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Survey of Optical Wireless Communication Technology for Communication System Applications in Transportation

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Abstract
Wireless communication has developed rapidly, especially in Optical Wireless Communication (OWC) for Transport Communications. The OWC for Transport Communications provides many long-term benefits. OWC for transport communications offers reliable and efficient technology to support increasingly sophisticated transportation systems, such as autonomous vehicles and smart traffic management systems. A literature review is used as a research method for searching, collecting, and reviewing the literature. Several discussions were obtained from the papers reviewed that focused on the development of optical communication technology and model design to improve the efficiency of optical wireless communication performance for transportation communications. Then, the challenges faced by OWC technology for transportation communications range from problems in resistance to physical disturbances, high mobility, and infrastructure costs to security and privacy. Thus, it is hoped that this paper review can be a reference for further research so that it can offer solutions to deal with it.

1. Introduction

Transportation is one of the most important means of moving goods and people from origin to destination. In recent decades, transportation has played an essential role in driving economic growth, increasing mobility, and facilitating the exchange of goods and services between regions. In the technology field, wireless optical communication has contributed significantly to optimising communication systems in transportation. The need for wireless optical communication for transportation in its application is such as a vehicle-to-vehicle

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communication system that allows vehicles to communicate with road vehicles by exchanging real-time information on road positions and conditions, public transportation systems such as high-speed trains and buses, as well as traffic monitoring and control systems [1].

Transportation communication is the exchange of information between various entities related to the transportation system, including vehicles, transportation infrastructure, road users, and parties involved in traffic regulation and supervision. Transportation communication aims to improve safety, efficiency, and user experience in transportation systems. [2].

Starting from research [3] Which aims to make vehicles communicate with other vehicles. However, its application using conventional radio frequency (RF) often experiences low packet reception and high latency, especially in congested road scenarios, due to the enormous amount of interference generated by a large number of nodes on the same network. In addition, RF does not have the accuracy to support this because the direction of the beam is omnidirectional.

Then, in the research [4] their paper was based on several evaluations from previous research related to the problem of communication between vehicles on the street. This study proposes a prototype of an improved channel reinforcement model by using relative distance, relative speed, and time to predict the position of other vehicles in the future. The proposed model uses a prediction-based channel for Visible Light Communication (VLC) to overcome the routing time lag. The model also ensures the quality and stability of the line by using the proposed route metrics to select the next relay vehicle.

The researcher wrote this paper to explore the latest developments in wireless optical communication technology for transportation communication. By collecting and analysing relevant literature, this research will present an in-depth understanding of technological developments, existing applications, challenges faced, and efforts to overcome these obstacles.

The application of wireless optical communication technology in transportation has great potential because it can provide high speed, large capacity, and high security. Light as a transmission medium enables fast data exchange, which is important for autonomous vehicles and trip optimisation. Wireless optical communication also provides more protection against cyberattacks and security breaches. With these various potentials, wireless optical communication can improve efficiency, safety, and convenience in increasingly complex and digitally connected transportation systems.

The results of this literature study are expected to provide valuable insights for researchers, practitioners, and policymakers in the field of transportation to understand the potential and limitations of wireless optical communication technology in the context of transportation communication. In addition, this literature study can also be the basis for further research and the development of more advanced technologies to support the advancement of smarter, safer, and more efficient transportation systems.

2. Research Method

This study contains a literature review obtained from scientific articles or journals related to the topic raised. Three steps were carried out to compile this research: collecting journal articles, identifying journals and proposals, and applying wireless optical communication for

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transportation communication. These steps are illustrated in Figures 1 and 2, which are the steps and flows that will be carried out in this study.

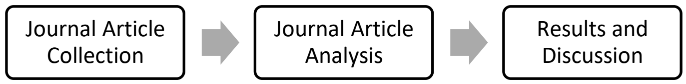

Figure 1. Research Method

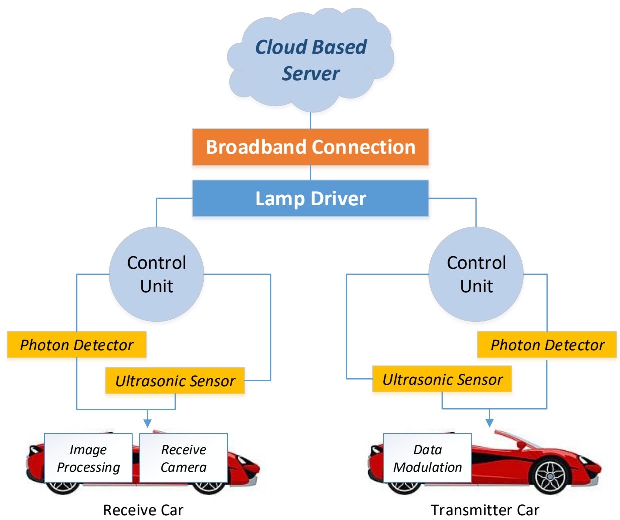

Figure 2. Framework OWC Vehicle-to-Vehicle (V2V)

2.1. Journal Article Collection

At this stage, the first step in the preparation of research is finding data sources that are suitable for this research. The data sources used include scientific articles and other sources related to the development of optical communication technology for transportation communication taken using IEEE Explore, Google Scholar, and Publish or Perish software by including keywords relevant to the research topic, including "wireless optical communication, wireless optics for transportation, and visible light communication for transportation communication" in The search is then arranged for the year from 2017 – 2023 as shown on Table 1. The main goal is to get in-depth and quality scientific journals that are still relevant to the current conditions. After a search, articles that match the research topic are then analysed.

Table 1. Number of Journals or Articles found for review (2017-2022)

No.	Journal Year	Number of Journals Reviewed
1	2017	Two journals reviewed (2)
2	2018	Three journals reviewed (3)
3	2019	Five journals reviewed (5)
4	2020	Six journals reviewed (6)
5	2021	One journal reviewed (1)
6	2022	Two journals reviewed (2)
Total Journals		Nineteen journals reviewed (19)

2.2. Journal Article Analysis

This step is to review all articles in table form. The data is sorted by the year of publication of the old research article to the latest research. This aims to make it easier for readers to understand

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and compare existing research. In addition, the elements identified include research results, challenges faced, and the latest progress of this research.

2.3. Result and Discussion

This step is the last process in this study, which discusses the solutions proposed by previous researchers to find out the problems of the design application that has been done. The problem must be assessed because technology design is not always perfect, and existing challenges must be solved. Other researchers can create difficulties in developing and improving the system, which previous researchers have done.

3. Result and Discussion

The study's results come from several journals and papers. Some of these studies have found two main problems: unpredictable traffic accidents and the solutions researchers offer to reduce delays in transmitting optical data for transportation communications. In addition, the papers will be sorted by the year of publication to make it easier for readers to read about the development of wireless optical technology from time to time.

3.1. Addressing OWC Technical Issues for Transportation Communications

The studies that have been studied with specific discussions are about how to overcome technical problems, as explained in the following explanations and Table 2.

Table 2. Overcoming Technical Problems in OWC for Transportation Communication

Reference	Year	Research Scope	Research Results
[3]	2017	Experiment	The study created a simulation scenario to test the VLC V2V system under real-world driving conditions. The prototype test was carried out with two cars driving on the highway with a total distance of 108 kilometres. As a result, the prototype can reach a range of 45 meters supported by a diode light collection system and repeated transmission in the middle of a driving scenario on the highway. It was found that the main factors of error performance were the distance and angle of arrival. The test also found *that the light-emitting diode* (LED) marker on the road produced narrow-band interference that caused transmission interference on *specific subcarriers*. However, these findings can be overcome with coding techniques.
[5]	2018	Experiment	The findings of this study indicate that VLC is an appropriate solution for vehicle communication. This study will examine the performance of VLC-based V2V communication. The results revealed that data speeds of 3.5 Mbps and 500 kbps were achieved at distances of 0.5 m and 15 m, respectively.
[6]	2018	Simulation	This reference discussion creates a synthetic image with the VLC transmitter to provide the specified test and evaluation conditions for each detection method mentioned. Based on initial testing, it has been determined that the method's performance varies with landscape conditions. The two main parameters have a significant impact on the color detection of LED emitters as well as the signal-to-noise ratio.
[7]	2019	Experiment	The study's findings are illustrated with images demonstrating the success rate of data transmission to the link range for two modulation depths, 50% and 100%, in focus and defocus camera modes. At an 80-meter link distance, the success rate in receiving bits from the traffic light drops to 98.5%. This only applies to defocus mode with 50% modulation depth. This is because the received power is spread across some pixels, resulting in a

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			lower signal-to-noise ratio (SNR). As a result, at 50% modulation depth, it is prone to errors.
[8]	2019	Simulation	The study uses a mathematical model to examine the effect of very sunny weather, rain, and snow damping on the VLC system. It was observed during simulations of the Infrastructure-to-Vehicle outdoor application system. Wet and dry snow are used, and each is measured at a different level of perception.
[9]	2019	Experiment	The study makes use of LED arrays and photodiodes for full-duplex communication, with spatial variation between the vehicle's headlights and taillights in the visible spectrum. The two lights in the front and back of the vehicle provide opportunities to investigate and analyze the possibility of multiple inputs and multiple outputs (MIMO). MIMO 2 × 2 configurations use sent and received variations to maintain communication at T-junctions between vehicles. The OWC system can communicate, but requires an SNR of ≥ 20 dB in the MIMO configuration to stay connected. Spatial variation in the transmitter and receiver enhances system performance when compared to SISO configurations.
[10]	2020	Simulation	The results of this study show that optical wireless optical communication technology focuses on cameras or image sensor receivers. The purpose of this study is to provide a detailed review of camera optical communication techniques on standardisation, path classification, modulation, scripting, synchronisation, and signal processing methods for camera optical communication networks. The results of this study showed that the camera was in the centre of its optics at the coordinates (500, 500, zero mm).

In reference [3] It is motivated by the idea of making vehicles able to communicate with other vehicles. However, its application using conventional RF often experiences low packet reception and high latency, especially in congested road scenarios, due to the sheer amount of interference generated by many nodes on the same network. In addition, RF does not have the accuracy to support this because the direction of the beam is omnidirectional. The purpose of this study is to try to make a prototype of a communication device between vehicles using VLC. VLC offers great scalability because it only communicates in a small, face-to-face sphere and within the same communication channel.

In reference [5] Motivated by an increase in highway accidents, the main issue is traffic congestion and an increasing number of vehicles on the highway. This study will look at the performance of VLC-based V2V communication. The study found that data speeds of 3.5 Mbps and 500 kbps could be achieved at distances of 0.5 and 15 m, respectively.

In reference [6] This study discusses the detection of the position of VLC transmitters for use in ITS. This paper describes the three main LED detection techniques for VLC transmitters and proposes new detection methods based on their output combinations. This article also compares three methods separately, including a colour segment-based method, a maximum image difference detection method, and a shape detection method. Probability values are calculated for each detection method to compare techniques in different scene conditions. Another way to represent the performance of this method is to calculate the distance between the simulated and detected LED positions.

In reference [7] Motivated by the growing use of light-emitting diodes in traffic lights, this presents an excellent opportunity for the integration of VLC-based wireless technology as part of an intelligent transportation system in a smart environment. In this study, an experiment was

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conducted to demonstrate a vehicle-to-infrastructure communication system based on VLC technology over a distance of up to 80 m using traffic lights and cameras.

In reference [8] It is motivated by rainy and snowy weather, which impedes movement. The goal of this research is to present a simple analytical model for thoroughly investigating the impact of rain and snow damping on outdoor VLC communication channels. The simulation results show significant differences in the information received under different weather conditions based on the modulation scheme used. Simulations have been conducted on two-lane roads, with a green traffic LED with a wavelength of 505 nm serving as a transmitter.

The reference [9] is motivated by the assumption of LED arrays and photodiodes for full duplex communication, with spatial variation between the vehicle's headlights and taillights in the visible spectrum. The two lights in the front and back of the vehicle provide opportunities to investigate and analyze the possibility of multiple inputs and multiple outputs (MIMO).

The reference [10] is motivated by the range of wireless optical communication, which can overcome transmission difficulties in several fields of use, ranging from factory mechanical units to vehicle systems. The purpose of this study is to provide a detailed review of camera optical communication techniques on standardisation, path classification, modulation, scripting, synchronisation, and signal processing methods for camera optical communication networks. The results of this study showed that the camera was in the centre of its optics at the coordinates (500, 500, zero mm).

3.2. Creating and Developing a New Model for Troubleshooting in OWC for Transportation Communications

The studies that have been studied with specific discussions are about making and developing a new model for solving optical communication in the explanation and Table 3 below.

Table 3. Creating and Developing a New Model for Troubleshooting in OWC for Transportation Communications

Reference	Year	Research Scope	Research Results
[11]	2017	Simulation	This study yields a proposed CSMA protocol with collision detection (CSMA/CD) that takes advantage of the available backlinks. LEDs serve as transmitters and photodiodes as receivers for direct feedback during parsing. The use of FD in VVLN can increase data transmission by up to 10%.
[12]	2018	Simulation	This study's findings include intelligent transportation system positioning techniques that use visible light communication and image sensors to determine the distance between vehicles. The proposed algorithm calculates distance using two image sensors and a single LED.
[13]	2019	Simulation	This study found that using Orthogonal Frequency Division Multiplexing (OFDM) in conjunction with channel estimation and bit loading, this system maintains a packet error rate (PER) of more than 2m at more than 100Mbps and more than 15m at 14Mbps, demonstrating that this system can produce significant results.
[14]	2019	Simulation	The results of this study show that the converged network infrastructure for 5G services, consisting of wireless and optical network technologies to connect remote units (RUs) with computing resources, is energy efficient. The paper proposes a two-stage optimisation framework for converged 5G infrastructure operations. The results show that selecting the right transportation network technology and allocating individual BBU functions

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			to the appropriate computing modules can improve the use and achieve higher energy efficiency.
[15]	2020	Experiment	The mmW antenna model, as well as the Tx and Rx circuits, were designed for visible light communication. The VLC and mmW components are characterised, and the antenna's performance is evaluated using real-world simulations. The study's findings revealed that a minimum data speed of 5 Mbps and 50 baud was suitable for VLC and mmW links. Based on this, antenna modelling can provide dependable vehicle communication in the future.
[16]	2020	Simulation	The LiDAR sensors used have an accuracy of 93.983% and 92.21%, respectively; the minimum *Pulse Width Modulation* (PWM) value required by using three pieces of 3.7 V batteries assembled in series so that the system can move 30 with a generated speed of 0.18 m/s and from the tests carried out, the system has an accuracy of 87.5%, this value is obtained from 40 experiments along the mixed trajectory, and obtained results of 35 successes and five failures.
[17]	2020	Simulation	Using a mathematical model approach, the study tested the attenuation effect in various weather conditions for different wavelengths on the VLC system. The results show that two wavelengths, 463 nm and 514 nm, are considered appropriate for transmission in various weather conditions. The 463nm wavelength excels in a wide range of weather conditions except fog, compared to the 514nm wavelength because it produces a smaller attenuation value.
[4]	2020	Simulation	This study develops a predictive channel gain model and proposes a relay-based multi-hop routing algorithm for VLC in vehicles. This model predicts the vehicle's future position before feeding a prediction-based channel gain model into the routing algorithm to select the next relay vehicle. The observation results revealed a decrease in performance when driving direction was abruptly changed, indicating the need for additional research to improve accuracy.
[18]	2020	Experiment	This study provides an overview of the optical camera communication (OCC) system and discusses practical obstacles such as instability, Color Shift-Keying (CSK) reading, visual display quality, and interference between the sender and receiver. Based on these various practical constraints, this study proposes data modulation techniques, camera structure development, post-processing of the obtained signals, and OCC without line-of-sight.
[19]	2021	Experiment	This study tests the optical camera communication (OCC) equipment as a solution that has the potential to be applied to wireless sensor networks. The network strategy concept test uses two transmitters at 90 meters and 130 meters that communicate simultaneously to one 8bps CMOS camera. The test was also carried out on various large areas such as plantations, roads, parks, and industrial facilities. The overall test results show that the OCC sub-pixel method is adequate in several wireless sensor network applications in capability, cost-effectiveness, and scalability. The evaluation shows that the Rolling Shutter - Optical Camera Communication (RS-OCC) scheme has significant limitations and requires sizeable optical equipment.
[1]	2022	Experiment	The study created a design model that implements wireless light communication for *Vehicle-to-Vehicle* (V2V) communication. The scenario created is that if there are two vehicles in the convoy, and the vehicle in front is going slower, it will send a message to the vehicle behind it to reduce its speed. The technology aims to provide a simple solution to reduce accidents.

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[20]	2022	Experiment	According to the experimental results on the testbed, the study's effective new architecture model for using 6LoWPAN between Internet of Things (IoT) gateways and IoT devices in OWC-based IoT networks offers up to a 5% latency increase and a 19.52% throughput increase when compared to the transport model Conventional IPv6. Therefore, a good way to achieve wireless connectivity on the Internet of Things (IoT) is to use Internet Protocol version 6 (IPv6) and Optical Wireless Communications (OWC) over Low Power Wireless Personal Area Networks (6LoWPAN).

In reference [11] Motivated by the direct relationship between vehicles and activities, a variety of new applications were launched, ranging from security to traffic management. To enhance the capabilities and performance of radio access technology, light-emitting diodes (LEDs) on the vehicle's front and rear lights can detect additional levels of connectivity via visible light communication (VLC) by establishing direct contact between the vehicle and the roadside. The purpose of this study is to determine the performance of Vehicular Visible Light Networks (VVLN) in terms of messaging rate when full-duplex capabilities are used.

In the reference [12] It is motivated by an intelligent transportation system's positioning technique, which uses visible light communication and image sensors to determine the distance between vehicles. This study proposes a method for accurately calculating the distance between two vehicles when the camera resolution is low. The simulation resulted in an initial distance of 50 m between the two vehicles. The estimator and target vehicles have average speeds of 45 and 50 kilometers per hour, respectively. Two vehicles' speeds can vary by 10% at random over time.

In reference [13] This study looks at vehicle-to-vehicle optical wireless communication (OWC) using Smart Corner automotive headlights. Vehicle communication, in addition to sensors such as radar, lidar, and cameras, is critical to the development of future autonomous vehicles. Marelli's automotive-magnetic lighting combines this technology into a single automotive light known as Smart Corner. This study describes the architecture, integration, and performance of the OWC system used in the third-generation Smart Corner, presented at the Consumer Electronic Show (CES) 2019..

In the reference [14] Motivated by the overall development of the 5G network, which goes far beyond the evolution of mobile broadband, we aim to enable the future digital world to transform various sectors of the economy. There is a need to transition from traditional closed and inelastic network infrastructure to an open, scalable, and elastic ecosystem capable of supporting a wide range of dynamically changing applications and services. This research aims to improve the energy efficiency and performance of the 5G network, as well as to develop an optimization framework that facilitates the selection of appropriate transport network technology and the identification of optimal operating conditions in terms of the separation of Baseband Unit (BBU) processing functions.

The reference [15] This is motivated by the author's claim that no feasible solution has been proposed that incorporates the hybrid front-end antenna, VLC, and Millimeter Wave (mmW), as well as the possibility of such a hybrid transmission configuration. This study designed and demonstrated a hybrid VLC mmW antenna for use in the vehicle communication network. VLC transmitters can be integrated into the network alongside LED-based vehicle front and rear lights, and high-frequency, directional mmW channels will reduce interference between channels.

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In reference [16] It is motivated by human activities that cannot be separated from transportation, especially land transportation. Therefore, it is necessary to have a system that can regulate transportation so that it can run autonomously and significantly reduce congestion, accidents, and pollution. A prototype is required before realising it. Therefore, a road marking tracking system was created to prototype an autonomous vehicle with a LiDAR sensor base and a wireless optical network.

In the reference [17] As new data-intensive applications on mobile networks continue to increase, more problems arise. The main problem is that adjusting mobile traffic demand drives researchers to find innovative solutions for modernising conventional wireless communication techniques. In addition, the expansion of VLC technology and the use of energy-efficient LEDs in various equipment has also encouraged the development of wireless visible light communication. The study examines the resilience of two wavelengths adequate for wireless light communication in various weather conditions. These wavelength-based tests use attenuation parameters to assess resistance in different types of weather.

The reference [4] It is motivated by several evaluations from previous research on the issue of communication between vehicles on the road. This study proposes a prototype for an improved channel reinforcement model that uses relative distance, relative speed, and time to predict future vehicle positions. To overcome the routing time lag, the proposed model implements a prediction-based channel for VLC. The model also ensures that the line is of high quality and stable by selecting the next relay vehicle based on proposed route metrics. Furthermore, the prototype supports V2V communication with an adequate Signal to Noise (SNR) ratio and a lower bit error rate. The advantage of this study is that it takes a lot of evaluations from previous research used as a reference to propose a new prototype expected to solve several problems in V2V communication.

The reference [18] was motivated by the practical constraints in the OCC system when this study was made. Practical problems include instability and drop of frame sensors, visual display quality, and blockages in the channel between the sender and receiver in the OCC system. This study also provides a solution by increasing data speed by modulation, rolling shutter navigation, and using high-speed cameras and cameras for low frame rates and unstable problems. Non-light-of-sight solutions are offered to overcome the problem of channel blocking between sender and receiver.

In reference [19] This study is motivated by uncontrollable atmospheric conditions, which are a challenge in outdoor wireless optical communication. It discusses that the OCC system can be a solution with good potential for the advancement of data communication technology development. The OCC system was chosen because of its low integration costs. Many end devices have OCC-supporting equipment. This study aims to prove that OCC can be a viable alternative. The tests conducted with 90-meter and 130-meter transmitters showed that sub-pixel OCC has significant potential if used as an alternative.

In reference [1] It is motivated by the increasing number of internet users, which makes it more difficult for groups to get the bandwidth they need. In addition, radio waves also harm plant and animal ecosystems. This study discusses wireless optical communication as an alternative to data exchange. Wireless optical communication is claimed to transmit high-speed data cheaply to power existing technology.

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In the reference [20], The number of Internet of Things (IoT) devices that use wireless communication technology, such as Wi-Fi, ZigBee, or Bluetooth, for real-time data collection and monitoring has grown rapidly in a variety of industrial trial domains. In this case, wireless communication technology is an important part of IoT services and VLC. The goal of this research is to evaluate a new architecture model that is effective for using 6LoWPAN (6 (IPv6) over Low Power Wireless Personal Area Network) between IoT gateways and IoT devices in OWC-based IoT networks, providing better performance than the general IPv6 model.

3.3. OWC Challenges for Transportation Communications

In its application, OWC technology for Transportation Communication has several challenges, including [5]:

1. Resistance to Physical Disturbances
   Wireless optical communication systems are susceptible to physical interference, such as light scattering, absorption, and reflection. In diverse transportation environments, such as highways or railway tracks, various physical elements can interfere with optical transmission, such as rain, fog, dust, and passing vehicles.
2. High Mobility
   Wireless optical communication in transportation must overcome the high mobility challenges in fast-moving vehicles. Rapid changes in vehicle position and orientation can lead to loss or degradation of optical signal quality. Therefore, it is necessary to develop efficient tracking and search technologies to ensure continuous connectivity while vehicles are moving.
3. Infrastructure Costs
   Implementing wireless optical communication infrastructure requires significant costs. Installing fibre optics, sensors, and other supporting equipment requires a high investment. This challenge is especially acute in building and expanding wireless optical communication infrastructure across vast transportation areas.
4. Data Security and Privacy
   Wireless optical communication in transportation must also maintain the security and privacy of transmitted data. Because optical signals can be easily intercepted and detected, strong security measures must be implemented to prevent unauthorised access and leakage of sensitive information.

4. Conclusion

OWC technology for Transportation Communication is one of the optical technologies with great potential in transmitting data at very high speeds with better coverage than conventional technology such as radio frequency (RF). This is because developments continue to be made and new findings are always found that support OWC technology for Transportation Communication can be used effectively and efficiently, such as the studies that have been reviewed in this paper to conduct and provide solutions to engineering problems by developing new models, and other research that can provide input on the development of OWC for Transportation Communication through experiments and or simulations. In addition, it will be important to know the challenges OWC technology faces for transportation communication,

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ranging from problems in physical resistance to physical disturbances, high mobility, infrastructure costs, security, and privacy. It is hoped that in the next research, this paper review can be a reference; besides that, with the knowledge of the challenges faced by OWC for Transportation Communication, the following research can offer solutions to deal with them.

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