An Adaptive Modulation For Free Space Optical (FSO) Systems

Report submitted to GITAM (Deemed to be University) as a partial fulfillment of the requirements for the award of the Degree of Bachelor of Technology in (write your respective branch)



DEPARTMENT OF ELECTRICAL, ELECTRONICS AND COMMUNICATION ENGINEERING

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**DECLARATION**

I/We declare that the project work contained in this report is original and it has been done by me under the guidance of my project guide.

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**CERTIFICATE**

This is to certify that (Student Name) bearing (Regd. No.:) has satisfactorily completed Mini Project Entitled in partial fulfillment of the requirements as prescribed by University for VIIth semester, Bachelor of Technology in “Electrical, Electronics and Communication Engineering” and submitted this report during the academic year 2025-2026.

[Signature of the Guide] [Signature of HOD]

**Table of contents**

**Chapter 1: Introduction 1**

* 1. Overview of the problem statement 1
  2. Objectives and goals 1

**Chapter 2 : Literature Review 2**

**Chapter 3 : Strategic Analysis and Problem Definition 3**

* 1. SWOT Analysis 3
  2. Project Plan - GANTT Chart 3
  3. Refinement of problem statement 3

**Chapter 4 : Methodology 4**

* 1. Description of the approach 4
  2. Tools and techniques utilized 4
  3. Design considerations 4

**Chapter 5 : Implementation5**

* 1. Description of how the project was executed 5
  2. Challenges faced and solutions implemented 5

**Chapter 6: Results 6**

* 1. outcome 6
  2. Interpretation of results 6
  3. Comparison with existing technologies 6

**Chapter 7: Conclusion 7**

**Chapter 8 : Future Work 8**

**References 9**

**Chapter 1: Introduction**

* 1. Overview of the problem statement

Free-Space Optical (FSO) communication is a wireless technology that uses a light beam, usually from lasers or LEDs, to transmit information through the atmosphere. It provides very high bandwidth, license-free spectrum, and secure communication, making it a promising alternative to radio frequency (RF) systems. FSO can be used for last-mile connectivity, enterprise networks, disaster recovery, and cellular backhaul.The main challenge of FSO is that the optical signal is highly sensitive to atmospheric conditions. Weather effects such as fog, rain, dust, and turbulence can cause attenuation, fading, and signal distortion, leading to high error rates and poor reliability. These problems limit the distance and stability of FSO links.To overcome these limitations, researchers propose adaptive modulation and coding techniques. In this method, the transmitter adjusts parameters like power, modulation size, and coding rate according to the real-time channel conditions. This makes the system more efficient and reliable, even under adverse weather conditions. This project focuses on designing and analyzing an adaptive modulation scheme for turbo-coded FSO systems using M-ary Pulse Position Modulation (M-PPM). The goal is to achieve better bandwidth efficiency, lower bit error rate (BER), and reduced outage probability compared to conventional non-adaptive systems.

* 1. Objectives

The primary aim of this initiative is to enhance the performance and reliability of Free-Space Optical (FSO) communication systems using an adaptive modulation approach. In particular, this project intends to examine what the fundamental workings of the FSO communication system and its challenges might be, in relation to atmospherically-induced effects like turbulence or fading. Thereafter, the project will develop an adaptive modulation scheme based on a turbo coding implementation with M-ary Pulse Position Modulation (M-PPM). The adaptive link will be tested and compared against non-adaptive schemes for the purpose of evaluating improvements in terms of bit error rate, outage probability, bandwidth efficiency, and transmission power. The objective of this project and its related simulations and analyses is to show that adaptive modulation can effectively make FSO communication more robust and efficient, as a practical solution to real-world high-speed wireless communication applications, at least in a simulated environment.

Goals

* To model and simulate a Free-Space Optical (FSO) communication channel in MATLAB.
* To analyze the impact of atmospheric turbulence, fading, and attenuation on FSO link performance
* Develop an adaptive modulation algorithm that selects optimal modulation size based on real-time Channel State Information (CSI).
* To reduce bit error rate (BER) and outage probability in FSO communication.
* Evaluate performance metrics like Bit Error Rate (BER), bandwidth efficiency, and outage probability for adaptive vs non-adaptive systems.
* To compare adaptive and non-adaptive systems in terms of BER, outage probability, transmission power, and spectral efficiency

**Chapter 2: Literature Review**

1)**Adaptive Coded Modulation for IM/DD Free-Space Optical Backhauling.**

**Author:** Ahmed Elzanaty and Mohamed-Slim Alouini.

**Journal:** Google Scholar

**Key Takeaways:** The paper proposes SpaDCoM, which uses probabilistic shaping (CCDM) + binary FEC to transmit a mix of shaped (sparse) and uniform (dense) symbols over FSO links. This design adapts to turbulence, works close to channel capacity (within 0.2 dB), saves power, and remains practical with standard FEC codes.

2) **Adaptive Subcarrier PSK Intensity Modulation in Free-Space Optical Systems**

**Author:** Nestor D. Chatzidiamantis, Athanasios S. Lioumpas, George K. Karagiannidis, Shlomi Arnon.

**Journal:** Google Scholar

**Key Takeaways:** This paper shows that Adaptive S-PSK Intensity Modulation allows FSO links to change modulation order depending on turbulence, improving spectral efficiency and reliability while keeping BER under control. It works best in moderate-to-strong turbulence and can be further enhanced with MIMO apertures.

3)**Power Control and Adaptive Digital Pulse Interval Modulation for Free Space Optical Links**.

**Author:** Mohammad Taghi Dabiri, Mohammad Javad Saber, and Seyed Mohammad Sajad Sadough

**Journal:** Google Scholar

**Key Takeaways:** The proposed technique uses Power Control combined with an Adaptive Digital Pulse Interval Modulation (DPIM) scheme to significantly mitigate the performance degradation caused by atmospheric turbulence (like scintillation and fading) in Free Space Optical (FSO) links, thereby achieving more reliable and efficient communication.

4)**Performance analysis of an adaptive optics system for free-space optics communication through atmospheric turbulence.**

**Author:** Yukun Wang, Huanyu Xu, Dayu Li, Rui Wang, Chengbin Jin, Xianghui Yin, Shijie Gao, Quanquan Mu, Li Xuan & Zhaoliang Cao

**Journal:** Google Scholar

**Key Takeaways:** This paper demonstrates that adaptive optics, if properly designed can dramatically improve the reliability and performance of free-space optical links under turbulence.

5)**Adaptive Modulation for FSO IM/DD Systems With Multiple Transmitters and Receivers**

**Author:** Hatef Nouri, Sadiq M. Sait, and Murat Uysal .

**Journal:** Google Scholar

**Key Takeaways:** This 2023 paper proposes adaptive modulation for multi-aperture IM/DD FSO systems, achieving much higher spectral efficiency and reliability compared to non-adaptive or single-aperture systems, particularly in turbulent channels.

6) **Adaptive Coded Modulation for FSO Links**

**Author:** K. Fatima, S. Sheikh Muhammad and Erich Leitgeb

**Journal:** Google Scholar

**Key Takeaways:** This 2012 paper shows that adaptive coded modulation (ACM) using PAM/PPM + LDPC improves FSO links by dynamically adjusting to weather/turbulence, achieving both high throughput in good channels and strong reliability in adverse ones.

**Chapter 3 : Strategic Analysis and Problem Definition**

* 1. SWOT Analysis
  2. Project Plan - GANTT Chart
  3. Problem statement

**Chapter 4 : Methodology**

* 1. Description of the approach

This project utilizes an overall methodology on the design and evaluation of an adaptive modulation scheme for turbo-coded Free-Space Optical (FSO) systems. The methodology will start with a characterization of the FSO channel model, considering the specifications of the atmospheric turbulence, path loss, and noise. The effects of turbulence will be simulated using a log-normal fading model.

The system considered will utilize a M-ary Pulse Position Modulation (M-PPM) system which will be turbo coded to provide error correction capability. The key aspect of the system is the use of an adaptive scheme that will change the modulation size and transmit power dependent on real time Channel State Information (CSI). This makes sure that the system will reduce the modulation size or stop transmission of data during weak channel conditions to mitigate errors and during good channel conditions that the modulation size is increased to increase efficiency.

Lastly the system performance is evaluated using Monte Carlo simulations and compared against a non-adaptive case. Evaluation metrics include Bit Error Rate (BER), bandwidth efficiency, outage probability, and transmit power.

* 1. Tools and techniques utilized

To implement and test the system, the following tools and techniques were used:

* Simulation Software: MATLAB/Simulink (for implementing modulation schemes, channel modeling, and performance analysis).
* Programming Techniques: Numerical modeling and Monte Carlo simulations for random channel conditions.
* Coding Techniques: Turbo coding with iterative decoding for error correction.
* Beers-Lambert law for path loss.
* Toolboxes : Communications Toolbox, Signal Processing Toolbox and others.
  1. Design considerations

During the design of the adaptive modulation scheme, the following considerations were taken into account:

* Channel Characteristics: The FSO channel is affected by turbulence, scattering, and attenuation. A log-normal fading model was selected as it accurately represents weak-to-moderate turbulence conditions.
* Peak Power Constraint: Transmission power was limited by eye-safety regulations and laser lifetime considerations, ensuring that the system does not exceed maximum safe power
* Modulation Scheme Selection: M-PPM was chosen due to its high power efficiency.
* Error Correction: Turbo codes were used because of their strong error-correcting capability in fading channels.
* Adaptive Mechanism: The design ensures that modulation size and power are dynamically adjusted based on CSI to balance efficiency and reliability.

**Chapter 5 : Implementation**

* 1. Description of how the project was executed
  2. Challenges faced and solutions implemented

**Chapter 6: Results**

* 1. outcomes
  2. Interpretation of results
  3. Comparison with existing literature or technologies

**Chapter 7: Conclusion**

Here write Suggestions for further research or development and Potential improvements or extensions

**Chapter 8 : Future Work**

Here write Suggestions for further research or development Potential improvements or extensions

**References**

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