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Investigating the performance of visible light communications with Multiple light sources in wireless channels

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Abstract: In recent years, we have witnessed an increase in the number of studies conducted on visible light communications and light-emitting diodes to provide both ambient light and data transmission. The main reasons for the success of this technology are the popularity of semiconductor lighting, increasing the life of LEDs, bandwidth and high data exchange rate, information security, no risk to health, and low energy consumption. On the other hand, motion telecommunication, multi-user support, inter-symbol interference and interference with ambient light, and the essential need to know the channel parameters are among the challenges facing visible light telecommunications. In this research, using optimal threshold devices, a plan to increase the transmission speed by switching modulation (disconnection and connection) and in the presence of inter-symbol interference is proposed, which we examine in two cases of the possibility or impossibility of using a memory device in the receiver. We will show that having a memory device will lead to optimal receiver design and thus improve system performance. However, if you do not have a memory device, you can use the sub-optimal receiver. It should be noted that although the simulation results for switching modulation are presented, the model of future problems and their corresponding solutions are generally considered.

Keywords: Wireless optical communication, light-emitting diode, memory device. Wireless channel

Introduction

Today, the bulk of Internet infrastructure comprises fiber optics, which transmit information at a speed of terabits per second. On the other hand, this high speed in the infrastructure sector is unavailable in the user sector. For this reason, it is not cost-effective in all cases to use cable infrastructure for any part of the network. Therefore, the importance of using wireless communications is increasing day by day, and its use in the end part of telecommunication systems in home departments, offices, and university environments is increasing day by day. Although wireless communications are more cost-effective than wired communications in terms of cost, application, and ease of use, there are challenges to using them. Radio frequencies of the electromagnetic spectrum below 10 GHz have been widely used in wireless communications. However, because existing bandwidth does not meet the demand for capacity and speed required, researchers are exploring new areas of research in wireless telecommunications. One of the proposed alternative solutions to the spectral traffic problem is to move toward the use of optical wireless telecommunications. Wireless optical systems provide high-capacity, high-speed wireless communication networks indoors. At present, there are challenges in the technology and legislation sectors in this field, and by overcoming these issues, it will be possible to achieve low-cost and high-speed telecommunication systems. Optical wireless telecommunication technology is expected to play a significant role in providing high-bandwidth communication in future generations of wireless telecommunication systems, especially in the end parts of the system where users connect to the network (Santamaria & Lopez-Hernandez, 1993).

History of Optical Wireless Telecommunications

Transmitting signals through smoke, fire, and sunlight can be considered a historical form of wireless optical communication. The first use of light for communication purposes is attributed to the ancient Greeks and Romans, who used their shields to reflect sunlight to send messages. Another historical case of optical wireless communications is the use of optical telephones invented by Alexander Graham Bell. In 1880, Bell transmitted the sound signal using light at 200 meters. His simple experiment was based on vibrations from the sound on a mirror on the transmitter side, reflected by sunlight and converted into sound at the receiver. Radiocommunications and fiber optics developed rapidly and overcame the global communications market. In 1960, just a few months after the public announcement of the 5,632-nanometer helium-neon laser, Bell Labs was able to send a signal 40 kilometers away using ruby lasers. In 1962, the Hughes Research Laboratory sent a sound signal modulated by helium-neon lasers over 30 kilometers. Also, in 1970, a two-way communication link was built using helium-neon lasers over a distance of 14 km by Nippon Electric Company, which was the first example of a commercial space optical telecommunication link (Ghassemlooy et al., 2019).

With the development of fiber optics in the 1970s, fiber optics were considered the best choice for long-distance optical data transmission, and the focus shifted from wireless optical telecommunication systems. However, its development has never stopped in military applications as well as in space applications laboratories (mainly the European Space Agency (ESA) and NASA), for example, with the support of the Lunar Laser Wireless Communication Project (LLCD '). Mali Tasa was formed to build the first open-air laser communication system capable of sending data at laser transfer rates of up to 622 Mbps to ground-based stations over 400,000 kilometers. In 2000, the KEIO research group in Japan, for the first time, introduced the possibility of using white LEDs for home wireless communication links. It established the Visible Light Telecommunication Consortium (mostly Japanese companies) in 2003 and developed the theory; and The first models followed the VLC channel in 2004. The IEEE also introduced the 802.15.7 standard for short-range visible light telecommunications technology in 2011, which addresses the physical layer and Mandatory access control layer (MAC) specifications. In parallel with research in space applications and advances in technology in the field of receiver and transmitter components for optical communications, optical wireless telecommunications, due to its high inherent security, has gained increasing attention in military applications. Wireless optical telecommunications can help service providers meet their customers' demands without spending much money on fiber optics. The speed of optical wireless communication laboratory systems competes with the speed of optical fibers (Wang et al., 2012).

Visible light communications

Visible light communications, or VLC for short, is another emerging field of optical wireless communications in which to transmit information from the optical signal in the visible region of the electromagnetic spectrum in the frequency range 790-385 terahertz; in other words, the wavelength range 780-380 The nanometer is used as the user's signal. In visible light telecommunications, information is transmitted by modulating the light intensity of light sources (mainly white light-emitting diodes) in the visible range of the electromagnetic spectrum. The optical detector receives the information at the receiver and retrieves the information after amplifying the signal. A light-emitting diode is an optical detector that produces an electric current in the receiver in proportion to the light received at its surface. Changes in the intensity of light in an optical transmitter occur at speeds beyond the speed of perception of the human eye, while for the human eye, it is seen as constant light. In this case, providing lighting of indoor environments and data transmission simultaneously using light-emitting diodes will be possible without the need for an additional telecommunication system (Kahn & Barry, 1997).

Light-emitting diodes are considered the most promising source of ambient light and transmitters in light telecommunication due to their unique ability to have high on and off speeds, high lighting efficiency, low energy consumption, long life, and low manufacturing cost. Visible in the future. Today, radio frequencies are the most popular frequency band in modern telecommunication systems due to their low interference and good coverage. However, due to the increase in traffic in the radio frequency spectrum and the increase in the traffic of wireless networks, the need for more bandwidth and expansion of the frequency spectrum is felt. Due to the rapid growth in the need for wireless data communications and the saturation of the radio frequency spectrum, visible light telecommunications is considered one of the leading complementary representatives of conventional radio telecommunications, especially in indoor data transmission (Liu et al., 2007).

Advantages of VLC systems

Due to the rapid growth of the need for wireless data communications and the saturation and increase of radiofrequency spectrum traffic, frequency spectrum management is rapidly becoming a critical issue. To solve this problem, research has been done on the use of the terahertz frequency range of electromagnetic spectrum between radio frequencies and microwave frequencies; But this requires the construction of a new class of infrastructure compatible with this band of electromagnetic waves which is costly. On the other hand, visible light has a bandwidth 1000 times wider than radio waves. Radio frequencies range from 3 kHz to 300 GHz, while visible light is in the 400-780 terahertz frequency band. Visible light telecommunication also allows unregulated telecommunication channels free from the range of electromagnetic waves. With radio signal-based telecommunication systems, visible light communications do not cause any electromagnetic interference (EMI). This makes it possible to use this technology in centers and places sensitive to electromagnetic waves, such as hospitals, aircraft cabins, mines, and industrial centers. Also, unlike radio communication, visible radio communication has no danger to human health and meets the eye and skin safety regulations, making it possible to use it in different scenarios with much higher radiant power than radio communication (Pahlavan et al., 2002).

Radio waves pass through obstacles and walls and are prone to potential eavesdropping, but because the light beam is limited to opaque boundaries (such as walls), it can increase the relative security of telecommunications systems. Since visible light communication is limited to the closed environment and is also very dependent on the direction of propagation and most of its power is sent in the direction of the direct line of sight, thus using a large number of non-interfering links together and also use Multiple bandwidths enables modulation in adjacent telecommunication cells, which increases the overall capacity of the network. LEDs are now widely used in indoor lighting applications, vehicles such as cars, planes, trains, and traffic lights. Also, due to the energy efficiency of LEDs compared to incandescent and fluorescent light sources, LEDs will be considered the primary light sources shortly. One of the essential features of LEDs is their ability to turn on and off with a very high frequency, which is not possible in any other existing optical technology. LEDs are light sources with long life, optimal energy consumption, lower production cost, size, and dimensions.

They are smaller than other light sources and produce less heat while generating light. As a result, visible light telecommunications is considered an environmentally friendly technology and green telecommunications. Visible light telecommunications can be easily implemented on indoor lighting production infrastructure (Barry et al., 1991).

Limitations of VLC telecommunication systems

The main limitation of achieving high-speed data transfer in VLC systems is the limit of LED bandwidth in the transmitter. Although RGB tricolor LEDs have a bandwidth of about a few hundred MHz, due to color changes over time and manufacturing costs, white light emits diodes made of blue LEDs with a layer of phosphor to produce light in environments. It is used internally, which has a bandwidth of about a few MHz due to the slow response time of the phosphor layer. One way to increase the bandwidth of this type of LED is to use a blue color filter to remove the yellow part of the light caused by the phosphor. This increases the bandwidth of the blue light but wastes some of the energy. The bandwidth of the white light section of this LED is approximately equal to 2 MHz, while the bandwidth of the blue light section is about 10 MHz (5) To increase the data transfer speed in these systems, solutions have been proposed so far. These methods include the use of complex multilevel modulations such as orthogonal frequency division modulation (DMT) (OFDM, filter bank, and the like) and SCFDE frequency compensation methods that complicate the system. MIMO multi-transceiver method can be used to use the spatial integration capability in the transmitter (Wang et al., 2012).

Another challenge in visible light communications is controlling the intensity of light, which affects link performance. Visible light telecommunication systems must maintain their efficiency even at low levels of brightness. The two main approaches are reduction - amplitude and pulse width modulation to control light intensity. In the first method, increasing the link power budget helps maintain the target performance of the link. Visible light communication systems are commonly used in spaces with a high level of ambient light from natural sources (solar light) and artificial light (incandescent and fluorescent lamps). The light from these light sources generates an interference signal in the wireless light receivers, which in case of ignorance, reduces the system performance. The average power of the full backlight creates a DC light current in the optical detector. Even when optical filters are used to remove light sources outside the band, the received signal power is much smaller than the power of the light sources in the environment. As a result, the output current in the optical detector is much larger than the output current in the received signal. In intense ambient light, shotgun noise is the predominant source of noise in the receiver, which is white Gaussian noise proportional to the apparent light cross-section (Zhou et al., 2012).

If the ambient light is low and absent, the predominant noise is from the preamplifier in the receiver, which is also independent of the signal and Gaussian. As a result, the presence of ambient light negatively affects the performance of visible light telecommunication systems. One of the most important parameters for achieving high transmission speed in this VLC is access to the optical lake with a direct line of sight in which the transmitter is placed in the receiver's direction. In the case of scenarios with an indirect line of sight and diffusion of light, the transmission speed is limited. As a result, we see a strong dependence of the capacity of the visible light telecommunication channel on the existence or absence of routes with a direct line of sight. Short-range technology also places limitations on its use (Jung et al., 2012).

Light reaches the receiver from different LOS and NLOS paths with different delays in visible light telecommunication systems. In addition, due to multiple arrays of LEDs, the system suffers from symbol interference, or ISI, which is another limitation of the VLC system for achieving high speeds. In visible light communications, the user signal has a frequency in the range of 1014 Hz, and typically the active area of the optical detector in the receiver of VLC systems has an area on the scale of several million times the square of the wavelength of light. Because the total light flux produced in the PD is proportional to the optical power at the entire optical detector surface, this scale difference causes inherent spatial diversion. As a result, indoor visible light transmission systems are effectively subject to blurring. They are not multipath, which is why in these systems, we encounter a slight and negligible Doppler expansion, and the channel can be considered invariant over time (except in the case where the beam system is blocked and with the phenomenon, In this case, the multipath propagation of the transmitted signal in these systems causes time scattering, which leads to interference between symbols and limits the transmission speed. The distance between the delays of different light paths is significant; the system will suffer from ISI at high transmission speeds. In addition to the room's dimensions, the scattering of the channel depends on the field of view of the receiver and the distance between transmitter and receiver. The light source with a narrower radiation angle, and the receiver also than the detector with a field of view. When used, the scattering of the channel due to multipath and the reception of reflections from the surfaces in the receiver is reduced (Garcia et al., 2009).

VLC applications

Applications of visible light telecommunication in indoor places In addition to creating light and transmitting information, usability can be used for positioning. Location services in open environments are widely accessible using the Global Positioning System (GPS). However, due to the lack of GPS signals indoors, this method is not applicable for indoor positioning. As a result, an alternative solution is needed for indoor environments. Among the available options, users' location has been examined using the access points of wireless radio networks. Another way to position yourself indoors is to use visible light communications. One of the advantages of this method compared to a location using a wireless radio network system is the high accuracy due to the higher density of access points than wireless radio network location systems in indoor environments. The accuracy limits of location estimation in this technology depend on the environment's geometry, the frequency and power of the transmitted signal, and the specifications of diodes and light receivers on a millimeter or centimeter scale. This accuracy is achievable due to more optical telecommunications infrastructure than access points in wireless radio networks. Due to the high accuracy and utilization of visible light infrastructure in indoor environments, positioning using visible light in the future will be the dominant method in positioning systems. Other applications of VLC include hospital environments, some of which are equipped with medical equipment such as MRI machines, where electromagnetic waves interfere with their function. VLC can also be used in medicine to send ECG and ECG signals and other vital signals to the patient's body. One of the most sensitive environments to electromagnetic waves is the cockpit. Inside the aircraft, due to disruption in its telecommunications system, it is not possible to use radio communications. As a result, by using visible light communications and creating light in the environment, the problem of electromagnetic interference can be solved. Also, due to the lack of need for extensive infrastructures such as radio communications and cables, the volume and weight of the aircraft will be reduced. This is an essential issue in aircraft design. In addition to VLC applications indoors, LEDs are also widely used outdoors. For example, due to the presence of LED lamps in vehicles and the infrastructure of traffic lights, traffic signs, and billboards, this telecommunication system can create a communication network between vehicles with each other and with optical infrastructure. He used roads, including street lamps and traffic lights (Chen et al., 2008).

Research Methods

In this research, using optimal threshold devices, a plan to increase the transmission speed by switching modulation (disconnection and connection) and in the presence of inter-symbol interference is proposed, which we examine in two cases of the possibility or impossibility of using a memory device in the receiver. . We will show that having a memory device will lead to optimal receiver design and thus improve system performance. However, if you do not have a memory device, you can use the sub-optimal receiver. It should be noted that although the simulation results for switching modulation are presented, the model of future problems and their corresponding solutions are generally considered.

Results

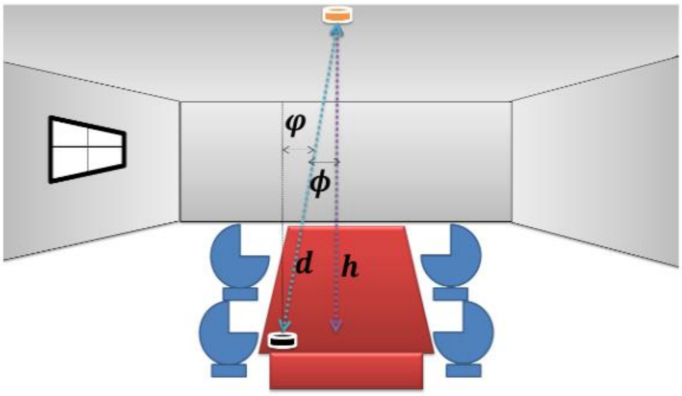

Figure 1. Outline of a location system in optical telecommunications considering direct vision arrangement

In this section, numerical and simulation results are presented to evaluate the performance of the proposed framework. The effect of the signal window on the Cramér–Rao bound is investigated in Figure 2.

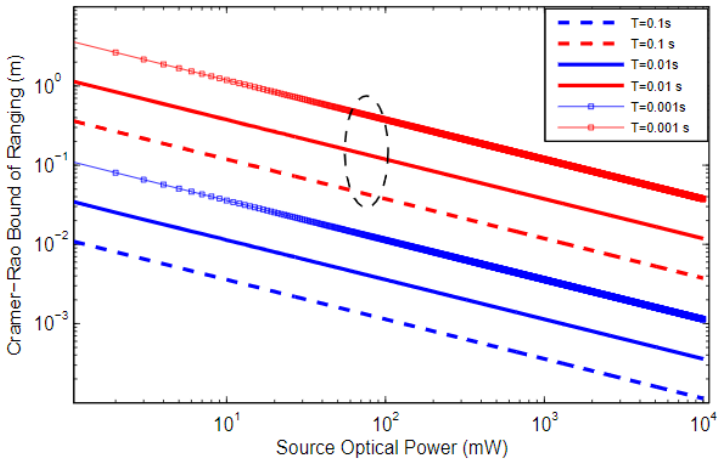

Figure 2. Cramér–Rao bound corresponding to the optical power in the presence of several different values for the signal window, the lines marked by the curve, show the results of previous work.

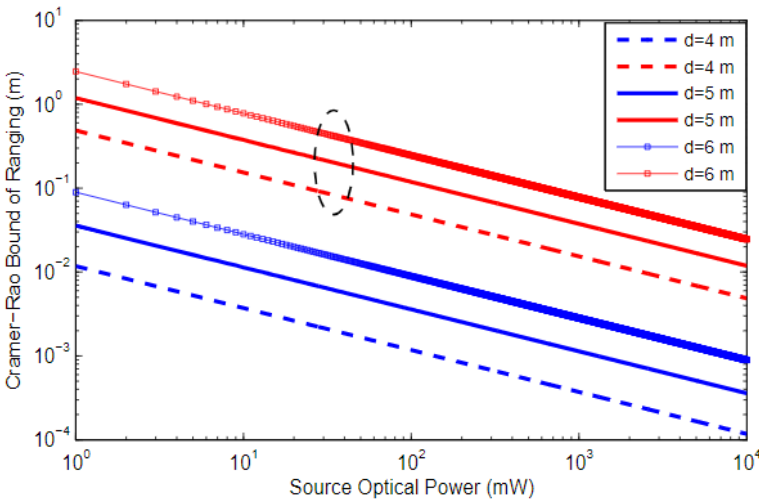

Figure 3. Cramér–Rao bound corresponding to the optical power in the presence of several different values of the distance between the transmitter and receiver, the lines marked by the curve show the results of previous work.

Now we want to examine the maximum likelihood at an unknown altitude. Figure 3 shows the effect of distance changes on this estimate.

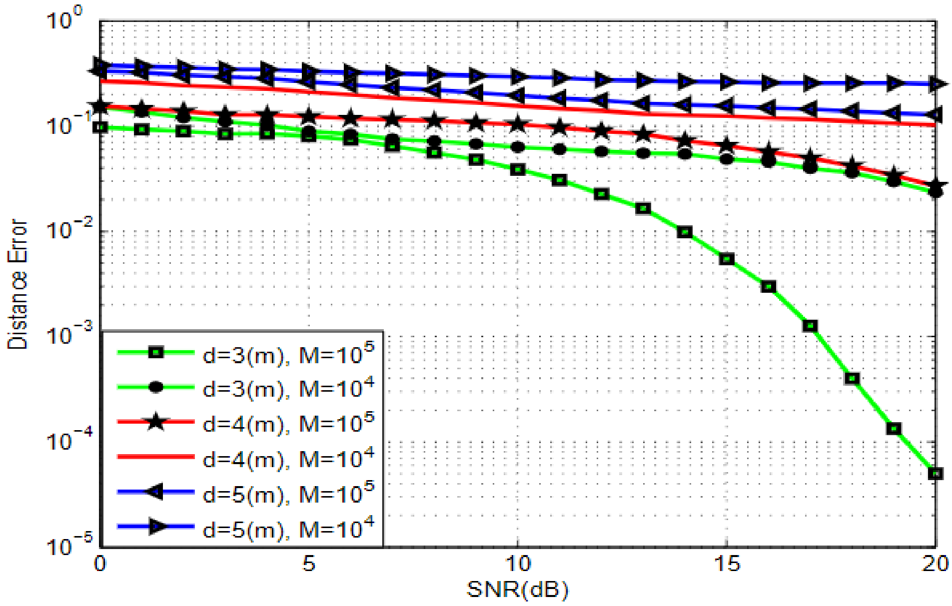

Figure 4. The amount of error in calculating the distance in terms of the signal-to-noise ratio at an unknown altitude and based on distance changes

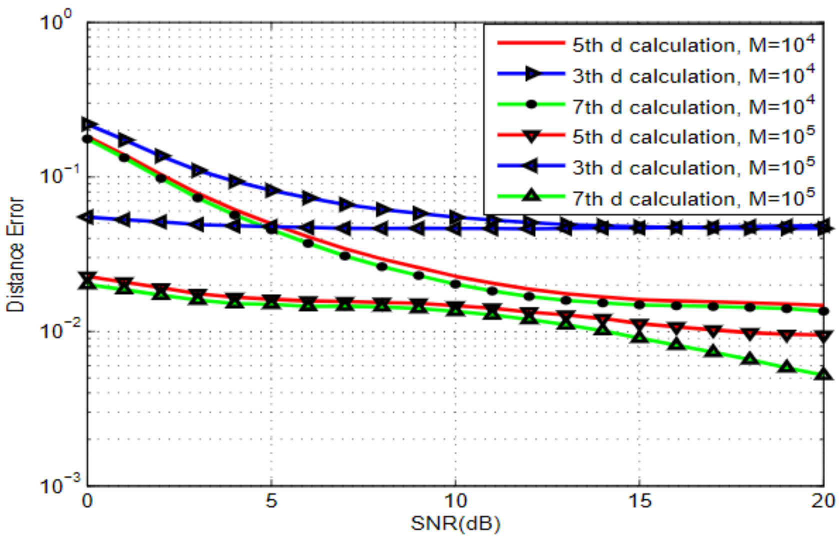

Figure 5. The amount of error in calculating the distance in terms of the signal-to-noise ratio at a known altitude using the return method

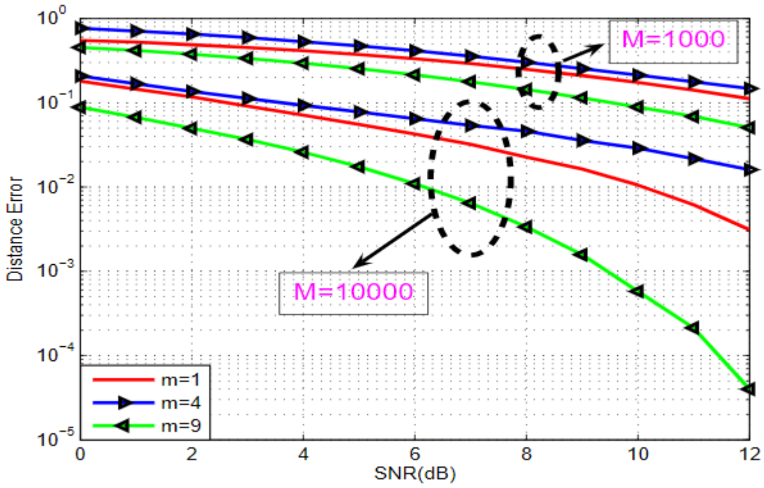

Figure 6. The amount of error in calculating the distance in terms of the signal-to-noise ratio at a known altitude, Considering d = 3m and for different values of m

Conclusion

In this study, the phenomenon of interference between symbols and the issue of location in visible light communications was investigated. When optical power reaches the receiver through reflection paths, the bandwidth of visible light is limited to 20 MHz; Although up to 5% of the optical power received through these paths reaches the receiver. The study of location based on the signal entry time technique in visible light communications showed that assuming that the received light power is limited to the open field of view and full synchronization between the transmitter and receiver, the maximum likelihood estimate is known if the size is unknown or not. He gained the height and finally presented this estimator in a closed-form. It also calculates the lower Cramér–Rao bound to be an indicator of the theoretical performance of the designed estimators.

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