

AN INVESTIGATION INTO VISIBLE LIGHT COMMUNICATION VERSUS TERAHERTZ COMMUNICATION

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Abstract

Nowadays, wireless communication technology has been developed into 5 Generation (5G), which can change the world in terms of Ultra-high-speed data communication. However, researchers and industries are continuing developing a technology that allows data communication up to Terabit per second (Tbps) level, so called Terahertz (THz) Communication. Moreover, another interesting technology is Visible Light Communication technology (VLC) allowing a wireless communication with some simple LEDs. Both technologies are able to support a lots of modern wireless networks such as an autonomous car, Vehicle-to-Vehicle communications (V2V) and Vehicle-to-Infrastructure communication (V2I). As well as in the field of medication, this new technology allows doctors to perform on-screen treatment such as remote surgery with a safe, fast, and efficient cure. According to the benefits mentioned earlier, this paper investigates the evolution of THz and VLC technologies, which demonstrate the next level of potential for wireless communication in the future. In this paper, we search and compare about advantages and disadvantages of both technologies including THz Communication and VLC for applications in the future.

Keywords: Visible Light Communication technology (VLC), Terahertz (THz) Communication

Introduction

The study and development of wireless networks for higher efficiency are still ongoing to support the need of various application usage in the future such as Artificial Intelligence (AI) and The Internet of Things (IoT). Furthermore, this development also allows a computer to be able to store more data and process faster. Also, the enhancement of communication services with various technical qualifications such as high speed, high capacity, low latency, and massive connectivity is achieved. These features can help increasing flexibility usage for wireless communication. In the last few years,

many leading countries in the world have developed a 6 Generation (6G) wireless network plan on high frequency range up to Terahertz (THz) (Yang *et al.*, 2019). This technology is able support data transfer up to Terabit per Second (Tbps) level including the usage of visible light in which humans can see with their naked eyes, so called Visible Light Communication (Pohlmann, 2010; Haas, 2015).

Figure 1 shows the spectrum of electromagnetic waves from the lowest frequency up to the gamma ray (Pathak *et al.*, 2015). As we can notice, the visible light is between the Infrared

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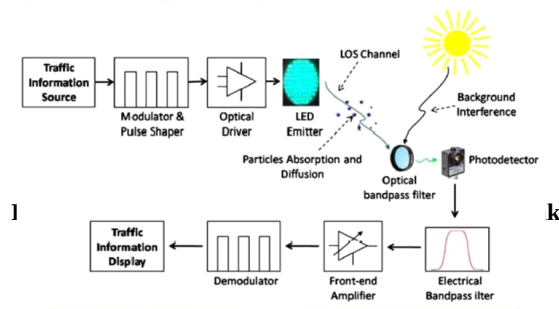


Figure 4. VLC system architecture (Matheus *et al.*, 2019)



Figure 2. Terahertz frequency band detail (Kasemsuk, 2019)

and the Ultraviolet bands, as its wavelength between 380-750 nm. On the other hand, Terahertz frequency band is between Microwave and Infrared bands covering the wavelengths from 30 μm to 3 mm as shown in Figure 2 (Kasemsuk, 2019). According to these two interesting technologies, this paper investigates into the evolution of Terahertz communication (THz) and Visible Light Communication (VLC) technologies. This paper also points out advantages/disadvantages, performances, applications, ongoing research and their future challenges.

The remainder of this paper is as follows. After this brief introduction, Section II discusses the background, research, applications and future challenges of VLC technology. Afterwards, Section III discusses the evolution of wireless networks, research, and application examples and future challenges for THz communication. Then, section IV shows the comparison between VLC and THz technologies. Finally, conclusion is given in section V.

Materials and Methods

Visible Light Communication (VLC) Evolution

A Visible Light Communication (VLC) is one type of communication in which the data is transmitted by the modulation of light waves from

the visible light spectrum with the wavelengths in the range of 380-780 nm using LEDs (Light Emitting Diodes). The reason of using LEDs to transmit data because the LED is an electronic device that provides brightness, saves a lot of energy and has a lifespan of 25 times longer than traditional bulbs with environmentally friendly behavior. In the future, LED bulbs will replace traditional bulbs, and will play a significant role in smart lighting being able to provide both illuminations and also can be used to communicate at the same time (Matheus *et al.*, 2019).

Light has been used for communication from the past to the present. For example, a photophone was invented in the late 19th century by Alexander Graham Bell and his assistant, Charles Toaster. The structure of this device is shown in Figure 3 (Wikipedia, 2020). Which was considered as the beginning of optical communication. The work started with the sunlight reflected into the glass surface, in which the light waves vibrate according to a person's voice, after that light waves will pass through the second lens to the receiver, which is a reflective curved glass (Bell, 1880; Dilhac, 2001). In 2000, LED bulbs gained lot of attention in which they can be utilized in the field of visible light communication by experimenting with the use of white LED bulbs for indoor communication, resulting in data communication rates of up to 400 Mbps (Tanaka *et al.*, 2003). And in 2011, the introduction of Li-Fi (Light Fidelity) technology was considered as the application of visible light communication applications during the TED Talk for the first time (Matheus *et al.*, 2019).

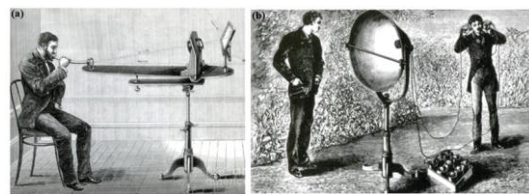


Figure 3. (a) Transmitter; and (b) Receiver of Photophone (Wikipedia, 2020)

The structure of VLC consists of 2 main parts, named as the transmitter and receiver. On the transmitter side, devices used to send signals are LEDs responsible for transmitting data through the flashing of light, resulting in the transmission of digital data. For example, data bit 0 means the light is off, and bit 1 means the light is on. While transmitting the signal, the LEDs are on state in which it may cause signal quality loss due to the interference from other light sources in the surrounding. This can be resolved using the optical

bandpass filter to reduce signal interference. The receiving device used to receive the signal is the photodiode responsible for receiving light and detecting some interference and converting it back into data, as shown in Figure 4 (Matheus *et al.*, 2019). In the future, there will be camera developments in smartphones to be able to receive data from the VLC transmitter. Also, the LED itself can also be used as a receiver due to the ability to detect images (Matheus *et al.*, 2019).

Research

This section discusses some research related to visible light communication (VLC), which is divided into 2 types including Indoor and outdoor communication.

1. Indoor communication

In 2003, Komine and Nakagawa have presented a work that studies the possibility of using LED bulbs in VLC systems. The authors have demonstrated an importance on the advantages of LED lighting. Also, they offered VLC systems that use these LED bulbs to transmit data in indoor environments using On-Off Keying Modulation (OOK). In their experiments, 3,600 LEDs (60×60) were installed in a room measuring 5.0×5.0×3.0 m. At the end of the research, the authors have discussed the influence of light reflected on the wall and the interference between them. The authors have shown that it is possible to create wireless communication using visible light at the very high data rate of 200 Mbps when considering from a perspective between 40 and 50 degrees. Also, they have shown the use of tracking techniques which is possible to dramatically reduce the view up to about 5 degrees if the VLC data transfer rate is up to 10 Gbps (Komine and Nakagawa, 2004).

Dambul *et al.* has demonstrated a research using an image receiver to retrieve the light data from the transmitter. In this case, the use of 2×2 LED array, NRZ OOK modulation and channel speed equal to 2 Mbps was employed (Dambul *et al.*, 2010).

One of the most promising modulations until now is MIMO-OFDM which the research has been widely carried out for 2 decades (Uthansakul and Bialkowski, 2004; 2006). Azhar *et al.* have also offered a system that uses an image sensor as a receiver and a different modulation MIMO-OFDM 2×9 system at a speed of 220 Mbps with a receiver at a distance of 100 cm from the transmitter (Azhar *et al.*, 2010). Two years later, the authors have introduced a similar system (4×9 MIMO-OFDM) and modified the modulation able to communicate at the Gbps range for example, 1.1 Gbps at 1 m (Azhar *et al.*, 2012). The authors have tested the MIMO in an indoor environment up to 50 Mbps at

a distance of 2 m (Burton *et al.*, 2014). Although MIMO technology can provide high capacity (Promsuvana and Uthansakul, 2008; Meerasri *et al.*, 2014), it cannot work properly using VLC communication.

The problem with indoor communication is whether day or night, you have turned on the light to connect the internet to communicate with each other. Therefore, it may cause inconvenience for users before going to bed, who doesn't need light but still need to have an internet connection. To solve this problem, Tian *et al.* have proposed a VLC system that can exchange data via light even the bulbs are "closed" or has a low intensity. The author said that the main idea of this event is encoding data into short pulsed light at very high frequencies. In this way, light waves cannot be seen by the human eye but can be detected using photodiodes. This work can be improved from the old system, which can communicate at a distance of only 10 cm, but the new system can communicate farther at 1.3 m with a data rate of 1.6 Kbps (Tian *et al.*, 2016a, 2016b).

2. Outdoor communication

In this section, we will give some examples of research on outdoor communication in the field of vehicle communication. The research on VLC's vehicle communication system has been begun to be developed since 2001. The authors have chosen a visible light emitted from an LED instead of using infrared waves to transmit data (Akanegawa *et al.*, 2001).

In 2013, Takai *et al.* have developed a VLC system in V2V using an image sensor to capture light waves, which has the speeds up to 20 Mbps/pixel (Takai *et al.*, 2013). There have been also measurements investigating the efficiency for distance and different lighting conditions, but some restrictions on the light interference has been introduced. Later, the authors have improved the efficiency to be more resistant to light interference, in which the objects with low light intensity will be eliminated making the system performance noticeably better than before (Takai *et al.*, 2014).

In 2015, Yoo *et al.* have offered and demonstrated real-life applications of the vehicle system using VLC. The authors have used LED lights in the front of the car as a data transmission device. In the experiment of Vehicle-to-Vehicle communication (V2V), the author controls the intensity of emitted light and uses Inverse M-ary modulation (I-M-PPM) for data transmission. On the receiving side using a receiver consisting of photodiode lens and colour filters, the encountered problems are interference caused by other light sources, especially on the sunny day. Sunlight can be distributed in all areas of the visible spectrum of

infrared and ultraviolet light, making it difficult to filter for the colour filter being used to reduce distractions. In their experiments, they were able to transmit data at rates up to 10 Kbps at distances of more than 30 m (Matheus *et al.*, 2019).

From literatures, it has been evident that research is still being carrying on to develop the VLC system both for indoor and outdoor communication.

Application of VLC

In the future, visible light communication will play a significant role, because visible light waves are not harmful to human health. It can also communicate at a very high data rate up to Terabit per second (Tbps) to support applications that will occur in the foreseen future. In this part, we will divide the sample application into 2 parts including indoor and outdoor systems.

1. Indoor system

The VLC is mainly used for indoor communication as there has a little interference with the surrounding light compared to outdoor systems which has a lot of interference from the sun. For example, the application has been seen through the communication in the office room, on the plane, or even in hospital as shown in Figure 5 (Kocharoen *et al.*, 2016; Khan, 2017).

Another interesting example of the VLC application is Li-Fi (Light Fidelity) technology as shown in Figure 6 (Haas *et al.*, 2020). The Li-Fi is wireless technology which works through transmission by light. The LED bulbs are used to send a signal, so no matter where you go with just the brightness of the LED bulbs, you can access the internet immediately (Hollister, 2010).

2. Outdoor system

Outdoor VLC usage has been evident in the field of vehicle communication as shown in Figure 7 (George *et al.*, 2014). Which is expected

to develop for greater communication distances with low data rates. This section divides vehicle communication into Vehicle-to-Vehicle communications (V2V) and Vehicle-to-Infrastructure communication (V2I).

Vehicle-to-Vehicle Communications (V2V) is the communication between vehicles and vehicles, the headlight act as a transmitter and a photodiode installed in the car responsible for receiving signals to communicate and exchange data such as traffic data both images and animation. This can help for decision to choose the route or avoid the traffic jam.

Vehicle-to-Infrastructure communication (V2I) is the communication between a vehicle and infrastructure such as electric poles or building, that can install VLC communication devices located on the path that the vehicle passed. It is a type of data transmission to forward the data to other vehicles, that moves followed. Moreover, this technology can continue to develop through advertising to disseminate information to vehicle moving around that area, in which vehicles can receive information from the infrastructure while parking to traffic lights or moving through (Cui *et al.*, 2012; Căilean and Dimian, 2017).

Visible light communication is considered to be highly secure and can also reduce the problem of electromagnetic interference as it can be used in a place surrounded by radio signals. Although this technology is very interesting, but the limitation of visible light communication is that it cannot pass through the opaque obstruction.

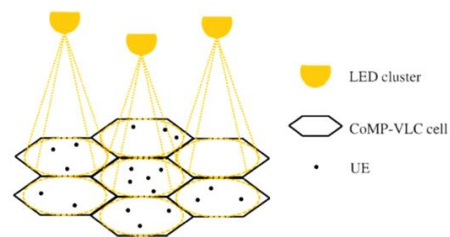


Figure 6. Light Fidelity Technology (Haas *et al.*, 2020)



Figure 5. Indoor system communication (Chukwuemeka, 2018). Under : (a) The communication in the office room (b) The communication on the plane (c) The communication in hospital

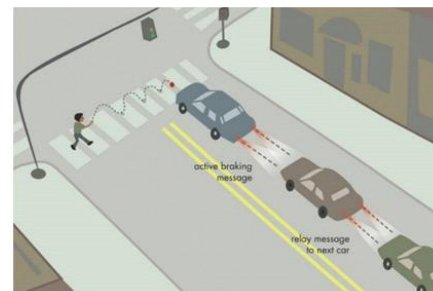


Figure 7. Vehicle communication (George *et al.*, 2014)

Terahertz Communication (THz)

Evolution

Nowadays, wireless communication technology is very important due to wireless communication networks, whether in the form of the internet or the field of telecommunication. This technology makes a possibility for a fast and convenient data connection. This section discusses the evolution of wireless communication from 1G in the past to 5G in the present and the future 6G wireless communication aspects.

1G – 2G

From Figure 8 (Huang *et al.*, 2019), the beginning of telecommunications services is analog communication in 1 Generation with the use of radio signals to transmit only voice signal. Later, the development of modern technology has increased rapidly. Therefore, the change from analog to digital communication technology in 2 Generation allows communication to be able to send SMS messages to each other, aside from just voice communication.

3G – 4G

In 3 Generation, the data rate has been improved up the rate of 100 Mbps. This generation has allowed the access to Internet. In 4 Generation, the data rate has been improved from 3G to 1 Gbps and it reduced the error in data transmission for both audio and video to support the increasing demand for users (Uthansakul *et al.*, 2020a, 2020b).

5G

In the 5 Generation, everything can connect to the Internet with data rate up to 20 times higher than 4G, about 20 Gbps. The use of mmWave frequency band was introduced to increase the data rate. The 5G has 3 general usabilities as follows (Liu and Jiang, 2016).

1. Enhanced mobile broadband (eMBB): providing high data rates for mobile users (up to 1 Gbps). The key success of eMBB is based on massive MIMO technology (Uthansakul *et al.*, 2018; Uthansakul and Khan, 2019a; 2019b; 2019c).

2. Massive machine-type communications (mMTC): focusing on a number of connected devices in IoT (up to 1 million wireless connections per square kilometer).

3. Ultra-reliable low-latency communications (URLLC): giving importance to reliability and response time for real-time applications such as vehicle communication and automation in the industry.

The 5G can connect various technologies, such as AI, Big Data, and IoT. There are opportunities for new services which has never been seen before, such as in the vehicle system connecting vehicles with

traffic control systems, or Augmented reality (AR) and Virtual reality (VR), which is a technology that allows doctors to perform on-screen treatment such as remote surgery.

6G

In 6 Generation (Zhang *et al.*, 2019), the future of communication will increase the efficiency of wireless communication with data rate up to Terabit per second (Tbps) and very low latency at the microsecond level using the Terahertz frequency band. The THz wave has a wavelength of 30 μm - 3 mm. Also, it has a special feature to safe for life and has a narrow wave beam helping communications to be more secure (Uthansakul and Uthansakul, 2011; Innok *et al.*, 2012). Moreover, 6G has also been developed to improve the quality of 5G communications in various fields.

1. Mobile ultra-broadband: providing services with higher data rates at the Tbps level.

2. Super IoT: improving the ability to connect and IoT coverage by working with satellite networks.

3. AI: configuring and intelligently customizing the future wireless networks to support various applications.

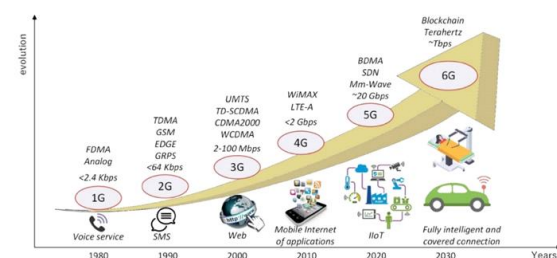


Figure 8. Evolution of wireless communication (Huang *et al.*, 2019)

Therefore, the approach to wireless communication in the 6G is to improve performance than existing models, whether in terms of data rate, latency, throughput, and security. This is to support the increasing demand for users to be able to receive and send data at high speed without interruption.

Research

In March 2019, the FCC has approved a trial for copyright use and unlicensed applications within the frequency band between 95 GHz and 3 THz and launched a new Spectrum Horizons license (a low barrier type license) (FCC, 2019).

In Europe, Horizon 2020, the EU's largest research and innovation project have funded many projects by calling "network research beyond 5G" most of which are aimed at THz technology.

IEEE began to standardize THz communications by establishing the Personal Wireless Network (WPAN) workgroup with IEEE 802.15 Working Group 3-D 100 Gbps. Also, they established wireless communication throughout first world standard in the frequency range 250-350 GHz, which channelizes the band into 32 channels 2.16 GHz. Also, the International Telecommunications Union (ITU) has classified 0.12 THz and 0.2 THz in wireless communication.

Ministry of Internal Affairs and Communications of Japan established a research and development project for important technology in the Terahertz frequency band and supported many related tasks, such as the CMOS technology in the THz band (Huang *et al.*, 2019).

In research (Fujishima, 2018), 300 GHz-band CMOS wireless transceiver aimed at 100 Gbps with wireless communication using the 300-GHz frequency band. The authors have described the 300 GHz band CMOS transceiver circuit and designed the chipset 300 GHz wireless band transceiver and module that connects the CMOS chipset to an external waveguide antenna to overcome the shortcomings of the low antenna of the antenna on the 6th Paper chip.

Single-chip gives the data transfer rate of 80 Gbps presented in the research of 9.5 an 80 Gbps and 300 GHz-band single-chip CMOS transceiver (Lee *et al.*, 2019). However, the high frequency, reflection, and cable attenuation link causes many problems in the design of the RF-frontend and baseband introduces the gain reduction (Lopacinski *et al.*, 2019). The authors have solved these problems by designing processors in the data link layer (DLL) to have a low chip area.

Application of THz

This section discusses some examples of Terahertz communication applications.

Medical

Doctors are able to perform on-screen treatment remote surgery as shown in Figure 9 (Hinck, 2016). For example, in China, doctors have performed the remote surgery treatment of patients with Parkinson's disease with brain stimulation (DBS). This is the first successful operation of a distance over 3,000 km with the technology of telecommunications companies, China Mobile and Huawei. And in the future, the remote surgery will be important for a safe, fast, and efficient cure (Gao *et al.*, 2019).

Also, Terahertz technology is used to check the skin's upper tissue by analyzing depth and tissue burns caused by exposure to chemicals, skin cancer examination or breast cancer, etc. In addition, Terahertz technology is used to detect nucleic acids

in cells applied to detect DNA mutations in the future (Kasemsuk, 2019).

Industrial

The autonomous car is a car that uses Automated Driving Systems (ADSs) as shown in Figure 10 (Browne, 2017). Which receives signals from the surroundings whether a light pole, traffic light or other things where the car is moving through. In addition, AI will be used in the future to decide where the fastest route to reach the destination and avoid the obstacles on the road. The major global car manufacturers such as General Motors and many car manufacturers in Europe, Japan, and South Korea are currently developing a completely autonomous car which will be available for sale in the foreseen future. Currently, some companies started experimenting with an autonomous car such as in China, Alibaba Company developed an autonomous car named G Plus to deliver things to customers. The Kroger in the United States introduced an autonomous car for shipping to the customer's home at the end of 2018 (National Highway Traffic Safety Administration, 2017).

In addition, Terahertz technology can be used to detect dangerous chemical explosive substrate type, which has been used to maintain security at foreign airports by replacing the original system with X-rays (Kasemsuk, 2019).



Figure 9. Remote Surgery Technology (Hinck, 2016)



Figure 10. The autonomous car (David, 2017)

Communication

Terahertz technology is very important for future communication due to very high frequency and the high data rate up to Terabit per second (Tbps) which provides real-time response. In the future, all previous communication systems or Wireless LAN will be replaced by Terahertz technology (Chen *et al.*, 2019). This communication can also pass through clouds, fog and steam, therefore the communication between spacecraft and the station on the earth or between satellites and satellites is allowed. Although the terahertz technology is very interesting, but the limitation of Terahertz Communication cannot pass through the metal obstruction.

Results and Discussion

Performance Comparison of VLC and THz Communication

In this section, we will show the advantages and disadvantages for the use in the future by comparing the similarities and differences between VLC and THz communication.

Table 1 shows the comparison between VLC and THz Communication presenting the similarities and differences between these two technologies. Starting from the spectrum of the VLC, which is in the visible light band, the wavelength is in the range of 380-780 nm at the frequency range of 10^{15} - 10^{16} . On the other hand, the Terahertz band is in the wavelength of 30 μ m - 3 mm at the frequency range of 10^{12} - 10^{15} . The transmission of the VLC must be in the Line of Sight (LOS) using LEDs to transmit signals, also the receiver must be on the LOS level of the transmitter. The light interference from other sources may be introduced. On the other hand, the transmission of THz Communication has to be in the Non-Line of Sight (NLOS) sending data through the distribution of waves around the areas. The

interference caused by electromagnetic radiation may be introduced.

Currently, there is a signal transmission experiment using VLC and THz communication with the data rates of 10 Gbps and 100 Gbps respectively.

The obvious advantages and disadvantages for both technologies are summarized in Table 2. In VLC, it can reduce the problem of electromagnetic interference, because it uses the visible light frequency as a transmitter instead of using radio signals. However, the limitations is that it can be easily disturbed by light waves from other light sources. Also, the light cannot penetrate through the opaque obstruction. In THz Communication, the electromagnetic wave has outstanding features which is not harmful to human health, safe for life and has a narrow beam helping the communication to be more secure. However, the limitations are introduced by interference from electromagnetic radiation. Also the wave cannot penetrate through the metal obstruction.

Table 3 shows some examples of VLC and THz Communication applications which can be used in the future for indoor/outdoor communication, Vehicle communication V2V and V2I in VLC, autonomous car, remote surgery, and 6G wireless communication in THz communication.

Future Researches of VLC and THz Communications

According to their advantages, the VLC and THz communications currently gain lots of attention because they are expected to be a technology for next-generation communication systems. VLC is an essential part of solving network problems in Radio Frequency (RF) wireless communication systems which involve system capacity and spectrum congestion. Therefore, VLC are becoming an add-on technology for RF wireless communications. For THz communications, as it provides coverage, low

Table 1. Comparison between VLC and THz communication

Specification	VLC	THz
Spectrum	Visible light	Terahertz
Frequency	10^{15} - 10^{16}	10^{12} - 10^{15}
Wavelength	380-780 nm	30 μ m-3 mm
Bandwidth	100 THz	10-100 GHz
Transmission	Line of sight (LOS)	Non line of sight (NLOS)
Electromagnetic radiation	No	Yes
Data rate achieved	10 Gbps.	100 Gbps.
Transmission power	Low	High
Infrastructure	Illumination	Access Point / Device
Coverage	High	High
Security	High	High
System complexity	Low	High
Interference	Other lights	Other radio wave
Obstruction	Opaque	Metal
Cost	Cheap	Expensive

Table 2. The advantages and disadvantages of VLC and THz

Observation	VLC	THz
Advantages	Reduce the interference of electromagnetic waves	Harmless to human health safe for life
	Can be used instead of radio signals	Can be used instead of X-ray
	Narrow beam more secure	
Disadvantages	Cannot pass through the opaque obstruction	Cannot pass through the metal obstruction
	Interference from other light	Interference from other radio wave

Table 3. The applications of VLC and THz

Applications	
VLC	THz
Li-Fi Technology	The autonomous car
Indoor system communication for example in the office room	Remote surgery
Outdoor system communication for example in Vehicle communication V2V and V2I	Detect dangerous chemicals explosive substrate type
	Important for future communication
	Used in communication between spacecraft and the station on the earth or between satellites and satellites

latency and supports the increasing needs of users in the foreseen future to achieve a high level of reliability and safety, THz communications are the integral part of the development of 6G wireless communication systems. According to previous points, researchers should implement with the above limitations to improve the performance of VLC and THz communication systems even further.

Conclusions

Advances in wireless communication technology are important to make human life more comfortable. For this reason, lot of researcher have studied and developed a wireless communication system for a better performance. In this paper, we have investigated the evolution of VLC and THz communication, as well as the above-mentioned researches and examples of applications in the future for both technologies. This has demonstrated the next level of potential for wireless communication in the future. Also, we have searched and compared the advantages and disadvantages of both technologies. One of the advantages of VLC is using LEDs for data transmission which is able to provide both illumination and continuous communication, especially in indoor environment such as home and office, etc. Even for outdoor communication such as Vehicle communication V2V and V2I, both technologies can help facilitate on the road for users. Also, THz communication will be an important part of future wireless communication with a variety of applications such as the autonomous car, substrate explosive detection and remote surgery for doctors.

These technologies can provide a safe, fast, and efficient cure.

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