Progress report on visible light communication in intelligent transportation environment

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Abstract: With the continuous and rapid development of modernization and motorization, the number of cars in China has maintained a high growth, which leads to problems such as increased traffic congestion and frequent accidents. The emergence of intelligent transportation system can effectively solve problems and contradictions between people, vehicles and roads in real time. In recent years, the development of visible light communication in the intelligent transportation environment has been more and more rapid. This paper briefly summarizes the research and development of visible light communication in the intelligent transportation environment. First of all, the main interference factors of outdoor visible light communication are summarized: background light and atmospheric turbulence. Then, some methods and techniques to suppress or weaken them, such as the average aperture and channel coding mainly reduce the influence of atmospheric turbulence on outdoor optical communication, and the error rate of the outdoor environment experiment system is $10^{-3}$-$10^{-7}$. Adaptive optical MIMO technology mainly inhibits the communication interference caused by background light. In the outdoor background light environment, the communication distance can reach 15m and the bit error rate is $10^{-4}$. Finally, the research direction of outdoor visible light communication technology and its application in the field of intelligent transportation are prospected.

1. Introduction

Intelligent transportation system (ITS) is a service management system for transportation based on modern information communication technology, which was proposed by the American society of intelligent transportation in the 1960s and gradually popularized worldwide. After so many years of research and development, intelligent transportation has become more and more mature, and more and more extensive in practical application. In 2017, Patra, S et al. developed an easy-to-popularize intelligent transportation system, which uses standard smart phones to help drivers overtake cars. This system automatically creates a network between vehicles close-range and provides drivers with real-time video of vehicles in front of them [1]. Traffic congestion is an important issue for intelligent
transportation systems. In 2017, Zambrano-Martinez, L improved the modeling method of traffic congestion, predicted the impact of different solutions on urban traffic flow, and evaluated the impact of traffic flow changes on the overall road traffic congestion degree [2]. In 2018, Zhang, G et al. proposed an extended vehicle tracking model to simulate traffic flow in the context of intelligent transportation system, considering the average headway of the front vehicle group. Through the simulation of space-time evolution of time headway, it was shown that considering the average time headway can effectively inhibit traffic congestion [3]. In 2018, Kolak, OI et al. proposed an optimization method for the planning and management of public transportation in large cities, which can help traffic authorities to better predict the results of strategic management decisions in realistic traffic models, laying a foundation for the intelligent traffic management decision support system [4]. In 2018, Vij, D et al. analyzed the accumulated acoustic signals collected by the microphone sensor of the user's smartphone, and proposed a low-cost road traffic condition inference method to capture the characteristics of different traffic scenes, which can effectively improve the accuracy of each traffic scene [5]. In 2018, Liu, Q C proposed a method for predicting urban road traffic status based on heterogeneous manifold learning, the method based on isometric feature mapping algorithm, using all the consistent of the traffic flow information, improve the prediction precision of the road traffic condition, the experimental results show that compared with the traditional prediction method, the value of the equal coefficient increases greatly, and the prediction error is much smaller [6]. In the United States, the priority goal of planning and implementing intelligent transportation system in the last 10 years is to reduce traffic accidents by 15% through effective control of traffic flow and effective establishment of accident response system, which can save 5,000 to 7,000 lives every year. And China in the field of intelligent transportation, has invested much manpower, material resources and financial resources, at present, it has been able to collect and analyze the traffic planning information of networked vehicles, provide road planning solutions that are more suitable for actual traffic conditions to improve the synergy of urban vehicle routing, was reduced by 18%~30% of the maximum number of stranded vehicles, and reduce the overall travel time cost of the vehicle by 14%~29%, to a great extent, alleviate the urban road congestion situation [7].

In the field of intelligent transportation, the intelligent transportation system based on visible light communication has become a research hotspot in recent years. In 2016, Wang, YG et al. in order to improve the intelligent transportation system performance and the signal transmission distance, the receiver diversity technology based on the maximum ratio combination is used to successfully realize outdoor communication of more than 100 meters In the outdoor visible light communication system, and the bit error rate is lower than $3.8 \times 10^{-4}$[8]. In order to reduce highway sunshine and cloud effect influence on outdoor optical communication system, in 2016, Kim, YH applied robust region detection (ZD) and adaptive decision threshold (ADT) algorithms to visible light vehicle communication systems on highways, improving signal-to-noise ratio by approximately 16dB to 26 dB[9]. In 2017, Wang and N mainly studied typical application scenarios between traffic lights and trucks. On the basis of theoretical analysis and numerical calculation, they obtained the relationship between the speed of trucks and the switching time of traffic lights. This result is of great significance to effectively reduce the potential accidents caused by frequent acceleration and deceleration of trucks [10]. In 2017, Qin ling et al. proposed a visible optical communication system using the spread spectrum technology and pulse position modulation, which is used to solve the communication problems between traffic lights and vehicles. The system can realize the transmission between the intersection traffic signal and the vehicle at the intersection [11]. The following Figure 1 shows a schematic diagram of intelligent traffic simulation.
In conclusion, it can be seen that the research on outdoor visible light communication in intelligent transportation has a very great significance. The research status of outdoor visible light communication and the technology and algorithm of suppressing background light and atmospheric turbulence are introduced.

2. The main influencing factors of outdoor visible light communication

Recent studies on outdoor optical communication in complex environments have been hot and focused on different aspects. We summarize the effects of background light and atmospheric turbulence.

2.1 The effect of background light

The sunlight penetrating the earth's atmosphere and the reflected light after reaching the earth's surface are scattered and refracted under the action of the atmosphere. Together with the sunlight and refracted light, background light is formed. The radiation intensity of background light varies with the Angle and time of the sun. The sun, moon, planet, star, and sky background light are the main background light sources in the optical communication system, especially the sky background light. In 2013, Khatoon et al. used software analysis to obtain various estimation methods based on the parameters of the sky background radiation channel for the radiation stray light of the infrared system [12]. In 2014, Xu Quanchun et al. conducted theoretical calculation of the earth background radiation in the satellite-ground laser communication, and designed a shading system to suppress the background radiation [13]. In 2016, Lu Qiang et al. analyzed the influence of sky background light on communication error rate, and proposed the method of calculating the radiation intensity of sky background and the method of numerical simulation for feasibility verification [14]. In 2017, Fan Xinkun et al. analyzed the influence of background light on the laser communication system, and established the sky background light noise model and conducted theoretical analysis and simulation research [15]. In order to overcome the interference of strong background optical noise in the channel, Qin Ling et al. established the strong background optical noise model in the same year, and respectively constructed communication systems under PPM, Gold code and Gold code+ PPM [16].

In summary, for the receiving system, in addition to the effective light source power, all other strong background radiation falling on the detector of the receiving unit will affect the whole system. The background light and signal light enter the receiving system together. As the main background noise in the outdoor optical communication receiving system, the sky background light has an important influence on the acquisition, tracking and communication units of the outdoor optical communication system. In order to improve the communication speed and other performance of the communication system, the measures to restrain the sky background light effectively have an
important influence on the outdoor visible light communication.

2.2 Effects of atmospheric turbulence

Outdoor visible light communication uses the atmosphere as the transmission channel. The gas molecules and aerosol particles in the atmosphere absorb and scatter the laser radiation in the infrared band, thus causing the loss of receiving power. In addition, the atmosphere is not a uniform optical medium, and its temperature, humidity and pressure change randomly in a small range and a short period of time. Research on the effects of atmospheric turbulence optical transmission signal, in 2017, Chen Mu put forward a kind of can quickly calculate the atmospheric turbulence environment Angle reflector laser flitting back strong analytical algorithm, got the turbulent environment the analytical expression of the laser wave strong back and discuss the incidence Angle, turbulence intensity and so on the effects of parameters such as light intensity distribution form [17]. In 2017, when considering the internal and external scale of turbulence, Ke Xizheng studied the transmission characteristics of beam in atmospheric turbulence, and concluded that the external scale of turbulence had a large influence on the drift of beam, and the external scale had a large influence on the expansion of beam and the distribution of light intensity [18]. In 2017, in order to reduce the performance problems caused by strong flicker, R Li proposed the coherent optical code division multiple access visible optical communication system and derived the error probability expression of atmospheric channel [19].

In summary, the main effects of atmospheric turbulence on the propagation of light waves include beam propagation, beam drift, and strong flicker. In outdoor intelligent traffic communication, it is necessary to design a reliable intelligent outdoor traffic communication system by considering the influence of the above adverse factors and understanding the propagation characteristics of light in the atmosphere.

3. Atmospheric turbulence and background light reduction measures

Because atmospheric turbulence and background light have a significant effect on optical signals, researchers have proposed measures to suppress these factors.

3.1 The average pore diameter

The smoothing effect of aperture is used to reduce the fluctuation of receiving light intensity and to overcome the atmospheric turbulence effect. In 2016, Ahmed, Md. Mobasher et al., based on the optical communication system under atmospheric turbulent channel environment, used the aperture average effect technology to simulate the same peak power under three modulation modes, i.e., the on-off key control (OOK), the multi-pulse position (m-ppm) and the differential pulse position modulation (DAPPM), which have better performance than the previous two modes [20]. In 2016, Gokce, MC et al. analyzed the influence of transmitter radius, receiver radius, receiver number, source size, receiver aperture radius and atmospheric structure constant on communication performance respectively based on the background that MIMO technology can suppress atmospheric turbulence effect [21]. In 2017, g. Aarthi et al. studied the average spectral efficiency of optical communication system under the modulation of OOK and POLSK, and analyzed the influence of changes in the diameter of the receiving aperture on the system under different turbulence conditions [22]. However, due to the random changes of transmission light intensity, phase and transmission direction caused by atmospheric turbulence, interference of coherent receivers decreases sharply, which seriously affects the signal to noise ratio of receivers and increases the bit error rate.

3.2 Channel coding

Outdoor optical communication systems are generally limited in power, so there is a limit to improve the signal-to-noise ratio by increasing the transmitting power. Therefore, strong error control technology is needed. In 2012, deok-rae Kim et al. proposed an outdoor visible optical communication system based on controller local area network, which realized the communication between vehicles
and vehicles and analyzed the influence of optical noise on communication performance [23]. In 2012, seok-ju Lee et al. analyzed the signal-to-noise ratio of intelligent VLC system in the actual environment, and the results showed that the communication during the day was good, but the signal-to-noise ratio needed to be reduced [24]. In 2013, Liu Y F et al. proposed the zero-return zero-dirty paper encoding method NRZI to reduce the background noise of VLC communication, and the results showed that the signal transmission rate at both ends of sending and receiving signals reached 10Mbps in the transmission range of 1 meter [25]. In 2015, a. m. Cailean et al. completed the communication between LED traffic lights with hardware [26]. In 2016, qin ling et al., based on the optical communication system of intelligent transportation, analyzed and compared the signal-to-noise ratio of receivers of MPPM and other modulation modes in sunny, dry, rainy and wet snow days, and verified several modulation modes by experiments [27]. In 2017, Liu Cheng et al. theoretically modeled the atmospheric attenuation channels in fog, rain and snow for two application scenarios of near-field laser communication and satellite-to-ground laser communication, and compared different modulation formats. BER performance, the results show that the use of appropriate modulation format for short-range communication can effectively suppress the effects of atmospheric turbulence. [28].

3.3 Adaptive optics

Adaptive Optics (AO) can correct the influence of atmospheric turbulence in real time. A large number of research results show that adaptive optics can not only improve the communication quality of non-coherent communication systems, but also improve the mixing efficiency of atmospheric communication, and decrease the bit error rate, increase the communication distance. Liu chao et al. conducted a study on the effect of the random changes of atmospheric turbulence on the laser communication in the atmosphere, and quantitatively analyzed the effect of the adaptive optical technology on the correction of atmospheric turbulence in the communication band [29]. Ha Duyen Trung et al. theoretically analyzed the effect of directionality error on FSO system in atmospheric channel with subcarrier intensity orthogonal amplitude modulation. In order to simulate the atmospheric turbulence channel, this paper uses logarithmic normal distribution to represent the medium and weak turbulence conditions, and uses gamma-gamma distribution to represent the strong turbulence conditions. The data results show the influence of directional error on system performance and how to improve the characteristics of such systems by adopting appropriate aperture size and beam width [30]. Moven-ui-ahsan et al. studied that in the FSO channel with fog, fog and background light radiation had a severe impact on system BER. When the angle between transmitter and receiver was optimal, the signal-to-noise ratio was the largest, and the BER of the system was the smallest [31]. Huan Chang et al. proposed a wavefront sensorless adaptive optics system based on GS phase recovery algorithm to correct the distortion of the actual orbital angular momentum beam, which can effectively compensate the actual orbital angular momentum and propose a new idea for an adaptive correction system [32]. However, a large number of experimental results show that the AO system can only effectively correct atmospheric turbulence under moderate and weak atmospheric turbulence conditions.

3.4 Detection algorithm

In outdoor visible light communication, using LED as a transmitter, but with all sorts of small molecules in the atmosphere, the visible light communication system after atmospheric channel, under the influence of atmospheric turbulence and the background noise of light, cause the loss of optical power, resulting in the receiver to receive the optical signal strength is high and low, influence the accuracy of signal detection. In order to suppress interference, a high performance detection algorithm is usually required. The main problem of outdoor visible light communication is to estimate the signal and detect the signal when the existing channel research is not sufficient. Common signal detection algorithms include symbol - by - symbol detection and sequence detection. In 2013, Zhang and I. et al. proposed an improved maximum likelihood by symbol detection with pilot frequency assistance in order to reduce the influence of error between channel fading coefficient and ideal fading coefficient.
on bit error rate. The results showed that the improved maximum likelihood detection algorithm could not only reduce bit error rate, but also achieve better communication performance [33]. However, since the calculation amount of the symbolic detection algorithm is much higher than that of sequence detection, sequence detection has been favored by people since Zhu, X M. et al first applied sequence detection to free space optical communication [34]. In 2014, Song T. Y et al proposes a generalized likelihood ratio test based victor than sex grid search sequence receiver, receiver only need a few pilot symbols, so not only do not significantly reduce the bandwidth efficiency, also in the condition of unknown channel can carry on the maximum likelihood estimation continuously, and accordingly adjust the ruling measure [35]. In 2015, Stamoulia, i. et al. proposed to use sliding window to realize the maximum likelihood sequence detection algorithm calculated by viterbi, which successfully reached the transmission rate of 10Gb/s [36]. In 2017, Zhu, Y. et al proposed a fast blind detection algorithm based on the principle of generalized likelihood ratio detection, and proposed the block coding scheme for the first time to solve the unique identification problem and the error plate problem [37]. In 2017, Dabiri m. T. et al used blind detection algorithm to estimate the channel and adjust the detection threshold value, and derived a closed expression for error rate of IM/DD system, greatly reducing the simulation time [38]. In 2017, Gurugopinath, S et al. proposed the sub-optimal blind detection algorithm, and also derived the expression of the corresponding closed form detection threshold value. This algorithm does not need to introduce any training symbols and has low computational complexity [39].

3.5 MIMO technology

As the optical signal can reach the receiver through direct ray, reflection, refraction or even multiple reflection, different routes to reach the receiver have different time delay, which will lead to signal distortion and affect the transmission rate and accuracy of the communication system. MIMO diversity technique, which is to transmit most of the irrelevant beams from emitters whose aperture spacing is greater than the degree of atmospheric coherence, which is non-coherent superposition at the receiving end to overcome the atmospheric turbulence effect and realize the effective compensation of atmospheric channels. The earliest viewpoint of Multiple input- multiple Output (MIMO) technology was put forward by Mareoni in 1908. In the 1970s, it was proposed to apply multi-input and multi-output technology to improve performance of communication systems, which promoted the progress of wireless communication. With the gradual development of visible light communication, IBRAHIM et al. first proposed the idea that diversity technology could be applied to free space optical communication system to improve transmission performance, in 1996 [40]. MIMO technology not only solves the fading problem of the channel, but also effectively inhibits the communication performance problems caused by atmospheric turbulence and strong background light of the channel. Relevant methods based on MIMO technology have been proposed and studied widely [41]. The correlation methods are generally divided into the following three categories: the first method is to establish the model of multipath fading channel visible optical communication system based on MIMO technology, and to improve the system performance by using new module method or combined with detection algorithm [42]. In 2016, Farahneh, Hasan et al. proposed the communication system model between vehicles and vehicles based on outdoor MIMO-VLC, and used a new modular method to model communication channels to improve system performance [43]. However, this method does not consider the influence of atmospheric turbulence and background light on the performance of channel modeling in the process of channel modeling. The second type is a CSI simulation model of self-correcting MIMO system based on optical properties, which can resist the influence of noise on system performance. In 2015, Minh, H L et al. proposed a method for self-correcting CSI-MIMO system, which can reduce the rank of CSI matrix according to the position of MIMO receiver. Even if the channel is missing and CSI pilot signal is determined, the system can realize data recovery of all channels [44]. However, the high complexity of this method is not suitable for outdoor intelligent transportation. The third method is use diversity techniques to suppress atmospheric turbulence and interference from strong background light based on different modulation modes. In 2016, Zhao Jiachi
et al. built an outdoor long-distance visible light diversity receiving system model based on intensity detection pulse position modulation (PPM) in the strong background light atmospheric turbulence channel model, and realized the simulation system transmission of 800mb/s PPM signal under the background light noise of dozens of microwatt power [45]. Compared with previous spatial modulation SM, Zhuang, Boyuan et al. proposed an angular diversity receiver for SM MIMO VLC system output from multi-input institute based on spatial modulation, the signal-to-noise ratio of that increased by 8dB and the bit error rate decreased by 10⁻³ [46]. In 2017, Deng, Peng et al. based on the MIMO-VLC system with two transmitting and two receiving signals, which using the method of spatial reuse and diversity to realized 12b/s signal transmission in 2m indoor communciation[47]. This series of research results show that MIMO technology can suppress background light and atmospheric turbulence well, and MIMO technology can also inhibit the fading of channels. In 2018, Werfli, K et al. proposed a multiplexing solution based on frequency and spatial domain, and the experiment proved that a 4-by-4 imaging multi-input and multi-output (MIMO) VLC system can significantly improve the signal transmission speed by using multi-band no-carrier amplitude and phase (m-cap) modulation [48].

4. Conclusion
In recent years, visible light communication has been greatly concerned, and relevant research has been planned for more than ten years. It has made great breakthroughs in both basic research and applied basic research. Since 2011, the domestic researches of LED optical communication have made rapid progress, and have been funded by the national natural science foundation and the national 863 program. A number of gratifying research results have been achieved, which laying a theoretical and research foundation for the application of LED light source in the field of outdoor optical communication intelligent transportation. Because optical communication has many advantages such as high bandwidth and large communication capacity, etc. It can transmit signals more efficiently and quickly, while the system can process information more quickly, which conforms to the requirements of intelligent transportation for timeliness and provides more options for future automatic driving technology. It is believed that outdoor visible light communication will shine brilliantly in the application of intelligent transportation in the future.

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