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Leveraging Li-Fi to Enhance Security and Performance of Medical Devices

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Abstract**—**The network connectivity of medical devices is increasing at a rapid rate. Many medical devices, such as vital sign monitors, share information via wireless or wired connections. However, these connectivity options suffer from a variety of well-known limitations. Wireless connectivity, especially in the unlicensed radio frequency bands, can be disrupted. Such disruption could be due to benign reasons, such as a crowded spectrum, or to malicious intent. While wired connections are less susceptible to interference, they inhibit the mobility of the medical devices, which could be critical in a variety of scenarios. This work explores the application of Light Fidelity (Li-Fi) communication to enhance the security, performance, and mobility of medical devices in connected healthcare scenarios. A simple bridge for connected devices serves as an avenue to connect traditional medical devices to the Li-Fi network. This bridge was utilized to conduct bandwidth tests on a small Li-Fi network installed into a Mock-ICU setting with a backend enterprise network similar to that of a hospital. Mobile and stationary tests were conducted to replicate various different situations that might occur within a hospital setting. Results show that in room Li-Fi connectivity provides reasonable bandwidth and latency within a hospital like setting.

Keywords**—**Hospital, light fidelity, Li-Fi, medical devices, security.

I. INTRODUCTION

THIS paper explores the use of Li-Fi communications in healthcare to improve security, performance, and mobility issues caused by an ever-increasing number of connected devices [1]. Security issues introduced by wireless devices can be devastating. Wireless signals can be snooped on by a third party, potentially leaking private patient data. Medical devices often bring their own issues with security (e.g., Health Insurance Portability and Accounting Act (HIPAA)). While providing confidentiality for wireless communications, standards such as Wireless Fidelity (Wi-Fi) Protected Access (WPA) and Wi-Fi Protected Access II (WPA2) are vulnerable to attacks that allow malicious actors to “access, read, and manipulate encrypted data” [2]. The United States Food and Drug Administration (FDA) has issued a warning for several wireless devices that have not implemented appropriate security standards, increasing the risk of an attacker manipulating the device [3]. Li-Fi provides the potential to improve security by removing a potential attack vector. Its signals are blocked by walls, have limited range within a room, and require an attacker to be between the user and Li-Fi emitter to snoop on packets and manipulate data.

Along with the security improvements, Li-Fi shows potential in increasing bandwidth for wireless devices, which will allow for more wireless connections and greater amounts of data to be collected and monitored. The Radio Frequency (RF) spectrum is severely congested, prompting investigations into the congestion within the 2.4 GHz band where currently there is a need for mitigating the congestion within this band [4]. This is further limited by the range of Wi-Fi access points, which puts a cap on how many individual access points may be placed in one area, such as a hospital. Li-Fi’s limited range within a room allows for multiple access points to be placed near each other without interfering with each other, increasing the available wireless bandwidth to devices. On top of the increase in access points, Li-Fi provides a bandwidth comparable to Ethernet while maintaining an equivalent mobility offered by Wi-Fi. This paper discusses introductory related work in integrating Li-Fi into medical environments followed by a summary of light-based communications and the operation of Li-Fi devices. The equipment and testing environment are discussed before the results of a Li-Fi network within a mock Intensive Care Unit (ICU). These tests consist of stationary and mobile tests meant to mimic the usage of a Li-Fi network in a hospital-like environment.

II. RELATED WORKS

As Li-Fi gets more popular, its usefulness in various scenarios is becoming more and more apparent to the point where popular articles are highlighting its benefits; one of these scenarios is the medical field [5]. Even the vendors of Li-Fi based products are conscious of their benefits in a hospital environment as shown in the advertisements of PureLi-Fi [6] and next Li-Fi [7]. However, limited research has been performed in its introduction into the medical field, specifically in hospital-like environments.

Researchers at Disney are performing some research into utilizing Visible Light Communications. One such effort is for their own VLC system named EnLighting. This system is similar to Li-Fi in that they use light as the physical layer in a normal ethernet stack. This communications system utilizes an LED for transmission with integrated photodiodes for receiving of signals on a light fixture with small System on Chip device for processing. Here the researcher showed that such a system can be used for varying applications with minimal bandwidth utilization [8].

More search from Disney examines VLC communications for use in interactive toys and other entertainment purposes. Again utilizing LEDs a low bandwidth information system was created for short distance communications. The intent of the system is to pass information between different devices,

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such as toy-to-toy or toy-to-smartphone. Researchers found that these type of systems could be useful for networking devices especially for low cost systems and expand the product interface for the IoT [9], [10].

One previous investigation, which highlights the benefits of Li-Fi in the medical realm, was performed by researchers from the Mewar University, India. Their work, from 2014, consisted of an introduction to Li-Fi technology, a theoretical discussion of the benefits to Li-Fi utilization in a medical environment, and a proposed theoretical placement of a Li-Fi system within a hospital. No experiments were performed as a part of this study [11].

III. LI-FI

A. Light Based Communications

Communications with light are not entirely new; Alexander Graham Bell created the Photophone in 1880, a means to transmit sound on a beam of light [12]. Using light as a means to transmit data would come in the 1980's when lasers would be used to perform data communications in fiber optic cables [12]. In the early 2000's wireless visible light communications would start being studied due to the advent of light emitting diodes [13], which is a precursor to Li-Fi.

In 2011 Harald Hass presented Li-Fi, a wireless communications protocol that utilizes visible light instead of RF. The purpose of Li-Fi is to perform wireless communications from other portions of the electromagnetic spectrum other than RF due to the bandwidth associated with each of the bands, focusing specifically on visible light which has ~10,000 times the amount of bandwidth as RF [14].

B. Li-Fi Operation

In short, Li-Fi is Wi-Fi for the light spectrum and utilizes similar protocols as those in IEEE 802.11 protocols. Li-Fi operates through a bi-directional data link with downlink in visible light and uplink in infrared (IR) [15]. The data are communicated through high speed fluctuations in LEDs; these high-speed variations are not visible to the naked eye and therefore don ot interfere with normal lighting functionality for humans. The uplink operates in the same fashion, just in IR. The reason for the change from visual light to IR is the operation of an individual user device. If the uplink were to operate in the visible range, a light would need to be shining toward the user's face, which could be considered inconvenient and IR does not have this problem [15]. Using this uplink/downlink system, it has been proven that Li-Fi can achieve significantly higher data rates than that of RF based communication solutions [16].

Li-Fi and other visible light-based protocols are governed by the IEEE 802.15.7 standard [17].

IV. LI-FI TESTING SETUP AND PROCEDURE

The Li-Fi Access Points and Li-Fi Dongles used for this study were purchased from PureLi-Fi. The Li-Fi devices were installed into a laboratory setting designed to mimic an ICU, henceforth referred to as the Mock ICU. The Mock ICU was outfitted with four Li-Fi lights. The lights were installed to provide access within a patient room and an adjoining hallway to facilitate testing scenarios. A photo of the Mock ICU and its layout are shown in Fig. 1, highlighting the installed Li-Fi APs. The following section discusses the network structure in which these devices were installed.

A. Hardware and Network Structure

Using the suggested setup from PureLi-Fi [15], the access points were connected to a Power over Ethernet (PoE) injector and an industrial network switch. This switch was connected to an enterprise network to the servers responsible for the network testing and configuration of the Li-Fi system.

The user hardware or surrogate medical equipment, used to perform the experiments, consisted of a Raspberry PI Model 3B+, hereby known as Pi, with the PureLi-Fi dongle with the appropriate software. This Pi is used as the end site for many of the tests performed within the Mock ICU. It is also used as a bridge for end devices that require such a bridge to connect to the network through Li-Fi. During the tests it was observed that the Pi does not deliver an appropriate amount of power via USB to the Li-Fi dongle and may hamper performance.

The network architecture, hardware setup, and usage are shown in Fig. 2.

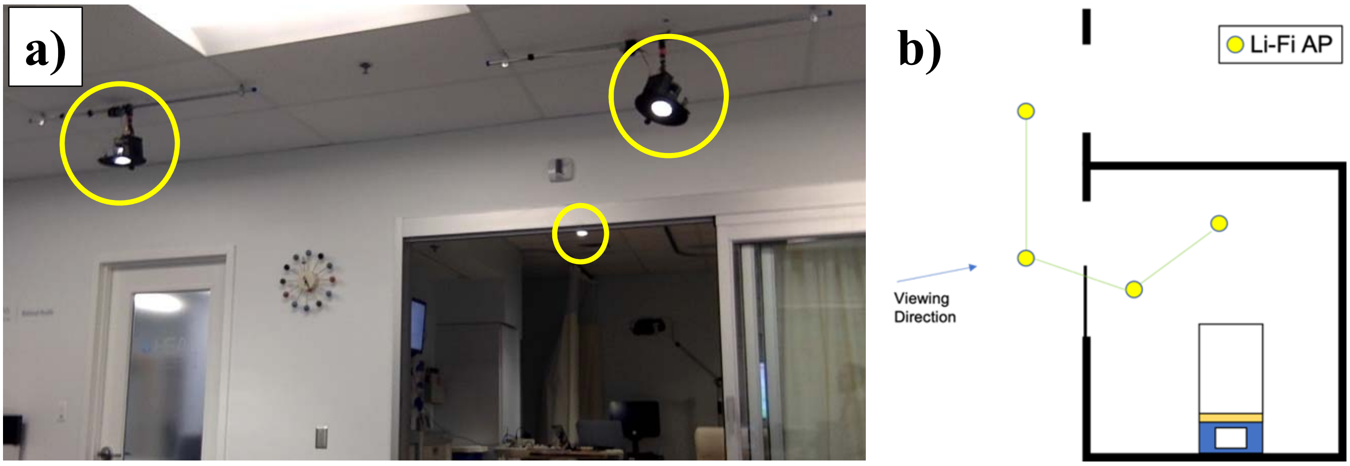

Fig. 1 Li-Fi Access Points in the Mock ICU (a) and a blue print of the location of the Li-Fi APs (b) showing the viewing angle of the picture

B. Test Procedures

The Pi in the mock ICU (ICU Pi) was placed on a cart at waist-height. Another Pi (Eth Pi) and a Linux machine (Eth Linux) were connected to the same network as the Li-Fi access points through the enterprise network in another building. Li-Fi performance was measured using iPerf3. The protocol used in all tests was User Datagram Protocol (UDP). The bandwidths measured were from 1 to 10 Mbps at 0.5 Mbps increments. Tests were run for 60 seconds for stationary tests. Two types of mobility tests were performed. The first maneuvered the imitation medical equipment beneath all the APs ensuring that a connection was made with each one. These tests lasted 120 seconds. In the second type of mobility test the equipment was moved within the beam of each AP but association with each AP did not occur. These tests lasted 60s. The iPerf3 default interval of 1 second reports was used for all tests.

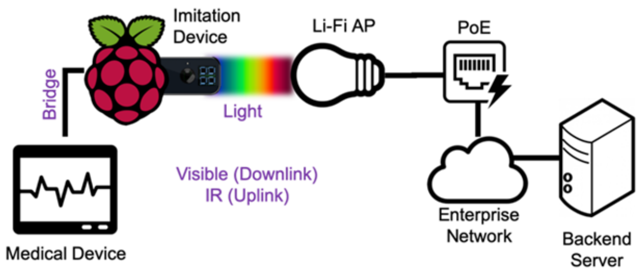

Fig. 2 Li-Fi Network structure block diagram and user hardware

A total of six test configurations were executed. The requested bandwidths were the same across all test configurations. The particulars of each test are shown in Table I. Only one set of tests were conducted for each of the test configurations in this study. If time permitted more tests would likely have eliminated some of the anomalies and outliers.

TABLE I
TEST CONFIGURATION PARAMETERS FOR LI-FI INVESTIGATION

Test Config	iPerf3 Server	iPerf3 Client	Encryption	Duration (s)	Action
1	ICU Pi	Eth Pi	No	60	Stationary
2	Eth Linux	MacBook	No	60	Stationary - Bridged
3	Eth Linux	ICU Pi	Yes	60	Stationary
4	ICU Pi	Eth Linux	No	60	Stationary
5	ICU Pi	Eth Linux	No	60	Moving fast from one AP to another without waiting under each AP for connection
6	ICU Pi	Eth Linux	No	120	Moving while waiting under each AP for connection

V. LI-FI TESTING RESULTS

Various tests were carried out to determine the performance of the Li-Fi network within the mock ICU. These tests are described in the following sections.

A. Stationary Tests within the Mock ICU

This test replicates the situation where medical equipment is in use within a patient room. The medical equipment could be mobile; however, it would stay under a singular Li-Fi AP and remain connected to said AP. The Pi communicated with the server passing data at incrementing data rates and the actual data rates were observed which is shown in Fig. 3. The discrepancy between the requested bandwidth and the actual bandwidth increases linearly with the requested bandwidth. This discrepancy is far lower than Wi-Fi the acceptable packet loss for Wi-Fi (1% to 2.5%) [18], as the requested bandwidth for Li-Fi only has about 0.14% of packets lost. Also shown in Fig. 3 is the bandwidth differential for encrypted traffic which is consistent with the unencrypted results. In Fig. 4 the jitter for the stationary test is shown. This shows that the jitter is fairly consistent over the range of the requested bandwidth. Again, Fig. 4 shows consistency between the unencrypted and encrypted jitter. These results together show that the network is keeping up with the various requested data rates with consistent delivery of packets. This means that in the Mock ICU, devices should have consistent performance and the ability to stream data through Li-Fi consistently. The results shown in Figs. 3 and 4 seem to indicate that the encrypted traffic has better performance however other unaccounted factors may account for this anomaly, such as the amount of traffic within the enterprise network during the tests. The presented results do show however that encrypted traffic has the same characteristics as unencrypted traffic.

B. Mobility Tests

This scenario mimics the movement of persons and equipment through the hospital, in two ways: the first is a slow-moving test which allows the imitation medical equipment time to associate with each AP as it passes by them, the other is a fast movement test where the user equipment would pass through the beam of each AP but not guarantee association.

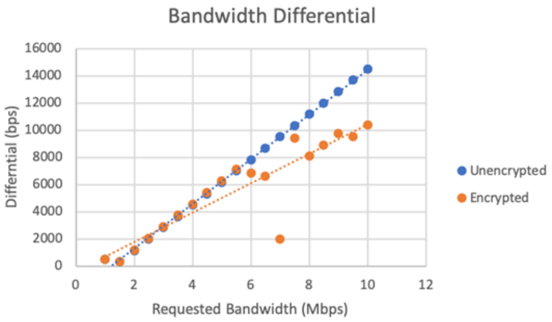

Fig. 3 Discrepancy between the requested bandwidth and the actual bandwidth

The first situation would be akin to a patient slowly moving themselves around their room and hallways with attached equipment, which would allow for persons to establish connections with each AP. Fig. 5 shows the interval bytes and dropped packets as the user equipment moves slowly between the APs. The drop off and reconnection between each of the four APs can clearly be seen. The 10 seconds it takes to reestablish the connection at the next AP is likely prolonged by the actual movement between each of the beams of light, thus showing the importance of the precise placement of the APs to minimize the effect of the handoffs. This also shows that, at least currently, mitigations need to be made for dropped packets of information when devices cross APs.

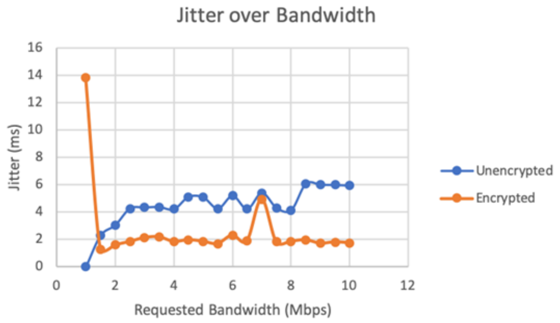

Fig. 4 Jitter in the stationary network test

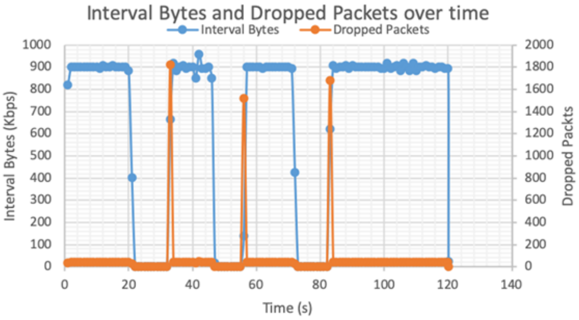

Fig. 5 Interval Bytes and dropped packet number for 10 Mbps requested bandwidth moving slowly from ICU into the hallway

The second situation would occur when equipment is rushed from one location to another, such as an emergency transfer to surgery, when associations will not occur due to rapid movement between APs. Fig. 6 shows the interval bytes and dropped packets as the user equipment moves rapidly between the APs. It can be seen that the equipment does not re-establish a connection at all during the transit from start to end. There is a correspondingly large amount of dropped packets once the equipment reestablishes connections.

VI. INTEGRATING LI-FI INTO MEDICAL EQUIPMENT

Integrating Li-Fi into medical equipment introduces a few challenges. Ideally, once Li-Fi becomes a common standard it would be built into various medical devices alongside the typical wireless connections. Until then, adapters could be used. USB Li-Fi dongles are a common solution, and if the medical device can support its use, then it would be an easy addition. If the medical device cannot support a USB dongle, a device could be introduced to bridge the medical device's ethernet connection to Li-Fi, like the Pi used in the tests for this study.

Utilizing the Pi as a bridge, a stationary test was performed with a connected laptop. This was carried out to determine if there were any blatant problems with bridging Li-Fi to ethernet in this way. The results of the test show that there was an average of 3.85% difference in the requested bandwidth with and without bridging. Fig. 7 shows the jitter over the requested bandwidths. Together these results show that there appears to be negligible effects in bridging devices to a Li-Fi AP from a dedicated bridge device

VII. OPPORTUNITIES FOR CONTINUED WORK

Based on results of this study, it is prudent to better understand the power consumption of the Li-Fi dongle for improvements to the bridge circuit and eventual integration into native Li-Fi medical devices. This could extend to performing a data speed investigation for the protocols used for communications for Li-Fi devices, for example using USB 2.0 versus USB 3.0. Finally, investigations on the placement of integrated Li-Fi device should be considered as Li-Fi requires line of sight for communications and suboptimal placement could hamper performance.

One limitation of Li-Fi, as shown by this research, is its coverage. For an un-supplemented Li-Fi network, the placement of Li-Fi APs should be carefully considered to provide the best illumination for Li-Fi coverage and the handover from one Li-Fi AP to another must be smoother for continuous operation. Other researchers have investigated hybrid Li-Fi WiFi networks. Utilizing a Li-Fi only network results in a large number of handovers between access points, when moving, causing a loss in performance [19]. As such, proposed hybrid networks that identify "quasi-static users" would be assigned to a Li-Fi access point, while mobile users were assigned to Wi-Fi [19]. This works well in a hospital environment, where most of the wireless equipment stays in a room or needs to be moved from room to room. Healthcare staff on this network [19] would gain the coverage of Wi-Fi as they travel throughout the hospital and when visiting patients, they gain access to Li-Fi with the speed and security it offers.

VIII. CONCLUSION

This study was an investigation into the utilization of Li-Fi in a medical setting. The results showed that there should be minimal concerns with the bandwidth and latency of the network when integrated with an enterprise network similar to that of a hospital. The results established that standard network style encryption does not hamper the performance of the Li-Fi network. Through testing it was found that there are some mobility issues with Li-Fi. To realize a complete Li-Fi network, for medical facilities, advancements in the device handoffs between APs must occur.

The restriction of being in the beam of the Li-Fi AP would serve to enhance the security of the medical equipment when used in conjunction with traditional network security protocols. Li-Fi networks would perform optionally allowing less EMI radiated on patients and decrease ISM Band Interference.

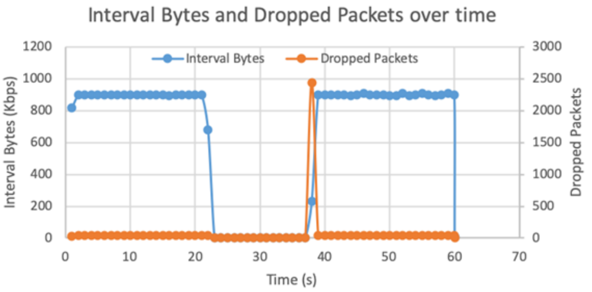

Fig. 6 Interval Bytes and dropped packet number for 10 Mbps requested bandwidth moving quickly from ICU into the hallway

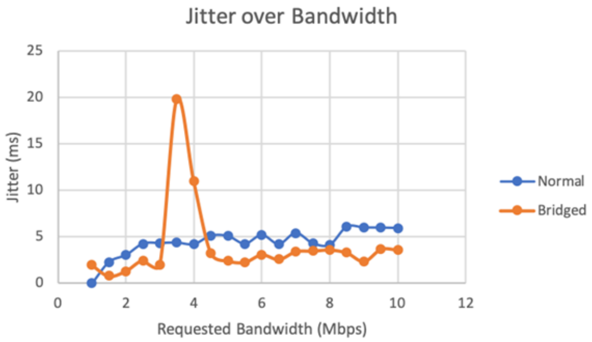

Fig. 7 Jitter in the stationary bridged network test

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