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Abstract of Doctoral Dissertation

Studies on Free-Space Optical (FSO) Systems Applying CDMA and OFDM over Fading Environment

フェージング環境下におけるCDMA/OFDM方式を適用した自由空間光システムに関する研究

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Advanced FSO communication technologies, has been considered as an alternative solution to bridging the backbone construction and end user. It offers the potential ability on future high-speed, large capacity applications in both of indoor and outdoor communication scenarios. Despite the many benefits in FSO technologies, however, different from the optical fiber has been considered as a predictable medium, FSO systems are over the link described by random process model then optical beam will experience the variation of channel effects, leading to the degradation of link availability and performance. Therefore, considering the case of near ground FSO communication systems (terrestrial link), there are three primary impact factors that can limit the quality of optical beam propagation, including the absorption, scattering and refractive index fluctuation. To satisfy the above mentioned challenges in existing FSO communication systems, thus, it is important to provide an insight on the channel fading reduction for FSO link performance improvement, especially in finding efficient turbulence mitigation methods.

The focus of thesis is investigation on the transmission performance of FSO system using the variation of mitigation techniques for fading through the atmospheric turbulence channels with the view to understanding its benefits and limitations. The primary research contribution is aimed at introducing solutions of characterization and measuring the influence of turbulence effects on the link performance in the designing of advanced FSO communication systems.

This thesis consists of six chapters. Chapter 1 provides an overview of FSO issues, and primary goal as well as the original contribution of this work are also presented. The rest of this work is organized as follows.

In Chapter 2, a review of FSO communication systems including the fundamental theory and its progress in application is presented. The most important influence factors that limit the quality of data transmission such as channel attenuation and intensity fluctuation known as optical scintillation were introduced. Further, different statistical models for describing the intensity fluctuation in varying degrees of turbulence strength are presented such as log-normal and Gamma-Gamma turbulence model, respectively. Then, variation of mitigation methods used to overcome the degradation of link performance as hopeful fading compensation way are outlined, in terms of the spatial diversity techniques, subcarrier intensity modulation (SIM), polarization shift keying modulation and coherent detection. Hence, I provided the detailed information for these methods including the definition, formulas and comparison to previous works in case of FSO communication systems.

In Chapter 3, an analytical approach is provided to evaluate the performance of OFDM-based RoFSO system with diversity reception over correlated log-normal turbulence channel, in terms of error probability and outage probability considering the effect of channel correlation and receiver combining schemes. I derived the expressions for OFDM signals bit-error-ratio (BER) and outage probability, taking into consideration both correlation coefficient parameter and optical scintillation. Moreover, a definite major purpose of this chapter is using a performance comparison with aperture averaged single receiver to highlight the benefits of diversity reception for combating the turbulence-induced fading in quality of signal. Finally, the evaluation results represent spatial diversity as an efficient solution to mitigate the channel fading as well as reduction of data error. The evaluation of the proposed system behaviors confirm that the use of the diversity reception and OFDM technique can lead to potential ability of performance improvement, especially as high demand on transmission capacity becomes more important in access networks.

Chapter 4 uses the advantages of combining PolSK and OCDMA technology in FSO system with direct detection over 1-km atmospheric turbulence link modeled by Gamma-Gamma distribution. First, detailed of designing in the proposed system architecture is described. Then, the transmission performance of PolSK modulated OCDMA signal over turbulent FSO link is evaluated, in terms of the BER and outage probability. I derived a closed-form expressions of BER and outage probability by Meijer-G function, taking into consideration the multiple access interference (MAI), and turbulence-induced optical scintillation is also considered. Further, the efficiency of PolSK modulation in enhancing the performance of OCDMA FSO link across the weak and strong turbulence regimes compared with OOK modulation is obtained from numerical results. Different from the optical fiber medium, analysis results demonstrated that the PolSK-OCDMA FSO system transmission performance is sensitive to the optical scintillation caused by atmospheric turbulence. Moreover, important performance metric parameter, such as the prime number, have been measured and analyzed to evaluate and quantify the influence of MAI effects on the proposed system. The obtained results indicate that a large number of active users can degrade the system performance due to the effect of MAI, while a larger prime number can potentially improve the overall system performance. Finally, I also conclude that the choice of PolSK modulation for the design of the FSO system is an optimum method for the mitigation of channel fading, which obtained from a comparison with OOK based FSO Link.

In Chapter 5, an analytical modeling is provided to characterize the performance of PolSK-OCDMA systems with heterodyne detection over turbulent FSO link across the whole turbulence regimes. First, a novel transceiver architecture and mathematical modeling for describing the PolSK-based OCDMA signal transmission through FSO link with heterodyne detection are presented. This work aiming at demonstrate the advantages of coherent detection technique in improving the sensitivity of receiver and background noise reduction, thus, it can be used as a useful mitigation method for overcoming the degradation of quality of signal in the presence of turbulence effect, especially in without adaptive threshold detection. Hence, I derived the closed-form expressions of the system error probability and outage probability over the gamma-gamma turbulence channel. The MPC parameter as a performance metric has been also considered and quantifies the impact of interference noise on the system load-ability. The conclusions obtained through numerical simulation indicate that the performance of the propose system is highly sensitive to turbulence-induced irradiance fluctuation and the MAI effect; the choice of heterodyne detection receiver offers an improved FSO link performance compared to the conventional cases and provides an effective and promising method for turbulence mitigation in the field of FSO communications.

Finally, the Chapter 6 provides a conclusion remarks of this thesis. Moreover, future plan has been made as: I will pay attention on further investigation for accurate describing the system modeling. In the case of turbulence model, several statistic model has been proposed in recent years, such as double- Weibull distribution and generalized gamma distribution. A more accurately analytical model based on these turbulence model will be considered and discussed. For the applications of FSO communication system, such as under water and multipath diversity which is as a promising solution for the future. Investigation of theses novel applications performance is important, especially in connection the existing construction.