

Performance Analysis of Relay-Assisted Hybrid Transmission Systems in SAGNs- Survey

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Abstract

This paper presents a novel approach utilizing relay-assisted hybrid transmission systems. These systems combine Free Space Optics (FSO) with various technologies, including Radio Frequency (RF), Terahertz (THz), and millimeter-wave (mmWave), and are contrasted against solely transmission systems. The study evaluates their performance in terms of outage probability (OP) and Bit Error Rate (BER) across Satellite-Aerial-Ground Networks (SAGNs). Through comparative analysis, the study aims to elucidate the advantages of hybrid configurations in enhancing network reliability and efficiency in diverse environmental conditions.

I. Introduction

Combining relay-assisted transmission with hybrid methods such as FSO/RF, FSO/THz, and FSO/mmWave significantly enhances the performance of OP and BER in SAGNs. Relays, including high altitude platforms (HAPs) and unmanned aerial vehicles (UAVs), serve to amplify and redistribute signals, extending coverage, mitigating outage events, and adding redundancy to communication paths.

Among these hybrid systems, hybrid FSO/RF configurations stand out due to their capability to maintain connectivity by dynamically switching between FSO and RF transmissions [1]. This flexibility effectively reduces OP, particularly in adverse weather conditions. FSO ensures reliability under clear sky, while RF acts as a backup during fog or rain, ensuring consistent communication links and resulting in lower BER and optimized throughput as the system adapts to environmental factors.

Similarly, hybrid FSO/THz configurations capitalize on the high data rates of FSO combined with the resilience of THz waves to atmospheric attenuation [2]. This combination minimizes OP by ensuring reliable connectivity even in challenging weather conditions. With both FSO and THz offering low BER, these systems maintain dependable communication links, making them suitable for scenarios requiring high throughput and reliability.

Lastly, hybrid FSO/mmWave setups provide redundancy against atmospheric attenuation by merging FSO with mmWave technology [2]. This

combination ensures reliable connectivity under varying weather conditions, resulting in low BER and optimized throughput. By dynamically switching between FSO and mmWave, these systems adapt to environmental changes, providing consistent high-speed data transmission in SAGNs.

II. Methods

Assessing OP and BER in SAGNs involves employing experiments, simulations, or field trials to evaluate network reliability and error rates across different scenarios. OP measures the percentage of time or instances when the communication link fails to meet predefined performance criteria. It can also represent the probability of the instantaneous SNR, denoted as γ , dropping below a predetermined threshold (γ_{th}), expressed as: $P_{out} = \Pr(\gamma \leq \gamma_{th})$ (1).

While BER quantifies errors by comparing received data with transmitted data. It quantifies the probability of incorrectly detecting bits relative to the received signal intensity, which can be expressed as:

$$P = P(0)P(e|0) + P(1)P(e|1) \quad (2)$$

Statistical analysis techniques are commonly used to characterize OP and BER performance, offering insights into network robustness, connectivity, and error correction rates.

Our investigation focuses on integrating HAPs and UAVs as relays to enhance hybrid transmission systems, which combine FSO with RF, THz, or mmWave technologies. This strategic fusion aims to address the requirements for high data rates, extended coverage, and dynamic weather challenges in SAGNs. Through comparative analysis, we

evaluate the performance of RF, THz, and mmWave transmissions across these parameters.

RF transmissions, spanning from microwave to millimeter-wave bands, offer moderate to high data rates and can cover substantial distances, particularly in lower frequency bands. However, susceptibility to atmospheric attenuation during adverse weather conditions poses risks of signal degradation and performance decline. In contrast, THz transmissions offer ultra-high data rates but are limited by atmospheric absorption, making them more suitable for short-range communications. mmWave transmissions provide comparable data rates to THz, with moderate coverage distances and superior resilience to atmospheric effects, especially when leveraging advanced beamforming techniques. The selection of transmission technology depends on specific application requirements, considering factors such as data rate, coverage distance, and resilience to atmospheric effects.

Among hybrid transmission systems, the FSO/RF hybrid transmission system is recommended for enhancing OP and BER performance in SAGNs. This combination leverages FSO's high-speed optical transmission, particularly effective in clear weather, with RF acting as a backup during adverse conditions like fog or rain [3]. Dynamic switching between FSO and RF mitigates outage events, ensuring consistent communication links and improving OP and BER performance in SAGNs. Additionally, RF transmissions augment FSO's reliability in hybrid systems, minimizing outages and reducing BER, particularly in environments prone to mild to moderate weather effects.

III. Conclusion

In conclusion, the integration of relay-assisted hybrid transmission systems, including FSO/RF, FSO/THz, or FSO/mmWave, has demonstrated significant improvements in OP and BER performance compared to single FSO transmission in SAGNs. By leveraging relay amplification and redistribution capabilities alongside the diverse strengths of hybrid technologies, these systems have shown enhanced resilience to atmospheric conditions, extended coverage, and reduced outage events. Such advancements underline the potential of integrated relay-assisted hybrid transmission systems to significantly enhance the reliability and efficiency of communication networks in diverse environmental scenarios encountered in SAGNs.

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REFERENCES

- [1] R. Samy, H.-C. Yang, T. Rakia, and M.-S. Alouini, "Hybrid sag-fso/sh- fso/rf transmission for next-generation satellite communication systems," *IEEE Transactions on Vehicular Technology*, 2023
- [2] P. K. Singya, B. Makki, A. D'Errico, and M.-S. Alouini, "Hybrid fso/thz- based backhaul network for mmwave terrestrial communication," *IEEE Transactions on Wireless Communications*, 2022.
- [3] T. V. Nguyen, H. D. Le, N. T. Dang, and A. T. Pham, "On the design of rate adaptation for relay-assisted satellite hybrid fso/rf systems," *IEEE Photonics Journal*, vol. 14, no. 1, pp. 1-11, 2021.