Optical Wireless Communications

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Abstract

Wireless communications have become a resource used just as routinely as electricity or gasoline. Every year the amount of users sending and receiving data on the network increases but the amount of usable radio frequency bandwidth remains the same. Many have made the argument that radio frequency spectrum has been used up to its limits. It is cleare that we are in need of an option besides radio frequency wireless communications. Optical wireless communications could possibly serve this purpose. Infrared wireless communications are already used for controlling our television and other short range wireless applications so making the jump to an entirely light-based wireless data network is definitely a possibility. In this paper we will look at the many advantages to switching from radio frequency to optical wireless communications, the challenges involved, and the current research being done to advance this promising technology to a commercial state. As more research is done every day we are getting closer to this idea becoming a reality.

Infrared Data Association (IrDA)

The infrared spectrum is currently used for some optical wireless applications both short and long range. Higher power infrared lasers are used for long range applications such as satellites and low power infrared is used common household devices like a television remote. When being used indoors infrared lasers must be low power in order to protect a users eyes and skin. The most well-known form of infrared light usage is the Infrared Data Association. IrDA is being used in mobile phones, PDAs, notebooks, medical devices, wrist watches, and industrial measurement equipment. This short range version of infrared provides a way to deliver wireless data efficiently over the last one meter. The most basic level of IrDA operates at wavelengths around 875nm and the standard rates to expect from this system are anywhere from 9.6kbps to 16Mbps. This form of wireless communication is useful but if we want it to replace our RF routers then we need a lot more data in a much shorter amount of time. There have been multiple advances made since the original version of IrDA. These advances have increased data rates through adding additional application layers and adjustments to current ones. An early advance was known as Ultra Fast infrared(UFIR) which was published with a data rate of an impressive 96Mbps. This system modulated its signal by using the dc-balanced 8B10B line code in combination with 2-ASK(Amplitude Shift Keying) modulation. Ultra Fast Infrared is only usable up to a maximum distance of one meter. The next major advance was the introduction of Giga-IR which was approved at the end of the year 2009 and is the latest commercially used form of IrDA. [1]

Giga-IR

The Giga-IR subset of IrDA has specified data rates of 512Mbps up to an impressive 1Gbps. Up to this point in infrared LEDs were the lighting source. The problem with LEDs is that they are limited to a maximum switching frequency of around 622 Mbps. Another limiting factor to consider is that as frequency increase the transmission power decreases. Instead of using a common 2-ASK 8B10B coding, the coding used for 512Mbps and 1Gbps was a 4-ASK modulation scheme with an adopted 8B10B codec. This bypassed the use of expensive laser diodes which can function at 1Gbps using the simpler 2-ASK coding. This advancement was a great breakthrough for both performance and cost. The IrDA had met its requirements for a high speed replacement for cables and connectors at a link distance of up to 10cm. Companies and research institutes are currently working on commercializing Giga-IR. [1]

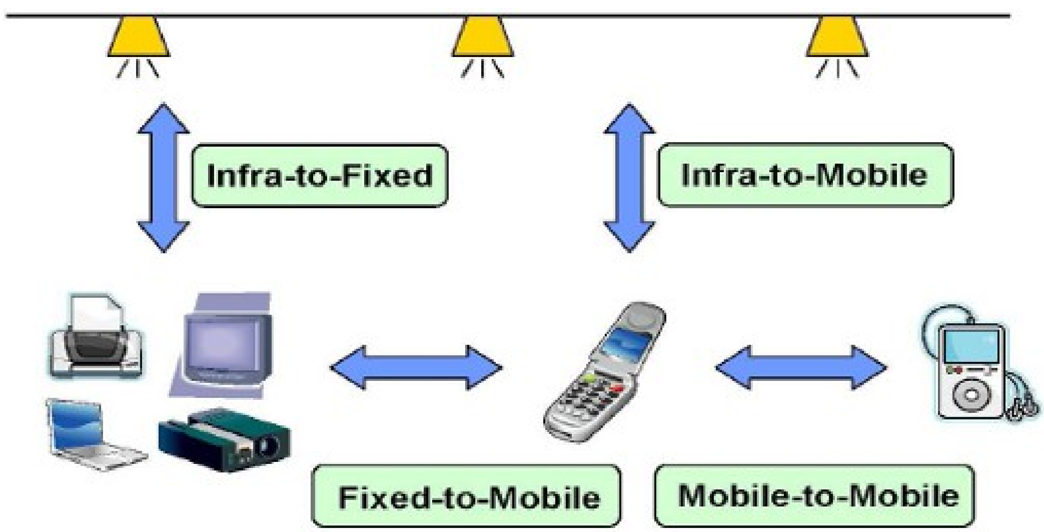

Figure 1. Giga-IR is purposed for short range connections such infrastructure-to-fixed, infrastructure-to-mobile, fixed-to-mobile, or mobile-to-mobile

The target applications for Giga-IR would be mobile-to-mobile and mobile-to-infrastructure communications. Examples of these applications would be mobile multi-media devices, docking stations and multi-media kiosks. The implemented speeds of Giga-IR when placed in small hand held devices is 640Mbps to 1.28Gbps(both are faster than USB 2.0) The hope is that Giga-IR will offer wireless communication that is even faster than USB 2.0. This means that someday you will be able to quickly transfer gigabytes of data to portable media players quickly without tedious wired connections.

Search and Scan Height Estimation

Due to low power limitations it is crucial to have a direct line of sight using a focused beam for optical wireless communications involving lasers diodes. In an experiment conducted by a group of students in Australia they were able to use a single channel imaging receiver in combination with search and scan methods to send wireless signals in multiple changing locations. The system is comprised of a 2-axis voice coil based actuator, an imaging lens, and a small photo-sensitive area photo diode. To estimate the height difference between the transmitter and the receiving system the received signal power and angle of arrival information is used in calculation simultaneously.[4] This solution is required since most users of wireless data communication are constantly moving and not in one fixed location to beam data towards.

Visual Light Communication (VLC)

Another form of optical wireless communications technology that is expected to be used as an alternative to RF-based communications in the near future is known as Visible Light Communication. These systems would be used for personal area networks such as home or office use. Visual Light Communications takes advantage of the sever decrease in cost of LEDs and the increase in brightness over the past 12 years. One of the most appealing aspects of using LEDs is that they can illuminate a room and simultaneously provide a steady data stream for multiple users. Since LEDs are in the visible spectrum, they are far less harmful to our skin and eyes which allows them to avoid the power constraints that limit infrared from reaching its full potential. This leads to increased data link distances which would be necessary for wireless data transfer to different users in a large room. There are definitely advantages to using VLC apposed to IR but there are other factors limiting the data rates of LEDs in this spectrum. As more research is done there are new solutions tested to increase data rates using LEDs as a source for wireless communication.

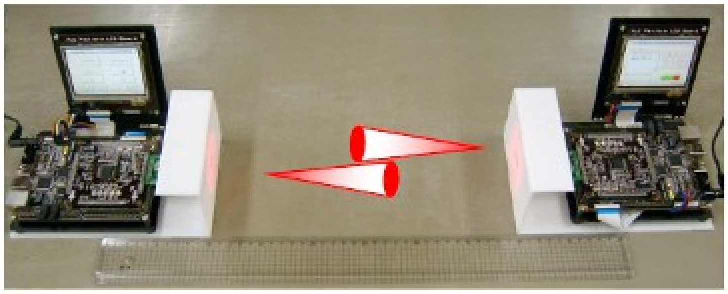

Figure 3. A full duplex 120 Mbps VLC demo implemented in a mobile multi-media platform including upper layers and mobile applications

LEDs are used in many places including but not limited to traffic lights, automotive-indicators, displays, flashlights, and slowly being used in place of fluorescent lighting. VLC takes advantage of the existing lighting infrastructure and combines it with wireless data communication with a very low cost to convert. There are a large amount of advantages to consider when using light to transfer data as apposed to radio signals. LED optical wireless communication is immune to electromagnetic interference which would allow it to be used in airplanes and more importantly for use inside hospitals.[1] Optical wireless also adds a high level of security without any need to add encryption since light cannot travel through walls the data could not travel anywhere besides the room the user is located.

Even with these great advantages there are some limitations for the practical implementation of a VLC system using white LEDs. One of the most problematic limitation is the direct modulation speed of a white LED is substantially slower when compared to the infrared spectrum of laser diodes. There are a wide variety of proposed techniques to solve this issue which include, pre-equalization, post-equalization, and advanced modulation formats like Discrete Multi-tone Modulation(DMT), Quadrature Amplitude Modulation(QAM), non-return to zero(NRZ) and on and off keying(OOK).[2]

	Pre-equalisation	Post-equalisation	Modulation scheme	Modulation bandwidth	Demonstrated data rate
White channel			OOK-NRZ	2 MHz	10 Mbit/s (BER < 10^{-6})
White channel	x		OOK-NRZ	25 MHz	40 Mbit/s (BER < 10^{-6}) [8]
Blue channel	x		OOK-NRZ	45 MHz	80 Mbit/s (BER < 10^{-6}) [12]
Blue channel		x	OOK-NRZ	50 MHz	100 Mbit/s (BER < 10^{-9}) [10]
Blue channel			DMT-QAM	25 MHz	100 Mbit/s (BER < 10^{-6}) [9]
Blue channel			DMT-QAM	50 MHz	231 Mbit/s (BER < 10^{-3}) [11]

Figure 3. Performance of a high speed VLC system demonstrating the advantages of using modulation schemes to increase data rates.

Manchester Coding

Another challenge that an LED system faces is the noise that is generated by AC-LEDs or conventional fluorescent lamps. One proposed solution to this problem is to use adaptive filtering to reduce the optical noise interference but this requires a feedback loop to be continuous. Another suggested method was to use wavelength filtering which would require red-green-blue LEDs and an optimized planning of illumination coverage. A recent paper suggests that using Manchester coding would mitigate the optical noise of an LED. The Manchester coding method allows both data 1s and 0s as well as clock to be recovered at the same time which provides signal synchronization. This form of coding does not require adaptive monitoring and feedback or optical filtering of wavelengths. This method only functions well when the noise frequency is less than 500khz but can easily be used in series with other forms of noise mitigation.[3]

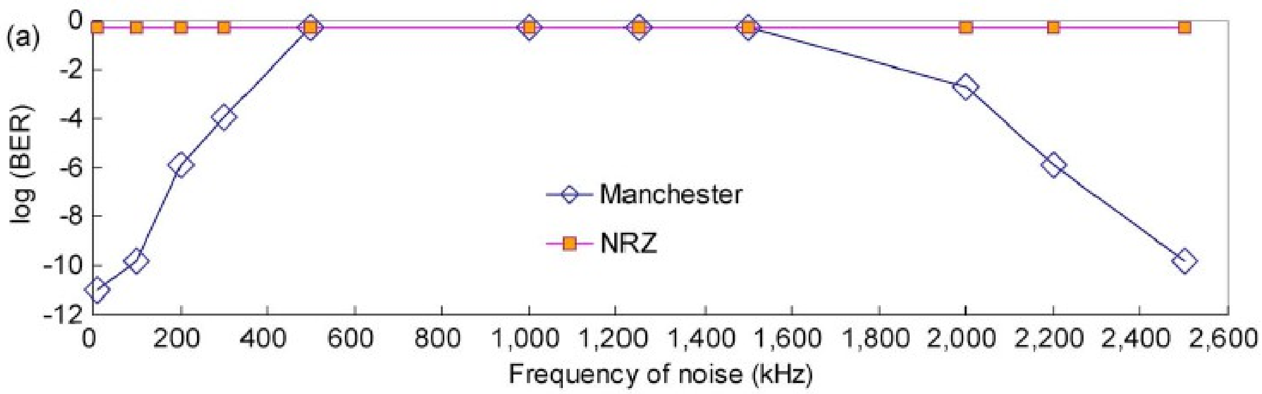

Figure 4. This graph shows the noise reduction of Manchester coding compared to the standard non-return zero format.

Li-Fi

Visual Light Communication represents a broad overview of the basics ideas and applications for optical wireless communications. A subset of VLC is know as Light Fidelity(Li-Fi). This technology was given its name by Dr. Harald Haas of Edinburgh University and organizations such as the Li-Fi consortium founded in October 2011.[1] Li-Fi is comprised of several optical wireless technologies such as optical wireless communications, navigation, and gesture recognition. Li-Fi does not stand for any one particular technology or service but instead stands for an attempt to merge many different optical wireless technologies into one full featured Li-Fi cloud providing seamless wireless service for a large number of users. Li-Fi is expected to be comprised of a large spectrum including infrared, visible light, and even down into the ultra violet spectrum. It will include sub-gigabit and gigabit communications speeds depending on whether short, medium or long range is needed. Li-Fi is not limited to just LEDs and laser technologies and hopes to stand as a framework for all optical wireless technologies to work together for a wide variety of different users and services. In a very recent article speeds of 155Mbps(one direction) were achieved using commercially purchased red, green, and blue LEDs as both emitters and detectors. With custom constructed LEDs the speed increases dramatically up to 4Gbps at only 5mw of optical power output. Using these enhanced LEDs wireless data speeds of 1.1Gbps were achieved at a distance of ten meters. This speed is expected to be able to increase even further to speeds around 15Gbps with the use of avalanche photo diodes as receivers. Harald Haas expresses his confidence in this technology when he said, “In 25 years, every light bulb in your home will have the processing power of your cellphone today”.[5] It is a definite possibility that Li-Fi networking systems will revolutionize the way we send and receive data.

Conclusion

Optical wireless communications could server as a replacement to a radio frequency spectrum that is fast approaching maximum capacity. Infrared has already proven to to useful for some short range application and with the addition of visual light communications the combined result could be a seamless wireless data stream for users on a wide variety of devices. Although OWC has many advantages pushing it towards commercialization, more research is needed to bring this technology up to suitable speeds if we want to justify it as a standalone replacement to our current wireless networks.

References

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