Optical Wireless – Indoor and Free Space Communication Systems

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ABSTRACT

Optical Wireless Communications (OWC) is a still developing technology that has overcome many milestones within the last half century. There are many advantages to this type of communication over standard Radio Frequency communications and wired backbone communication systems. Optical Wireless Communications offer a much higher bandwidth and a much high data rate potential than standard RF communications. The light spectrum that optical wireless operates on is unregulated, allowing it much more flexibility than radio. Not only is the spectrum segment unregulated, but the spectrum in which humans can see lies within it, allowing LEDs to be used to communicate data at a high rate and provide virtually constant white light to illuminate an entire room. In this paper, a summarization of the overall concepts and procedures of typical Optical Wireless Communication systems is provided as well as a the outlook on the future of these systems as it applies to the world [8].

1. HISTORY

Records of light being used to serve as a means of wireless communications dates back to before 800 B.C. Fires were built and used as beacons to signal as well as smoke signals to communicate long distances. Sunlight was used in combination with mirrors to send light at an aimed, desired location and travelled in a line of sight path. In the late 19th century lamps were used to communicate between ships as well as light houses were used to tell incoming ships of the shallow, hazardous water conditions [1].

2. CLASSIFICATION

To begin, Optical Wireless Communication (OWC) is a form of optical communication in which unguided visible, infrared or ultraviolet light is used to carry a signal. Ultraviolet Optical Communication (UVC) is wireless optical communication that uses only light waves from 100nm to 400nm. Visible Light Communication (VLC) operates with signal wavelengths from 400nm to700nm and this is the spectrum that the human eye can detect and process. Free Space Optical Communication (FSO) is typically used within the infrared spectrum of light from 700nm to 1000nm. These all together classify the Optical Wireless Communication spectrum and operate from 100nm to 1000nm wavelengths.

3. TRANSMISSION RANGES

All of the types of wireless optical communications, VLC, FSO and UVC, can operate at a great distance spectrum but are designated to certain ranges to capitalize on advantages. There are five different ranges that are classified within wireless optical communications [6].

Ultra-Short Range

Ultra-Short Range optical wireless communication systems operate on the order of millimeters. These systems are typical found at the chip level and are used to communicate between different chips or between the same chip. These ideally will replace the copper-based interconnections that exist between and on these chips and will offer a much lower latency. The systems at this level are either guided or unguided. Guided system are set in place and provide a direct, narrow light path from transmitter to receiver. Some problems arise with these types of system such as if the guided path is interrupted or some of the structure is bent. Many of these problems are solved with unguided systems. Unguided systems are much more flexible and allow for parallelism, which is having multiple receivers for one unguided transmitted signal [5].

Short Range

Short range systems operate on the order of centimeters, but typically under one meter. A common situational use for a short range system is implemented within Wireless Personal Access Networks (WPAN) as well as Wireless Body Access Networks (WBAN). Infrared technologies are commonly used within these systems. An example for this type of system in a WBAN is for hospitals. Hospitals could eliminate all the wires on patients if all their monitoring equipment attached to patients like blood pressure monitors operate within the optical wireless communications spectrum [5].

Medium Range

Medium range is where the wireless indoor communication systems fall. These systems are being developed to operate in the visible spectrum so that Visible Light Optical Communication (VCL) technology can be used. Medium range is defined on the order of meters but not usually more than 10 meters of transmission distance. Technology that is being develop is very promising, yielding a potential long life expectancy, high humidity tolerance, low power consumption and lowered head dissipation. This lower power consumption comes from the advancing technology in Light Emitting Diodes (LEDs) and in the last twelve years have cut the price per watt down to 100 times less [5].

Long Range

Long range systems operate on the order of kilometers but usually not more than a few km. This is used to for the "Last Mile" communications with optics. Wireless Metropolitan Access Networks (WMAN) are being developed within this range using Free Space Optical Communication. Many long range systems are used for temporary, emergency situations. During the 9/11 terrorist attacks, much of the wired backbone communication systems within, to and from the world trade center was destroyed. These free space optical communication systems were easily deployed to temporarily replace those systems during that emergency. Long range optical wireless communication is also being tailored to aircrafts. The major difference for these system is that either the receiver, the transmitter or both the receiver and transmitter are moving. This requires another system to track the desired transmission location with the use of pointing-acquisition-tracking algorithms [5].

Ultra-Long Range

Ultra-Long Range optical wireless communications makes the biggest jump within the different range categories. These systems are designed to operate from ground to satellite, satellite to satellite or from planet to planet! On the order of tens of thousands of kilometers, free space optical communication is implemented. In October, 2013, NASA's Lunar Laser Communication Demonstration, 622 Mbps was achieved from the Moon to the Earth at 384,600 kilometers [5].

4. OWC vs. RF

With very little disadvantages over Radio Frequency Communication, it is very surprising the amount of advantages that optical wireless communication has. The biggest advantage, only because it involves money, is the overall cost of operating wireless optical communication is about half that of radio frequency. Much less energy is required to pump indoor optical wireless systems than indoor radio frequency systems. The next biggest advantage is the fact the the wavelength spectrum that OWC operates in is unregulated, and the wavelength spectrum that RF operates on is heavily regulated. This is very useful because no permits are required and there are no rules or regulations as to who or what has rights or permission on those frequencies. Much higher data rates are acquired with optical wireless communications than with radio frequencies as well, allowing for faster internet, connection speeds and data transfers. The only disadvantage of OWC is that it does not pass through walls. This, in turn, leads to a different advantage over radio frequencies that can pass through walls. Radio frequency has a very low security. It is typically unguided an able to be synchronized to from a very common receiver. Because optical signals do not pass through walls, this in turn increases is security greatly. You must be in the line of sight of the transmitting optical signal to tap into the data. This line of sight has to be in the same room and even able to access the same line of sight as you. This greatly increases security, although limits the transmission flexibility slightly.

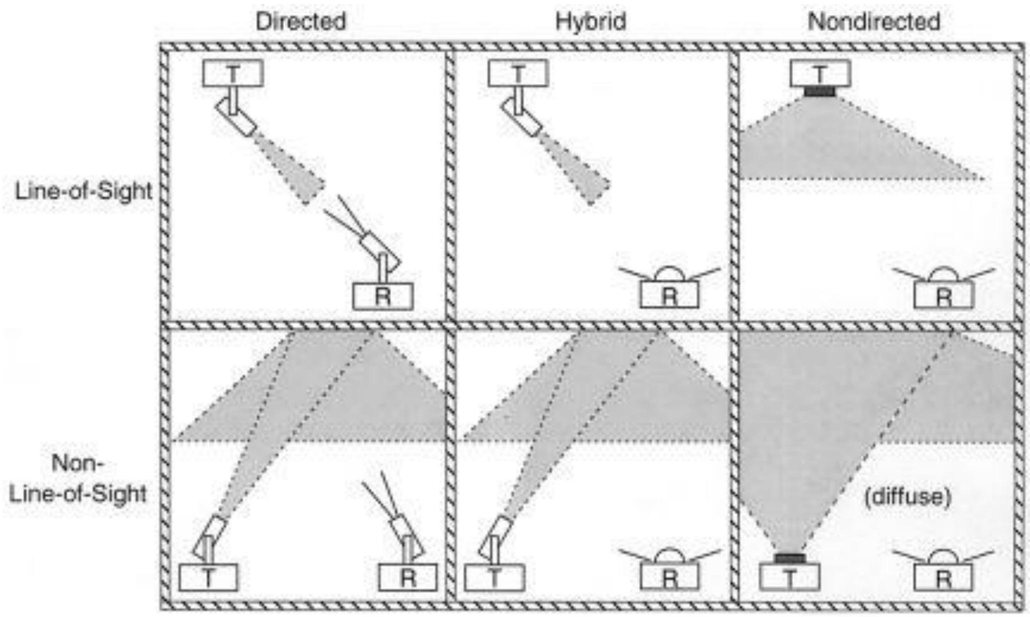
Table 1.1. Comparison of wireless optical and radio channels.

Property	Wireless Optical	Radio
Cost	$	$$
RF circuit design	No	Yes
Bandwidth Regulated	No	Yes
Data Rates	100's Mbps	10's Mbps
Security	High	Low
Passes through walls ?	No	Yes

5. INDOOR VLC SYSTEMS

Up until the late 1990s, the majority of optical wireless communication was done through Free Space Communication (FSO) which was operating within the Infrared portion of the electromagnetic spectrum. It wasn't until the early 2000s when the implementation of Visible Light Communication was developed. The visible light spectrum operates from 375nm wavelengths to 780nm. This wavelength spectrum is able to be received and analyzed by the human eye. The major benefit to this is that the systems will essentially be killing two birds with one stone. The first bird is the obvious goal of transmitting the data at a high rate and the second bird is actually lighting up the room in which data is desired to be collected. The goal of these systems is to produce a pure white light through a Laser Emitting Diode and is done so by combining the three primary colors: Red, Green and Blue [7].

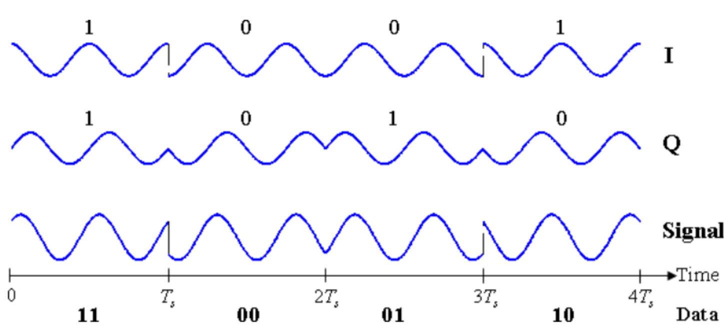
Within visible light communication, there are different ways to implement the system. The main types are listed below with the different combinations of each category. Although this is purposed for an infrared spectrum, the concepts apply to a visible light communication system as well.

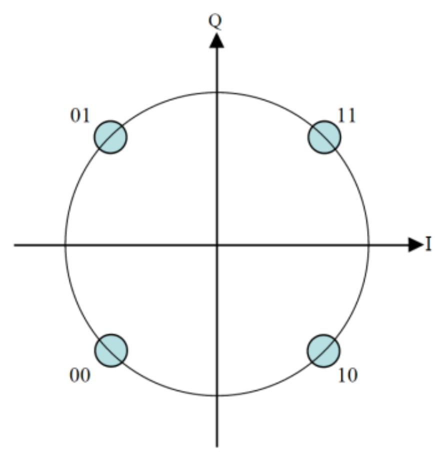


Directed transmitters and receivers allow for the maximization of power efficiency. Ideally, all of the power and data that is transmitted gets received and none is dissipated or dispersed through the room through path loss. Although less power may be consumed, the directed transmitters do not do a great job at lighting up a room. The nondirected transmitters have a wide angle transmission and produce light throughout a wider path, much light a typical LED light bulb can do. "Non-Line of Sight link design increases link robustness and ease of use, allowing the link to operate even when barriers, such as people or cubical partitions, stand between the transmitter and receiver. The greatest robustness and ease of use are achieved by the nondirected-non-LOS link design, which is often referred to as a *diffuse link* [2]."

6. MODULATION

There are many motivations for moving into the optical wireless communication kingdom. One of the main reasons is the potential for extremely high data rates on the order of Terabits per second. Just to get a reference on an order of this magnitude, imagine that one bit was the size of a golf ball. That means just one terabit of golf balls would stretch around the Earth and then some and all that was sent in just one second. This is an incredible amount of data and would not be possible without the modulation techniques that have been developed with this technology. There are different types of modulation, but the core definition of modulate is that signals are essentially mixed together into a new signal that can represent the same amount of data. Within an electromagnetic wave, you can vary three things: the amplitude, the phase and the frequency. Since frequencies are usually set in place at a desire frequency or wavelength, phase is typically varied. The process of varying phase is called Phase Shift Keying, or PSK. A more advanced type of PSK is called Quadrature Phase Shift Keying and this used the four quadrants to represent different bit sequences [3].





These figures illustrate the mixing of signal and the representation of quadrature placement. The signal is compost of two sub signals I and Q. Typically, I = $\cos(\varphi_i)$ and Q = $\sin(\varphi_i)$. The four different combinations are represented in the bottom trace. Each new signal now represents two bits. Now, when the receiver gets that one signal, it knows that it represents the bit scheme XY, where X and Y are either 0 or 1. This is the basic principles of how QPSK works. The real data transmission starts when you combine four bit schemes or eight bit schemes or sixteen bit schemes. Then, four, eight or sixteen bits will be represented by one individual signal. This allows for an exponential growth in data rate, but comes at a cost. BER will become an issue since the higher bit scheme you represent, the closer and closer individual signals representations of those bit schemes appear. Higher and higher sensitivity is required within the receivers the higher bit scheme you go [4].

7. CONCLUSION

This paper has provided an overview for most of the basic working principles of an Optical Wireless Communication system. Composed of ultraviolet, visible and infrared light waves, optical wireless communications along with visible light communications and free space optical communications has an increasingly high potential to replace existing Radio Frequency systems in place now. There are five major distances in which OWC can operate and they range from nearly micrometers to well over hundreds of thousands of kilometers. With much greater bandwidths and data rates on the order of Terabits per second, the outlook on optical wireless communications is very promising.

8. REFERENCES

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