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A Survey on Visible Light Communication

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Abstract: ***This paper introduces the concept of visible light communication (VLC). Visible-light communications (VLC) is a technology for wireless communication using light that can be perceived by the naked eye. VLC uses frequencies other than radio, and they are unrestricted and licence free. The urgent need of VLC is to overcome the problems faced in RF communication. Unlike existing methods of wireless communication, the visible light portion of the electromagnetic frequency spectrum is used in VLC to transmit information. Visible light communication (VLC) refers to the communication technology which utilizes the visible light source as a signal transmitter, the air as a transmission medium, and the appropriate photodiode as a signal receiving component. This paper provides an overview of applications and design challenges for VLC, compare it with other existing communication technologies and presents the modulation techniques used.***

Keywords: Visible Light Communication, Radio Waves, Infrared Communication, Light Emitting Diode, Modulation Techniques**.**

1. Introduction

VLC is basically a short range optical wireless communication using LEDs for illumination and communication simultaneously. It is a data communication technology that uses visible light between 380 nm and 780 nm. These wavelengths correspond to a frequency range of approximately 384 THz to 789 THz. VLC is the technology which utilizes the visible light source as a signal transmitter, the air as a transmission medium, and the appropriate photodiode as a signal receiving component. Data transmission in VLC is done by changing the light intensity. Change in amplitude is so small for a naked human eye that it is un-noticeable.

By utilizing the advantage of fast switching characteristic of the LEDs compared with the conventional lightings, i.e., modulating the LED light with the data signal, the LED illumination can be used as a communication source. Since the illumination exists everywhere, it is expected that the LED illumination device will act as a lighting device and a communication transmitter simultaneously everywhere in a near future[1][2].

2. Comparison with Other Communication Technologies

2.1 VLC versus Radio Waves

Although radiofrequency communications is the most popular technology today, it also has disadvantages. VLC is compared with radiofrequency using five main concepts [1]:

Capacity: Radio spectrum is full and it is difficult to find radio capacity to support the demand of wireless data transmissions for media applications. The radio waves are limited, expensive and there is only a certain range of it. By using VLC more spectrums will be available and due to the infrastructure of LED-based lights installed in the world there is a potential for VLC as transmitters.

Efficiency: Radio waves consume a lot of energy while VLC is highly energy efficient since illumination and transmission of data are done at the same time.

Cost: VLC transmitters and receivers devices are cheap, there is no need for using expensive RF units.

Safety: Radio wave creates Electromagnetic Interference (EMI), known to interfere with airplanes' instruments and equipment in hospitals, and is potentially dangerous in hazardous operations, such as power/nuclear generation or oil and gas drilling. On the other hand, VLC uses light instead of radio waves, which is intrinsically safe and does not create EMI. Hence, this technology can be used in many places.

Security: Radio waves penetrate through walls and they can be intercepted. By using VLC data is transmitted where the light is because light does not penetrate through walls, that is to say, VLC provide a secure data communication.

Human Health: The transmission power of radio waves van cannot be increased over a certain level because there are serious health risks for humans. VLC is an attractive candidate in a consumer communication system.

2.2 VLC versus Infrared Communication

Infrared Technology is a safe and widely used technology[2]. The differences between VLC and infrared communication are summarized in the following points;

Data Rate: Infrared Communication sends data at a rate of 20Mb/s while VLC can send data up to 100Mb/s.

Distance: The transmission distance for VLC is possible up to several meters due to its illumination requirement. Since the infrared communication is used for a remote controller, the maximum distance is ~ 3 meters

Noise Source: Due to the wavelength of the light source, the noise sources will be different. For infrared communication, noise comes from ambient light containing infrared light. In the case of VLC, the sunlight and other illumination light can be noise sources.

Services: Infrared Technology is used in communication only while VLC is used both for illumination and communication.

Application: Infrared Technology is used in remote control and point-to-point connection while VLC can be used in many applications such as

3. LEDs in VLC

The VLC technology is driven by LEDs light because it is the strong candidate for future illumination devices. It has greater efficiency and longer lifetime. LEDs last for 100,000 hours, an efficiency rating of 30% and as an added benefit, LEDs do not contain mercury, a hazardous material that is hard to be recycled in the current illumination industries. Comparing the LED illumination with the conventional illumination such as fluorescent lamps and incandescent bulbs, the LED illumination has many advantages such as high-efficiency, environment-friendly manufacturing, design flexibility, long lifetime, and better spectrum performance. Table 1 shows the comparison between LED and incandescent and fluorescent lamps[3].

Table 1: Comparison between LED and incandescent and fluorescent lamps

	LED	*Incandescent bulbs*	*Fluorescent lights*
Electricity used	6-8Watts	60 Watts	13-15Watts
Contain mercury	No	No	Yes
CO2 emissions	451pounds/year	4500pounds/year	1051pounds/year
Turns on instantly	Yes	Yes	No
On/Off cycling effect	None	Some	Yes
Failure Modes	Not typical	Some	Yes
Heat emitted	3.4 btu's/hour	85 btu's/hour	30 btu's/hour
Sensitive to humidity	None	Some	Yes
Fragility	Durable	Not Durable	Not Durable

3.1 Types of LEDs

There are two types of visible wavelength LEDs; Single color LED such as red (R), green (G), blue (B) LEDs and white LED. Typically, red, green, and blue LEDs emits a band of spectrum, depending on the material system. Red LEDs emits the wavelength around 625 nm, green LEDs around 525 nm, and blue LEDs around 470 nm. On the other hand, the white LED draws much attention for the illumination devices. The visible radiation detectable to the human eye is between 480nm to 750nm [2]. White light emission from an LED is by mixture of multi-color LEDs or by the combination of phosphors with blue LED emission [3]. The first type is fabricated by mixing light from the three primary colored chips (RGB). Three chips emit each color simultaneously and at the output white light is produced. The other type consists of a blue LED chip with a phosphor layer coated on top of it. When electric current is applied to the LED chip, blue light is emitted and part of it is absorbed by the phosphor to generate second color—yellow light. The combination of blue and yellow lights results in white light. The phosphor white LED has the advantage of low cost. However, the nature of phosphor light conversion makes it unsuitable for high speed direct modulation because the response time of phosphor is much lower than the LED chip, and the direct modulation speed is usually limited to a few MHz. From the illumination viewpoint, the RGB or white LEDs can be used for VLC. From the communication viewpoint the phosphor based white LED has longer rise/fall times due to phosphor absorption/re-emission times. It is noted that each LED can find its appropriate applications for VLC systems [4].

4. VLC Modulation Techniques

There are a number of different methods that can be used to modulate the data over the visible light spectrum, the main methods are [4];

On-off keying (OOK): As the name suggests the data is conveyed by turning the LED off and on. In its simplest form a digital '1' is represented by the light 'on' state and a digital '0' is represented by the light 'off' state. The beauty of this method is that it is really simple to generate and decode. However, this method is not optimal in terms of illumination control and data throughput

Pulse width modulation (PWM): This method conveys information encoded into the duration of pulses. More than one bit of data can be conveyed within each pulse, but they may have to be longer pulses than for OOK, so there is no great advantage with this scheme. It is also possible to transmit data in an analogue format using this scheme which is also relatively simple to implement

Pulse position modulation (PPM): For PPM the data is encoded using the position of the pulse within a frame. Again more than one bit can be transmitted in each pulse, however the duration of the frame must be longer than for a single OOK bit, so again it is not necessarily more efficient. It does have the advantage of containing the same amount of optical energy within each frame

Variable Pulse Position Modulation (VPPM): This is similar to PPM but allows the pulse width to be controlled for light dimming support. Pulse amplitude modulation (PAM), As the name suggests, the information is carried by the amplitude of the pulse. A number of data bits could be conveyed in a single pulse. e.g. off =00, 1/3 amplitude =01, 2/3 amplitude =10, full amplitude =11. In this example four different amplitude levels are used to carry two bits of information. PAM can carry more data in each pulse than OOK, but it is more complex and more susceptible to noise on the optical channel.

Colour shift keying (CSK): This can be used if the illumination system uses RGB type LEDs. By combining the different colours of light, the output data can be carried by the colour itself and so the intensity of the output can be constant. The disadvantage of this system is the complexity of both the transmitter and receiver.

Orthogonal Frequency Division Multiplex (OFDM): This modulation scheme has been widely used for digital TV and radio and also for WiFi. It can be modified for use in optical communications. OFDM uses a set of sub-carriers each at different but harmonically related frequencies. There are a number of advantages including good spectral efficiency but this method is quite complex to implement.

Spatial Modulation (SM): There are a number of techniques that allow one to determine the source of an optical signal. If one can determine its source one can either use the multiple sources of information to convey multiple stream of independent data (one from each source), or one can use the source of the signal as part of the information encoding itself. The multiple sources could be multiple LEDs within a single fixture.

5. VLC Potential Applications

As far as LEDs based system applications are concerned, their domain is very versatile ranging from commercial purpose, academic and industrial research. From inner satellite to military purpose, from hospitals (where electromagnetic interference must be avoided) to aircrafts, from lighting to automobiles, LED applications are extended.

Aviation: Radio waves cannot be used by passengers in aircrafts. LED-based lights are already used in aircraft cabins and each of these lights could be potentials VLC transmitters to provide both illumination and media services for passengers. Furthermore, this will reduce the aircraft construction costs and its weight as shown in Figure (1).

Figure 1: VLC in Aviation

Smart Lighting: Smart buildings require aesthetic lighting. Smart lighting with VLC provides the infrastructure for both lighting and communication and reduces the circuitry and energy consumption within an edifice.

Hazardous Environments: In environments such as petro-chemical plants, mines, etc, RF is potentially dangerous because there are explosion risks, so communication becomes difficult. VLC can be used in this area as it is a safe technology and provides illumination and communication at the same time.

Device Connectivity: By directing a visible light at a device one can have a very high speed data link and security because a beam of light is shined in a controlled way.

Vehicle and Transportation: Traffic lights and many cars use LED-based lights. Cars can communicate with each other to prevent accidents and also traffic lights can communicate with the car to ensure road safety as shown in Figure (2)

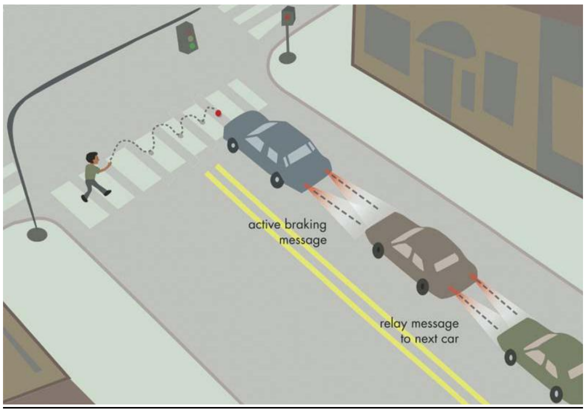

Figure 2: VLC in Transportation

Defense and Security: VLC can enable secure and high data rate wireless communications within military vehicles and aircraft.

Hospitals: In hospitals, some equipment is prone to interference with radio waves, so using VLC has many advantages in this area.

Underwater Communications: VLC can support high data rates beneath the water, where other wireless technologies like RF do not work. Thus, communications between divers or remote operated vehicles are possible.

6. VLC Challenges

VLC is still in the early stage that there are many severe problems or limitations needed to be solved.

Line Of Sight (LOS): LOS is a definite advantage because the signal will be stronger. Visible light signals can be reflected but does not penetrate most of objects in our daily life which can be a security advantage and perhaps a coverage disadvantage [1][2]. This characteristic can be also considered as a disadvantage that preventing the signal from spreading among multiple rooms. And furthermore, reflection can absorb much energy so that the rate of communication without LOS between the transceivers is greatly limited [3]. Not any optical spread signal under power regulation can be strong enough to let reflected signals still preserve enough power for communication. If light levels are low and VLC receiver can collect photons, it can receive data at a lower data rate. Like radio technology that indirect signals have a lower power and hence the data rate reduces [4].

Duplex Transmission: VLC is a broadcast communication, and providing an upstream communication channel is challenging. Several approaches have been considered, such as using the infra-red (IR) or flashlight LED in the portable device for the upstream communication. The use of radiofrequency (RF) to provide an upstream channel has also been considered. At present there is no concrete conclusion as to which solution is the best, and further work is required to develop potential techniques and compare alternatives.

Transmitter Sources: Specialist LEDs with ideal characteristics for VLC would be great. Solid state LED lighting is currently being sold based on its performance for illumination purposes only. Communications performance is not even a secondary consideration so it is entirely impractical to expect the lighting industry to aspect this into designs at this stage. In a practical sense excellent results can be achieved with COTS LED devices. If better devices are available for VLC then great otherwise to implement VLC existing LED devices can be considered [3].

Dimming Control: Another challenge in VLC is how to communicate when the lights are "off". If the lights are usually "on", VLC transmission power comes free as it is already used for the illumination. However during daytime, people tend to switch off the room lights. In order to maintain the communication link, the LED should be "on". In this case, similar to RF wireless communications, the power consumed for the data transmission is not free. One technique that may be used is to reduce the LED brightness to a level low enough so that people will accept that the light is "off" which solution is the best, and further work is required to develop potential techniques and compare alternatives.

Interference from sunlight: This problem is also associated with a wide transmission beams. In visible light, this becomes more critical since the ambient light could be very strong that the resulting SNR is low [1]. It is relatively simple to eliminate the vast majority of interference from natural and artificial sources using optical filters [2]. After the photo-detector further analogue and digital filtering ensure remaining interference is negligible.

Equalization: The channel response can be equalised at the transmitter (pre-equalisation), at the receiver (post-equalisation) or a combination of both. At the moment it is not known which technique will provide highest data rates.

Complex Modulation: A high-SNR, low-bandwidth channel is typically suited to high bandwidth efficiency multilevel modulation schemes. 100Mbit/s is possible using Discrete Multi-Tone Modulation (DMT). At present there is little work in this area, and further studies are required in order to assess the relative benefits of analogue equalization with relatively simple modulation, or complex modulation and limited channel bandwidth.

Regulatory Challenges: In most cases VLC is subject to regulation by a non-communications standard. This can be an eye-safety standard, illumination regulation, or an automotive standard in the case of traffic signals or signal lights. A VLC standard must therefore encompass both communications and associated illumination practices. This is distinct from most other communication standards, and presents the challenge of coordination across regulatory bodies and frameworks. Currently there are activities in several areas. Within Japan VLCC has developed several national standards [4], and the IEEE 802.15c Study Group on VLC is currently working on producing the necessary documents to become a working group. Interest in these activities continues to grow, but perhaps the major challenge for the VLC community is to develop links with other relevant regulatory bodies to ensure compatibility of any techniques.

7. Conclusion

A survey on visible light communication has been presented. VLC can be exploited for simultaneous function as illumination and data. For future short range applications, VLC present a viable and promising supplemental technology to radio wireless systems. Although there are many challenging issues, VLC remains one of the most promising technologies in the future.

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