VISIBLE LIGHT COMMUNICATIONS BASED TRAIN CONTROL

MEHMET ALI DAGLI
Aselsan Electronics Industry and Trade, Inc., Turkey

ABSTRACT

Within the rail environment, as well as in any part of life, communication is one of the most important topics. With the advanced features gained via the new communication technologies, train control systems are improving too, especially at the urban transport level with reduced distance between the running trains, more trips can be performed. Continuous communication is the most important role in that improvement. Within this paper a new communication utility is proposed for the urban transport signalling systems. Using the state of art visible light communication (VLC) technology, we show how to design the illuminations of the underground lines as the communication medium between the central processors and the trains. In addition to the signalling systems, thanks to the high capacity bandwidth of VLC, big data transfer used on the other systems like real time monitoring and managing of the trains can be supported. Another proposed design is for providing new features to the recent conventional signalling systems via upgrading the light bulbs with the VLC-enabled LED ones. With all of these aspects shown in the paper it is worth mentioning that existing conventional systems can be upgraded, new communication medium can be implemented or provide more redundancy and availability can be added to the present wireless communication systems.
Keywords: visible light communication, VLC, CBTC, signalling, railway.

1 INTRODUCTION

The ever-increasing population of people living in metropolitans brings with it increasing capacity needs in public transportation systems. As in many areas of life, this increase need in this area is tried to be solved by automation. At the same time, system risks that need to be taken into account with high frequency transportation increase. In other words, in the railway transportation system, in which it is included many sub-systems like infrastructure, energy, rolling stock, operation management, maintenance other than train control [1]. Each system receives, produces or transmits the data it needs. Looking at the entire ecosystem, daily data produced can be at the level of terabytes. This brings need for the high capacity transmission of these data.

2 CBTC TECHNOLOGY

With an effectively established infrastructure, railway metro systems can bear the biggest load in urban public transportation. The importance of operating at a high frequency has increased even more these days due to the density of passengers in the train can cause dissatisfaction. Communications based train control (CBTC) systems are used in many parts of the world with the need to operate at high frequency.

A CBTC system is a continuous, automatic train control system utilizing high-resolution train location determination, independent of track circuits; continuous, high-capacity, bidirectional train-to-wayside data communications; and train-borne and wayside processors capable of implementing automatic train protection functions, as well as optional automatic train operation and automatic train supervision functions [2]. With this system, operation can be performed in 90 seconds frequency [3].

Being able to operate this frequency requires the fastest communication and action of trains and all components in the railway system. The status of the trains and the equipment

WIT Transactions on The Built Environment, Vol 199, © 2020 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/CR200081

on the track is monitored instantaneously; all the components are automatically monitored and controlled by real-time commands by evaluating the incoming data.

Increased levels of automation, as mentioned in the introduction, can also increase system risks and require the use of other supportive systems to ensure safety. This makes it important to transmit and store big data. For instance, in the driverless subway systems, many parameters of the trains and in-car camera images shall be transferred to the control centre. With this supporting system, hundreds of cameras may need to stream instantly.

3 VLC TECHNOLOGY

Visible light communication is an increasingly popular technology in the field of communication. It has become a technology that is in use worldwide with the widespread use of light-emitting diode (LED) technologies and the standardization studies of the related joint committees.

In optical wireless communications, data is transmitted by intensity modulating optical sources, such as LEDs and laser diodes, faster than the persistence of the human eye. Optical wireless communications merges lighting and data communications in applications such as area lighting, signboards, streetlights, vehicles, traffic signals, status indicators, displays, LED panel, and digital signage [4].

There are various advantages to use the visible light communication. One of these is visible light is very safe for human. And, the data can be transmitted by the visible light communication even through a high voltage of home/office lighting. Another one is the lightings are set everywhere. Then, the data wireless transmission system can be easily established through the visible light communication device attached to the lightings. On the other hand, the radio wireless communications have several problems although they are widely in use of cell phones and wireless LAN. One of these is the electric transmission power cannot be increased because of the bad effect to human body. Another one is due to the radio wave restriction, there is no room to use more radio frequency [5].

On the other hand, visible light frequencies vary from 430 THz to 770 THz, which is 10,000 times larger than the entire radio frequency spectrum [6]. Thanks to the high frequency of light waves, VLC searches have already obtained impressive results, reaching speeds of 100 Gbps [7].

There are various VLC structures consist of transmitter, receiver or transceivers. A sample diagram of a VLC transceiver is seen is Fig. 1 where OFDM is rate-adaptive orthogonal frequency division multiplexing and TIA is trans impedance amplifier [8].

3.1 VLC use cases

There are many use cases about the VLC. Main application areas are indoor internet or entertainment streaming applications, indoor positioning applications, underwater communication applications, transport and vehicular systems applications. Vehicle communication is most attractive area because of intense usage of LED light on the vehicles and the transport environments.

The use cases from the road traffic have similarities with the railway transportation. Both has regulations via the signalling systems. One of the use case from Japan focused on the implementation of the VLC technology by changing the infrared sensors with LED headlight and photodiodes.

As shown in Fig. 2, because of the distortion coming from the daylight they narrow down the field of view by using lens in front of the photo diode. As seen in Fig. 3, they performed

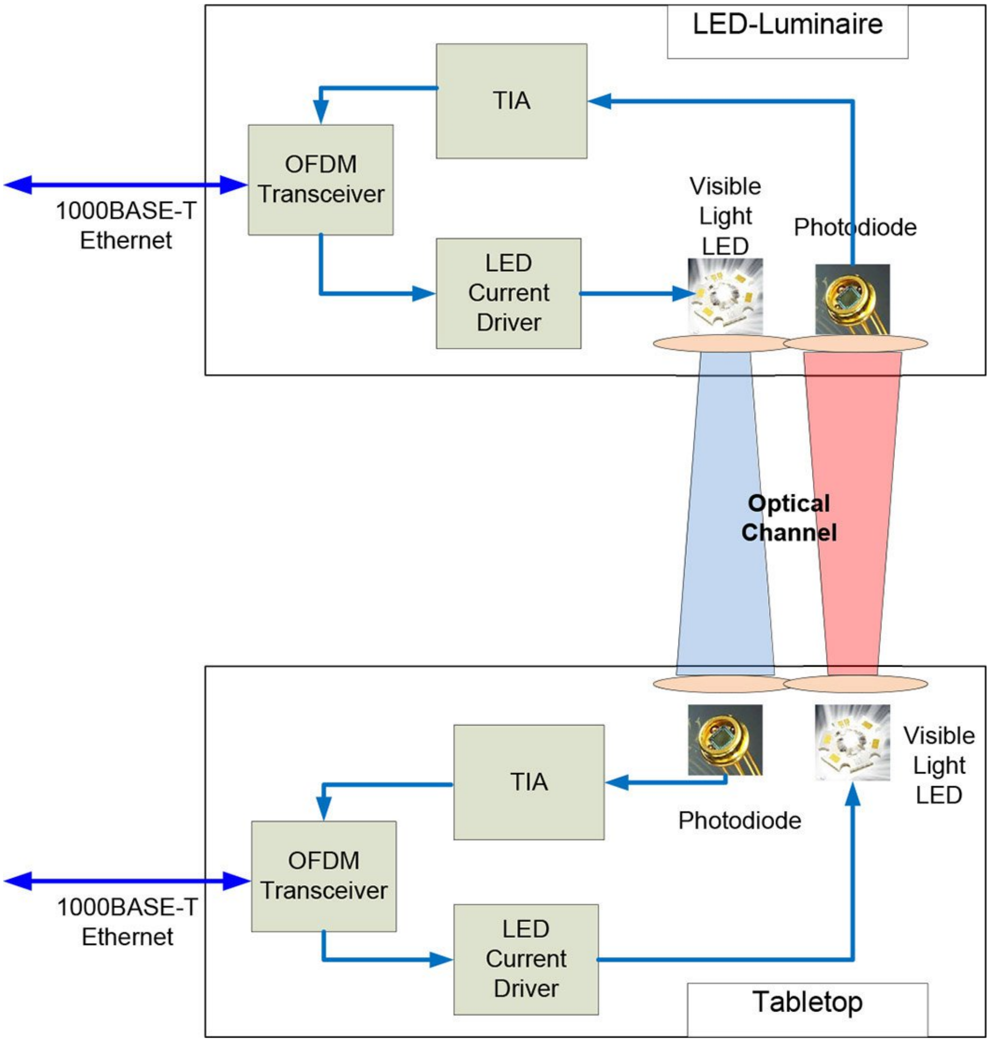

Figure 1: The overall scheme of a bidirectional real-time LOS visible light communication [8].

several measurements and they find the 25 m distance from the car headlight and 5 m height from the ground suitable for the receiving enough illumination values.

After experiments at a sunny day, with a car moving at 20 km/h speed they reached 3.1 Mbps throughput. They maintained higher throughput but packet success rate decreased [12].

There are other experimental VLC studies about the vehicular communication which used several measures to prevent the negative effect of other light sources like using colour filters [13]. Because of the environmental effects and the lack of off the shelf successful products, data rates are far from the theoretic rates that VLC can present.

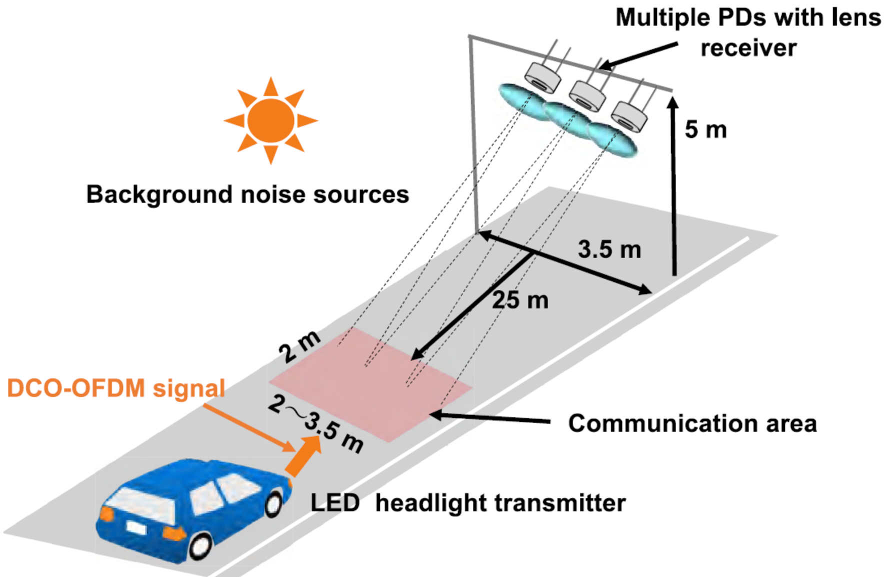

Figure 2: The uplink VLC beacon system. The transmitter is an LED headlight and the receiver is multiple PDs, each with a lens [12].

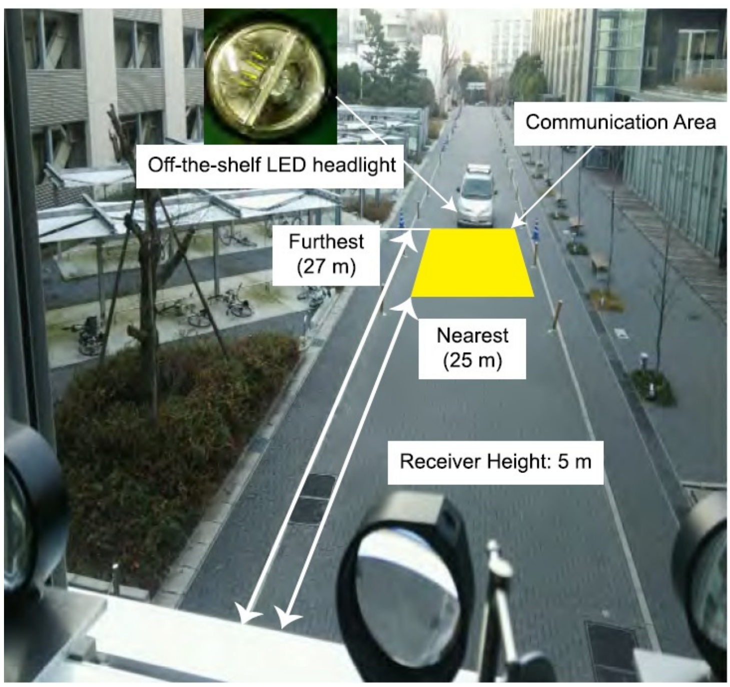

Figure 3: Experimental setups for SNR measurement at the farthest (27 m) and nearest (25 m) communications area [12].

3.2 VLC for CBTC

One of the important features that distinguishes the CBTC system from traditional fix block signal systems is that it reduces equipment maintenance costs in the field. Sensitive and frequent train position information can be obtained by dividing the line into small pieces with the moving block principle [9]. To provide the same frequency of information with rail circuits or axle counters, a large number of equipment will need to be placed on the site.

Although CBTC has provided a reduction in the number of equipment, it is a considerable number in the other equipment it brings with it. With this system, depending on the geometry of the tunnel, it is assumed it may be necessary to place a wi-fi access point with an average of 200–300 m [3].

There is a need for a large number of access points to meet the need to monitor vehicle information and in-car camera images centrally in CBTC operations, which are in unassigned train operation infrastructure. In this monitoring system, although efforts are made to use the common wi-fi infrastructure with the signalling system, it is still preferable to set up a separate network for security reasons. Also cyber security issues may be brought to the agenda in communications over wi-fi and extra measures are needed.

In the use of another communication equipment, balise or RFID transponder equipment on the track and reader units are installed in each vehicle. There may be damage to the equipment, various maintenance in the field or misplacement in renewal situations.

Visible light communication is a technology, which is suitable for use as a communications infrastructure in CBTC and the supporting systems, which ensures the maintainability of the operator company. Environments where lighting is provided, VLC can be used as a communication tool. This infrastructure can be provided by replacing the tunnel lighting on the subway lines with VLC technology LED lighting or using these lighting products directly on the new lines. Opposing these lamps, which will work as data transceivers, there should be transceivers on the vehicles. In this way, bi-directional communication environment can be provided. With these lighting products, which are frequently placed in the tunnel, continuous communication between the train and the centre will be provided. Transceivers can be installed more than once in the upper part of the vehicle, as demonstrated in Fig. 4, and the data accuracy can be increased and redundancy can also be provided. Since the lighting units in the tunnel will be at more frequent intervals than wi-fi access points, signal performance will also be high).

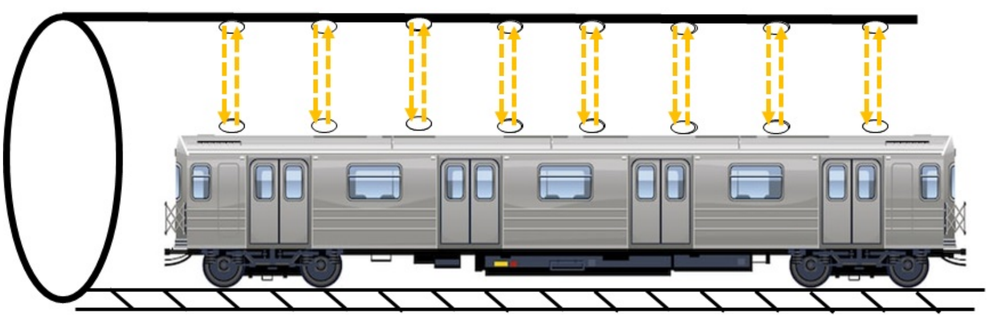

Figure 4: Tunnel lights for the bidirectional visible light communication.

3.3 VLC for main lines

The blocks separated in fix block signal systems are separated by signal lights, and the train drivers get the information that the region they are about to enter is occupied or not. In some cases, the vehicle can be stopped automatically with the balise connected to the signal at the wayside and a sensor on the vehicle. These signal indications, which are a visual warning for the train driver, can also be detected by VLC transceiver, a virtual eye to be placed in front of the vehicle as shown in Fig. 5. The information to be transmitted may be information pertaining to the stop or departure perceived by the train driver, and the information that is in use, such as automatic stop information obtained from the balise, and the speed limit information to be obeyed in the relevant region, can be transmitted with this new medium [10].

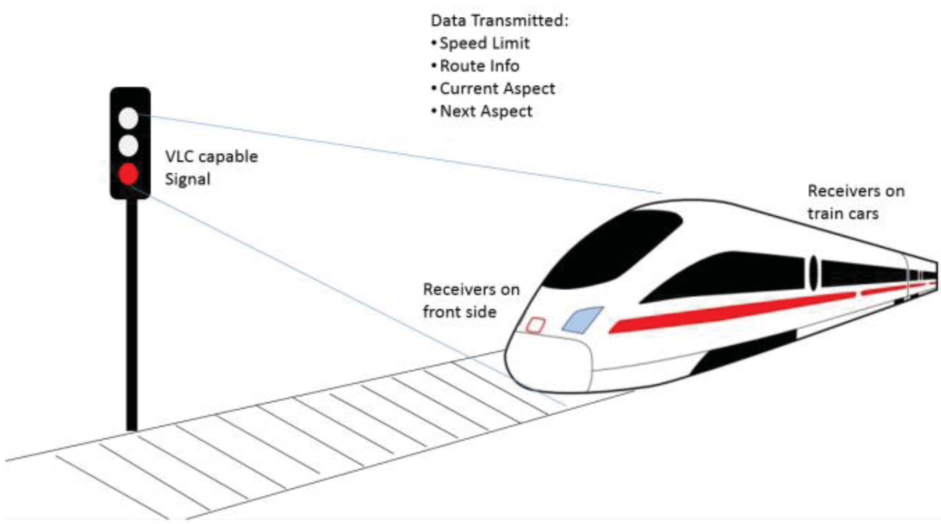

Figure 5: Signal lights for the communication transmission to the train [10].

In addition to these, information which comes with CBTC system technologies such as speed limit and movement authority information, information about arrival to the next station, information about the train in front of it, information about a few blocks ahead can be transmitted from the signal light to the train. Similarly, vehicle information such as direction, speed, fault status information can be transmitted from the vehicle to the centre. Signals at the station entrances and exits can also be enhanced with different information such as station stop/departure detail information or door status information. With new information to be added such as these, the information circulating and processed in traditional signal systems can be increased and features close to CBTC systems can be gained.

4 CHALLENGES

Light is spreading on the air by reflection and it cannot pass through the obstacles like walls. So the limit is the line of sight. Not only the walls also weather conditions like rain, fog, snow have effects on the line of sight, so to the light too. In subway tunnel applications, these environmental effects would be less but for the outdoor applications like main lines it will be a big issue.

In a wi-fi network, devices that transmit on the same frequency can interfere with each other. When light is used as a communication medium, natural light becomes a source of interference in communication, degrading VLC, especially in the case of outdoor applications. In addition to natural light, artificial lights also interfere with communication, and may even saturate the receiver.

Another challenge is the lack of required products. Especially at signalling system there are various standards or regulations to be ensure the safety and reliability of the system. The hardware chosen for these systems are railway specific products. For now there is lack of railway compliant proven VLC products to use.

A useful communication system built with VLC must allow uplink and downlink. LED light bulbs can be used for both, as a VLC transmitter and as a light source. In the receiver, a simple photodiode can be used to receive modulated light, which will be further decoded. In this sense, the downlink, i.e., the transmission from a LED light to devices, is straightforward.

However, sending data from devices to a LED light bulb is more challenging. A number of research papers consider the use of Visible Light Communication for both downlink and uplink. To remove the effect of signal reflection interference, researchers propose the use of techniques such as time-division duplex (TDD). TDD decreases the data rate since slots of specific duration are allocated both for downlink and uplink. However, high-level modulation mechanisms, such as OFDM can achieve better performance [11].

5 CONCLUSION

The importance of high speed big data management is increasing in the CBTC system and other supporting systems in underground train operations that need high frequency trips. This brings together the need for continuous improvement in communication systems. VLC has been increasing day by day in the developments in communication technologies. In many areas, efforts are being made to implement communication over light rather than RF communication. Although it is a technology that has not yet completed its development, thanks to its advantages, its usage in the railway business is promising as it is in many areas where the studies continue. With the production and the use of equipment suitable for the railway environment, the usage of VLC in CBTC systems will become widespread.

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