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QoS IN MIMO USING UNLICENSED WIRELESS SPECTRUM

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Abstract

The demand for wireless throughput has increased immensely, and high data rate wireless communications, nearing 1 Gbps transmission rates, is of significance in emerging wireless local area networks (WLANs) and home multimedia networks. Meanwhile, the quantity of the available electromagnetic spectrum has never increased and or expanded. Thus, designing a very high-speed wireless link that offers good QoS (quality-of-service) and range capability in NLOS (Non-Line-of-Sight) environments constitutes a significant research and engineering challenge. Therefore, there is a need to investigate the emerging technology, multiple-input multiple-output (MIMO) wireless, that offers significant promise in making 1 Gbps wireless links in NLOS vicinity a reality. The study investigates the QoS in MIMO system technology using unlicensed wireless frequency.

Keywords**:** MIMO, unlicensed wireless frequency, QoS, Gbps transmission, home multimedia networks, NLOS

Introduction

Over a decade now, multiple-input-multiple-output (MIMO) technology has built its system from solely hypothetical performing studies that assured vast capability improvements [1, 2] to genuine inventions for the wireless marketplace [3, 4]. Though several MIMO systems are yet to be adequately verified under pragmatic propagation environments and thus, their incorporation into actual applications can be believed to be in the embryonic stage. This fact buttresses the significance of substantially profound yet easy-to practice approaches to comprehend and imitate the wireless channel and the fundamental radio propagation [5].Thus, the shaping of MIMO radio channels has enticed much awareness. Originally, the utmost frequently used MIMO model was a spatially flat-fading channel. This matches to a so-called "affluent scattering" narrowband setting. It was soon comprehended that various propagation atmospheres result in a spatial association. At the same time, concern in wideband technology made it crucial to integrate frequency selectivity. Since then, more state-of-the-art models for MIMO channels and propagation have been presented [6].

Two facts are apparent, and they are: first, the need for wireless throughput will increase endlessly; second, the capacity of the accessible electromagnetic spectrum will certainly remain the same.

Wireless communication is different from optical fibre communications in that extra fibre can always be installed, so regardless of the intelligence of optical researchers, there is a belief that future optical demand will continuously be met. On the contrary, there is no straightforward answer for wireless throughput. The essential and perpetual wireless bug is a physical layer difficulty: how to offer ever-increasing full wireless throughput consistently in a specified area [7, 8].

All recommended resolutions seem to fall into one of three groupings:

i. Utilization of spectrum that is presently unexploited or underutilized
ii. Placement of additional access points, each covering a lesser area
iii. Use of access points with several antennas.

The first two actions as exemplified by millimetre wave technology and minute cells. The third action is known as MIMO (multiple inputs multiple outputs) [9].

Additionally, high data rate wireless communications system, close to 1 Gbps transmission rates, is of attention in emergent wireless local area networks (WLANs) and home multimedia networks. At present, research has shown that WLANs proffer highest rates of 10 Mbps, with 50 to 100 Mbps becoming accessible shortly. Though, 50 Mbps is insufficient when challenged with the demand for greater access speeds fitting to the rise in rich media content and rivalry from 10 Gbps wired LANs. Moreover, upcoming home multimedia networks will reinforce various high-speed high-definition television (HDTV) streams, which require close to 1 Gbps data rates.

Another challenge confronted by WLANs and home networks as well as outdoor wireless wide area network (WWAN) technologies for static and mobile access is non-line-of-sight (NLOS) propagation, which makes arbitrary instabilities in signal level, known as fading.

Likewise, inventing very high-speed wireless links that offer effective quality-of-service (QoS) and range capacity in NLOS atmospheres creates a substantial research and engineering challenge. Disregarding fading for now, in principle, the 1 Gbps data rate prerequisite can be met if the product of bandwidth (measured in Hz) and spectral efficiency (measured in b/s/Hz) equals 10^9. As will be explained later, a diversity of cost, technology, and regulatory restraints make such an instinctive force solution horrible, if not unfeasible.

Earlier it was mentioned that an emergent technology, known as MIMO wireless technology, proffers capacity in attaining 1 Gbps wireless links in NLOS situations a realism [10] and upsurges the spectral efficiency by numerous orders of magnitude, as demanded imminent 5G wireless networks and beyond. All these decadences in high-speed wireless network led us to the perception of MIMO technology which uses a natural radio-wave phenomenon called multipath. With multipath, the transmitted information rebounds off walls, ceilings, and other objects, reaching the receiving antenna multiple times at diverse angles and slightly different times. In the past, multipath produced interference and slowed down wireless signals. With multipath, MIMO technology uses various smart

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transmitters and receivers with added spatial dimension, expanding performance, transmission range and higher energy efficiency, higher spectral efficiency, lower latency and simpler access layer. MIMO upsurges receiver signal-capturing power by aiding antennas to combine data streams arriving from diverse paths and at various times. Smart antennas use spatial diversity technology, which puts excess antennas to effective use. When antennas surpass spatial streams, the antennas can add receiver diversity and enlarge range. Additional antennas typically link to better speeds. Thus, arouter (wireless adapter) with three antennas can have a speed of 600 Mbps while another with two antennas has a speed of 300 Mbps. The router needs multiple antennas and has got to completely adopt all pieces of 802.11n to achieve the maximum speed thinkable. Legacy wireless devices use Single-Input Single-Output (SISO) technology. They can just send or receive one spatial stream at a time. To device MIMO, the station (mobile device) or the access point must support MIMO. For the best functioning and range, mutually the station and the AP must support MIMO [11].

Besides, the investigation has shown that the number of devices accessing network will exceed the populace on earth in 2020, so it will devour more energy. Thus, a green, energy reduction and an environmental guard is an imperative problem in high-speed WLAN, 5G network and beyond. Resource management, allocation and equally QoS is an important aspect to the wireless communication system.

Lastly, looming wireless technologies necessitate vital and crispy thoughtful of design ethics and control systems to professionally operate network resources.Resource allocation plans lie at the core of wireless communication networks since they intend at ensuring the essential QoS at the user level while certifying resourceful and enhanced process at the network level to make the most of operators' revenue. Resource allocation management in wireless communications undoubtedly will comprise a wide spectrum of network functionalities, such as scheduling, transmission rate control, power control, bandwidth reservation, call admission control, transmitter assignment, and handover [12 – 14].

Related Works

Demands for imminent wireless communication networks are to offer high data rates, improved QoS whilst sustaining an open architecture for a multiplicity of international standard wireless network technologies ranging from 2G/3G/4G cellular radio systems as Global System for Mobile Communication (GSM), General Packet Radio Service (GPRS), Universal Mobile Telecommunications System (UMTS) to Wireless Local Area Networks (WLANs), Broadband Radio Access Networks (BRANs), Digital-Video Broadcast (DVB) and Digital-Audio Broadcast (DAB) networks [15 – 17]. Even though the offered radio spectrum is a scant resource, increasing user demand for extreme bandwidth applications with diverse QoS guarantees over wireless networks has generated an extraordinary technological challenge to develop effective coding and modulation schemes along with cutting-edge signal and information processing algorithms to advance the quality and spectral efficiency of wireless communication links [18, 19].

Furthermore, it is commonly acknowledged that large-scale multiple-input-multiple-output (MIMO) is a crucial technology to upsurge the spectral efficiency by numerous orders of size, as demanded future 5th generation wireless networks and beyond [20, 21]. MIMO is built on using a hundred antennas concurrently to serve tens of users in a similar time-frequency resource. The variety of huge quantity of antennas infers quasi-orthogonality amid the users' channels in consequence of the law of large numbers. Henceforward, linear transmitters and receivers such as zero-forcing (ZF), maximal ratio transmission (MRT) and maximal ratio combining (MRC) attain great operation [22, 23]. MIMO technology proffers [24] advanced energy effectiveness, sophisticated spectral productivity, reduce latency and straightforward access layer. These advantages cannot be fully utilized without sufficient resource apportionment tactics which expands the Quality of Service (QoS). Thus, researchers have explored this resource apportionment matter with distinct network architectures and theories.

In [25], the authors obtain the least number of transmitting/receive antennas fulfilling outage possibility limitation in point-to-point massive MIMO technology. The glitches of antenna choice, user arrangement and power distribution stood the concentration of [26, 27].

In [26], a shared antenna choice and user slating policy are initiated for downlink massive MIMO technology supposing a restricted number of radio frequency chains.

In [28], the authors considered a combined antenna selection and power-sharing structure that exploits the sum-rate in a big cloud radio access network.

A polynomial-time algorithm is recommended in [29] to improve the beamforming path and choose the set of antennas with an utmost signal-to-noise ratio (SNR). Distributed massive MIMO technology with restrained backhaul power are studied in [30]. The antenna adoption issues under an inadequate number of radio frequency chains are also examined in [31] for calculated massive MIMO channels.

In [32], a small density antenna choice algorithm is considered based on productive interference for throughput boosting considering matched filter receiver in downlink massive MIMO technologies.

Methodology

Hardware and Software Requirements

Software Requirements

The software requirements for the deployment of this project are:

i. *A network management software called UniFi Controller*
ii. Operating System (Linux, Mac OS X, or Microsoft Windows 7/8/10)
iii. Java Runtime Environment 1.6 (or above)
iv. Web Browser
v. *A workstation (PC/Laptop)* running the UniFi Controller software, located either onsite and connected to the same Layer-2 network, or off-site in a cloud or NOC.

Hardware Requirements

The hardware requirement is the Transmitter (wireless access point), Receiver, Switch, Router, Laptop, LAN cables.

i. ***Transmitter:*** *The two transmitter that was used are ubiquity unifi access point long rang (UAP-LR) that support 802.11ac MIMO technology, which is capable of transmitting 867 Mbps data. This provides a wireless signal to mobile users in other to investigate the roaming algorithm. Table 1 shows the detailed* specifications *of the access point.*
ii. ***Receiver:*** *In this study, the following mobile phones models are used iPhone 6, iPhone 7 and Samsung S7 edge, S8 edge as well as various laptops brand.*

iii. ***Router:*** *This route packet to and fro the network and also connect the network to the internet gateway, it also assigns an IP address for the connected users using DHCP.*
iv. ***Switch:*** *It provides access to devices that are connected via wired LAN.*
v. ***Laptops:*** *The unifi controller will be configured and installed on the laptop for all-inclusive management of the network.*
vi. ***LAN Cables:*** *These are to provide access to the local area network for devices directly connected to the switch and the router.*
vii. A DHCP-enabled network for the wired AP to obtain an IP address as well as for the wireless AP after the deployment

Table 1: Ubiquity UniFi AP-LR Datasheet and Specifications.

Dimensions	175.7x175.7x43.2mm (6.92x6.92x1.70")
Weight with mounting kits	240g (8.5 oz) 315g (11.1 oz)
Networking interface	10/100/1000 Ethernet port
Buttons	Reset
Power method	802.3af/A PoE 24V passive PoE (Pairs 4, 5+; 7.8 Return)
Power supply	24V,0.5 Gigabit PoE Adapter*
Power save	Supported
Maximum power consumption	6.5W
Maximum TX power 2GHz 5GHz	 24dBm 22dBm
Antennas	Dual-Band Antenna, Tri-Polarity,2.4GHz: 3dBi, 5GHz: 3 dBi
Wi-Fi Standards	802.11 a/b/g/n/r/k/v/ac
Wireless security	WEP, WPA-PSK, WPA-Enterprise (WPA/WPA2, TKIP/AES)
BSSID	Up to 8 per radio
Mounting	Wall/ceiling (kits included)
Operating temperature	-10 to 70C (14 to 158 F)
Operating humidity	5 to 95% Noncondensing
Certifications	CE, FCC, IC, DFS
Environment	Indoor
2GHz MIMO	3x3
5GHz MIMO	2x2
Wireless Uplink	Supported
Advanced Traffic Management	
VLAN	802.1Q
Advanced QoS	Per-User Rate Limiting
Guest Traffic Isolation	Supported
WMW	Voice, Video, Best Effort, and Background
Concurrent Clients	250+
Supported Data Rates (Mbps)	
Standard	Data Rates
802.11ac	6.5 Mbps to 867 Mbps (MCS0-MCS9 NSS1/2, VHT 20/40/80)
802.11n	6.5 Mbps to 450 Mbps (MCS0-MCS23, HT 20/40)
802.11a	6.9, 12, 18, 24,36, 48, 54Mbps
802.11g	6.9, 12, 18, 24, 36, 48, 54Mbps
802.11b	1, 2, 5.5, 11 Mbps

Ubiquity UniFi Access Point Configuration

This configuration is crucial to allow users to connect to have access to the network wirelessly. The steps involved to configure the access point are:

Setting up the UniFi AP, UniFi Controller is first installed on a PC after downloading the latest Unifi Controller software from unifi.com website. Thereafter, it was launched (Figure 1).

When a browser is launched to manage the network by clicking on the necessary button (Figure 1), a browser is opened (Figure 2). Ifyou are new to UniFi AP (UAP), then there is a need to create a username and password to log into a dashboard and setup the UAP. After Login, as an administrator, the UAP can be setup and, on real-time, manage the UAP.

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UniFi Controller (5.7.20) started.

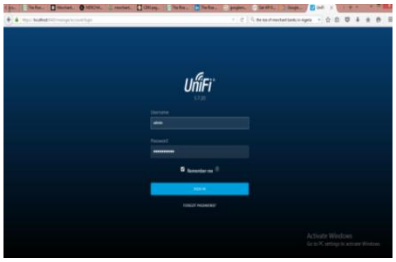


Figure 1: The UniFi controller utility interface.

Figure 2: Webpage for Login as an administrator.

After logging in, on the dashboard (Figure 3), on the right corner is the channels available for use. These include 2.4GHz and 5GHz channels which indicate that the UAP is a dual-band transmitter. Also, at the upper right corner is the name for the access point and the Login account details.

Also seen in the figure is WAP, type of devices connects to the WAP, how long they have connected, throughput information, the channel used, transmission indicator and the number of the access point that the user is managing (in this figure, only one WAP is being managed, IP address allocated to the device, status of connection (green colour indicates that the WAP is active)).

The UniFi dashboard allows network administrator too remotely or onsite install, control, manage WAP. Furthermore, it has added advantages such as a map. Location can be uploaded onto the dashboard via the google map. Also, architecture design or layout design of an area being measured can be drawn using the dashboard.

In Figure 4are shown tab of how many clients are connected to the WAP device, the IP address allocated to client/user, when connected, uplink and downlink data rate respectively.

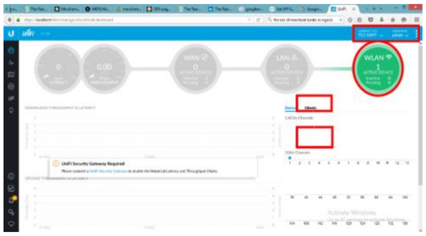


Figure 3: UAP Dashboard

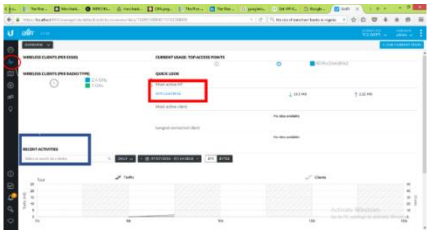


Figure 4: UniFi WAP device statistics

While on the setting tab (Figure5 through 7), the WAP, password, SSH authentication, wireless network, IP address allocation for clients that are connected, controller settings and update of controller software are setup and configured.

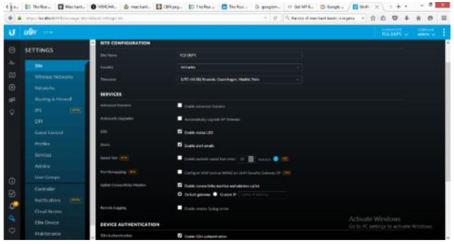


Figure 5: UAP Settings

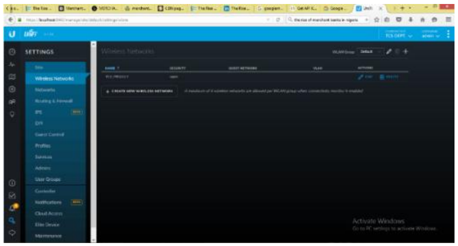


Figure 6: Wireless network setting

Among other changes or configuration that could or need to take place is the changing of the radio channel (Figure 8), download and upload information of all connected devices, type of service being used by the client.

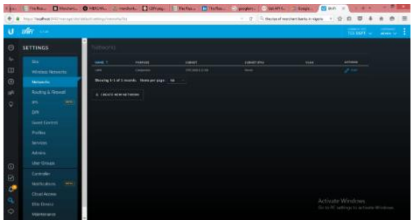


Figure 7: LAN IP address configuration

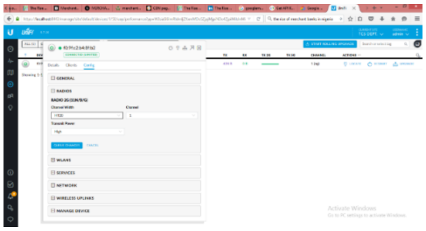


Figure 8: Configuration of radio channels

Wireless LAN Channels

According to Table 2 (approved tables for wireless LAN channel for US, Europe, Canada and Japan respectively), the approved channels that can be used each separated by 5 MHz are specified. Channel 14 is unused by any regulated body, as agreed. IEEE 802.11 b/g/n supports the above table and it is illustrated using Figure 9. According to Figure 9, channel 1,6,11 are the only non-overlapping channels. The effect of using each channel would be investigated and, the best channels that are visible to users would be proffered.

Table 2: Frequency Channel Plan

Channel ID	Carrier Frequency	US	Europe	Japan	Canada
1	2.412	X	X	X	X
2	2.417	X	X	X	X
3	2.422	X	X	X	X
4	2.427	X	X	X	X
5	2.432	X	X	X	X
6	2.437	X	X	X	X
7	2.442	X	X	X	X
8	2.447	X	X	X	X
9	2.452	X	X	X	X
10	2.457	X	X	X	X
11	2.462	X	X	X	X
12	2.467		X	X	
13	2.472		X	X	
14	2.484		X	X	

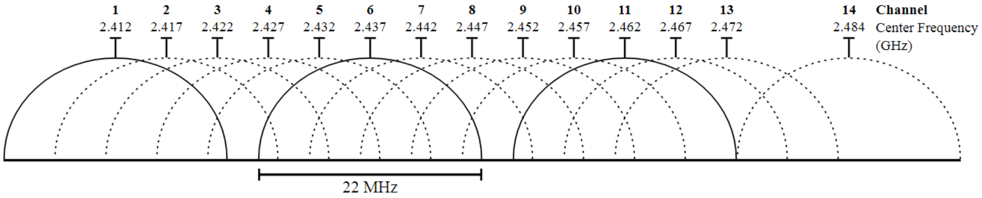


Figure 9:Carrier Frequency of WLAN channel

TESTS AND ANALYSIS

Consistent network performance has long been a significant aspect of many network applications. Investigation and performance analysis of the QoSin MIMO wireless technology and the QoS metric such as delay, throughput, latency, packet dropped and jitter are the objectives of this study.

To evaluate the performances of the MIMO wireless system technology, the analysis was based on verifying the packet sent, the packet received and packet dropped, using the following tools: ping command in windows operating system, MikroTik router board, R package and Ubiquiti UniFi controller.

The analysis was performed varying the number of users (1 to 20). The metrics used for the performance comparison include Packet Dropped (packet), Delay (sec), Round Trip (ms), Traffic Load (bits/sec), and Throughput (bits/sec). A graph was plotted for each analysis done using the user-friendly graphical interface of R package. The screenshots of these graphs form the basis of analysis.

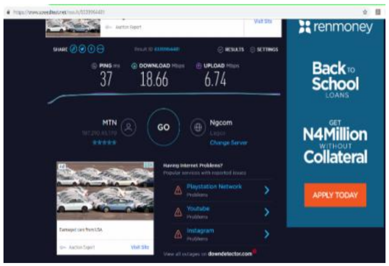


Figure 10: Bandwidth speed test result.

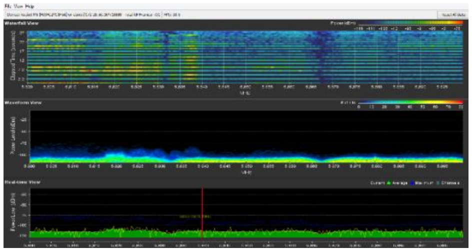


Figure 11: Spectrum Analysis before the congestion

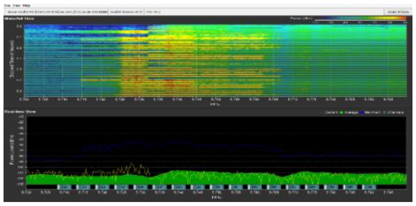
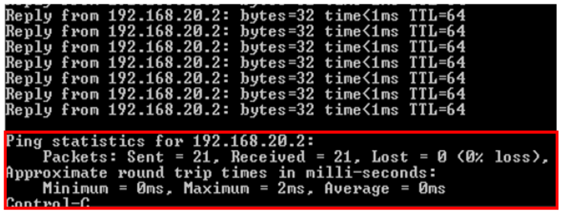


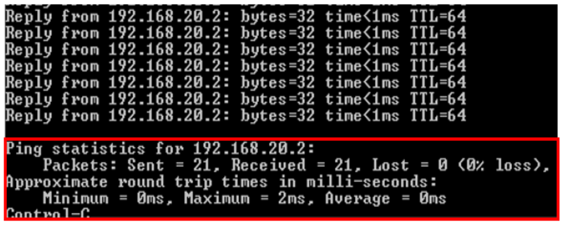
Figure 12: Spectrum Analysis after the deployment of the MIMO enabled the AP.



```
Reply from 192.168.20.2: bytes=32 time<1ms TTL=64
Reply from 192.168.20.2: bytes=32 time<1ms TTL=64
Reply from 192.168.20.2: bytes=32 time<1ms TTL=64
Reply from 192.168.20.2: bytes=32 time<1ms TTL=64
Reply from 192.168.20.2: bytes=32 time<1ms TTL=64
Reply from 192.168.20.2: bytes=32 time<1ms TTL=64
Reply from 192.168.20.2: bytes=32 time<1ms TTL=64

Ping statistics for 192.168.20.2:
    Packets: Sent = 21, Received = 21, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 0ms, Maximum = 2ms, Average = 0ms
Control-C
```

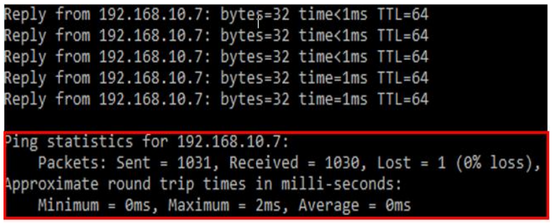
Figure 13: The delay, the packet sent, the packet received, the packet dropped and the Round-Trip time after the deployment of MIMO AP.



```
Reply from 192.168.20.2: bytes=32 time<1ms TTL=64
Reply from 192.168.20.2: bytes=32 time<1ms TTL=64
Reply from 192.168.20.2: bytes=32 time<1ms TTL=64
Reply from 192.168.20.2: bytes=32 time<1ms TTL=64
Reply from 192.168.20.2: bytes=32 time<1ms TTL=64
Reply from 192.168.20.2: bytes=32 time<1ms TTL=64
Reply from 192.168.20.2: bytes=32 time<1ms TTL=64

Ping statistics for 192.168.20.2:
    Packets: Sent = 21, Received = 21, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 0ms, Maximum = 2ms, Average = 0ms
Control-C
```

Figure 14: Second Ping did for the delay, the packet sent, the packet received, packet dropped and Round-Trip time after the deployment of MIMO access point.



```
Reply from 192.168.10.7: bytes=32 time<1ms TTL=64
Reply from 192.168.10.7: bytes=32 time<1ms TTL=64
Reply from 192.168.10.7: bytes=32 time<1ms TTL=64
Reply from 192.168.10.7: bytes=32 time=1ms TTL=64
Reply from 192.168.10.7: bytes=32 time=1ms TTL=64

Ping statistics for 192.168.10.7:
    Packets: Sent = 1031, Received = 1030, Lost = 1 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 0ms, Maximum = 2ms, Average = 0ms
```

Figure 15: Third ping statistics for the delay, the packet sent, the packet received, the packet dropped and the Round-Trip time after the deployment of MIMO AP.

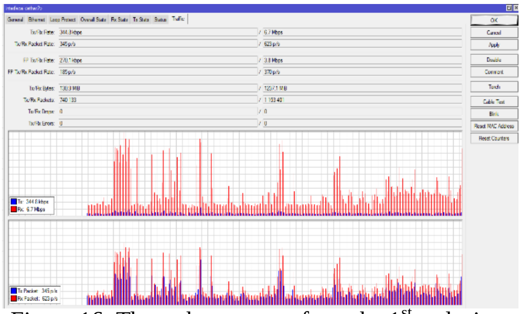


Figure 16: Throughput gotten from the 1st analysis.

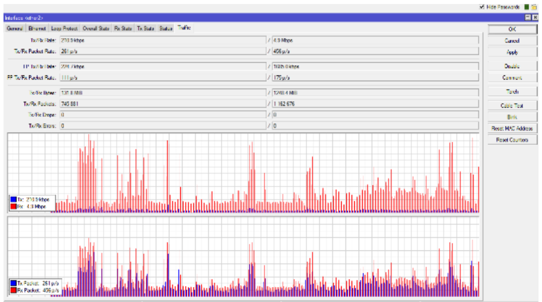
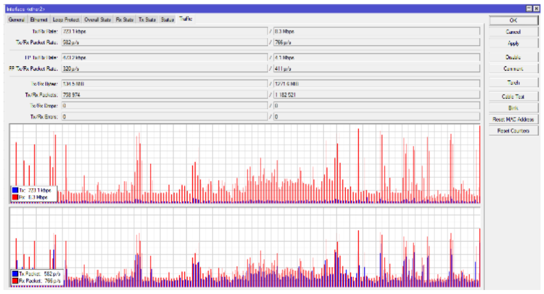
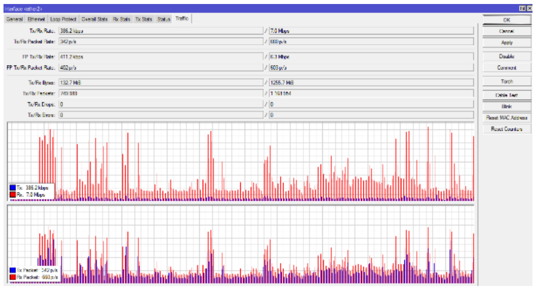


Figure 17: Throughput gotten from the 2nd analysis.



Tx/Rx Rate: 223.1 kbps / 8.3 Mbps
Tx/Rx Packet Rate: 582 p/s / 766 p/s
FP Tx/Rx Rate: 473.2 kbps / 4.1 Mbps
FP Tx/Rx Packet Rate: 320 p/s / 411 p/s
Tx/Rx Bytes: 134.5 MiB / 1271.6 MiB
Tx/Rx Packets: 758 974 / 1 182 521
Tx/Rx Drops: 0 / 0
Tx/Rx Errors: 0 / 0

Figure 18: Throughput gotten from the 3rdanalysis.



Tx/Rx Rate: 386.2 kbps / 7.0 Mbps
Tx/Rx Packet Rate: 342 p/s / 880 p/s
FP Tx/Rx Rate: 411.2 kbps / 6.3 Mbps
FP Tx/Rx Packet Rate: 402 p/s / 603 p/s
Tx/Rx Bytes: 132.7 MiB / 1255.7 MiB
Tx/Rx Packets: 749 888 / 1 168 564
Tx/Rx Drops: 0 / 0
Tx/Rx Errors: 0 / 0

Figure 19: Throughput gotten from the 4thanalysis.

Table 3: Summary of Ping Result Analysis

Obstacle Nodes	Packet Sent (bit/sec)	Packet Received (bit/sec)	Packet Loss (bit/sec)	Round Trip Time (milli-seconds)	Average Round Trip Time (milli-seconds)
1	152	152	0	1	2
2	180	180	0	1	2
3	298	298	0	1	2
4	298	298	0	1	2
5	299	299	0	1	2
6	2358	2358	0	1	2
7	1031	1031	0	1	2
8	207	207	0	1	2
9	1879	1879	0	1	2
10	1638	1638	0	1	2
11	1800	1800	0	1	2
12	2500	2500	0	1	2
13	3000	3000	0	1	2
14	3500	3500	0	1	2
15	4000	3800	0	2	2
16	4800	4600	0	2	2
17	5200	5000	0	2	2
18	5800	5600	0	2	2
19	6900	6600	0	3	2
20	8800	8500	0	3	2

Table 4: Summary of Throughput Result Analysis

Obstacle Nodes	Throughput (Mbps)	Obstacle Nodes	Throughput (Mbps)
1	18.39	11	15.55
2	18.20	12	14.69
3	18.10	13	14.44
4	18.00	14	14.00
5	17.98	15	12.93
6	17.87	16	12.82
7	17.40	17	12.40
8	16.97	18	12.80
9	16.60	19	12.60
10	16.20	20	12.20

DELAY

The end to end delay is the average delay faced during transmission of packets from the source to the destination. Figure 20 shows the graphical representation of the delay encountered between wired and wireless connection to the cloud server, it was perceived that wired users experienced more delay as the user density increased, but wirelessly connected users maintain a certain level of delay for low user density but incur the highest delay as the user density increased.

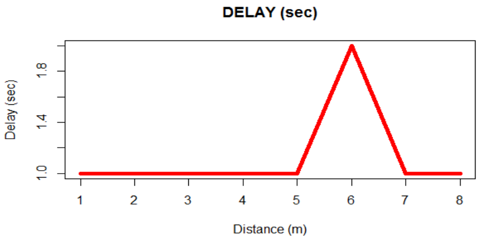


Figure 20: Transmission Delay from the MIMO Tx to the MIMO Rx.

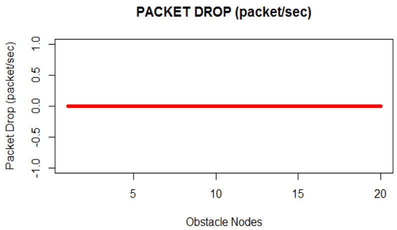


Figure 21: Packet Drop from the MIMO Tx to the MIMO Rx.

Table 5: Summary of the Delays (sec)

Delay (sec)	Distance (m)	Delay (sec)	Distance (m)
1	1	1	4
1	2	1	5
1	3	2	6

PACKET DROPPED

Packets are dropped during data transmission due to contact failing retransmission. However, the study shows that there is no packet drop during data transmission with MIMO enabled AP and receiver (Figure 21).

Figure 21 shows the graph of the performance and evaluation of the MIMO enabledAP and receiver with varying number of obstacle nodes.

THROUGHPUT

Throughput is the number of packets that are delivered successfully from the sender to receiver; it is measured in bit per second or data packet per second. Figure 4.12 shows a graph of the performance of the MIMO enabled access point. From the graph, it can be deduced that MIMO enables device still perform effectively despite there are obstacles and interference.

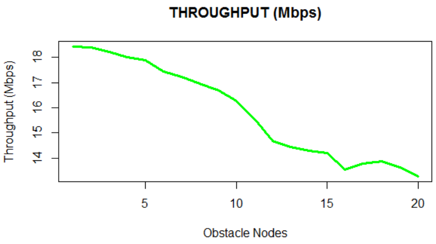


Figure 22: Maximum Throughput Obtained Against the Obstacle Nodes.

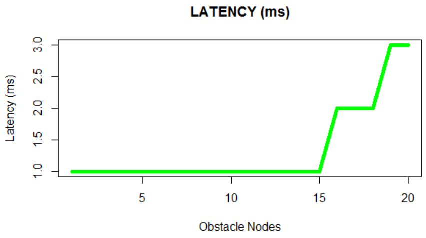


Figure 23: Latency obtained from the access point to the receiver.

LATENCY

Latency is the round-trip time taken for the packet to get to the receiver and to send back an acknowledgement to the sender. Figure 23 shows the graph of the latency from the AP to the receiver with obstacles in between the line of transmission.

In Summary, having introduced MIMO wireless system technology, it was observed that when a device is MIMO-enabled, it performs better in obstacle and highly densified environment. The latency to the AP would be low compared to the Non-MIMO device. Furthermore, users experience high throughput and low delay while transmitting data faster (Table 6).

Table 6:Summary of the QoS Metrics

Obstacle Nodes	Throughput (bit/sec)	Latency (milli-second)	Packet Dropped (packet/sec)	Obstacle Nodes	Throughput (bit/sec)	Latency (milli-second)	Packet Dropped (packet/sec)
1	18.39	1	0	11	15.55	1	0
2	18.20	1	0	12	14.69	1	0
3	18.10	1	0	13	14.44	1	0
4	18.00	1	0	14	14.00	1	0
5	17.98	1	0	15	12.93	2	0
6	17.87	1	0	16	12.82	2	0
7	17.40	1	0	17	12.40	2	0
8	16.97	1	0	18	12.80	2	0
9	16.60	1	0	19	12.60	3	0
10	16.20	1	0	20	12.20	3	0

CONCLUSION AND RECOMMENDATION

CONCLUSION

From the tests and analysis carried out, the performances of MIMO-enabled wireless transmitter and receiver devicebased on certain metric using ping command, Ubiquity unifi integrated spectrum analyzer, Unifi controller software and MikroTik router board; it was deduced that MIMO-enabled device is the best wireless transmission option for a highly obstructed and large network environment as it provides better throughput, high data rate, reliable delivery of data, low delay, wider coverage and easier mobility of users (it make use of multipath effect in the line of transmission).

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