ACM for improving Throughput and Spectral Efficiency in FSO-based SAGNs

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Abstract

The free space optical (FSO) link, whether terrestrial or non-terrestrial, offers several benefits including license-free bandwidth and a cost-effective approach for achieving higher data rates. However, it faces challenges from different weather conditions, particularly atmospheric turbulence. In response to this challenge, this paper introduces an adaptive Coding and Modulation (ACM) technique designed to counteract these effects. ACM operates as an adaptive transmission method, dynamically altering transmission parameters like modulation scheme and code rate according to the Channel State Information (CSI). This adaptability serves to reduce the likelihood of errors and data loss, thereby sustaining higher throughput and spectral efficiency.

Ⅰ. Introduction

FSO communication has gained recognition for its capacity to deliver high data rates, along with inherent security advantages and straightforward installation processes. Nonetheless, the transmission of optical beams through the atmosphere encounters obstacles such as turbulence, fog, rain, and snow, resulting in signal attenuation and diminished performance, particularly within FSO-based satellite-aerial-ground networks (SAGNs). To overcome these challenges, various mitigation techniques have been developed to enhance FSO communication performance. Among these techniques, Adaptive Coding and Modulation (ACM) stand out. ACM aims to improve performance by dynamically adjusting transmission parameters based on Channel State Information (CSI). By adapting modulation schemes and code rates in real-time, ACM endeavors to counteract the adverse effects of turbulence and weather conditions on FSO communication [1].

Ⅱ. Methods

The implementation of ACM technique in FSO communication systems significantly enhances throughput and spectral efficiency. In an adaptive FSO communication setup, the transmitter emits a modulated instantaneous intensity (I) from a light source. At the receiving end, this optical intensity signal is converted back into an electrical signal (S), establishing IM/DD system. As the transmitted signal is optical, it must remain nonnegative. The FSO channel model is represented as follows [2]:

$$S = h_I + n \qquad (1)$$

Here, I represents the transmitted optical intensity signal, h signifies the channel gain, S denotes the received electrical signal, and n stands for the additive white Gaussian noise. The channel gain h is described by the following components [3]:

$$h = h_s h_l h_g \qquad (2)$$

Where h_s represents the scintillation loss, h_l denotes the atmospheric loss, and h_g signifies the geometric loss. The proposed ACM system design is depicted in fig.1. ACM dynamically adjusts modulation and coding schemes in FSO communication systems to optimize performance in response to changing channel conditions and environmental factors. Real-time monitoring of signal quality metrics like SNR and BER, along with environmental parameters such as temperature and visibility, enables ACM to adapt parameters efficiently. This adaptability ensures optimal utilization of the communication link, minimizing errors, data loss, and maintaining high throughput and spectral efficiency. By continuously adjusting modulation and coding schemes based on prevailing conditions, ACM ensures reliable communication and efficient spectrum utilization.

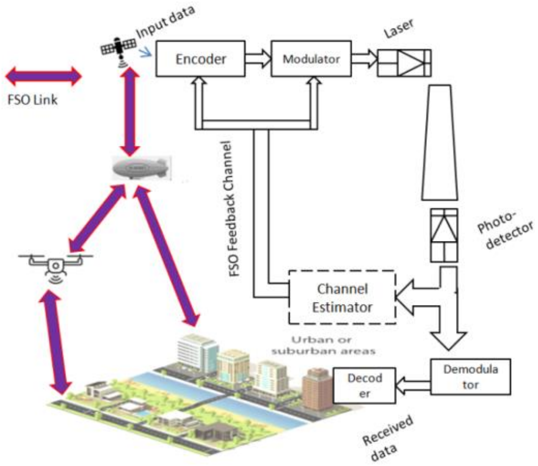

Fig. 1. ACM technique with FSO CSI feedback.

ACM optimizes bandwidth utilization by selecting the most suitable modulation and coding schemes. In favorable conditions, high-order modulation schemes like 16-QAM or 64-QAM are employed to maximize data rate and spectral efficiency. Conversely, in adverse conditions such as fog or turbulence, low-order modulation schemes like BPSK or QPSK are used to ensure reliable communication despite lower spectral efficiency. Furthermore, coding scheme adaptation enhances performance by employing error correction codes tailored to prevailing conditions. High-rate codes maximize data rate in favorable conditions, while low-rate codes enhance error correction capability in adverse conditions, optimizing communication reliability and spectral efficiency.

Additionally, ACM enhances error resilience by incorporating forward error correction techniques that vary in redundancy based on link conditions. Less redundant coding schemes are used under favorable conditions to enable higher data transmission rates and enhanced spectral efficiency. Conversely, more redundant coding schemes are employed under poor conditions to ensure data integrity, minimizing the need for retransmissions and maintaining efficient spectrum use. Furthermore, ACM's adaptive approach minimizes link outages by quickly adapting to changes such as temporary blockages or atmospheric disturbances, ensuring consistent data flow and efficient spectrum use in complex FSO communication environments.

III. Conclusion

In this paper, we explore ACM techniques for FSO-based SAGNs. By dynamically optimizing modulation and coding schemes, ACM enhances throughput and spectral efficiency in response to real-time channel conditions. This adaptability ensures optimal performance, maintaining high data throughput, reducing errors, and improving spectral utilization. Continuous adjustment of modulation and coding schemes addresses FSO channel variability, allowing efficient spectrum use and reliability across diverse conditions.

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