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Evaluation of heterogeneous wireless networks' (HWNS) performance and handoff using an opnet simulator

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Research Article

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ABSTRACT

In order to move into the fourth generation of wireless networks, heterogeneous wireless networks (HWNs) like WLAN, WiMAX, and UMTS must be coupled. In order to function better in such heterogeneous networks, algorithms for these networks must be devised, particularly handoff algorithms. In order to make intra-technology handoff (horizontal handoff) switching in each network and inter-technology handoff (vertical handoff) by interworking between two HWNs, a number of projects with various network types were implemented and simulated in various case studies provided by OPNET simulation. The findings of the OPNET simulation demonstrate the higher performance of WiMAX on the WLAN and UMTS networks. WiMAX throughput outperforms other networks by more than thirty percent. Additionally, the simulation results demonstrate the effective deployment of WLAN into WiMAX and UMTS networks via the use of numerous network interfaces. It was discovered in this study that the vertical handoff between WLAN-WiMAX and WLAN-UMTS is very difficult to do without meticulously and precisely building the WLAN network because it highlights the basic differences in HWNs.

General Terms: OPNET Simulator, Mobility Management, Wireless Networks, and Handoff Procedure.

Keywords: Handoff management, OPNET simulation, WLAN, WiMAX, UMTS, and Heterogeneous Wireless Network (HWN).

1. INTRODUCTION

In terms of coverage, QoS assurance, implementation, operational cost-supported features, etc., mobile consumers' rising demand for mobile communication services is driving technical advancement toward integration into the different modalities of wireless access communications. The movement of users between access points should be considered in the integration. Mobility management in wireless networks allows mobile users to maintain a connection while switching between subnets according to their service requirements. Users will be able to choose radio access technology that best suits the necessary multimedia applications with the highest performance and lowest cost thanks to this heterogeneity, which delivers improved quality, data speed, and mobility. While using HWNs, it is essential to make sure that the internet application's efficient state is preserved. This is one of the reasons I am doing this job.

In this regard, the networking industry faces significant challenges related to vertical handoff and interoperability across diverse wireless access networks. To retain the best possible network connection, mobile users would want to move between the various access networks in a smooth and dynamic manner. In this situation, it becomes crucial to decide which network to connect to and when to start a vertical handoff request. One of the most crucial aspects of mobility management is handoff management. The mobile user must be able to smoothly handoff to the roughly best connection among all available candidates based on certain

parameters that guarantee no disruption will occur to any continuing connection. Therefore, meeting these criteria under the various networks and services explains why handoff has grown in significance and is likely to remain a key topic of interest as newer technologies and services continue to spread across the wireless networking industry [1][2]. The necessity for a method to integrate and connect these heterogeneous networks, such as coupling WLAN and any cellular networks, is another driving force behind mobility and handoff management.

Numerous scholars have written on the range of heterogeneous networks, seamless mobility, and vertical handoff; some have written about how it might enhance network performance, while others have written about how to optimize its operations. In [3], Mark Stemm investigated ways to use 802.11 networks set up to function as a single umbrella network to provide seamless mobility in wireless LAN networks. Using the integration of heterogeneous networks in 3G cellular and wireless local area networks with MIP enabled by loosely-coupled architectures, Zahran [4][5] investigated the performance of vertical handoff. In order to assess the HWN, the dissertation in [6] suggested virtual wireless services, using a client/server architecture. A test of HWN was constructed using OPNET modular 14.5.

Three alternative HWN types—WLAN, WiMAX, and UMTS—were developed and evaluated in this work using a variety of carefully chosen mobile node applications. OPNET 14.5 modeler simulation will be used to create and simulate three distinct projects with various network kinds. The performance of these diverse networks will then be assessed using a variety of applications, including VoIP, FTP, and video conferencing. This article will address the integration, interoperability, and deployment of WLAN-WiMAX and WLAN-UMTS in HWN, as well as the handoff implementation and assessment for HWN. While using HWNs, it is essential to make sure that the internet application's efficient state is preserved. This is one of the reasons I am doing this job.

2. HANDOFF MANAGEMENT IN HWNS

In essence, 4G wireless networks represent HWN's future. Several wireless access technologies make up a HWN. Regarding coverage, QoS assurance, installation, operating expenses, supported features, etc., each of these technologies has unique characteristics [7]. These days, mobile devices often feature built-in support for various network interfaces, and heterogeneous settings are growing. Ubiquitous computing depends on seamless roaming or mobility, which necessitates network management procedures to prevent service degradation. Mobility management includes both location management and handoff management. There are two procedures involved in location management. The network mobility and mobility support processes for wireless networks are headed by the first phase, known as location registration or location update, in which the mobile terminal regularly notifies the network of its present position. Horizontal handoff refers to wireless terminal handoff management inside a single network, whereas vertical handoff refers to handoff management across several wireless networks that may be based on various wireless access protocols [8].

As shown in Figure 1, the three stages of the handoff process are Network Discovery, Handoff Decision, and Handoff Implementation [9]. The system looks for a better network on a regular basis so that the mobile terminal may be transferred. Depending on the algorithms and the handoff objectives, a variety of factors are taken into account.



Figure 1: Handoff Phases

The mobile terminal chooses which networks may be used during the system discovery stage. Additionally, these networks may promote the Quality of

Service (QoS) characteristics and supported data rates [10]. To determine when to handoff, an algorithm that optimizes based on a predetermined set of criteria is used. The choice is quite important, and a number of intriguing alternatives were put out to deal with the issue [11]. The mobile terminal decides whether to move to a different network or keep the connections on the existing network during the decision phase. The choice may be influenced by a number of factors, such as the kind of application (such as conversational or streaming), the minimum bandwidth and latency needed by the program, the cost of access, the transmit power, and the user's preferences. The mobile terminal's connections are smoothly rerouted from the current network to the new network during the execution phase. A user's context information is also sent, authorized, and authenticated at this step [12]. As a result, vertical handoffs are used across heterogeneous access system cells, which vary in a number of ways, including higher QoS, bandwidth, data rate, and frequency of operation [13].

3. IMPLEMENTATION AND SIMULATION OF HWN

Three heterogeneous wireless technologies—WLAN, WiMAX, and UMTS—were developed and simulated using a variety of carefully chosen applications that were run on the mobile node: VoIP with PCM quality, Heavy FTP, and Heavy Video Conference. This project uses a mobility simulation speed of 10 km/h with several location nodes at predetermined vector trajectories.

and the duration of the simulation was around fifteen minutes. Metrics including average latency, throughput, and received traffic were computed and analyzed, along with the performance of specific applications like VoIP, video conference, and FTP.

3.1 WLAN Performance Evaluation

The performance of WLAN network assessment utilizing various application kinds is examined in this case study. The OPNET modulator describes a WLAN paradigm based on IEEE802.11x specifications. The wireless workstation, wireless server, and wireless router or access point AP are some of the node types included in this paradigm.

This case's goal is to evaluate application performance and examine how Wi-Fi networks operate. The network architecture in this instance is shown in Figure 2. In this instance, we used three distinct programs: Voice over IP, Video Conferencing, and FTP. We suggested a network architecture with one access point and six clients, each of which has the same application and covers an area of 1000 by 1000 meters with a coverage of around 100 meters. Since this project uses IP cloud, packets arriving on this cloud interface will be routed to the output interface according to the target IP address. The cloud's routing tables may be automatically and dynamically created using the Routing Information Protocol (RIP) or the Open Shortest Path First (OSPF) protocol, which also allows for adaptive route selection.

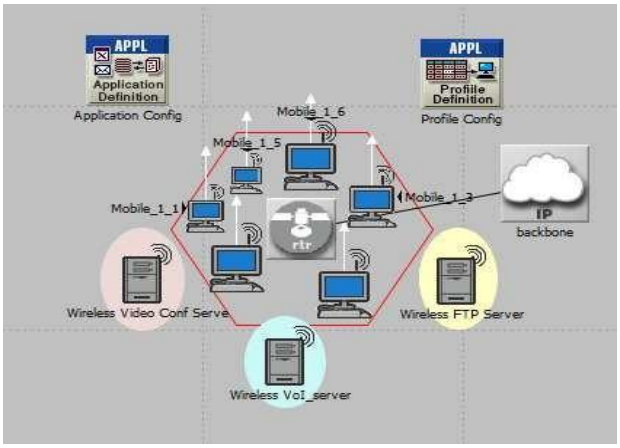


Figure 2: Wi-Fi Network Scheme Implementation

The wireless workstation node model comes in two versions: the basic model and the advanced model. The advanced model offers all of the upper layer protocols, but the basic model just contains the physical and multiple access control MAC layer.

The average delay, throughput, load, and received traffic are the performance measures employed in this study since the suggested model's performance is evaluated by running data, voice, and video traffic.

The system parameters at the simulation setup used in the first case study are shown in Table 1. The direction and velocity of a vector-based trajectory may be altered during execution. By setting the site's trajectory property to VECTOR, we may indicate that a site will use a vector-based trajectory. However, if a site's bearing is altered in OPNET Modeler, the site's route may alter during simulation. In this instance, the site's current latitude and longitude coordinates serve as the new origin, and a new "great circle" route is calculated using the new bearing and origin. For this project, the simulation time is assumed to be 15 minutes in every scenario.

Table 1: WLAN Simulation Environment Parameters

System Parameters	
Simulation time	15minutes
Data rate	54Mbps
Communication Range	100m
Physical characteristic	Extended rate 802.11g
MAC Type	802.11 DCF
Transmit power (w)	0.005
Reception power threshold	-95dBm
AP Bacon interval	0.02sec
Propagation model	Free space
Trajectory	Vector Based

3.2 WiMAX Performance Evaluation

A discrete event simulation model in the WiMAX model suite enables us to examine network performance in wireless metropolitan area networks. The IEEE 802.16e standard's capabilities are included in the

WiMAX model suite, which comes in two varieties: basic and advanced node models. The WiMAX object palette comprises routers, base stations, workstations, and other WiMAX-capable nodes.
We suggested a network architecture plan for this case study, which is shown in Figure 3, in order to comprehend the basic work and performance analysis of WiMAX network technology. All of the apps used by the MN in this network case study may be defined and attributed using WiMAX setup and profile configuration. FTP, video conferencing, and voice over IP are the three applications that are used. Seven Base Stations and seven cells make up the suggested WiMAX network concept; each cell contains four mobile nodes to support all kinds of applications. In this case, a vector-based trajectory is also used. One cell may cover an area of around 4 km by 4 km.

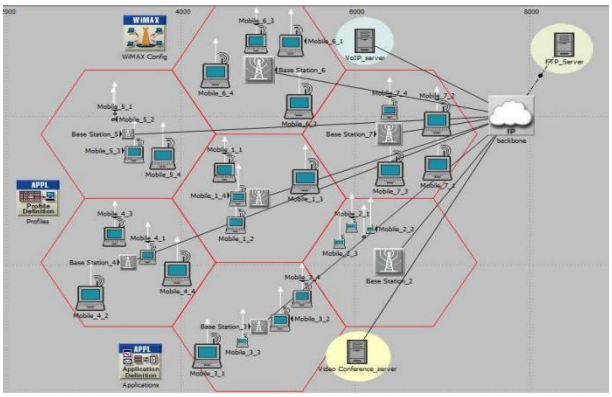


Figure 3: WiMAX Network Scheme Implementation

First we will use the same metrics used in the WLAN case study. Table 4.2 displays the system parameters at the simulation setup in the second case study.

Table 2: WiMAX Simulation Environment Parameters

System Parameters	
Simulation time	15minutes
Data rate	11Mbps
Basic rate	1Mbps
Antenna Gain	15 dBi
PHY profile	Wireless OFDMA 20MHz
PHY profile type	OFDM
Max. Transmit power (w)	0.5
Path loss	Vehicular
BS MAC address	Distance based
Trajectory	Vector Based

3.3 UMTS Performance Evaluation

This scenario's goal is to examine the UMTS network's performance using the same set of applications and performance indicators as earlier examples. The OPNET modulator's UMTS and UMTS_advanced object palettes include several node models from the UMTS specialized model library, including routers, repeaters, stations, RNCs, and more. The UMTS advanced node models were used in our simulation.

The UMTS model, which is based on the Third Generation Partnership Project (3GPP) standards, is one of the specialized models used in OPNET simulation. This model's architecture is present in both basic and advanced nodes. The MN model has features for mobile termination, which is in charge of cutting off the radio connection, and terminal equipment. Models for Node B and RNC make up the UTRAN portion.

In order to accomplish the goal of this case study, a simulation scenario was created and executed. The network architecture in this scenario is shown in Figure 4; as the same sets of apps are used, we employed the same metrics (throughput, latency, and traffic received) as in the preceding scenario. Node_B, RNC, MN, and SGSN/GGSN nodes make up the suggested topology of the UMTS network model. One cell may cover an area of around 5 km by 5 km.

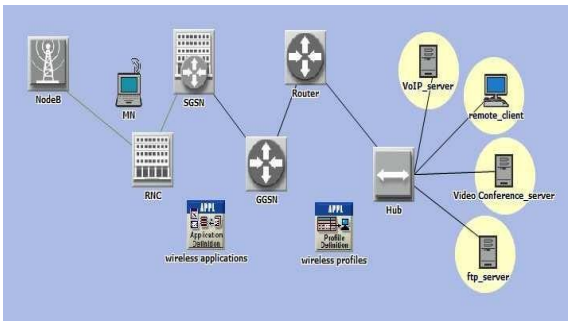


Figure 4: UMTS Network Scheme Implementation

The following simulation parameters were used to obtain the results as shown in Table 3. The path loss can be calculate by taking the difference between the transmitted signal strength in the uplink direction at the mobile station and the received signal strength at Node B.

Table 3: UMTS Simulation Environment Parameters

System Parameters	
Coverage area	5km *5km
Simulation time	15minutes
UMTS MN cell state	Cell_DCH
UMTS RLC process time	0.015
CPICH transmission Power	1W
Shadow fading Standard deviation	10
Processing time	0.02sec
Path loss	Outdoor to indoor and pedestrian environment
UMTS GMM Timer	15/30/10

3.4 Performance Analysis of Different HWN Technologies

Three heterogeneous wireless technologies—WLAN, WiMAX, and UMTS—were put into practice and evaluated using a variety of carefully chosen mobile node applications, including VoIP with PCM quality, Heavy FTP, and Heavy Video Conference.

Table 4: The General Statistic Information of Video Conference. Traffic Sent

WiMAX Statistic Inf. kb/s	Wi-Fi Statistic Inf. kb/s	UMTS Statistic Inf. kb/s
horizontal, min : 0 max : 900 vertical, min : 0.0 max : 91,4 initial value : 0.0 final value : 91,3 expected value : 79,988 sample mean : 79,988 variance : 886,482 standard deviation : 29,77	horizontal, min : 0 max : 900 vertical, min : 0.0 max : 15,206 initial value : 0.0 final value : 15,2 expected value : 13,345 sample mean : 13,345 variance :24,529 standard deviation : 4,952	horizontal, min : 0 max : 900 vertical, min : 0.0 max : 15,262 initial value : 0.0 final value : 15,26 expected value : 13,254 sample mean : 13,254 variance : standard deviation : 5,089

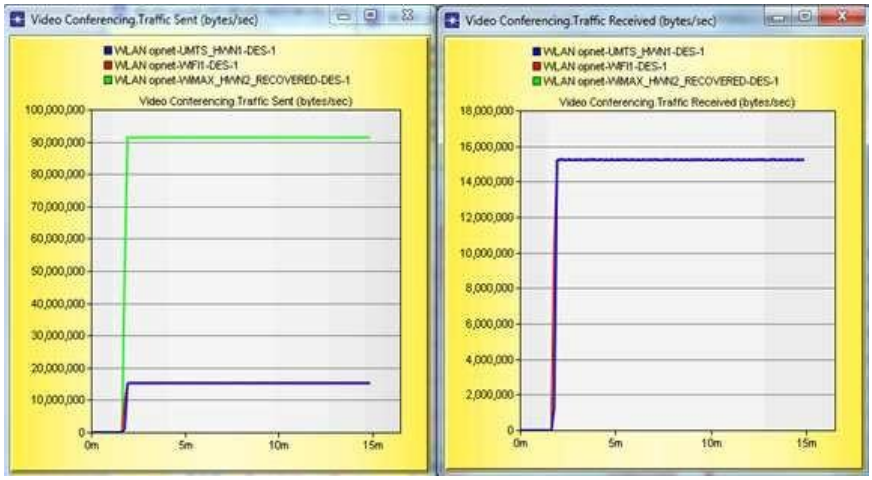


Figure 5: Video Conference Sent and Received Traffics

The simulation period for this project was around fifteen minutes, and the mobility employed was 10 km/h with various location nodes at specified vector trajectories stated in chapter four. Metrics including average latency, throughput, and received traffic were computed and analyzed, along with the performance of specific applications like VoIP, video conference, and FTP.

The video conference traffic delivered and received for all HWN (Wi-Fi, WiMAX, and UMTS) is shown in Figure 5. Some of the performance's general statistical data are included in Table 4. As a consequence, we can demonstrate that WiMAX traffic transmission was optimal in around 60% of cases, although all responses to received traffic were comparable.

However, Figure 6 and Table 5 depict and explain the VoIP transmit traffic in this project; they demonstrate that WiMAX throughput outperforms other networks in sent and received traffic by around 30–100%.

As shown in Figure 7, the third application's response is FTP throughput. The statistical data for transmitted FTP traffic is shown in Table 6. They lead us to the conclusion that Wi-Fi and UMTS networks have better WiMAX performance thanks to this effort. The global delays and throughput in each network are shown in Figures (8–10). The UMTS network displays the highest latency and minimum throughput. Conversely, WiMAX networks display the highest throughput and the smallest latency.

Table 5: The General Statistic Information of VoIP. Traffic Sent

WiMAX Statistic Inf. kb/s	Wi-Fi Statistic Inf. kb/s	UMTS Statistic Inf. kb/s
horizontal, min : 0 max : 900 vertical, min : 0.0 max : 31,564 initial value : 0.0 final value : 25,226 expected value : 23,015 sample mean : 23,015 variance : 78,521 standard deviation : 8,861	horizontal, min : 0 max : 900 vertical, min : 0.0 max : initial value : 0.0 final value : 10,728 expected value : 10,201 sample mean : 10,201 variance : standard deviation : 4,231	horizontal, min : 0 max : 900 vertical, min : 0.0 max : 11,57 initial value : 0.0 final value : 7,928 expected value : 7,591 sample mean : 7,591 variance : standard deviation : 3,204

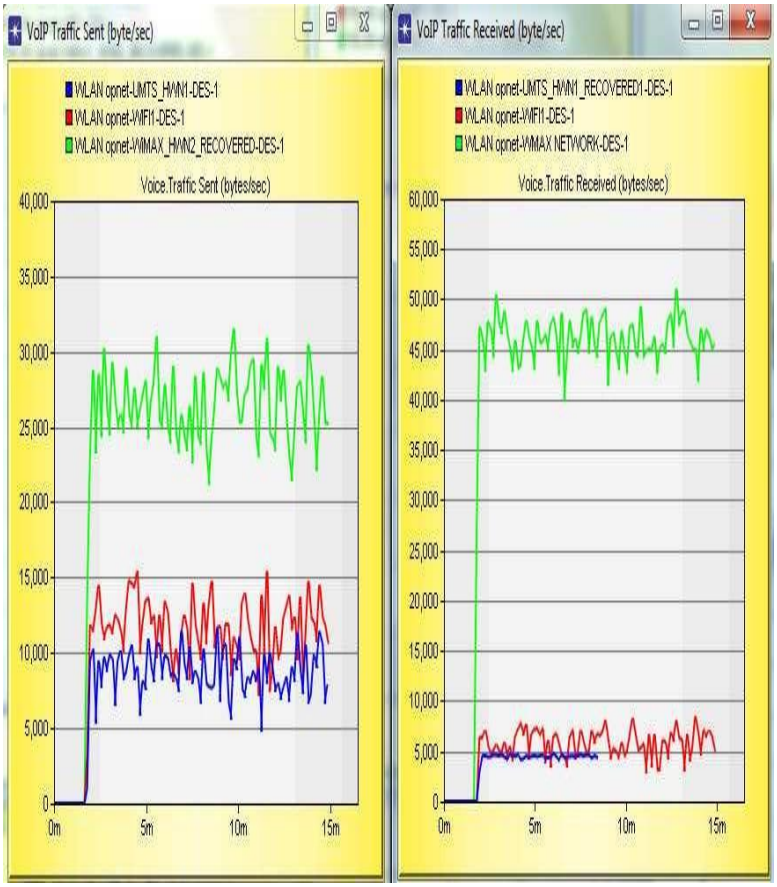


Figure 6: VoIP Sent and Received Traffics

Table 6: The General Statistic Information of FTP. Traffic Sent

WiMAX Statistic Inf. kb/s	Wi-Fi Statistic Inf. kb/**s**	UMTS Statistic Inf. kb/s
horizontal, min : 0 max : 900 vertical, min : 0.0 max : 556,124 initial value : 0.0 final value : 139,173 expected value : 261,375 sample mean : 261,375 variance : 21,939.000 standard deviation : 148,120	horizontal, min : 0 max : 900 vertical, min : 0.0 max : initial value : 0.0 final value : 16,837 expected value : 22,225 sample mean : 22,225 variance : standard deviation : 8,619	horizontal, min : 0 max : 900 vertical, min : 0.0 max : 5,612 initial value : 0.0 final value : expected value : 224.49 b/s sample mean : 224.49 b/s variance : standard deviation : 1,009

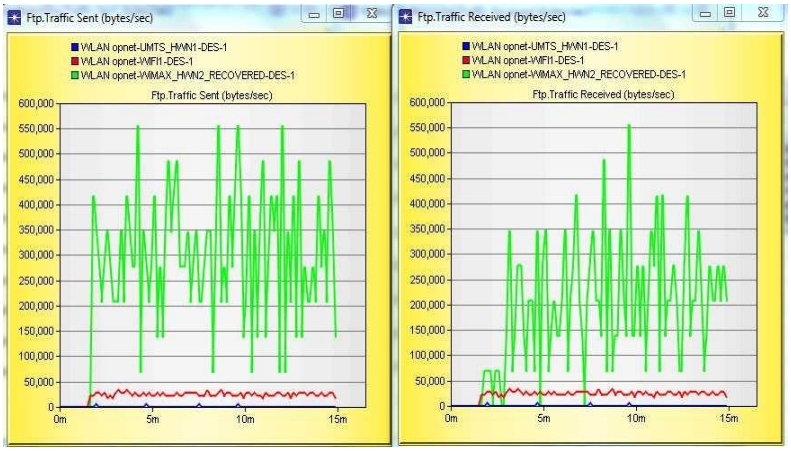


Figure 7: FTP Sent and Received Traffics

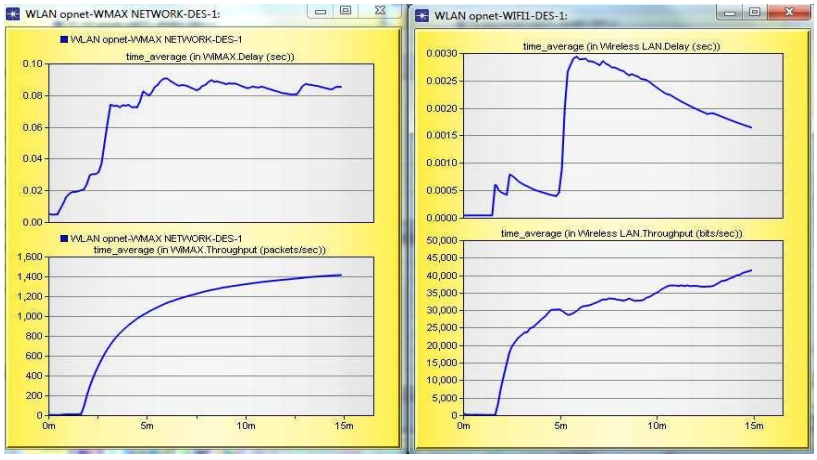


Figure 8: Throughput and Delay in WiMAX and Wi-Fi

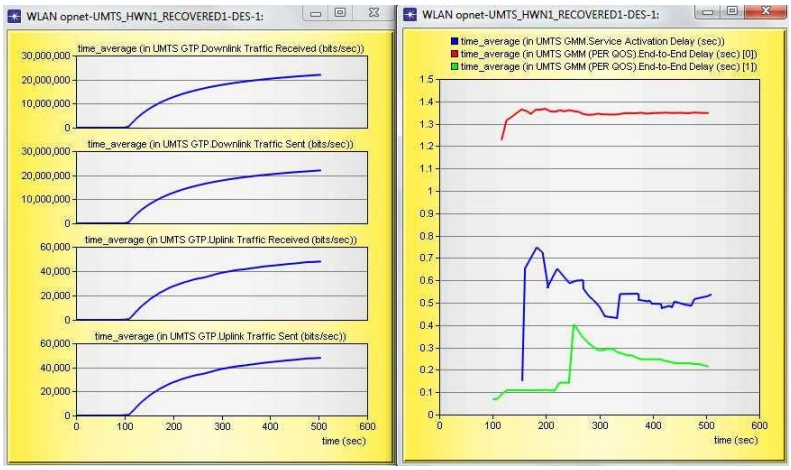


Figure 9: Throughputs and Delays in UMTS Network

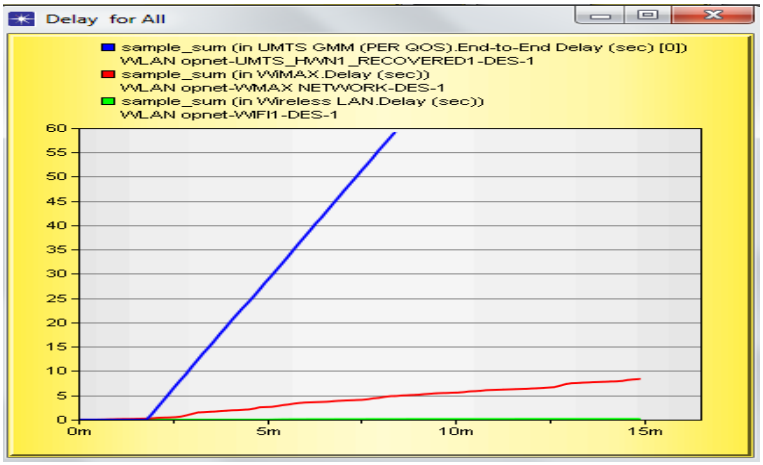


Figure 10: Overall Delay in the Three Networks

4. HANDOFF IMPLEMENTATION AND EVALUATION OF HWN

Three distinct case studies for implementing and assessing Handoff (HO) across WLAN, WiMAX, and UMTS networks are included in this section.

4.1 Handoff in WLAN

In this case study, we dispersed 42 Mobile Nodes (MNs) with Wi-Fi connections throughout seven cells using three access points and internet protocol. Using a previously determined trajectory vector between seven wireless access points, the mobile nodes travel at random. These APs provide WLAN_802.11g service with a 54 Mbps data throughput and roaming capabilities. The goal of this scenario is to demonstrate how to achieve HO while MN is flowing across cells at a pace of around 10 km/h during an hour of simulation time.

In this project, all nodes in the simulation were established using the same set of measurements. The features of the suggested HO_WLAN topology are shown in Figure 11.

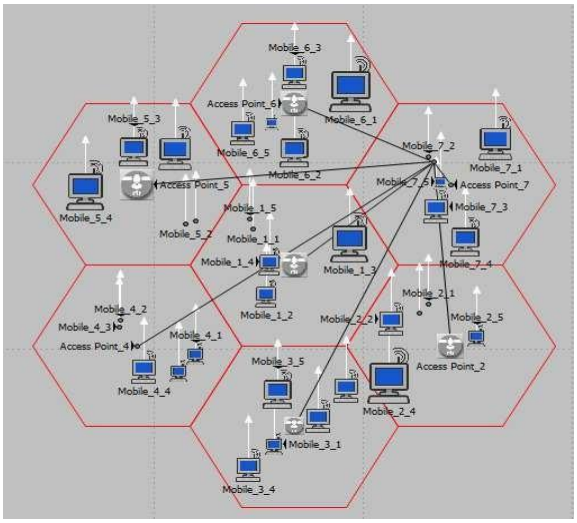


Figure 11: HO_WLAN Network Scheme Implementation

4.2 Handoff in WiMAX

This instance examined how WiMAX technology performs when MN shifts between a base station's coverage area and HO takes place. This research aims to investigate the impact of various BSs supporting WiMAX IEEE802.16e on performance during handoff events. Thus, the same predetermined set of measures was applied. In this case study, a 15-minute simulation period is assumed.

The suggested WiMAX topology design is shown in Figure 12. Seven BSs were part of the WiMAX configuration. The MN or MS travels along a predetermined path such that it alternatively roams close to the coverage regions by these BSs. The sole difference between the symmetrical BSs was their MAC address. MS was also configured to enable the WiMAX BSs' services as the efficiency mode on WiMAX setup was attributed to mobility and range capabilities. In this instance, IP cloud was used to facilitate MN mobility across BSs. The suggested actual placement applied in a chosen area for BSs and the MS trajectory traveling around these BSs is shown in Figure 12.



Figure 12: HO_WiMAX Network Scheme Implementation

4.3 Handoff in UMTS

The UMTS platform configuration, seen in Figure 13, consists of six BSs, or node_B, directly coupled to an RNC node for UTRAN. Six BSs alternately roamed the coverage regions using three MN A, B, and C nodes that followed predetermined trajectories. The sole difference between the symmetrical BSs was their MAC addresses. Additionally, the MS was credited with supporting the services of the UMTS BS. The corresponding node, which represented the SGSN node, was directly connected to the RNC. All mobile nodes were assigned to the interactive traffic class and discussion. In this instance, the UMTS UE cell (such as A node) status has to be set in cell_DCH prior to the successful handoff. The suggested actual placement applied in a chosen area for BSs and the trajectory around these BSs are shown in Figure 13. In this instance, the simulation lasted around ten minutes.

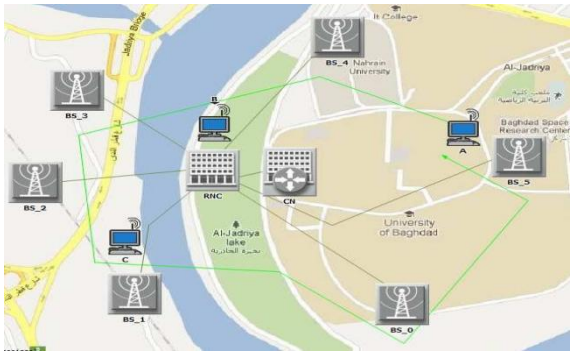


Figure 13: HO_UMTS Network Scheme Implementation

4.4 Performance analysis of Handoff Implementation in HWN

Three case studies—the assessment of HO in WLAN, HO in WiMAX, and HO in UMTS—were included in the findings and comments.

The throughput and delay for case study one are shown in Figure 14 with the selected vector trajectory and simulation length of 60 minutes, as per the simulation and implementation in section 4.1. It is evident that throughput has a high of around 30,484 kb/s at 1800 seconds and a low of 2.1 kb/s at 1950 seconds.

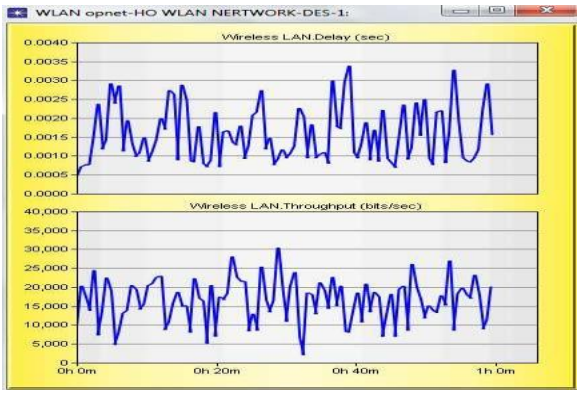


Figure 14: Throughput and Delay of Case Study 1-WLAN

Figure 15 illustrates the WLAN AP connectivity for several selected mobile nodes during different locations and HO occurs in about one hour.

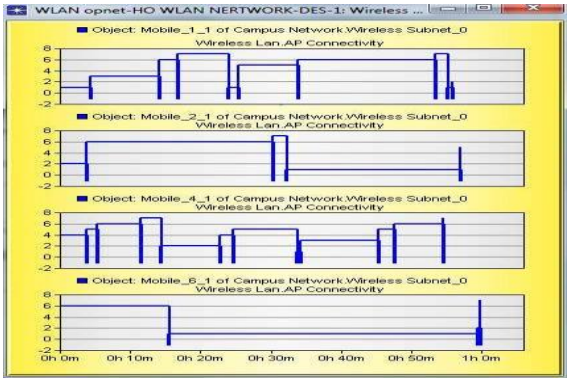


Figure 15: AP Connectivity for Selected Nodes

Figure 16 describes the throughput and latency for each AP from one to seven. Because AP1 is located in the middle of the coverage region, it can be seen that the maximum value is 20,647 Kb/s and the maximum mean value is 5,632 Kb/s. Additionally, as illustrated in Figure 17, the maximum delay at AP2 is about 4.12 ms between 200 and 400 s; this happens because the nodes' mobility is outside of AP2 coverage during these periods.

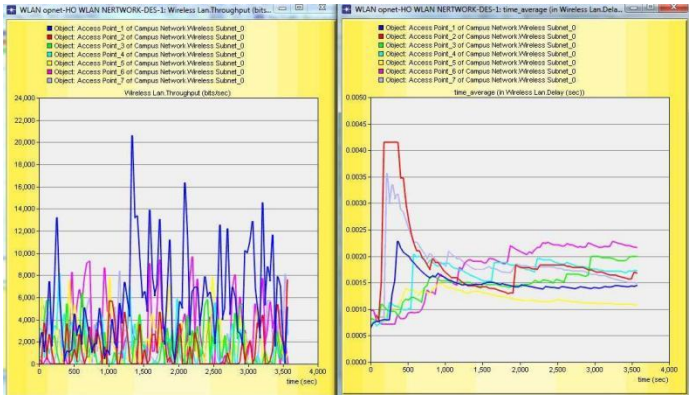


Figure 16: Access Points Throughput and Delay

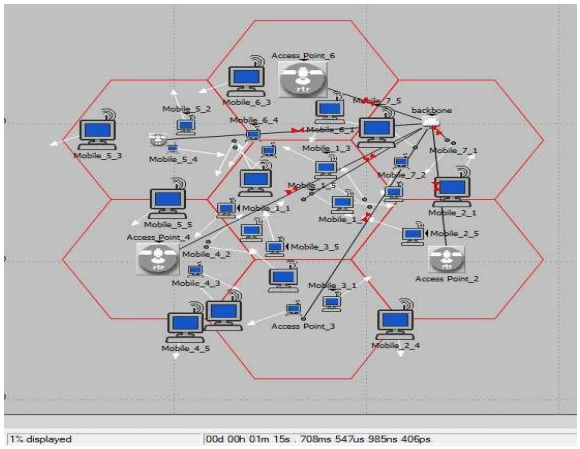


Figure 17: Two Dimension Animation Viewer of WLAN Subnet

Figure 18 displays the throughput, delay, HO delay, advertising received, and mobility serving ID for this case study based on the WiMAX simulation and implementation in section 4.2. With a simulation duration of around fifteen minutes, the same chosen vector trajectory from the prior case study was used. Because MN is going well beyond of BS5 and BS6's service region, Figure 18 shows that the maximum throughput is 397 p/s at around 520 seconds and the minimum throughput is 35 p/s at 490 seconds.

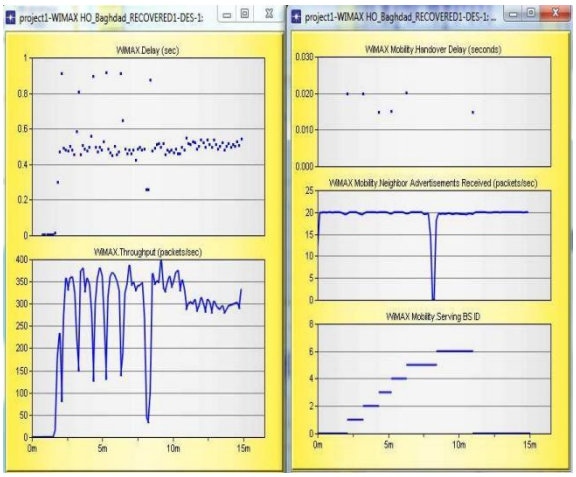


Figure 18: Throughputs, Delay, HO delay, Advertisement Received and Mobility Serving ID

From Figure 19, we can see the throughput of all used BSs in the topology. The MN was connected to BS0 at the start and moved through BSs, and then at the end of the specified trajectory, it was back to BS0.

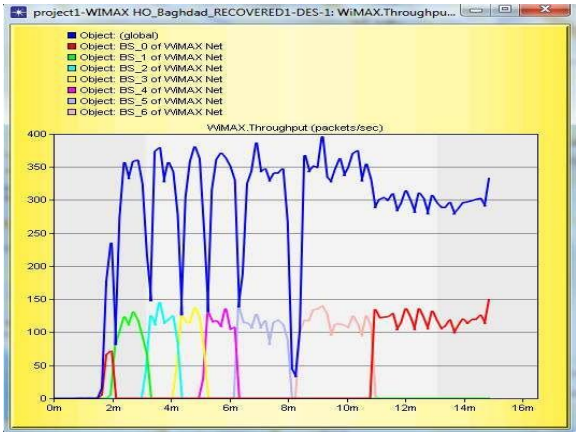


Figure 19: The BSs Throughput in WiMAX Subnet

Figure 20 displays the results of UMTS HO's implementation and simulation in the third case study. Because three mobile nodes were employed in the simulation, three active sets were used; the statistic shows the number of cells in the surrounding MN's active set, which fluctuates during handoffs. Every MN is initially only connected to one Node-B. As a result, the statistic's starting value is 1. Next, throughout the simulation, each time an

When a cell is added or removed from the Active Set, the new cell count is noted.

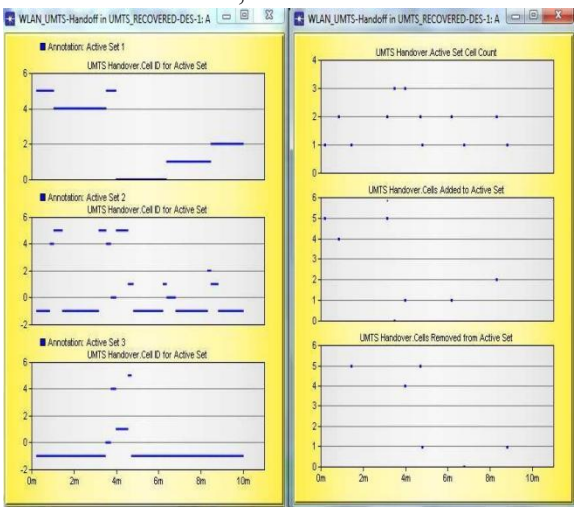


Figure 20: UMTS HO Results

Figure 21 displays the uplink throughput of each BS in the UMTS subnet, the overall traffic received throughput, and the end-to-end latency per QoS. The MN halting close to the BS5 coverage region causes throughput to drop after 355 seconds, with a maximum throughput value of 5.6 Kb/s at BS0.

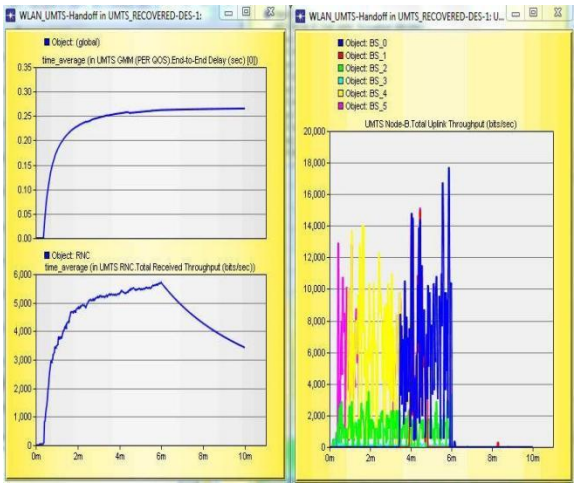


Figure 21: Throughput, End to End Delay and Uplink Throughput in BSs

5. INTEGRATION, INTERWORKING AND DEPLOYMENT IN HWN

This will be approached from two different angles. In order to function as a single network, the first direction covers how to integrate the Wi-Fi network with the WiMAX network. In order to function as a single network, the second approach incorporates the interoperable Wi-Fi network into the UMTS network.

5.1 Integration of Wi-Fi / WiMAX Network

Implementing and assessing the Wi-Fi/WiMAX integration networks is the aim of this case study. Because the two wireless services in this case study vary in terms of coverage, data rate, operating frequency, etc., each network must adapt its protocols, interfaces, and services to meet the interoperability criteria [14][15]. In order to do this, additional interfaces were introduced to the WiMAX base station and Wi-Fi access point. As shown in Figure 22, the WiMAX setup, application profile, and application configuration were established to support the one chosen application HTTP.

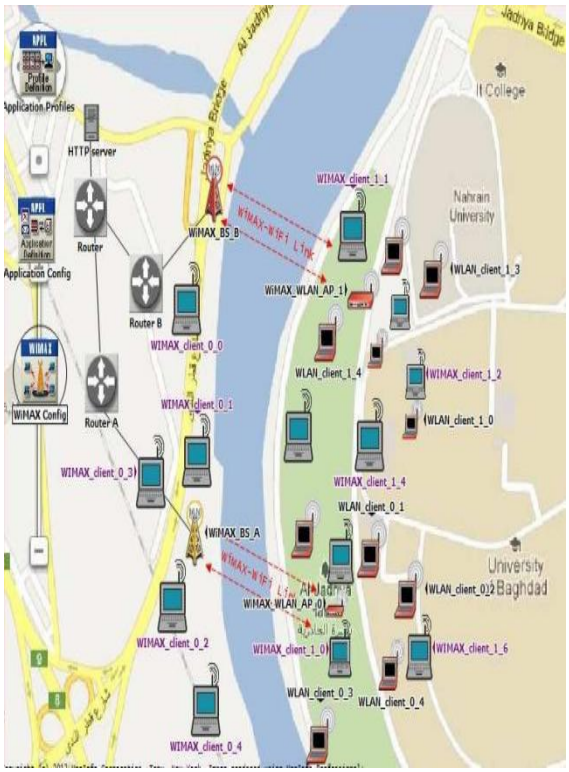


Figure 22: Implementation of Wi-Fi/WiMax Integration

5.2 Integration WLAN into UMTS Network

In order to enable researchers to examine and validate the trade-offs for integrating infrastructure-based wireless LAN (WLAN) technologies into cellular systems, particularly UMTS, this case study aims to construct, simulate, and test a network system environment. The circuit switched domain was not necessary in our case study as we focused on how WLANs interact to provide data services. In this instance, the tight coupling strategy was used. As a result, the RNC firmly connected the WLAN-UMTS system, using WLAN technology as a backup radio access method for "hot spots." This scenario was accomplished in a simulation that included the Enhanced Core Node (SGSN/GGSN), the Enhanced WLAN Access Point (WLAN_UMTS_AP), and the Enhanced User Equipment (UW_1). In our suggested system, the improved node models from [16] were used, put into practice, and then assessed.

With a 15-minute simulation duration, the application traffic models used in this instance generate traffic based on common applications like HTTP and email. The suggested WLAN_UMTS interworking topology implementation in the OPNET simulator is shown in Figure 23.



Figure 23: Implementation of WLAN/UMTS Integration

In this situation, the GMM protocol has to be used. The authentication and fundamental signaling methods for managing mobility into the UMTS domain are provided by the GMM protocol, which logically functions between the MN and the SGSN [17]. The activities of the visitor location registry (VLR) and authentication center (AuC) were hindered by the SGSN/GGSN upgraded node.

5.3 Performance Analysis of the Integrated Networks

This section evaluates two case studies. The findings and discussion of WiFi/WiMAX integrated networks are presented in the first part, while the results and discussion of interworking WiFi networks into UMTS networks are presented in the second section.

For a 24-minute simulation period, Figure 24 shows the throughput and latency in WLAN/WiMAX deployment. The lowest figure is around 106.6 Mb/s at 3 minutes, while the maximum value is 1.75 Mb/s at 17 minutes. We may see that the WiMAX network's latency is ten times higher than that of Wi-Fi. The trade-offs for integrating infrastructure-based Wireless LAN (WLAN) technologies with WiMAX technology were shown in this picture.

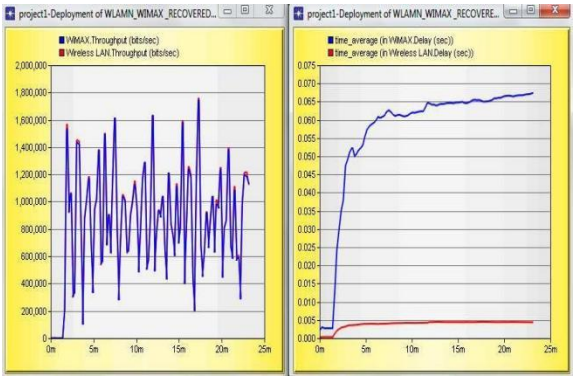


Figure 24: WiMAX/WiFi Throughput and Delay

Figure 25 illustrates the HTTP traffic received and transmitted throughput. Based on the static information, the highest and minimum throughput values are (15.6, 4.8) Kb/s at (9, 21) minutes, respectively.

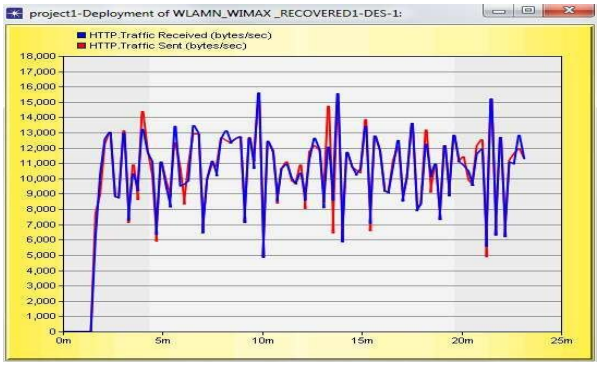


Figure 25: The HTTP Traffic Received and Sent Throughput

It is clearly shown that the BSS_0 and BSS_1 was equal load. The load mean value according to the static information is about 630b/s due to the same numbers and the same types of MN as shown in Figure 26.

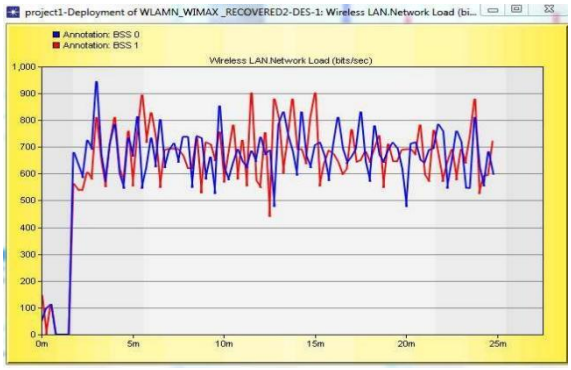


Figure 26: WLAN Network Load

In the second part of case study two analyses, Figure 27 illustrates the delay and throughput of WLAN, it can be note that the max value of throughput is 12801b/s and the max delay value is at 65ms.

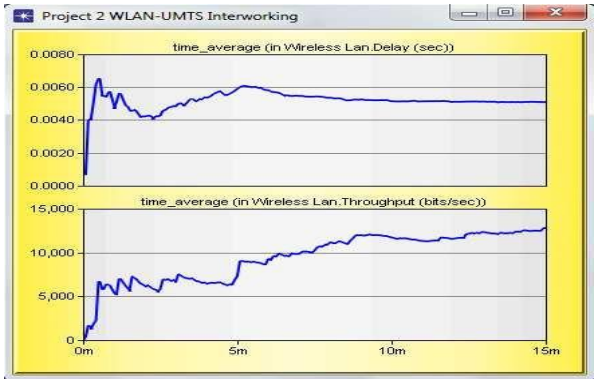


Figure 27: WLAN Delay and Throughput

Figure 28 represents the response of the selected applications HTTP and E-mail over the integration between the two networks. It can be shown the HTTP traffic sent and received throughput is 10 times greater than the E-mail application due to servings.

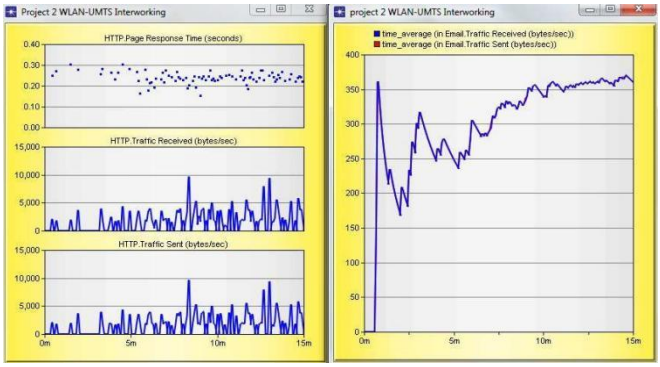


Figure 28: HTTP and Email Application

Figure 29 shows the UMTS GMM delay in several cases. It is very clear that the delay in WLAN is less than that in UMTS.

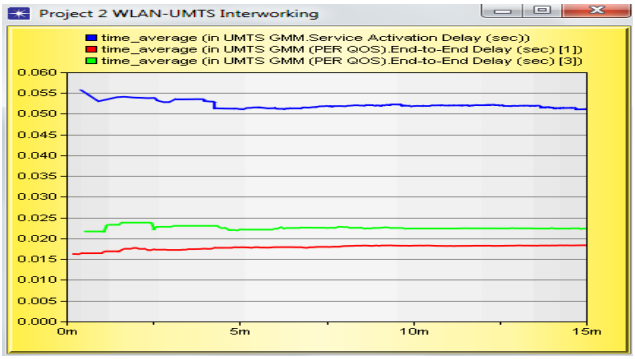


Figure 29: UMTS GMM Delay

6. CONCLUSIONS

In this work, we use the OPNET simulator to offer a performance analysis of many wireless network types with a wide range of applications and handoff kinds. According to the OPNET simulation findings, WiMAX outperformed WLAN and UMTS in terms of highest throughput, followed by WLAN; however, WLAN outperformed WiMAX in terms of shortest latency. Additionally, the simulation results demonstrate the effective deployment of WLAN into WiMAX and UMTS networks via the use of numerous network interfaces. Because it highlights the basic differences in HWNs, it was discovered that it is very difficult to correctly complete the vertical handoff between WLAN-WiMAX and WLAN-UMTS without carefully and precisely building the WLAN network.

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