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Comparing Network Performance Between Pure and Hybrid Li-Fi Networks

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***Abstract*:- Li-Fi stands for Light Fidelity. This is a Visible Light Communications (VLC) innovation that allows information to be communicated through light using a Light Emitting Diode (LED) light bulb. A light sensor receives light signals, and a signal conditioning device converts the data into a streamable substance [1]. Currently, the web has become one of the fundamental methods of correspondence as well as a wellspring of data. There are numerous ways to connect to computer networks in order to have access to the internet. The most prevalent are wireless connections to access points and wired connections via network cables [2].**

Wireless Fidelity (Wi-Fi) innovation makes use of radio waves, which cannot be used everywhere, such as in circumstances where they interfere with medical instruments, such as in hospitals [3]. Because radio waves are available wherever there is a signal, they pose a security threat in some systems, necessitating the implementation of robust security measures [4]. For security purposes, banks and hospitals may wish to have control over the signal and be able to control where it flows. Using Li-Fi communication instead of Wi-Fi could be a viable option. Li-Fi is suited for confined locations with high density wireless broadband coverage. It's a viable option in locations where radio interference is a challenge. Its attributes contribute to a wireless system's security and capacity [5].

This research looked at how effective Li-Fi communication systems may be deployed for Small Medium and Micro-Enterprises (SMME). Different network topologies were used in the tests. A pure ADSL network, a pure radio network, and hybrid networks that integrate Li-Fi with ADSL and Li-Fi with radio are among them. On the basis of throughput, jitter, and delay, a comparison was made between pure networks and their hybrid equivalents with Li-Fi networks.

Keywords*: *Light Fidelity (Li-Fi), Visible Light Communications (VLC), Wi-Fi, LED, Asymmetric Digital Subscriber Line (ADSL), Botswana Telecommunications Corporation Limited (BTCL), User Datagram Protocol (UDP), Universal Serial Bus (USB), Intelligent Transportation System (ITS), Radio-Frequency Identification (RFID), Liquid Crystal Display (LCD)

1. INTRODUCTION

Light Fidelity (Li-Fi) is a recently invented form of wireless communication that uses Light Emitting Diode (LED) illumination to send data at this era of digital connection bottlenecks [6]. In today's fast-paced society, data transmission is one of the most important everyday routines. When several gadgets are connected to the web, today's wireless networks quickly become congested.

In a similar way to Wireless Fidelity (Wi-Fi), Li-Fi is a Visible Light Communication (VLC) system which utilizes light as a channel to offer high-speed data transfer. The basic premise of Li-Fi technology is that data may be conveyed by altering light levels using LED lighting [7]. In a Technology, Entertainment, and Design (TED) Global talk on VLC in July 2011, German physicist Harald Hass first mentioned Li-Fi technology as "data through illumination" [8], [9]. Instead of Wi-Fi wireless routers, Li-Fi uses transceivers with LED lamps to light a room while also transmitting and receiving data.

If the underutilized visible light spectrum could be added to the currently free radio waves for transmission of data, Li-Fi might play a critical role in reducing the tremendous loads experienced by the present wireless infrastructure. Using the visible spectrum with Li-Fi will also aid in reducing the negative effects that electromagnetic radiation through Wi-Fi have on human health. Correspondence through Li-Fi innovation guarantees security since information can't be procured when light is not accessible [10]. In this manner, Li-Fi can be of extraordinary advantage in banks, centers, emergency clinics, airplanes, schools and thick conditions like shopping centers in Botswana.

The effectiveness of Li-Fi communication networks was explored and tested in this word. Performance testing was conducted on test networks that had been set up and in terms of throughput, latency, and jitter, a comparative study was conducted between pure and hybrid networks. Pure Wi-Fi network arrangements over radio and Asymmetric Digital Subscriber Line (ADSL) backbone networks, as well as hybrid Li-Fi/Wi-Fi network setups over radio and ADSL networks, were among the architectures. The results of tests based on jitter, throughput, and end-to-end delay also assisted us in determining the impact of adding and increasing load on a network, as well as analyzing network performance after integrating the Li-Fi network with existing technologies.

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2. LITERATURE REVIEW

This chapter discusses, in summary, the research work carried out by different authors regarding Li-Fi technology applications and benefits.

A prototype of a model that helps inpatient monitoring in hospitals using Li-Fi to stop radio frequency contact with the human body and the medical equipment has been introduced in the work of [11]. Temperature, pulse, insulin, and respiration detectors are employed in this system to collect data from the body. The acquired data is transformed to digital form and then fed into the Li-Fi unit. The data collected is then displayed as a graph on a screen attached to the receiver section of the Li-Fi system.

A design of a prototype of a system that transmits user information from a vehicle to a toll using the power of Li-Fi wireless communication has also been briefly discussed [12]. Every vehicle has a microcontroller, a memory, and a configuration that is utilized to send important encrypted data through LED, such as the vehicle number, personal identification number, and payment gateway password. The Li-Fi receiver has a microprocessor that processes the toll tax bill corresponding to the kind of vehicle via a wallet linked with the car number and sends users SMS verification of the toll payment.
In [13], a VLC based indoor blind navigation system has been presented. VLC-assisted domestic positioning is meant to guide blind persons instead of use of standard wireless navigation systems that use radio waves technology due to the sheer advantages of electromagnetic interference rejection and accuracy. Transmitters are placed on the object or location that blind individuals will use to identify it. Whenever the mobile receiver comprising of a voice playback chip, Li-Fi reader, speaker, and a PIC microcontroller gets into visual range, a transmitter component consisting of a Li-Fi transmitter, PIC microcontroller, and toggle switch communicates specified object or location information.

The author in [14] presented a VLC based Intelligent Transportation System (ITS) framework for truck fleets going through the traffic lights without slowing down through theoretical analysis and quantitative measurement approaches to determine the relationship between truck fleet velocity and traffic signal transition time. The result is critical in reducing the risk of accidents caused by frequent lorry speed fluctuations. The VLC transmitter is mounted on the highway interchange where it delivers traffic control real-time information in the innovative VLC-based infra-to-vehicle prototype system [15]. The receiver is fitted on each car and, depending on the signal it receives, dictates if the smart vehicle will proceed straight ahead or turn.

The author of [16] proposed a workable model for purchasing that included smart goods detection and Li-Fi-based intelligent invoicing. Payment and invoicing, product identification, the cart, and the database are the four main components of the scheme. Each product is identified with a Radio-Frequency Identification (RFID) tag that contains information and a unique 14-digit number. The cart is equipped with a Li-Fi transmitter, RFID reader, Liquid Crystal Display (LCD) display, and a microprocessor that stores the rest of product's details. The reader sees all the goods that have been put to the cart, and if one or more of them are removed at the same time, they will be eliminated from the system. The trolley's Li-Fi connects to the server's Li-Fi and uploads the information as needed.

We can see that Li-Fi has attracted implementation and research in hospitals, cable harness reduction in automotive, vehicle toll gate systems, indoor blind navigation systems, automatic product detection and smart shopping billing and many more applications. There are few applications where Li-Fi technology has already been deployed. Studies indicate that Li-Fi has potential for many other implementations such as dense urban environments, submarine communication, cellular communication, electromagnetic sensitive environments such as aircrafts and more. No implementation or active research has been carried out currently in many developing countries such as Botswana. Li-fi has many potential due to security and health reasons. Therefore, this work entails testing performance of Li-Fi based networks.

3. METHODOLOGY

To acquire desirable output, tests were conducted on various network designs. The goal of the first experiment was to determine the behaviour of a pure Wi-Fi network with ADSL as the backbone network. We also wanted to see how the performance varies as the network load changes. Testing was done at three distinct load levels: low load, where four YouTube videos were played on the network during the experiment, medium load, where eight YouTube videos were played, and high load, where twelve YouTube videos were played. This was done in order to focus on connection types in Botswana, where we have SMMEs with three to fifteen people. Because YouTube.com is a high-bandwidth site that uses User Datagram Protocol (UDP) and does not re-transmit, its videos were utilized to increase traffic on the networks and to vary load. Throughput, latency, and jitter were the network performance parameters tested using speed.io internet network testing tool using a virtual server from Botswana Telecommunications Corporation Limited (BTCL) located 5 kilometres from the testing centre.

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Table 1: Load level descriptions

LOAD LEVEL	NUMBER OF YOUTUBE VIDEOS PLAYING
Low load	4
Medium load	8
High load	12

In the second experiment, the same network parameters were tested on hybrid networks. This involved integrating a pure Li-Fi network with the current ADSL Wi-Fi network, with a typical distance of 1.4m between the access point and the Universal Serial Bus (USB) station. During testing, the load was varied between low, medium, and high levels. Eight sets of findings were acquired in each experimental test, and an average was derived to get a clear picture of network performance at various times. A pure Wi-Fi over radio network and a hybrid Li-Fi with Wi-Fi over radio backbone network were also used in the experiment. The Li-Fi network coverage was measured at the university laboratory and the network operations center office. This was primarily to determine the radius of the Li-Fi network's coverage cell in those places.

Network Topology Scenarios

In terms of throughput, latency, and jitter, two backbone network topologies were utilized to assess the performance of pure Wi-Fi and hybrid Wi-Fi with Li-Fi networks. The ADSL network (shown in figure 1) and the radio network (shown in figure 3) are the two backbone networks. The tests were conducted on both pure backbone networks and hybrid versions of the networks that included an extra switch and Li-Fi equipment at the end points. Figure 2 depicts Hybrid Li-Fi with Wi-Fi on the ADSL backbone network, while Figure 4 depicts Hybrid Li-Fi with Wi-Fi on the radio network uplink.

ADSL Backbone Network

Figure 1 presents Pure Wi-Fi network over ADSL backbone network.

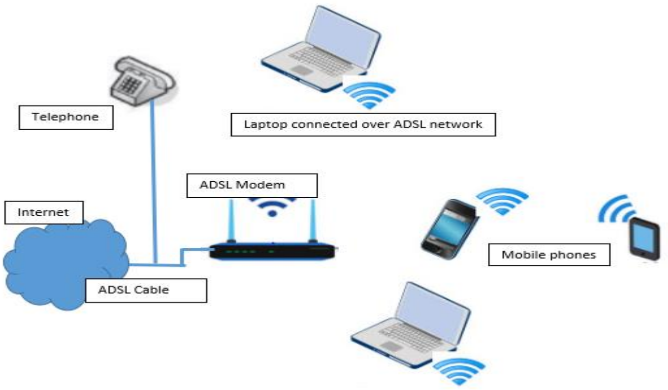

Figure 1: Pure Wi-Fi on ADSL Network

Figure 2 displays an ADSL backbone network with Hybrid Li-Fi and Wi-Fi. The pure network now includes an additional switch, an access point, and a Li-Fi luminaire.

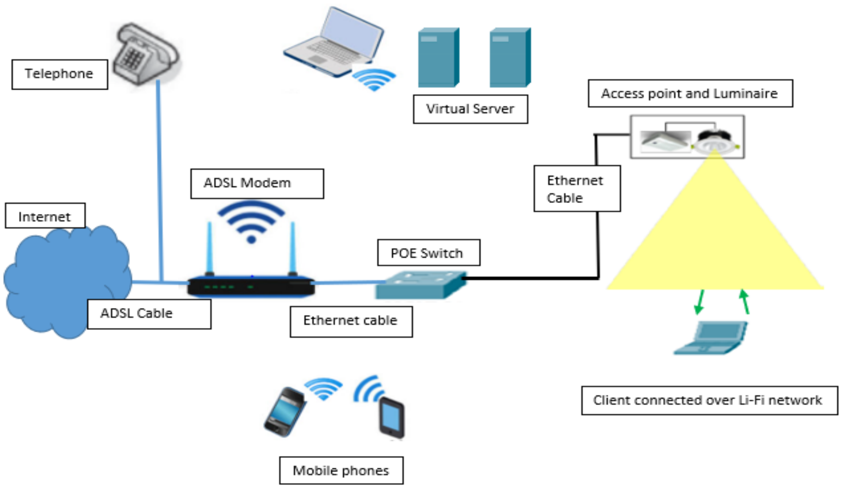

Figure 2: Hybrid Li-Fi with Wi-Fi on ADSL network

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Radio Backbone Network

Figure 3 presents Pure Wi-Fi network over radio backbone network.

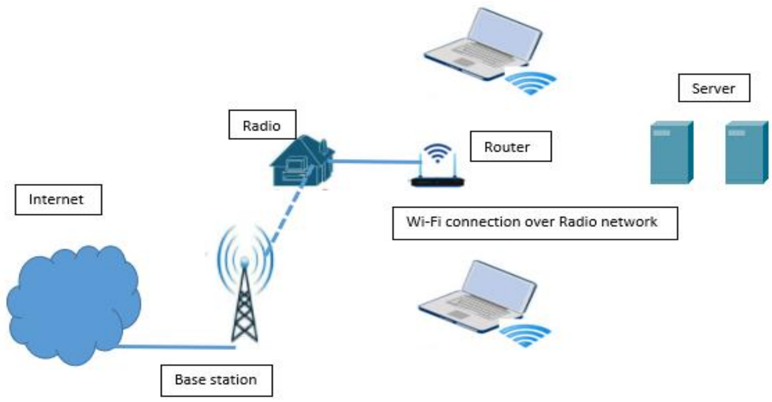

Figure 3: Pure Wi-Fi on Radio Network

Figure 4 depicts a hybrid Li-Fi network with Wi-Fi over radio backbone. The pure radio network now includes an additional switch, an access point, and a Li-Fi luminaire.

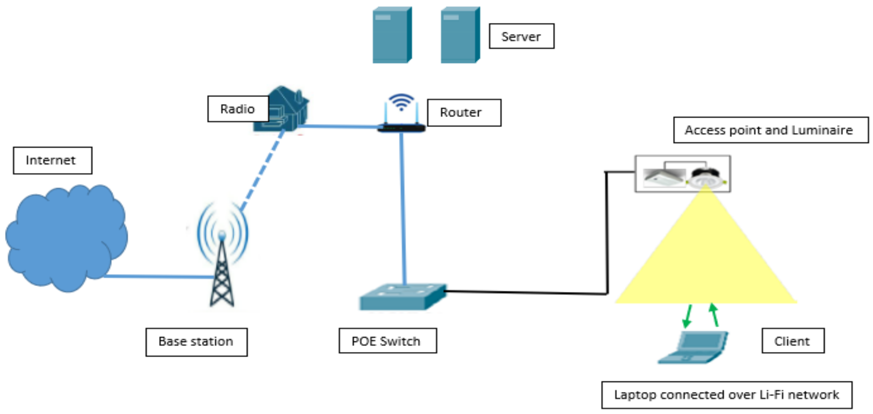

Figure 4: Hybrid Li-Fi with Wi-Fi on Radio network uplink

Network performance testing tool

Speed.io

Speed.io is a web-based network performance measurement tool that measures upload and download bandwidth, as well as latency and jitter. The network parameters were measured on the BTCL server, which is 5 kilometers from the testing site in Botswana.

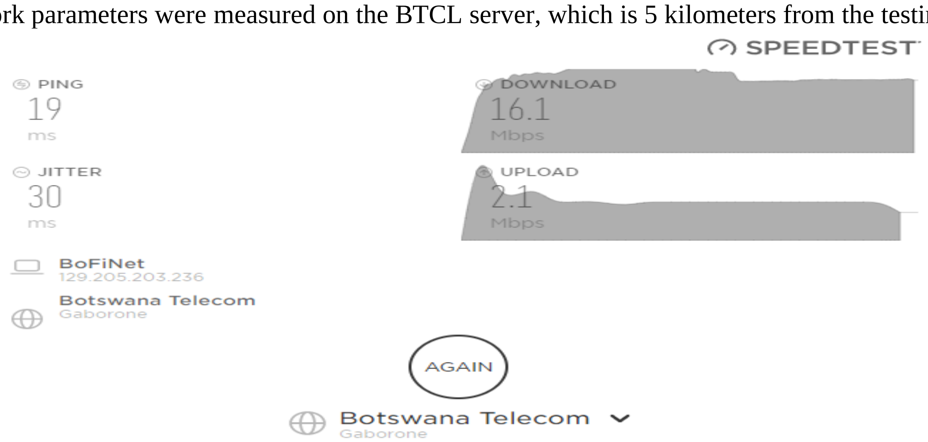

Figure 5: Speed.io online network performance testing tool interface

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4. RESULTS AND DISCUSSION

This section summarizes the findings of network performance tests conducted on pure Wi-Fi on ADSL, pure Wi-Fi on Radio, Hybrid Li-Fi with Wi-Fi on ADSL, and Hybrid Li-Fi with Wi-Fi on Radio networks. On each of the networks, network performance was evaluated based on throughput, jitter, and latency, with traffic loads ranging from low to medium to high. During the testing, four YouTube videos representing low load, eight YouTube videos representing medium load, and twelve YouTube videos representing high load were played. This part of the dissertation also includes results from Li-Fi network coverage tests conducted at a university laboratory and a network operations center office.

Tests on ADSL 4Mbps backbone network

Figure 6 depicts throughput test results of a Pure Wi-Fi and Hybrid Wi-Fi with Li-Fi on ADSL network. Figure 7 displays the latency of a Pure and Hybrid Wi-Fi with Li-Fi on ADSL network. Figure 8 displays jitter of a Pure Wi-Fi and hybrid Wi-Fi with Li-Fi on ADSL network.

When the load on a 4Mbps pure Wi-Fi on an ADSL backbone network was increased from low to medium, throughput dropped by a significant margin on average. When testing under low load on a pure Wi-Fi network, the maximum recorded throughput was 2.9Mbps, with an average of 2.3Mbps recorded. When tested on a medium load network, an average throughput of 0.49Mbps was obtained. The network throughput had decreased by 79 percent. The hybrid Li-Fi with Wi-Fi on ADSL network system had an average throughput of 1.43Mbps at low load and 0.34Mbps at middle load, resulting in a 76 percent loss in throughput. With the same load, the hybrid network's throughput is lower than that of a pure Wi-Fi network due to the inclusion of Li-Fi equipment to the pure network.

On a pure ADSL network, latency rose by 47 percent as load increased from low to medium level, and by 35 percent as load increased further to high level. When the load on the hybrid Li-Fi with Wi-Fi on ADSL network was increased from low to medium, there was a considerable increase in latency as well. At low load, the average latency was 71.6ms, but it increased by 50% to 107.75ms. This illustrates the impact of the additional switch and access point on the pure network, as the latency was higher for the same load levels when compared to pure network results. After increasing the load to a high level, latency rose to 119ms, a 10% increase above the medium load findings.

When the pure Wi-Fi on ADSL system was at low load, the jitter was generally minimal, with the lowest jitter being 40ms and an average of 43.6ms. When the load was elevated to medium, the average jitter rose by 240 percent to 148.5ms. When the load was increased from medium to high level, jitter increased by more than four times, from 148.5ms to 624ms on average. Over a hybrid Li-Fi with Wi-Fi on ADSL network, a significant rise in jitter was noticed as load was increased from low to medium. From 166ms to 356.6ms, the average jitter rose by 115 percent. As the load escalated to a high level, the jitter increased to 988ms. The inadequate system capacity, which could not handle the traffic volume also contributed to the poor performance.

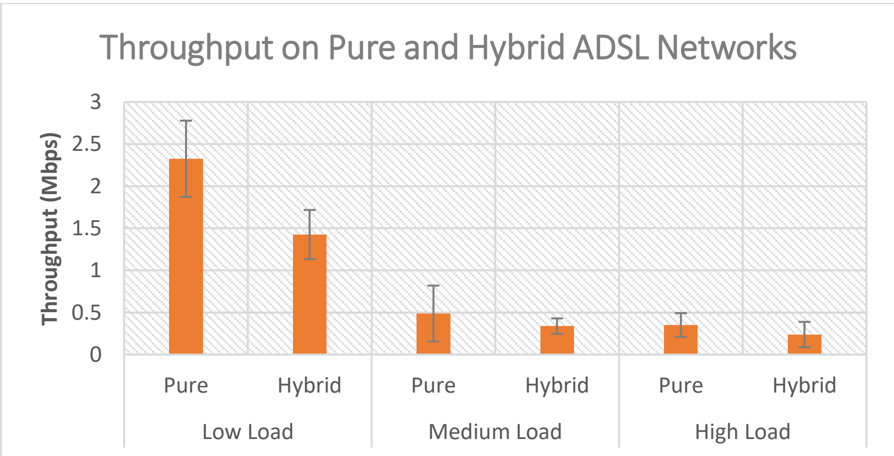

Figure 6: Throughput on a Pure and Hybrid ADSL networks

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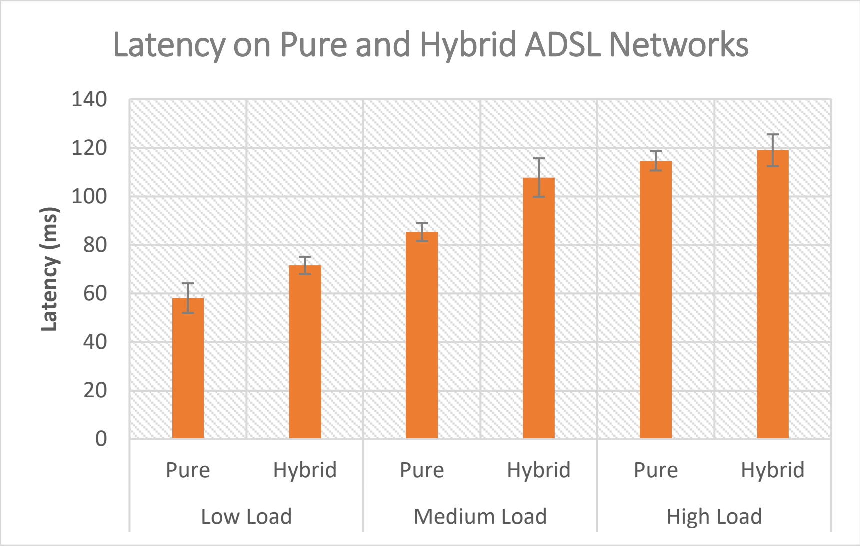

Figure 7: Latency on a Pure and Hybrid ADSL networks

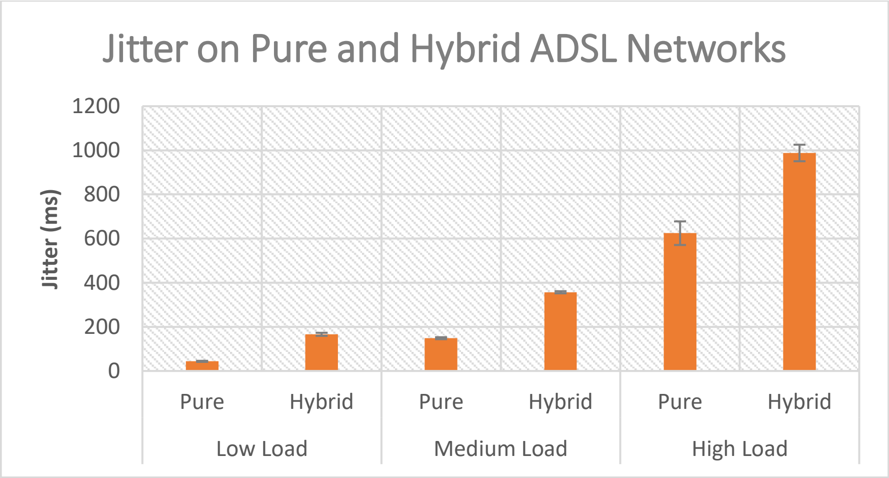

Figure 8: Jitter on a Pure and Hybrid ADSL networks

Tests on 20Mbps radio backbone network

Figure 9 shows the results of a radio backbone network throughput test for pure and hybrid Wi-Fi with Li-Fi. The latency of a Pure and Hybrid Wi-Fi with Li-Fi on a radio network is shown in Figure 10. Figure 11 shows the jitter of pure and hybrid Wi-Fi and Li-Fi networks on a radio backbone network.

On a pure Wi-Fi on radio backbone network, the testing results showed a general drop in throughput when the load was raised. The average throughput reported when the system was under low load was 21.41Mbps, which was higher than the radio link capacity. When the load was increased to medium, the average throughput dropped by 24.9 percent to 16.075Mbps. After adding extra load to the system, the throughput dropped by 34.4 percent to 10.54Mbps. As the load on the hybrid Li-Fi with Wi-Fi on the radio backbone network escalated, the network's throughput degraded. The system's average throughput was 19.26Mbps at low load, but it dropped to 13.825Mbps when more traffic was added, putting it at medium load. After more load was introduced to the network, the throughput dropped by 45.7 percent to 7.5Mbps.

When the traffic on the pure Wi-Fi on radio network was increased, test results showed an increase in latency. The average network delay at low load was 11.29ms. When the load was adjusted to medium level, the latency increased by 0.34ms to 11.63ms. This is a 3.0% gain. After increasing the load to a high level, the latency grew to 14.38ms. Latency on a hybrid Li-Fi with Wi-Fi on radio network started at 14.25ms at low load and grew by 2.63 percent to 14.625ms when the load was increased to medium level. After raising the load to heavy load, the latency increased even more to 14.875ms. These findings corroborate prior findings that increasing network load affects network performance and that merging Li-Fi networks with current traditional technologies reduces their performance.

On a pure Wi-Fi on radio backbone network, the jitter was shown to be low at low and medium load levels. When the load was low, the jitter averaged 2.5ms, but when the load was medium, it escalated threefold to 7.5ms. At high load, the average jitter increased to 9.625ms, a 28 percent increase. The results of a hybrid Li-Fi with Wi-Fi on radio network showed an increase in jitter as the network's load increased. When compared to the ADSL network, the radio network has significantly less network jitter. It was also found to be within the ideal useable range.

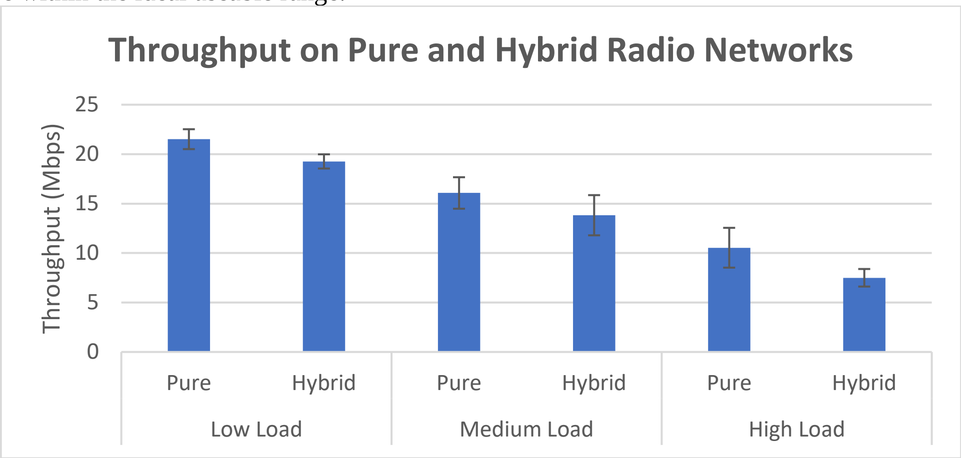

Figure 9: Throughput on Pure and Hybrid Radio Networks

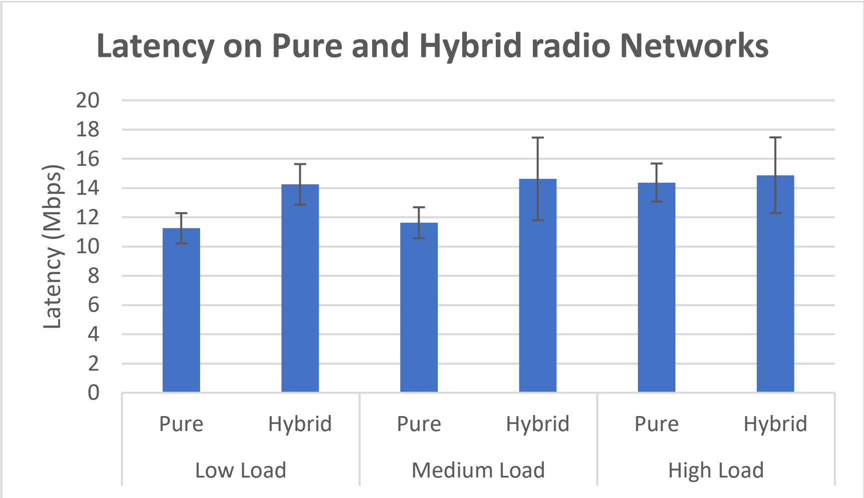

Figure 10: Latency on Pure and Hybrid radio Networks

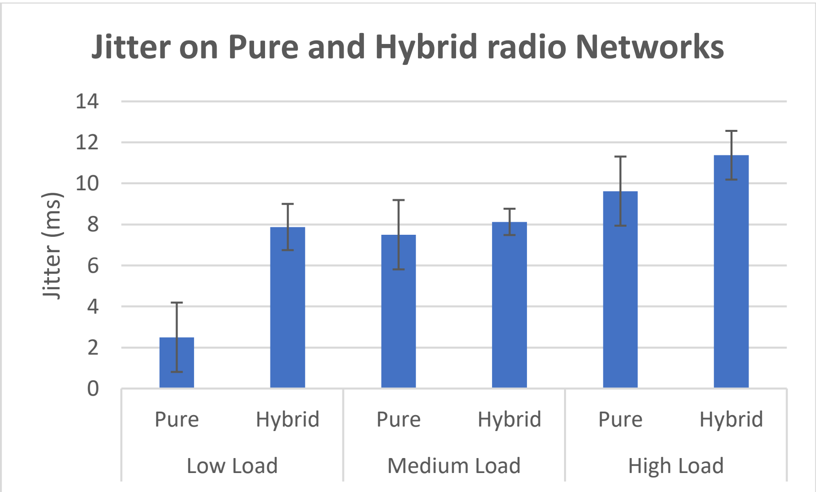

Figure 11: Jitter on Pure and Hybrid radio Networks

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5. CONCLUSION

According to test results acquired from the investigations, the degradation in network performance in terms of throughput on a pure radio network was observed to be better than that on a pure ADSL network when load was increased from low to medium, as well as from medium to high load levels. Although Li-Fi provides security and interference benefits, terminating it on radio and ADSL uplinks has been found to impair the performance of these network technologies due to the additional switch introduced on these networks. The bandwidth of these technologies has also been proven to influence performance reduction. When using a Li-Fi network, the lower the uplink bandwidth, the worse the degradation. As traffic was generated on the networks, results showed a modest performance degradation on hybrid networks compared to pure Wi-Fi networks. Hybrid Li-Fi networks have thus proven to be acceptable for small micro enterprises since, while they reduce network performance, the reduction is slower as the network load increases, and the networks remain stable and useable. Audio, video, and data transmission are all still functioning well. In comparison to current technologies, the platform also offers security and a healthier environment.

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