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WiMax Network Design and Simulation for Middle Technical University Campus Using OPNET Modeler

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Abstract

This study aims to build a wireless computer network for a large company or university to enhance mobility and allow university users to stay connected at any time or place, which is achieved by applying the Universal Interoperability for Microwave Access (WiMax) technology. WiMax is based on the 802.16 sets of standards and has the most efficient and advanced hardware capabilities to meet the demands of teachers and students to browse the web or download files quickly. OPNET Modeler version 14.5 was used to determine the quality of service parameters of WiMax.

Keywords: WiMax, BS, OPNET, MOS, MIMO

تصميم ومحاكاة شبكة WiMax لحرم الجامعة التقنية الوسطى باستعمال OPNET

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الخلاصة

الغرض من هذه الدراسة هو بناء شبكة حاسوب لاسلكية لشركة أو جامعة كبيرة لتعزيز التنقل والسماح للمحاضرين الجامعيين والطلاب بالبقاء على اتصال في أي وقت أو مكان وهذا تم تحقيقه من خلال استعمال إمكانية التشغيل البيني العالمي للوصول إلى الموجات الدقيقة (WiMax) استنادًا إلى مجموعة معايير 802.16 جنبًا إلى جنب مع إمكانيات الأجهزة الأكثر كفاءة وتقدماً لتلبية متطلبات المعلمين والطلاب بغرض تصفح الشبكة العنكبوتية أو تنزيل الملفات بسرعة. تم استعمال الإصدار 14.5 من OPNET Modeler لتحديد معلمات جودة الخدمة لل WiMax.

1. Introduction

Generations of mobile communication systems have been frequently labeled, with 1G as the first mobile analog radio system in the 1980s, 2G as the first digital mobile system, and 3G as the first mobile system capable of handling broadband data. The race between successive

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generations of mobile phone systems is a matter of names. What matters are the actual capabilities of the system and its evolution. However, to deliver a satisfying user experience over the Internet, it was essential to provide the necessary quality of service to fourth-generation wireless technologies like WiMax [1].

WiMax meets both current and future quality of service requirements, making the concept of quality of service even more important. Broadband wireless access (BWA) can be effectively supported by the physical (PHY) and medium access control (MAC) to improve the all-IP broadband wireless access technologies, resulting in more users with better data rates, availability, and coverage. Based on the Wireless Metropolitan Area Network (WMAN), WiMax has been developed under the IEEE 802.16 standard for VoIP, where various techniques, including mobile cellular access and point-to-point communication, are used to provide wireless connectivity over long distances [2].

WiMax offers data rates up to 75 Mbps over a 50-kilometer radius and uses 10-66 GHz frequency ranges to serve a large geographic area with either licensed or unlicensed spectrum. It offers many service classes for both real-time and non-real-time traffic, supporting quality of service [3]. WiMax comes in two basic types: 802.16-2004 (Fixed WiMax), which serves fixed devices, and 802.16e or 802.16-2005 (Mobile WiMax), which offers services such as supporting mobile voice over IP, providing higher data, and enabling users to interact while driving or walking [4]. The advantages of WiMax over Wi-Fi include the ability to serve more users, the larger coverage area, the excellent speed rates, and the possibility to support end devices with WiMax wireless controllers (receivers), in addition to Wi-Fi interface cards, because of the relatively simpler network architecture.

2. Literature Review

Internet accessibility has expanded in recent years. It is no longer limited to emails and Web browsing, so the next generation has emerged to expect multimedia services like voice-over-IP (VOIP) and media streaming. Wireless Broadband Access (BWA) came on the scene to offer users this type of connection, ensuring seamless access to megabytes of internet [5]. Based on IEEE 802.16 to provide a metro area with broadband wireless access, WiMax was one of the many technologies that appeared under the umbrella of BWA [6]. With the motivation to create a wireless broadband air interface standard, the IEEE 802.16 working group established in 1998 mainly focused on the development of a point-to-multipoint line-of-sight (LOS)-based wireless broadband system for use in the 10-66 GHz waveband.

The original IEEE 802.16 standard, completed in December 2001, was based on a burst time division multiplexed (TDM) MAC layer with a single carrier physical (PHY) layer. Moreover, many concepts related to the MAC layer have been adapted for wireless from the popular cable modem DOCSIS (data over cable service interface specification) standard [7]. To enable NLOS applications using orthogonal frequency division multiple access (OFDMA) in the 2GHz–11GHz band, the IEEE 802.16 family later developed the 802.16a, an update to the 802.16 standards [8]. As development continues, a new standard known as IEEE 802.16d-2004 emerged in 2004 as a result of incremental improvements to replace all previous versions and serve as the basis for the first WiMAX solution [9].

Later, a modification to the IEEE 802.16d (2004 standard), termed IEEE 802.16e (2005 version), was introduced and approved to provide operational mobility by the IEEE Group in December 2005 and frequently referred to as mobile WiMAX. Although WiMax has a variety of unique features and exciting applications, several problems need to be thoroughly investigated before a wide industrial deployment can be anticipated. However, these problems and difficulties, which represent unsolved problems and open issues, should be addressed in the WiMax environment. The last several years have seen a rise in interest in the study of WiMax. At various problem levels, almost every part of the network was investigated.

The most critical challenge of WiMax is the lack of quality, as there are hundreds of users trying to get access to the same tower, which makes it hard to maintain high quality due to heavy traffic. The other WiMax challenge is the range. This study aims to create a WiMax network and evaluate its performance on a university campus while considering the challenges provided by the lack of quality and range. The WiMax is designed to support the growing volume of data traffic based on the IP backbone and consists of the following units [10]:

- **Network Reference Model (NRM)**

In order to establish an end-to-end WiMax network, the WiMax architecture is built on NRM. The NRM makes sure that different WiMax-enabled devices and operators can communicate with one another. The NRM includes four units: the first unit is the Access Service Network (ASN), which consists of the Base Stations (BSs) and ASN Gateways (GWs) to create a Radio Access Network (RAN) at the edge. The second unit is the Base Station (BS), which grants the Mobile Station (MS) an air interface. Additionally, BS is in charge of many tasks, such as multicast group management, session management, key management, DHCP proxy, handoff triggering, radio resource management, and quality of service policy enforcement. The third unit is the Access Service Network (CSN), which offers IP connectivity to corporate networks, the Public Switched Telephone Network, and the Internet. The CSN performs many tasks like location management, roaming, mobility among different ASNs, and management of IP addresses. The last unit is the mobile station (MS), which the subscribers use to establish a connection to the network.

- **Air interface**

The time division multiplexing (TDM) and frequency division multiplexing (FDD) radio access modes are supported by the WiMax network. In order to respond to diverse demands, such as high throughput, this system uses a combination of different modulation methods. WiMax networks also support Multi-Input Multi-Output (MIMO) technology, particularly 2x2 MIMO. A system with MIMO has a minimum of two antennas at the base station and the mobile station. The performance of WiMax is developed by a MIMO system comprising spatial multiplexing, diversity, and interference reduction. The two MIMO system types that WiMax supports are closed-loop and open-loop MIMO systems.

- **Multiple Access Technology**

The multiple-access technology orthogonal frequency division multiple access (OFDMA) serves as the foundation for uplink and downlink transmission in the WiMax network. OFDMA is defined as a digital multi-carrier modulation technique that operates on the idea that variations in the frequency, phase, or amplitude of the carrier signal could be used to send information across a radio channel where a parallel combination of low-data-rate streams is being multiplexed from the high-data-rate input stream rather than being transmitted on a single RF carrier signal. The inverse fast Fourier transform (IFFT) modulates the parallel streams in the frequency domain onto variable subcarriers and then broadcasts them across the channel.

The fast Fourier transform (FFT) transforms a time-varying complex waveform down to its spectral components at the receiver to recover the initial subcarriers with their modulation and the original digital bit stream. WiMax uses modulation techniques such as 64QAM, 16QAM, QPSK, and BPSK at a low symbol rate. The FFT sizes that match WiMax are 128, 256, 512, 1024, and 2048. However, cyclic prefix (CP) guard intervals are placed between each symbol in the time domain to prevent inter-symbol interference at the receiver caused by multi-path delay dispersion in the radio channel. The usual WiMax CP is 1/8 the length of an OFDMA signal.

- **WIMAX-QoS**

In WiMax technology, quality of service requirements are essential due to the need to confirm their performance when multiple types of connections are present, like active calls, new calls, and the handoff connection. The quality of service in WiMax includes the following parameters:

1. **Throughput**

Throughput may be defined as the rate of packets that can be successfully transmitted from a base station (BS) to a subscriber station (SS) through the network in a certain period or the measurement of how many packets have been successfully delivered in a network. The throughput could be deployed to calculate a network's efficiency. It is expressed in packets per second or per time slot and can be expressed as either individual station throughput or system throughput. The mathematical throughput formula is listed below:

Throughput = (Total_Byte_Sent × 8)/ (TimeLPR − TimeFPR)……….......... (1)[11]

TimeLPR and TimeFPR are when the last and first packets are received, respectively. As the TimeLPR and TimeFPR of the simulation's overall duration indicate, the value of throughput, as described in WiMax form, should be high; otherwise, it affects all service classes in the network. Thus, the primary metric that will be utilized to assess the effectiveness of our suggested algorithms is throughput.

2. **Jitter:**

The interval between arrival frames for packets arriving at a destination in a series of frames is known as "jitter." Jitter is monitored to determine which traffic can tolerate a specific degree of delay. Jitter measurement is essential to assessing a network's performance in terms of consistency and stability. A network with constant latency has no jitter. The bit error ratio (BER), combined random, and deterministic jitter are used to calculate the value of jitter from the end-to-end delay. The jitter mathematical formula is listed below:

Jitter (Pkt) = TDCurrent (pkt) − TDPrevious (pkt)……………………….. (2)[11]

where TDPrevious (pkt) represents the transmission delay of the previous packet and TDCurrent (pkt) represents the transmission delay of the current packet.

3. **Delay**

Network delay describes the time it takes for a packet to successfully traverse the network from the source to the destination. It is often used to evaluate the performance of high-speed services like voice, data, and video. The delay can be classified as processing, classification, transmission, or propagation and can vary from packet to packet depending on the exact pair location of the communication nodes. The mathematical formula for the delay is listed as follows:

Delay = Propagation time + Transmission time + Queuing time + Processing Delay…. (3)[11]

The ITU's Standard Recommendation for Delay is listed below in Table 1.

Table 1: Standard Recommendation of Delay [12]

Value in Milli-seconds	Feature
Above 400	Not appropriate for use in regular network planning
Between 150 and 400	Acceptable provided that administrators are informed of the transmission time and how it affects the user apps' transmission quality.
Between 0 and 150	Acceptable

4. MOS

The MOS offers an index to investigate the quality of VoIP applications in WiMax. The mathematical formula is determined by the use of a non-linear mapped factor, namely R, represented as below:

$$MOS=1+0.035R+7\times10^{-6}[R \quad (R-60) \quad (100-R)]$$ ……......................................(4)[1]

R = 100 – Is – Ie – Id + A....…………………………………………….. ……. (5) [13]

where:

Is: represents the voice signal impairment effects.

Ie: represents the impairment losses mainly due to the codec’s and network

Id: represents the impairment delays especially the mouth-to-ear delay.

R: represents the mean opinion score factor.

The classification of MOS is listed in Table.2

Table 2: MOS Classification [12]

MOS	Quality
1	Bad
2	Poor
3	Fair
4	Good
5	Excellent

3. Methodology

This section designs and simulates the WiMax coverage and quality of service (quality of service) of the Middle Technical University campus. The network model is implemented and created using the educational edition of the Optimized Network Engineering Tool (OPNET), version 14.5. The OPNET is selected for a variety of reasons, such as that it is effective for analyzing the performance of current systems based on user needs, useful for evaluating novel network models and architectures' designs, and that there are pre-defined network architectures and designs available for user development. The OPNET sets up a 4-celled WiMax network, including three SS within the BS range. Moreover, an IP backbone links BS to the core network. A 30 km radius has been selected for the WiMax cell, as shown in Figure 1. The rest of the essential OPNET network configuration parameters are listed in Table 3, and the properties of the network components are shown in Table 4.

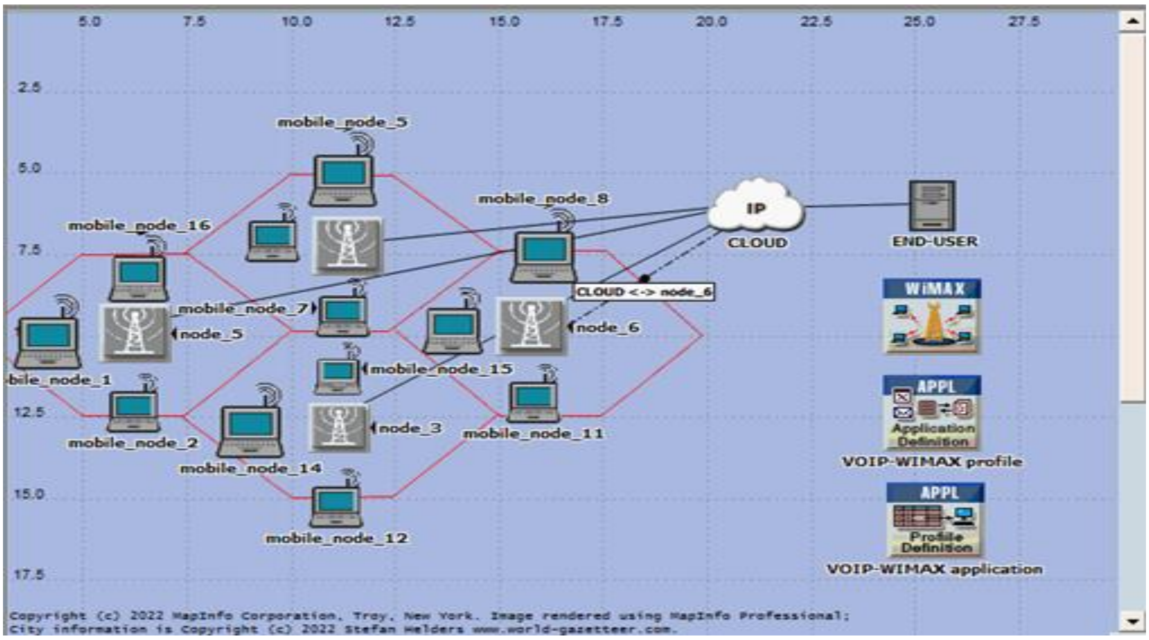

Figure 1 Middle Technical University Campus Network Topology

Table 3: Network Topology Configuration

Middle Technical University Network	4-cell
Cell radius	30-Km
Number of Campus Base Stations (BS's)	3
Number of subscriber mobile stations (SS's) per Base Station	4
Time of the simulation	600 sec
Cell radius	
Campus Base Station Model	WiMax_bs_ethernet4_slip4_router
Subscriber Station Model	WiMax_ss_wkstn
IP Backbone Model	ip32_cloud
Link Model	PPP_DS3

Table 4: Network Components Configuration

Campus Physical Layer	OFDMA 20Mhz
Campus MAC protocol	802.16e
Number of Campus Base Stations	4
The Multi-path Channel Model	ITU Vehicular A
The Number of Transmitters in Each Base Station	SISO
Type of Scheduling	ertPS
Application	VoIP
Voice Codec	G.711

4. RESULTS AND DISCUSSION

The obtained results are of the type called "global statistics," which refers to the fact that they were calculated for the entire network, including all devices and branches. In WiMax technology, quality of service requirements become crucial for confirming its performance when multiple types of connections are present, including active calls, new calls, and the handoff connection. The WiMax network takes approximately 1:45 minutes to activate. This time frame is necessary for wireless devices to establish connections and reach peak performance. The fetch, receive, and acknowledge signals are needed to obtain an IP address from a DHCP server.

The authentication procedures are responsible for the time delay in the curves depicted in Figures 1–7. Regarding the global overall network throughput, 1.7 Gbps is transferred across the network, which grows over time at about 10 minutes after the network's start, as shown in Figure 2. This is caused by several factors, such as the IP address, the amount of time required for signals to travel to mobile devices, and other activities, such as acknowledgment replays and signal propagation, etc. The throughput result demonstrates a reliable bit rate, which leads to outstanding network performance for the transmitted data stream.

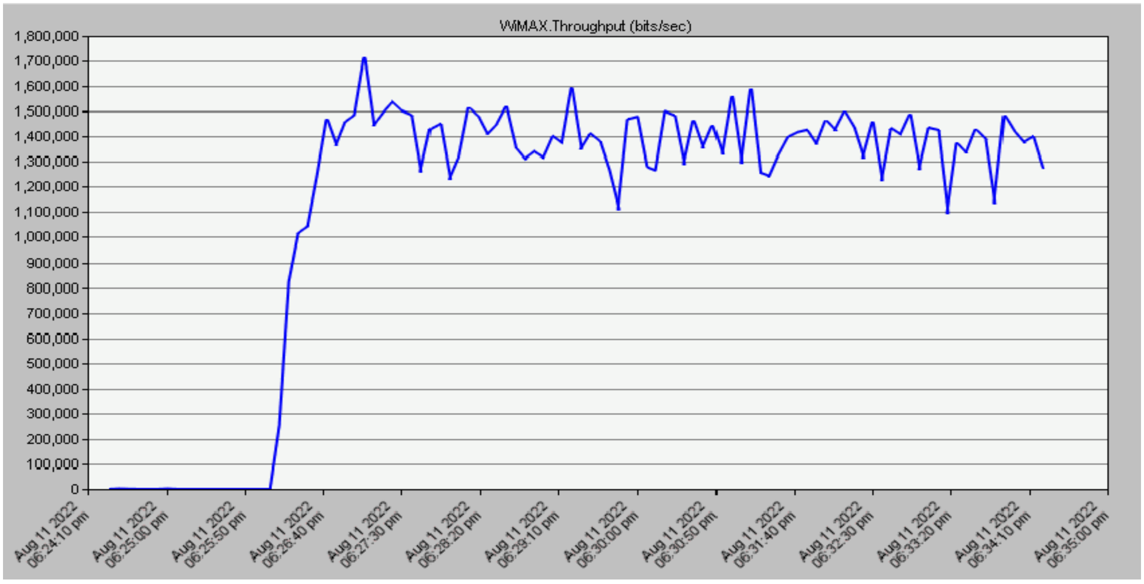

Figure 2: Global Network Throughput (bits/sec)

The other parameter to consider is the global overall network load, which usually refers to the amount of data (traffic) carried by the network. According to Figure 3, the overall network load demonstrates a good network value of about 3.5 Gbps.

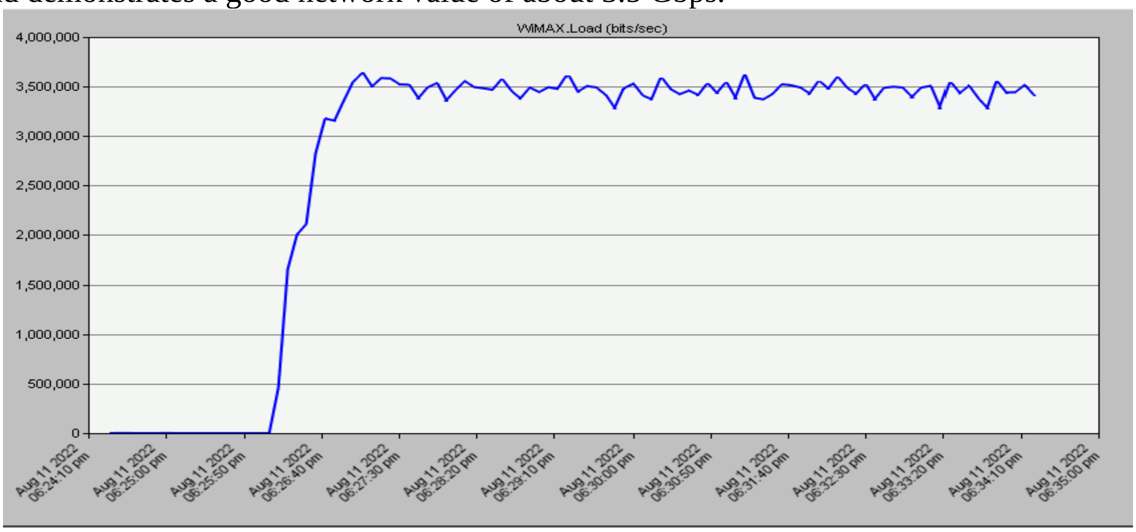

Figure 3: Global Network Load (bits/sec)

The other parameter to consider is the global overall network delay, which records a maximum value of 0.35 seconds and a minimum value of 0.001 seconds, as shown in Figure 4. However, it should be noted that delay, or latency, is one of the most important factors or deterministic properties of any computer network. Excessive delay creates bottlenecks that prevent data from filling the network pipe, thus decreasing the adequate bandwidth. The impact of latency on network bandwidth can be temporary (lasting a few seconds) or persistent (constant), depending on the source of the delays.

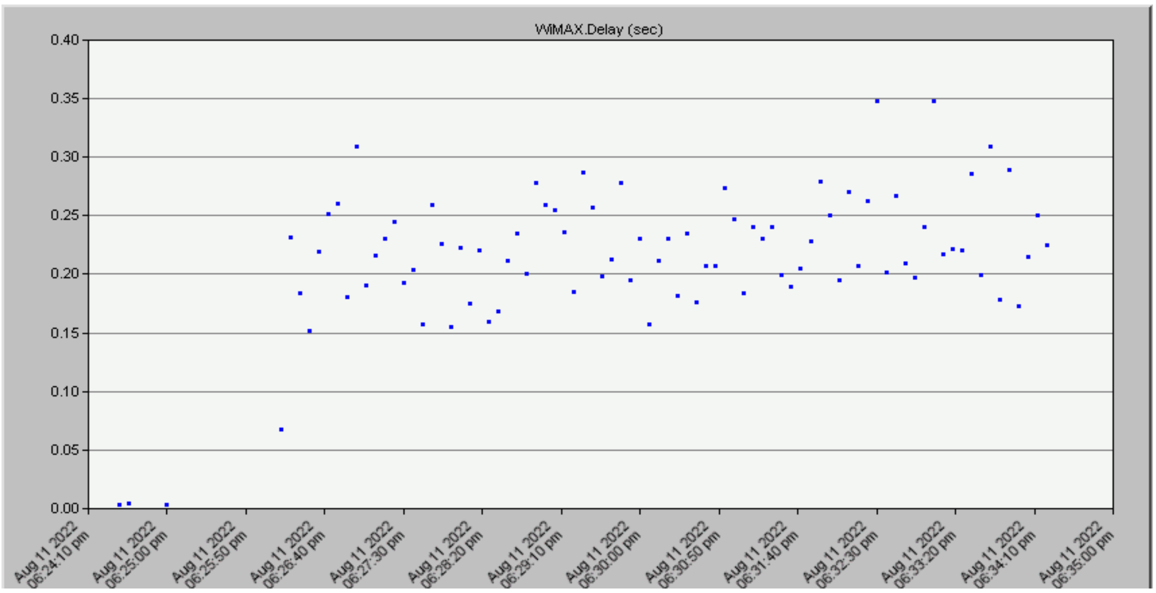

Figure 4: Global Network delay (sec)

The MOS, which expresses the quality of VoIP application in the WiMax network, records about 3.7 for the maximum and 1 for the minimum starting from the first second of network operation, as shown in Figure 5. These values indicate that the quality of the VoIP application is approximately "good."

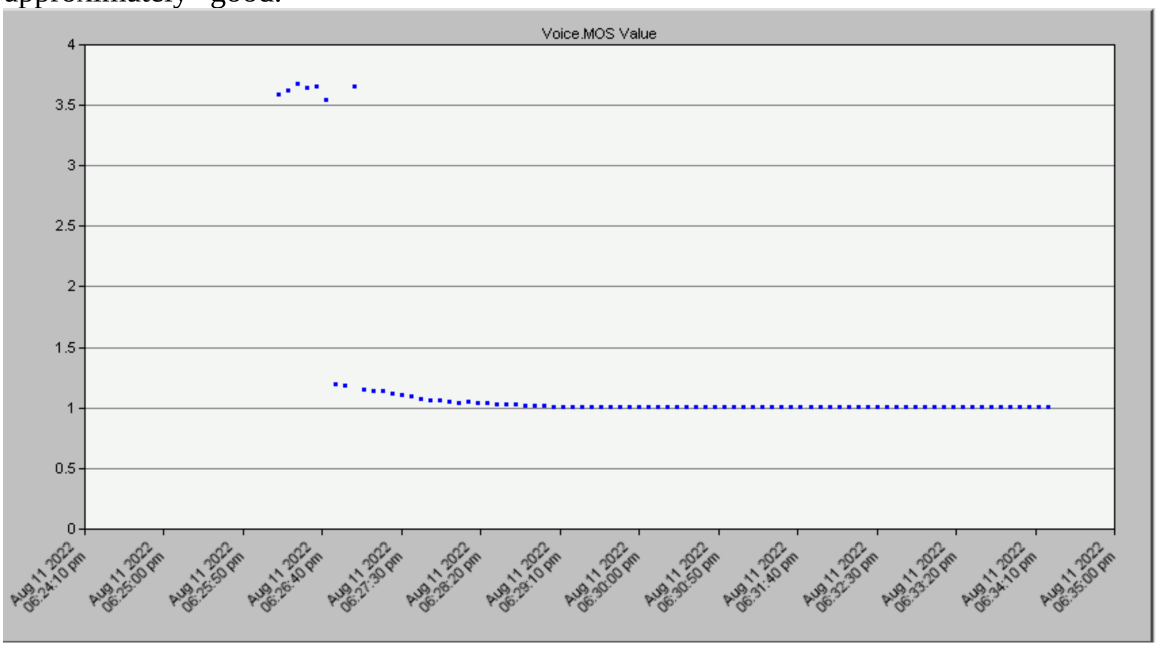

Figure 5: Global MOS of VOIP Application in Network

The last parameter to investigate is the global network jitter, which reaches 0.0017 seconds at its maximum, as shown in Figure 6; the monitoring of these statistics is critical when it comes to voice and video traffic because when voice and video packets are different due to high jitter, it may cause synchronization failures and degrade the network user experience.

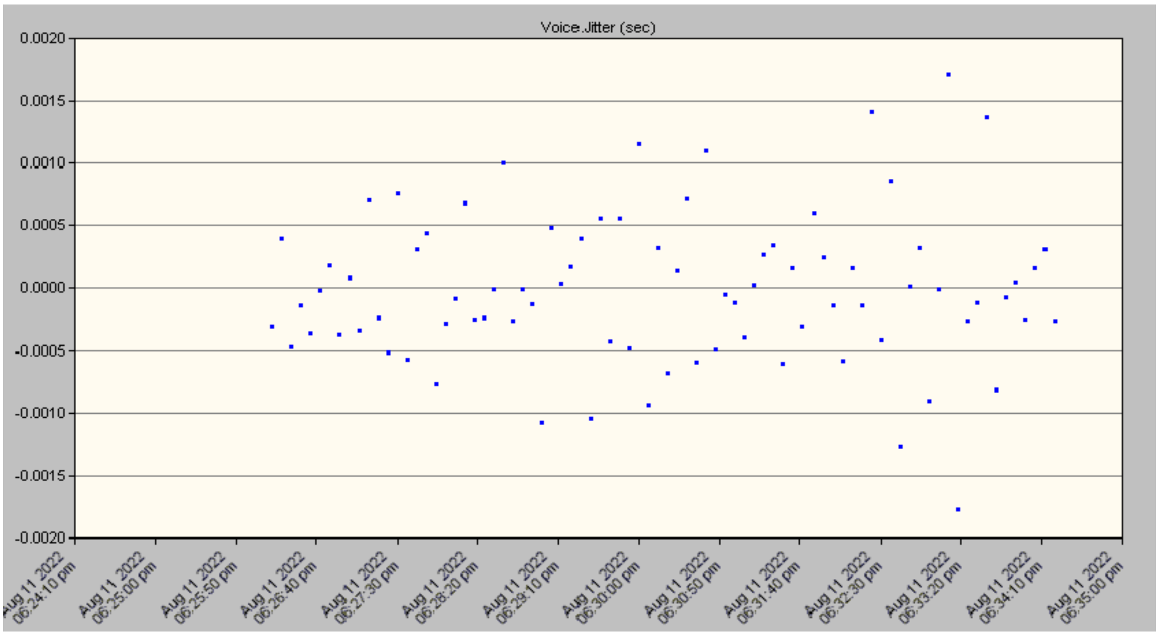

Figure 6: Global Network Jitter (sec)

5. CONCLUSION

This article aims to design and simulate the WiMax coverage area of the Middle Technical University Campus. Some WiMax specifications linked to the services have been optimized for the region for better system design and increased system efficiency by using the OPNET modeler. Based on the results, the design achieved a high throughput of 1.7 Gbps, and the delay was acceptable at 350 msec. The MOS index of the VOIP application running within the WiMax network recorded 3.7, which was classified as "good." According to MOS specifications stated in Table 2, it can be concluded that the design of the network campus was efficient and successful.

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