Comparative Analysis of Interference-Free Alternatives to Wi-Fi

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Abstract

Current Wi-Fi technologies occupy oversaturated 2.4 GHz and 5GHz frequency bands. In areas with high router density, this results in poor Wi-Fi performances, and, especially, slow data transfer rates at a time when demand for high-speed networks is rising. To minimize these effects, new technologies taking advantage of the availability of higher frequencies have been developed. In particular, Li-Fi and WiGig aim to transfer data wirelessly at rates faster than Wi-Fi and, more importantly, without interference. This paper assesses the viability of these two technologies as interference-free alternatives to Wi-Fi based on 3 standard networking attributes: data transmission capabilities, security, and vulnerability to interference. The analysis concludes that Li-Fi can transfer data at higher rates than WiGig, can be used to implement location-based security levels, and, unlike WiGig, is impervious to interference from neighbouring cells. For the aforementioned reasons, Li-Fi is the most promising candidate for an alternative to Wi-Fi, vastly outperforming current implementations of WiGig.

Keywords: Li-Fi, WiGig, wireless interference, Wi-Fi, wireless data transmission, wireless security

Introduction

Mobile technologies depend heavily on the reliability of wireless data transfer to connect devices to the Internet. Wi-Fi, the most widely accepted standard in local wireless networking, is at the center of an estimated 94 million hotspots delivering Internet to users around the world [1]. However, the success of Wi-Fi is also one of the main causes of its pitfalls. Indeed, its widespread adoption is currently causing wireless saturation, meaning that the 2.4 GHz and 5 GHz frequency bands the technology occupies are being overused [2]. Multiple routers located in a given area and communicating on the same Wi-Fi channels generate interference, which has a negative impact on overall network performance in terms of speed and reliability.

Generally speaking, network performance plays a key role in the rise of new technologies relying heavily on high data transfer rates. Virtual reality gaming, 4K video streaming, and 360° videos are all emerging technologies that require the sharing of large amounts of data. For instance, 360° videos require “bit rates 3 to 10 times greater” than traditional HD videos [1]. Therefore, any dip in data transfer rates due to wireless interference can take away from the user experience by not fully taking advantage of the features offered by these new technologies.

Although gaming and streaming are particularly affected by slower Internet connections, interference negatively impacts all data transmitted over Wi-Fi. Any device connected to a Wi-Fi network is thus likely to suffer from poor network performance due to interference. Even though using a wired Internet connection could prevent interference, it may not be an optimal solution for mobile devices, as their portability relies heavily on the use of wireless connections.

Moreover, fiber-optic based Internet delivery to homes and businesses is becoming increasingly popular. Offering Internet speeds of up to 100 terabits/sec, it vastly outperforms cable Internet [3]. Wi-Fi, with its current limitations, acts as a bottleneck; it is only able to transfer data at a fraction of the rates offered by fiber-optic cables. This, combined with interference, causes mobile devices to be restrained to cable-like speeds even when routers are connected to fiber-optic Internet.

The need for an interference-free alternative to Wi-Fi has led to the development of two new wireless transmission standards: WiGig and Li-Fi. To assess which of these emerging technologies is better suited to replace Wi-Fi, this paper compares and contrasts each solution's data transmission capabilities, security, and vulnerability to interference. Overall, the high data transfer rate offered by Li-Fi technology, combined with its use of the visible light spectrum, makes it the most promising candidate for a low-interference substitute to Wi-Fi, vastly outperforming current implementations of WiGig.

Background

Many countries have regulatory bodies, similar to the United States' Federal Communications Commission, that govern the use of radio wave frequencies. These organizations dedicate certain frequencies for specific use, such as radar or AM/FM radio, in order to ensure the proper functioning of these technologies. However, in doing so, they restrain the frequencies that can be used by other devices to what is called the unlicensed spectrum, which represents a fraction of the totality of the electromagnetic (EM) spectrum [2]. Within this spectrum, only the 2.4 and 5 GHz frequency bands possess the range and bandwidth needed for Wi-Fi to operate [2]. To maximize the use of these bands, the Wi-Fi standard divides them into different channels. Within the 11 channels available in the United States in the 2.4 GHz band, only 3 (channels 1, 6 and 11) span frequency ranges that do not overlap, as illustrated in Fig. 1 [2]. As an example, it can be seen that channels 2, 3, 4 and 5 all use frequencies already allocated to channel 1.

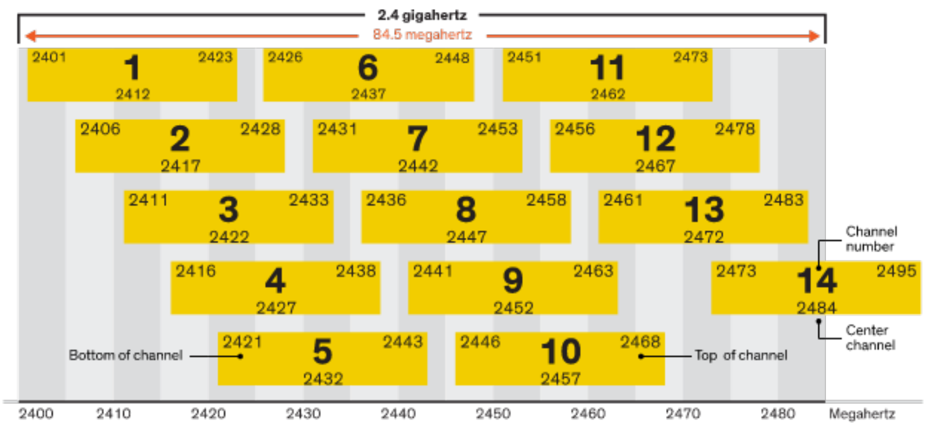

Figure 1: Wi-Fi channel allocation in the 2.4 GHz frequency band [2].

Due to the overlap, interference can become an issue for data transmission. When two devices attempt to transmit data packets at the same time on overlapping channels, collisions occur [2]. To minimize this effect, a process known as wireless backoff stops all communications, forces devices to wait a certain amount of time, and then allows them to transfer data again [2]. This time delay increases exponentially based on the number of collisions happening and results in Wi-Fi becoming increasingly slow and unreliable when multiple Wi-Fi hotspots are located in the same vicinity [2]. This happens for instance on university campuses, as the implementation of campus-wide Internet drastically increases the density of routers around a location.

To remedy this problem, Wireless Gigabit (WiGig) has been proposed as a viable alternative to Wi-Fi. Also known as the IEEE 802.11ad standard, WiGig transfers content in the radio frequency spectrum by modulating data into waves and broadcasting the latter to devices equipped with wireless receivers, which then process the signal [4]. Moreover, WiGig takes advantage of the unlicensed 60 GHz frequency band, which "has more bandwidth available than all the other unlicensed bands combined" [4]. Indeed, depending on local regulations, around 3 GHz to 7 GHz of bandwidth is available in the 60 GHz band, compared to 585 MHz when combining the 2.4 and 5 GHz band used by Wi-Fi [4]. This has the benefit of drastically increasing the number of non-overlapping channels available. In addition, the larger bandwidth allows for the transmission of data at rates far greater than any current implementation of Wi-Fi.

However, the increase in frequency is correlated to a decrease in wavelength, which causes significant path loss (a reduction in power density) as the distance between the receiver and the transmitter increases [4]. This path loss is due to the use of high-frequency millimeter waves and results in a large absorption rate, meaning physical obstacles such as walls or any large objects have the ability to block the transmitted waves [4].

To minimize the effects associated with this phenomenon, the antennae used by WiGig routers rely on beamforming, which more efficiently aims the generated waves towards devices after a connection to the network is established [4]. As seen in Fig. 2, the beamforming technology behind WiGig broadcasts waves linearly, which differs from the traditional circular propagation pattern used in Wi-Fi. This ensures a more constant signal strength, represented in the figure by the color intensity, as distance increases. It must be noted that the consumer-grade antennae used in commercially available WiGig routers tend to be incapable of generating purely linear beams as they also produce significant side lobes when emitting signals [5]. These side lobes, which are demonstrated in Fig. 3, can be a source of interference [5].

Figure 2: Comparison between beamforming and current waves propagation technology [6].

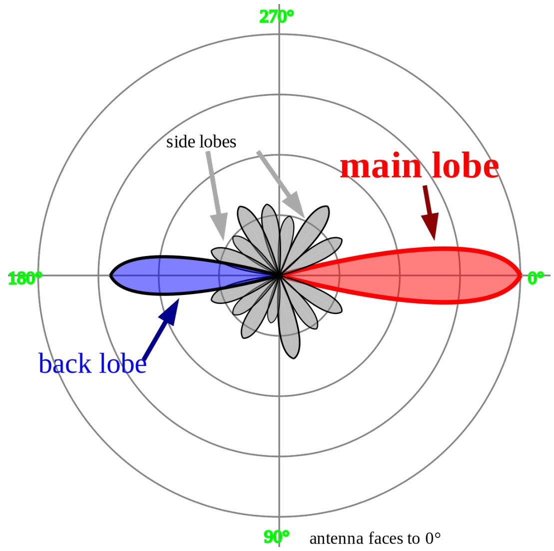

Figure 3: Side lobes produced by consumer-grade antennae [7].

Another promising alternative to Wi-Fi is light-fidelity (Li-Fi). Li-Fi is a light-based approach to wireless communications which uses light emitting diodes (LEDs) to transmit data. Data is relayed by turning the light on and off at a rate significantly higher than the human eye can perceive [8]. A Li-Fi dongle, which connects to mobile devices via USB, then captures the emitted light using a photo detector and converts the signal into data readable by devices, as illustrated in Fig. 4.

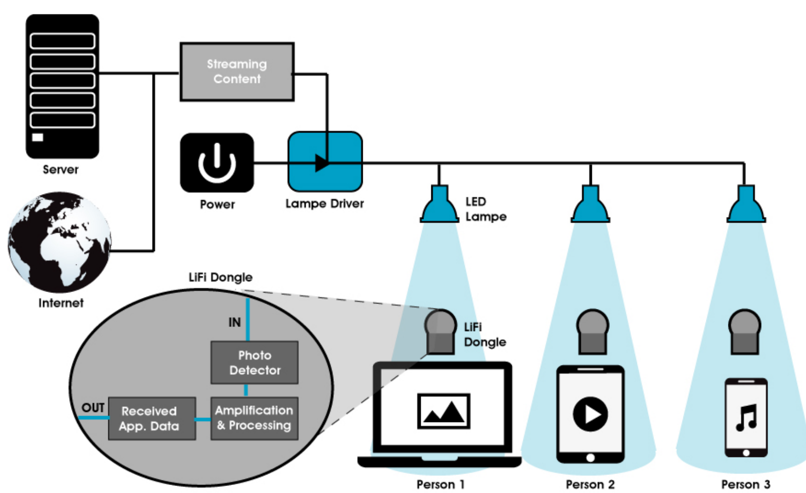

Figure 4: Network architecture of a Li-Fi system [9].

The visible light spectrum used by Li-Fi is 10 000 times larger than the radio frequency spectrum and thus allows the use of a large number of frequencies [12]. The main drawback to using light as a data carrier is that the transmitted waves cannot penetrate physical barriers, since light is governed by the same laws as WiGig in terms of wave absorption [8]. Data is, therefore, only optimally transmitted when the receiving device is in direct line-of-sight of the light source, a scenario commonly referred to as line-of-sight transmission. However, light reflected off of walls or other surfaces can still be used to transmit data at speeds comparable to what is offered by Wi-Fi [10].

To maximize the probability of line-of-sight transmission, Li-Fi diverges from the single access point model typically used in radio frequency transmission. Multiple LEDs, or access points (also referred to as “cells”), can be strategically deployed in an area to optimize coverage [11]. The protocols used to implement Li-Fi ensure the seamless handoff of the connection from one LED to another, allowing users to move freely without any interruption of the data transmission [11]. To allow for this, the installation process takes into account the range of frequencies available, which depends on the type of LEDs used, as well as the cell radius, which varies from 1 to 4 meters [11]. The frequencies are then divided evenly among the cells overlapping in a given room.

In order to determine whether WiGig or Li-Fi is the best interference-free alternative to Wi-Fi, the individual performance of both solutions will be assessed according to a set of 3 criteria. These criteria highlight essential attributes of any wireless network and can be used to draw a general portrait of the performance and reliability of the compared solutions. First, the data transmission capabilities of both technologies, based on the maximum data transfer rate and the range at which devices can wirelessly operate, will be determined. Furthermore, the security of the two solutions will be evaluated by how well they can be used for range control and the implementation of location-based security levels. Finally, their vulnerability to interference will be compared based on the range of available frequencies and how the two solutions respond to the use of more than one access point in the same environment.

Analysis

Data transmission capabilities

One of the key criteria to consider when assessing a wireless network's data transmission capabilities is how fast it is able to deliver data to a mobile device. Current commercial implementations of Li-Fi can transmit data at 10 Gb/s, which, to provide a sense of scale, would allow users to download 18 movies in 1 second [12]. New techniques developed recently have managed to raise the speed of Li-Fi in commercial applications to 42.8 Gb/s, which is still considerably slower than the 224 Gb/s measured in lab tests [13, 14]. WiGig, on the other hand, can only reach speeds of 6.76 Gb/s [15].

In terms of range, both Li-Fi and WiGig networks tend to be restrained to rooms due to the nature of the waves they use to transmit data, whether it be light or high-frequency radio waves. Moreover, in open settings, both technologies can be used to reach multi-gigabit speeds at distances of up to 10 meters from the access point [16, 17].

Overall, although the two solutions perform similarly when it comes to range, it is clear that Li-Fi surpasses WiGig in terms of data transmission capabilities, being able to reach speeds that are 32.4% to 84.2% faster than what WiGig can attain in its current implementations.

Security

Any wireless data transmission technology must have strong security features in order to ensure that the stream of data cannot be intercepted by network intruders. When it comes to range control, both Li-Fi and WiGig use high-frequency electromagnetic waves that cannot penetrate physical objects. Therefore, any network implemented using these two technologies can be constrained to specific rooms or buildings, which drastically enhances the security of the data transmission as outside attackers have no means of detecting the network.

Moreover, due to Li-Fi's use of multiple LEDs to provide Internet to an area, specific security levels can be assigned to individual lights [18]. WiGig, which broadly covers an area by sending waves in every direction, cannot implement such fine-tuning of its security by location [5].

As a result, although both Li-Fi and WiGig can be similarly restrained to specific rooms, Li-Fi's ability to implement different security levels based on the users' location makes it the best solution in terms of security.

Vulnerability to interference

To minimize the risk of interference, a large number of frequencies needs to be available, thus ensuring neighbouring devices can transmit data over different parts of the EM spectrum. Depending on local regulations, WiGig tends to be constrained to a frequency range of around 3 to 7 GHz [4]. In comparison, the range of frequencies Li-Fi can operate at is 10000 times larger than the entire radio frequency spectrum, going from 400 THz to 800 THz [17].

Moreover, it is important to consider how Li-Fi and WiGig react to the presence of multiple wireless access points in the same environment. The installation process for Li-Fi systems, described in the Background section, emphasises the allocations of different frequencies to neighbouring cells, and ensures that individual cells do not interfere with each other [11]. WiGig, however, is designed to only have 1 access point around a location. In theory, the beamforming technology at the core of WiGig, along with the availability of 4 non-overlapping channels, guarantees that beams coming from multiple routers do not generate interference [15]. In practice, this does not hold. Consumer-grade antennae lack the directionality needed for proper beamforming and can therefore generate side lobes, which, along with signal reflection off of walls and other surfaces, may cause significant interference [5].

For these reasons, it is clear Li-Fi is a better candidate than WiGig when it comes to dealing with interference, possessing a much wider range of available frequencies and being designed to prevent interference from neighbouring cells.

Conclusion

In conclusion, Wi-Fi's vulnerability to interference due to the oversaturation of the 2.4 GHz and 5 GHz frequency bands has given rise to an array of new wireless data transmission technologies. The two most promising ones are Li-Fi and WiGig, which rely on higher frequencies to minimize the risk of interference and transmit data at rates far greater than what current implementations of Wi-Fi can achieve. WiGig, on one hand, tends to perform similarly to Li-Fi when it comes to range and its ability to restrict network access through range control. However, limitations of commercially available beamforming hardware make WiGig more vulnerable to interference than Li-Fi. Moreover, Li-Fi can reach considerably higher data transfer rates when compared to WiGig, and can implement location-based security features, thus making it the most secure solution. Although cost was not analyzed due to lack of data, it is clear that Li-Fi, for the aforementioned reasons, is better suited as a replacement to Wi-Fi than WiGig is. This technology possesses all the features necessary to pave the way for a new era of high-speed and secure wireless data transmission.

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