithm is proposed to rank the various technologies in IEEE 802.11 standards.

Objective Two: To create and develop a clear algorithm that calculates the packet loss ratio in OPNET Modeler using the MATLAB program.

Achievement: The Boolean value (0.0 or1.0) corresponding to the acceptance or rejection of the packet loss parameter is used to generate the performance of the OPNET Model. While in the literature, the evaluation of the packet loss parameter using OPNET Modeler was taken as a Boolean value and did not explain how to measure its exact percentages either for best effort or for real-time services on the OPNET platform. However, this study involves the value of packet loss as a numerical aspect. Two methods are developed to measure the percentage of packet loss of each application: one with Excel Office software and the other with MATLAB to code that as well. The code has been programmed on the basis of a mathematical definition of packet loss to develop a method for calculating its percentage for all applications and scenarios that have been established in this work, either mixed or stand-alone applications. Both methods can be directly related to the OPNET Modeler for a given application to generate a particular percentage of packet loss. This value has, however, been produced for each particular technology.

Objective Three: To rank the existing IEEE 802.11 technologies for both stand-alone and mixed network applications, setting an importance coefficient for each application statistics.

Achievement: The objective of this research is to construct many scenarios in order to rank the current IEEE 802.11 standards for stand-alone and mixed applications by inventing a coefficient of importance for the metric parameters of each application. For each application, the criterion of satisfaction (acceptable threshold) for each QoS metric parameter is defined where these threshold values are identified from the literature (Zawia, Hassan, & Dahnil, 2018); (Al-Shaikhli, Esmailpour, & Nasser, 2016). These qualitative variables will be translated into quantity figures as they are to be taken into account in the simulation. It is worth mentioning that, in terms of its effect on the quality of the service, an important coefficient is assigned to each application parameter (ICP) and a specific equation has been derived to measure this value for each QoS parameter for each application, either in stand-alone or mixed services for each IEEE technology. The literature review showed that neither previous work had calculated the value of the coefficient of importance for either of these metric parameters or any of the internet services.

Objective Four: To build a systematic framework that provides the opportunity to identify and implement the optimal Ad hoc, BSS or ESS network configuration.

Achievement: Literature analysis has shown that no previous work has measured best efforts (HTTP, FTP and Email) or real-time (VoIP & VC) QoS metrics of various IEEE 802.11 technologies for the purpose of establishing the best technology across infrastructure and independent network architectures. Moreover, three different Network Architectures (Ad-hoc, BSS and ESS) were considered in this thesis, while up-to-date research is considered only a stand-alone network architecture. The literature did not demonstrate the performance of all three network architectures for the same inputs data for both types of services, stand-alone and mixed services.

Objective Five: To create a readily accessible and readily usable web-based tool for clients, planners and network designers that gathers, integrates, and organizes a vast amount of critically important information about WLAN technologies and network architectures to overcome many implementation hindrances and promote more widespread use to achieve the research objectives.

Achievement: This work will result in a web-based application that utilizes a database produced by a comprehensive set of system simulations to autonomously select an appropriate wireless protocol based on user requirements. However, the ability to deploy and utilize this web-based tool has been summarized in five domains WLAN framework steps, as shown in Figure 8.1.

- Firstly, the user will decide the service type that he prefers, either stand-alone or mixed services.
- Secondly, the user identifies the network architecture that is going to be used; with or without an access point, that gives the tool the ability to track him to suitable network architecture that fits the required configuration.
- Thirdly, the number of nodes will be specified by the user/designer, because they know what their business is, they know how many nodes/workstations will be used to set up their company/shop/lab.
- Fourthly, at this stage, the web tool will identify the best spatial distribution and tells the user/clients how to allocate the nodes to get the maximum and best performance for the required configuration.
- Finally, the rank order of the best WLAN technologies will be produced to inform the client of the standard (or a mix of standards) that will result in the best overall performance.

The ultimate use for the results of this research, therefore, contributes to the development of tools that are linked to the results of this work and that accept multiple inputs, such as the number of nodes, applications in a variety of proportions, the spatial distribution of nodes, physical layer technology, and network configurations, to decide on the most appropriate protocol for those inputs.

The novelty of the work presented in this thesis is demonstrated by the frame/algorithm design and the ability to implement a method to analyse network performance to achieve the most efficient network set-up based on the technologies currently available; in addition, to identify which IEEE technology and network architecture can be implemented for future Internet applications and services. Moreover, this work design optimization mechanism allows network designers or users to evaluate the network requirement on the basis of the bandwidth needs of the application.

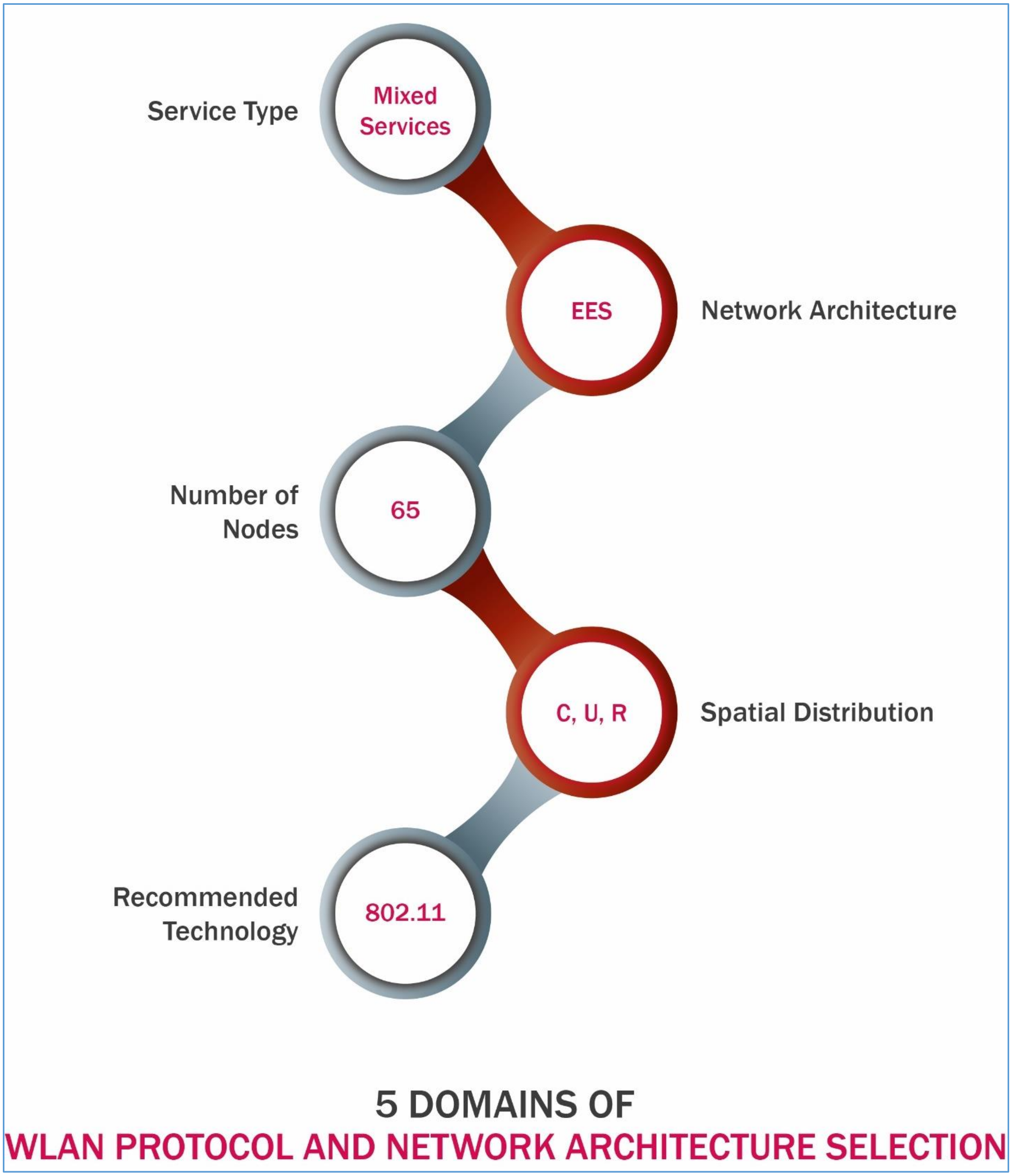


Figure 8. 1 Web-based domains of WLAN framework steps

8.2 Future Work

A future direction for this research is to examine other real-time and best-effort qualities and upcoming ones with the same techniques introduced in this work to define the optimum IEEE standard to be used with various application services. In addition, we plan to propose and deploy additional applications for the service mix created based on larger network dimensions and other network protocols. However, there is still a considerable range of potential pathways for further work, such as:

8.2.1 Internet of Things (IoT)

A number of physical devices are being linked at an exponential pace to the Internet, reflecting the concept of the Internet of Things (IoT). It ranges from mobile phones, refrigerators, speakers, smartwatches, and lots of other items with a switch that can be linked to the internet. There are several other sectors and areas where the IoT can contribute and enhance the world for the better. Such services include transport, health, information technology, and emergency response to environmental disasters where it is difficult to make human decisions.

The IoT helps physical devices, as shown in Figure 8.2, to see, listen, interpret and perform jobs by making them speak together, exchanging knowledge and organizing decisions. By leveraging its underlying technologies, such as widespread computing, sensors, networking technologies, wearable devices and communication technologies, the IoT transforms these physical devices from conventional to smart.

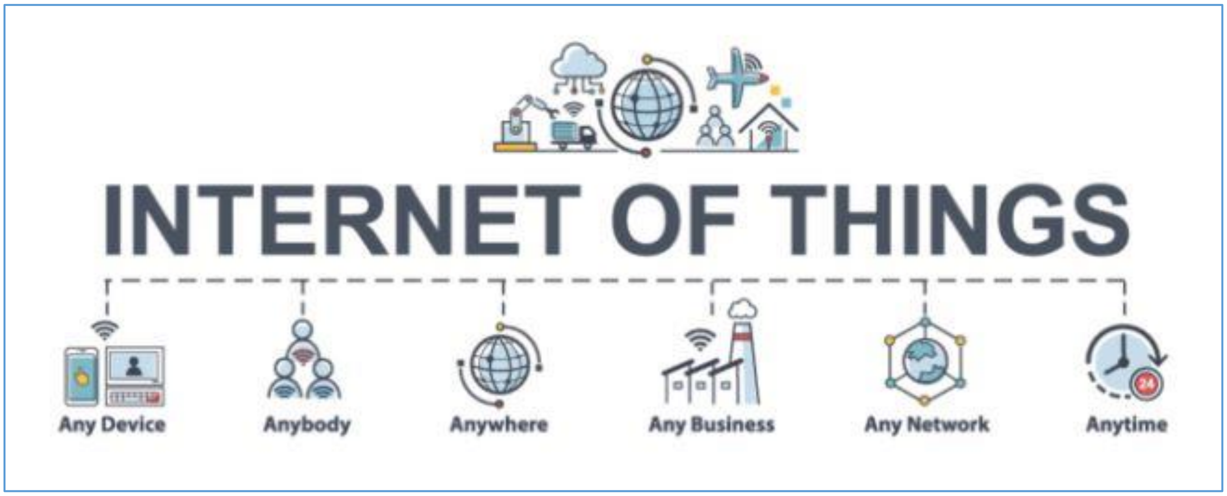


Figure 8. 2 IoT implies combining devices and hardwires through an internet connection (Smartek Technology, 2019)

IoT has developed from basic communication between machine-to-machine (M2M). Connecting a computer to the cloud, controlling it and gathering data is what organizations and businesses benefit from using M2M communications. M2M provides the connectivity that makes IoT, as its core. It could be used for the management process, the capacity to remotely capture information in real-time to control devices.

In order to enhance corporate strategies, IoT is something businesses are trying to find out how to appropriately utilize. It is necessary to first outline the business priorities, targets as well as what benefits you will anticipate before putting in place any IoT projects.

According to a report from Gillett, et al. (2020), IoT helps boost business benefits in three ways:

1. **Design**: Reshape current or future goods.
2. **Operate**: Utilizing improved automated platforms and better data to boost physical procedures.
3. **Consume**: Use context data as well as data from IoT clients that belong to external entities to develop programs, processes or products.

The capacity to significantly minimize potential mistakes and manual labour is one of the greatest advantages of IoT. For the purpose of IoT, two aspects have already stated are vitally important: efficacy and reducing costs. These are the key elements that businesses assume once introducing this technology. In essence, what IoT is all about, either for industrial or business uses, is the opportunity to gather, evaluate data and then take the right decisions depending on the outcomes. The primary objective of IoT is not to eliminate human work entirely, but to develop and optimize it.

In addition, A major challenge to the IoT infrastructure is determining the optimal networking technology for end devices – sensors and actuators. The requirements of end devices – low battery consumption and potentially high data traffic when many end devices are involved – mean that conventional networking infrastructure is unsuitable for IoT systems. As the field is still in its infancy a lot of work is still ongoing in all of the layers involved in the Internet of Things. There is a need for a system to support IoT engineers and designers in determining the best networking technology to use for any given end-device configuration. Further work based on my research could focus on providing such a system for IoT infrastructure. In this context, El-Mougy, Ibnkahla, & Hegazy (2015) present promising solutions based on Software-Defined Network (SDN) to some persistent challenges in the IoT.

SDN is a network that largely relies on software that can be managed or configured smartly and directly with software applications. As businesses use it to link up their office locations to the cloud, SDN implementation may well be extended. In conventional business models, the unprecedented rise of digital media, the proliferation of cloud technologies, the influence of rising smartphone use, and continuing business demands to minimize costs while profits remain steady are all turning to cause problems. There would be a single main networking platform with a software-driven network and cloud services. Bandwidth management, recovery, confidentiality, and rules and regulations can be incredibly smart and streamlined with such centralized control and SDN-based network offerings, and an enterprise can achieve a comprehensive understanding of the network.

8.2.2 5G technology

Radio waves move in the electromagnetic media in wireless communication. The compromises and trade-offs that we take when constructing wireless technology determine QoS parameters such as delay, throughput, bandwidth, power usage, geographic dispersion, spectrum, and cost. For this exact cause, there is really no single wireless answer that can potentially solve all current networking and communication concerns at once.

Faster transmission and less delay at a speed of at least 40 times faster than 4 G LTE are promised by 5G technology. This ensures that the way we use the mobile web and various applications every day will be enhanced and that large media, such as video, will transfer far more rapidly to connected devices. New business models will be immense and there will be a full improvement in user experience.

The 5G technology has the following objectives:

- Provide much more connectivity to allow various applications, services and machine-to-machine connections.
- Allow greater data rates.
- Allow low delay (for IoT connectivity and machine-to-machine services).

An improved fibre network is the core of many of the IoT networks. In the business or house, you may also have an installed fibre network. In addition, 5g architectures are SDN-based systems that use software to control networking functionality. Developments in cloud services, IT, virtualization and automation, make for a flexible and scalable 5G-architecture which gives users access anytime and wherever they are.

Various technological development will be used for the infrastructure of homes, companies, and several public places: Wi-Fi 6. The new standard for Wi-Fi 6 (recognised as 802.11ax) shares features with 5G, including enhanced performance. moreover, the users could leverage the benefits of Wi-Fi 6 to provide greater geographical coverage with lower costs.

In addition, the new technology of the internet would speed up existing Wi-Fi and enable users to stay connected in congested areas without impacting their devices' battery life. Next significant transformation in networking and communication will be the integration of this wireless technology (802.11ax) and 5G. This will launch a new perspective for future work to explore combining WLAN with rapidly evolving 5G technology in our proposed algorithm to determine the best WLAN technology and configuration of the network based on user requirements.

8.2.3 Machine Learning and Artificial Intelligence

Machine Learning (ML) algorithms and Artificial Intelligence (AI) will become the main pillar for a broad variety of technologies and applications. Depending on the network information, ML can reach answers and predictions. So, in the broader sense, based on those predictions, AI can also take intelligent action. However, automation is not just artificial intelligence or machine learning; now automated processes may take up thousands of everyday and routine duties.

Computers will learn to forecast network patterns, and artificially intelligent technologies will effectively bring up and invoke network adjustments depending on the machine's experience. On the other hand, we will not see networks operating completely independently but more sophisticated automation and analytical methods will be available instead.

Advanced analytics and automation are becoming quite prevalent that these advanced analytics can indeed be embedded directly into such automation systems, which will also be turned into validation processes and the start of a self-operating network.

This research provides an overview that offers the user optimal technology and network configuration without wasting resources nor presenting random choices of various technologies and then redesigning the complete configuration. It is, therefore, our aim, through ML and AI, to find a mechanism to take advantage of and integrate these advanced technologies for the development of both our proposed algorithm and its corresponding website, to ensure the maximum possible benefit for the client and society, as well as to keep abreast of successive developments in the digital world.

8.2.4 Wi-Fi 6 (IEEE 802.11ax) and Wi-Fi 7 (IEEE 802.11be)

Wireless networks have undergone a steady and rising prominence that has lured an ever-increasing number of users. This has led to a major rise in the use of digital information on all platforms. There is no question that an already diversity of network services and the precision of performance criteria will become a theme in the growth of wireless networks, such as IoT, social networks, and other networks, posing daunting WLAN demands. Consequently, the IEEE 802.11 framework will keep carrying out analysis on major technology and to revise the standard.

WLANs based on IEEE802.11, are by far the most common and efficient wireless indoor services, have developed into an important technology that encompasses mid-sized to large-scale businesses. These communities have a variety of AP nodes that support a large number of users. Furthermore, enhanced coverage and increased data speed are the main accomplishments of these WLAN technologies.

Wi-Fi 6, up to 9.6 Gbps (Qu, Li, Yang, Yan, & Zuo, 2017), makes the Internet and the digital world faster. This is critical because most of us work from home on our mobile device, watch movies, and share updates on social media. As such, there is a need for something to cope with all the increased demand. Wi-Fi 6 offers new and existing networks improved speed and readiness for next-generation applications by providing greater performance, versatility, and expandability.

Wi-Fi 7, the most recent standard, is 802.11be. Although this technology is still a little further away, over Wi-Fi 6, it has some improved capabilities. It can transmit information simultaneously on multiple frequencies, use two bands (or perhaps three) instantly, and further expand the information data it can transmit on the network.

Network service diversity leads to a range of QoS specific requirements for various services, such as throughput, latency, jitter, packet loss, and bandwidth. Accordingly, IEEE 802.11 should investigate how to meet the standard variety of QoS specific requirements. However, a more effective allocation scheme is required to distribute wireless services to individuals with a variety of QoS requirements.

This study provides a detailed overview of the QoS behaviour of various networks for both stand-alone and mixed services for different IEEE technologies. However, in our future study, Wi-Fi 6 (802.11ax) and Wi-Fi 7 (802.11be) will be considered and implemented in our algorithm and mathematical model. Simulation systems, such as OPNET, should also integrate these technologies into their software applications to enable the academic community to use them. In addition, this will provide a valuable opportunity for researchers, network designers and businesses to conduct their researches and apply these technologies to assess and examine its potential performance.

Moreover, further directions for future work will be to evaluate these new technologies using our proposed algorithm and its related configurations to implement it in a geographically broad area, such as a stadium or an airport, to evaluate network efficiency in order to achieve the most efficient network set-up and to identify which IEEE technology and network architecture can be used in such wide geographic regions.

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APPENDICES

Appendix A

Statement of Co-Authors Contribution for the papers published in this Thesis

By means of this text, I declare that all the papers presented and published in this thesis are original work done at the University of Huddersfield during my studies (as stated in the list of publications). We the candidate student (Ali Mohd Ali), main academic supervisor (Dr Mahmoud Dhimish), the co-supervisor (Dr Peter Mather), former main supervisor (Dr Martin Sibley) and former co-supervisor (Prof. Ian Glover) confirm and verify that the contribution work used in published research materials associated with the thesis has been accepted by all co-authors. We have since approved the contribution from each candidate mentioned in the originality statement below:

STATEMENT OF ORIGINALITY		
Journal Article No.01		
Manuscript Title	**Publication Status**	**Chapters covered by the research published**
WLAN 802.11e evaluation performance using OPNET	The manuscript has been submitted to International Journal of All Research Education & Scientific Methods (IJARESM), 5(1), 35-38.	Chapters 1 & 2
Contributor	**Statement of Contribution**	
Ali Mohd Ali	Majority Contribution (80% - 100%) (Writing the paper, analysing the problem, conducting analysis, implementing the problem-solving methodology, conducting experiments, and interpreting experimental design data).	
Martin Sibley	Has contributed to the work (10% – 20%) (Suggestions and discussion in article or manuscript format).	
Ian Glover	Has contributed to the work (5% - 10%) (Examination of the document or manuscript and English Proof).	

Journal Article No.02 & Conference Proceeding No.01		
Manuscript Title	**Publication Status**	**Chapters covered by the research published**
WLAN Protocol and Network Architecture Selection for Real-time Applications.	The manuscript was submitted to the Proceedings of Academics World 142nd International Conference (pp. 45-51) World Research Library and was subsequently selected to be published as a journal in the International Journal of Advance Computational Engineering and Networking (IJACEN), 7(11), 8-14.	Chapters 1, 2, 3 & 4
Contributor		
Ali Mohd Ali	Majority Contribution (80% - 100%) (Writing the paper, analysing the problem, conducting analysis, implementing the problem-solving methodology, conducting experiments, and interpreting experimental design data).	
Mahmoud Dhimish	Has contributed to the work (10% – 20%) (Suggestions and discussion in article or manuscript format).	
Peter Mather	Has contributed to the work (5% - 10%) (Examination of the document or manuscript and English Proof).	

Journal Article No.03		
Manuscript Title	**Status/ Date of Publication**	**Chapters covered by the research published**
Algorithmic Identification of the Best WLAN Protocol and Network Architecture for Internet-Based Applications.	The manuscript has been submitted to Journal of Information and Knowledge Management, 19(1), 2040011.	Chapters 1, 2, 3, 4, 5, 6 & 8.
Contributor	**Statement of Contribution**	
Ali Mohd Ali	Majority Contribution (80% - 100%) (Writing the paper, analysing the problem, conducting analysis, implementing the problem-solving methodology, conducting experiments, and interpreting experimental design data).	

Mahmoud Dhimish	Has contributed to the work (10% – 20%) (Suggestions and discussion in article or manuscript format).	
Peter Mather	Has contributed to the work (5% - 10%) (Examination of the document or manuscript and English Proof).	
Malek Alsmadi	Has contributed to the work (2% - 5%) (Discussion and overview of literature).	
Journal Article No.04 & Conference Proceeding No.02		
Manuscript Title	**Publication Status**	**Chapters covered by the research published**
Identifying the Optimum Network Architecture and WLAN Technology for Video Conferencing Application	The manuscript was submitted to the Academicsera 57th International Conference (pp. 20-25) World Research Library and was subsequently selected to be published as a journal in the International Journal of Advance Computational Engineering and Networking (IJACEN), 8(2), 31-36.	Chapters 1, 2, 3, 4, 5 & 8.
Contributor	**Statement of Contribution**	
Ali Mohd Ali	Majority Contribution (80% - 100%) (Writing the paper, analysing the problem, conducting analysis, implementing the problem-solving methodology, conducting experiments, and interpreting experimental design data).	
Mahmoud Dhimish	Has contributed to the work (10% – 20%) (Suggestions and discussion in article or manuscript format).	
Ian Glover	Has contributed to the work (5% - 10%) (Examination of the document or manuscript and English Proof).	
Journal Article No.05 & Conference Proceeding No.03		
Manuscript Title	**Publication Status**	**Chapters covered by the research published**

<table>
<tr><td>WLAN Protocol and Network Architecture Identification for Service Mix Applications</td><td>The manuscript was submitted to the Academicsera 57th International Conference (pp. 13-19) World Research Library and was subsequently selected to be published as a journal in the International Journal of Advance Computational Engineering and Networking (IJACEN), 8(2), 24-30.</td><td>Chapters 1, 2, 3, 4, 5 & 8.</td></tr>
<tr><th>Contributor</th><th colspan="2">Statement of Contribution</th></tr>
<tr><td>Ali Mohd Ali</td><td colspan="2">Majority Contribution (80% - 100%)
(Writing the paper, analysing the problem, conducting analysis, implementing the problem-solving methodology, conducting experiments, and interpreting experimental design data).</td></tr>
<tr><td>Mahmoud Dhimish</td><td colspan="2">Has contributed to the work (10% – 20%)
(Suggestions and discussion in article or manuscript format).</td></tr>
<tr><td>Ian Glover</td><td colspan="2">Has contributed to the work (5% - 10%)
(Examination of the document or manuscript and English Proof).</td></tr>
<tr><td>Journal Article No.06</td><td colspan="2"></td></tr>
<tr><th>Manuscript Title</th><th>Publication Status</th><th>Chapters covered by the research published</th></tr>
<tr><td>An Algorithmic Approach to Identify the Optimum Network Architecture and WLAN Protocol for VoIP Application</td><td>The manuscript has been submitted to Wireless Personal Communications. Submitted (under review).</td><td>Chapters 1, 2, 3, 4, 5 & 8.</td></tr>
<tr><th>Contributor</th><th colspan="2">Statement of Contribution</th></tr>
<tr><td>Ali Mohd Ali</td><td colspan="2">Majority Contribution (80% - 100%)
(Writing the paper, analysing the problem, conducting analysis, implementing the problem-solving methodology, conducting experiments, and interpreting experimental design data).</td></tr>
<tr><td>Mahmoud Dhimish</td><td colspan="2">Has contributed to the work (10% – 20%)
(Suggestions and discussion in article or manuscript format).</td></tr>
<tr><td>Peter Mather</td><td colspan="2">Has contributed to the work (5% - 10%)</td></tr>
</table>

	(Examination of the document or manuscript and English Proof).
Malek Alsmadi	Has contributed to the work (2% - 5%) (Discussion and overview of literature).

Candidate's signature
 Monday, 15 February 2021

Co-authors' signatures			
Name	**Title**	**Date**	**Signature**
Dr Mahmoud Dhimish	Academic Supervisor	16/09/2020	M Dhimish
Dr Peter Mather	Co-Supervisor	16/09/2020	P Mather
Dr Martin Sibley	Former main supervisor	16/09/2020	M Sibely
Prof Ian Glover	Former co-supervisor	16/09/2020	I Glover
Malek Alsmadi	Research collaborator	16/09/2020	M Alsmadi

Appendix B

SUS Survey - WLAN Protocol and Network Architecture Selection

The survey and outcomes of the System Usability Scale (SUS) could be seen in Figure B.1 and Table B.1, respectively. The questionnaires were administered in a number of ways: via the WPNAS website, Google Forms, social media and smartphone applications. The findings of SUS were extracted and illustrated in Chapter 7.

WLAN Protocol and Network Architecture Selection

Please think about the usability and performance of the WPNAS for the next list of questions. If you don't mind your answer, or if you believe you can't response to it, just label in the middle and choose 3. Please use the following website: www.wpnas.net

Question	Responses						
1. I think that I would like to use this system frequently	Strongly Disagree	1	2	3	4	5	Strongly Agree
2. I found the system unnecessarily complex							
3. I thought the system was easy to use							
4. I think that I would need the support of a technical person to be able to use this system							
5. I found the various functions in this system were well integrated							
6. I thought there was too much inconsistency in this system							
7. I would imagine that most people would learn to use this system very quickly							
8. I found the system very cumbersome to use							
9. I felt very confident using the system							
10. I needed to learn a lot of things before I could get going with this system							

These next types of questions are multiple-choices. A text window is available if you'd like to justify your selections. Label your selection explicitly either by crossing the other choices or circling it.

11. Which service type fits your usage?

a) Mixed b) Stand-alone

12. If Mixed, which scenario fits your usage?

a) 20All b) 40VOIP c) 50VC d) 60HTTP e) Best-effort

13. If Stand-alone, which service fits your usage?

a) VOIP b) VC c) FTP d) HTTP e) Email

14. The number of nodes been used?

a) 1-5 b) 6-10 c) 11-20 d) 21-40 e) 41-65

Figure B. 1 SUS Survey for WPNAS website

Table B. 1 WPNAS SUS results

Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	SUS
5	1	5	2	5	1	4	1	5	1	95
4	1	5	2	5	1	4	1	5	1	92.5
5	1	5	2	5	1	5	1	5	2	95
5	3	5	5	5	1	5	3	5	5	70
5	1	4	4	4	2	4	1	4	3	75
5	1	5	2	5	1	5	1	5	2	95
4	4	4	5	3	1	5	3	3	4	55
5	1	5	2	4	1	5	1	4	2	90
4	1	4	1	5	1	4	1	5	1	92.5
4	1	5	3	5	1	3	2	1	4	67.5
4	1	4	4	5	1	4	1	4	4	75
5	1	5	1	4	1	4	1	4	2	90
4	1	4	1	5	1	4	1	5	1	92.5
5	1	5	2	4	1	5	1	5	1	95
5	1	5	1	4	1	4	1	5	2	92.5
5	1	5	2	5	1	5	1	5	1	97.5
5	1	5	2	5	1	5	1	5	2	95
5	1	5	1	5	1	5	1	5	1	100
4	2	5	3	5	3	4	4	4	3	67.5
5	1	5	2	5	1	4	1	4	1	92.5
3	3	4	5	3	3	5	2	4	5	52.5
5	1	5	3	4	1	3	2	4	2	80
5	1	5	1	4	2	4	1	5	1	92.5
4	1	5	1	5	1	5	1	5	1	97.5

4	1	1	1	5	2	4	1	5	2	80
5	5	5	5	5	5	5	5	5	5	50
4	3	3	3	3	2	4	2	2	2	60
4	2	5	1	4	1	5	4	5	2	82.5
4	2	3	3	2	3	5	2	5	2	67.5
4	1	1	2	5	1	4	1	4	1	80
4	3	5	4	4	4	3	3	4	4	55
4	3	4	5	4	3	3	4	3	4	47.5
4	1	3	2	3	2	4	3	4	3	67.5
3	3	3	3	3	3	3	3	3	3	50
4	5	5	5	5	5	5	4	5	2	57.5
4	3	3	2	3	3	4	3	3	3	57.5
5	3	4	1	5	1	5	3	5	3	82.5
5	4	4	5	4	5	5	5	5	4	50
3	3	3	3	3	3	3	3	3	3	50
5	4	4	5	4	5	5	5	5	4	50
4	3	5	4	4	4	3	3	4	4	55
4	1	5	1	4	1	5	1	5	2	92.5
5	1	5	2	5	1	4	1	5	2	92.5
4	2	5	1	4	1	5	1	5	2	90
5	2	5	1	5	1	5	2	5	1	95
4	1	5	2	3	2	3	3	5	2	75
4	5	4	4	4	2	4	4	4	4	52.5
4	3	4	4	4	4	4	4	3	3	52.5
4	1	5	1	5	2	4	1	5	1	92.5

4	1	5	2	3	2	3	3	5	2	75
4	1	5	1	5	1	4	1	5	1	95
4	2	5	1	4	1	5	1	5	2	90
3	3	3	3	3	3	3	3	3	3	50
5	1	4	2	5	1	4	1	5	1	92.5
5	4	4	2	2	4	5	1	5	1	72.5
5	2	5	2	4	2	4	1	5	1	87.5
2	4	5	2	5	1	5	1	4	3	75
2	5	1	4	2	4	2	5	2	4	17.5
4	1	4	2	5	1	4	2	4	1	85
3	1	2	3	4	1	4	3	4	3	65
4	2	5	2	4	2	5	2	5	2	82.5
5	2	4	1	4	2	5	3	5	2	82.5
4	2	5	1	4	2	5	1	4	2	85
4	1	5	1	5	1	4	1	5	2	92.5
4	1	5	2	5	1	4	1	5	1	92.5
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5	1	5	1	5	1	4	1	5	2	95
5	2	4	2	4	2	5	1	5	2	85
3	5	3	4	4	4	3	3	3	5	37.5
3	5	3	4	4	4	3	3	3	5	37.5
4	1	5	1	5	1	4	1	5	1	95
4	1	5	1	5	1	4	1	5	1	95
4	1	5	1	5	1	4	1	5	2	92.5
4	1	5	2	5	1	5	1	5	1	95

4	1	5	1	5	2	5	1	5	2	92.5
5	1	5	2	5	1	5	1	5	1	97.5
5	1	5	2	5	1	4	1	5	1	95
4	1	5	1	5	1	5	1	5	1	97.5
5	1	5	2	5	1	5	1	4	1	95
5	2	5	2	5	1	5	1	5	1	95
5	1	5	1	5	1	5	1	5	1	100
5	1	5	2	5	1	4	1	5	2	92.5
5	1	5	2	5	1	4	1	5	1	95
5	1	5	1	5	1	4	1	4	1	95
5	1	5	2	5	1	5	1	5	1	97.5
5	2	5	2	5	1	5	1	5	1	95
5	1	5	2	4	2	4	1	4	1	87.5
5	1	5	2	5	1	4	1	5	1	95
5	1	5	2	5	1	4	1	5	1	95
5	1	5	2	4	1	5	1	4	2	90
4	2	5	1	5	1	4	1	5	2	90
5	1	5	1	5	1	4	1	4	1	95
5	1	5	1	5	1	4	1	2	2	87.5
4	1	5	1	5	1	5	1	5	2	95
5	1	5	2	5	1	4	1	5	1	95
4	1	5	2	3	2	3	3	5	2	75
5	2	5	1	5	1	4	1	5	1	95
4	1	5	1	5	1	4	1	5	1	95
5	1	4	2	5	1	4	1	5	1	92.5

5	1	5	2	5	1	4	1	5	1	95
5	1	5	1	4	2	4	1	5	2	90
5	1	5	2	5	1	4	2	5	1	92.5
5	2	5	1	5	1	4	1	5	2	92.5
4	1	5	2	3	2	3	3	5	2	75
4	1	5	2	5	1	4	1	5	1	92.5
5	1	5	2	5	1	4	1	5	2	92.5
5	2	5	1	5	1	5	2	5	1	95
5	1	5	1	5	1	5	1	5	1	100
5	2	5	1	5	1	4	1	5	1	95
5	3	4	5	4	1	4	2	5	5	65
5	1	5	2	5	1	4	1	5	1	95
5	1	5	1	5	1	5	1	5	1	100
5	1	5	1	5	1	5	1	5	1	100
5	3	4	5	4	1	4	2	5	5	65
4	1	5	1	5	1	4	1	5	2	92.5
5	1	5	1	5	1	5	1	5	1	100
5	1	5	2	5	1	4	1	5	1	95
4	1	5	1	5	1	4	1	5	1	95
5	1	5	1	5	1	5	1	5	1	100
5	1	5	1	5	1	5	1	5	2	97.5
5	1	5	2	5	1	4	1	5	1	95
5	1	5	1	5	1	4	2	5	2	92.5
5	1	5	1	5	2	4	1	5	1	95
4	1	5	2	5	1	4	1	5	2	90

5	1	5	3	5	1	4	1	5	1	92.5
5	1	5	1	5	1	5	2	4	1	95
4	1	5	1	5	1	5	2	4	1	92.5
5	1	5	2	4	2	4	1	4	1	87.5
5	1	5	2	4	1	5	1	4	1	92.5
5	2	5	2	5	1	5	1	5	2	92.5
4	2	5	1	5	1	5	1	5	1	95
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4	4	2	5	4	3	4	3	4	4	47.5
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5	3	4	4	4	2	3	2	3	4	60
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3	4	4	4	4	2	2	3	2	4	45
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5	1	5	1	5	2	4	1	5	1	95
1	1	1	4	1	4	3	3	5	3	40
3	3	3	3	3	3	3	3	3	3	50
5	1	5	1	5	1	5	1	5	1	100
5	1	5	2	4	2	5	1	5	2	90
4	5	5	1	3	2	4	2	5	3	70

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5	1	5	1	5	1	4	1	5	1	97.5
5	5	1	5	5	3	2	2	2	5	37.5
5	3	4	5	4	2	5	5	5	3	62.5
4	5	5	1	3	2	4	2	5	3	70