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FSO in Satellite Communication

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ABSTRACT
This project focuses on understanding the different factors involved in establishing communication between ground station and satellite. With the help of m-QAM and different simulation channels analyze the way channel affects the transmitted signal and data. And design system which will cover the disadvantage occurred due to line of sight and non-line of sight communication and the channel effect and data loss occurring due to these issues. This project is a work for creating a lossless communication between ground station and satellite, without any range issue between satellite and ground station. This communication system surpasses the competition of increasing data rate and focuses on sending bulk data in compressed form or sending mass information in few bytes of data.

KEYWORDS
Channel effect, lossless transmission, compressed data.

1. INTRODUCTION

As now we see the use of optical fibers for light speed communication in industries and Satellite communications are in big demand for all telecommunication, military and many other sectors for establishing communication and having information exchange. Free space optics (FSO) if known for its high data rate transmission and satellite communication is known for establishing communication at high coverage or high range for accessing vast area in same time. In free space we use lasers for high bit rate communication. And in satellite communication we see different techniques for covering most of the area and countering the various harsh conditions for establishing communication. As there are advantages of both combining together there are many disadvantages which hinders the main objective of communication systems. The main objective of any communication system is to send or transmit the information to the receiver without any error and data loss as fast as possible, this is the main reason of implementation of 5G and many other current and advance systems. Generally in every communication system the data is sent bit by bit either serially or parallel which means the information which will be loaded on receiver will be one by one this situation you can imagine the example as teacher orally dictating all students same paragraph word by word and line by line and students are writing this word by word and line by line waiting for teacher to speak the next word to complete the sentence, and there would occur many errors like the student sitting further from teacher might miss word or two and then the speed of teacher reciting the paragraph, some students might be comfortable some students might not be many again miss some words. Now to solve this issue imagine teacher telling us to write the same paragraph from the book by just telling the page number and paragraph number and if necessary start of the paragraph, the students with their own writing speed can complete the task having all information by their side with such less data transmission and sending the data they wanted.

We can achieve same results by sending few data we can get much more data we wanted, and it just not handles the bit rate or fast data transfer part but also encoding and decoding blocks in communication systems and reduce the data loss mostly it will be lossless form. For getting these results we need to look upon the iterating equation, pattern detection, fractals[1-5].

2. Literature Review

The literature review aims to provide a comprehensive overview of existing research and studies related to FSO in Satellite communication and fractals. This section explores and tells about the concept of fractals used in this system and the FSO sat-comm details. Fractals: - fractals are the geometrical shapes containing detailed structure at arbitrarily small scales. There are many fractal patterns that exists like Mandelbrot set, Julia sets, Sierpinski carpet, A simple tree, Koch snowflake, Sierpinski gasket etc. For this research project we used 2 fractals one Mandelbrot and Julia sets. Julia set is a subset of Mandelbrot set we can say that infinite number of Julia sets are stored in one Mandelbrot set. Both have common iterating equations but there are minor differences. In their pattern and other parameters which we will discuss in a while. The equation of both equations is $z(n) = z^2(n+1) + C$. were z is the complex number from -2 to 2 in both X & Y plane. As you can see the above equations for both Julia and Mandelbrot sets there are some key differences in both. In Julia set the "C" value from the equation is fixed complex number and in Mandelbrot set it varies by iterations and if you check the escape count for both sets you can see Julia set escape count is same in whole pattern and in Mandelbrot set the escape pattern will change or vary with iterations[6].

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Free space optics gives significant advantage over normal RF communication systems like lower latency, immunity to electromagnetic interference and higher bandwidth. These are important parameters for higher speed data transmission in Satellite communication applications for example internet access, remote sensing, inter-satellite communication and various other uses. There are some atmospheric challenges by using FSO in satellite communication for example scattering, turbulence, weather induced impairments, degrading signal quality and limited link availability[7].

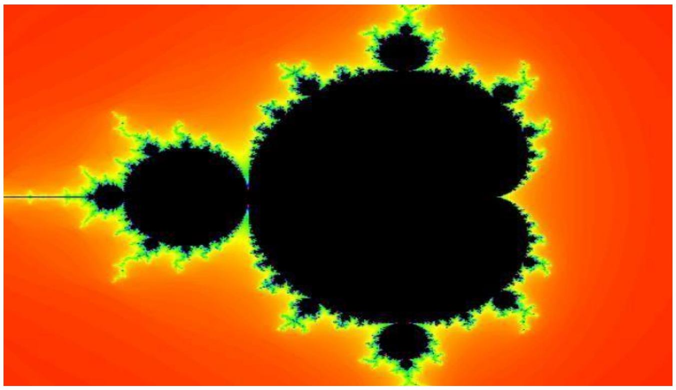

Fig. 1 MANDELBROT SET

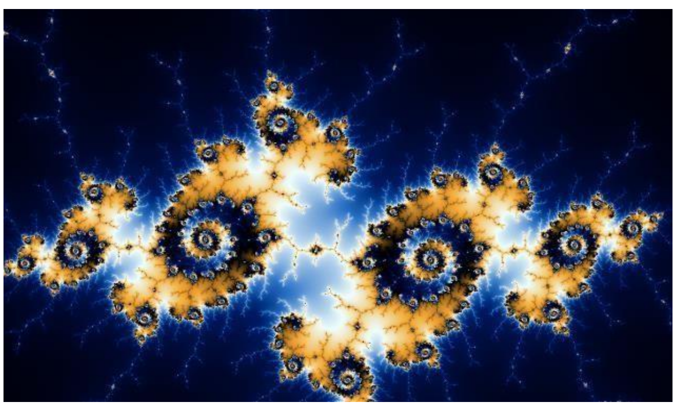

Fig. 2 JULIA SET

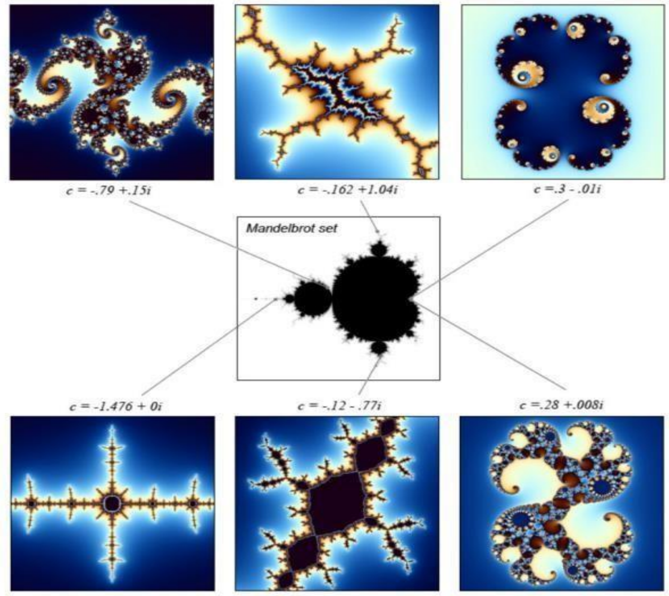

Fig. 3 JULIA SET IN A MANDELBROT SET

Advancements in FSO Modulation Schemes for Satellite Links: Research by explore the latest advancements in modulation schemes specifically tailored for FSO communication in satellite links. The study investigates the performance of different modulation techniques, including Quadrature Amplitude Modulation (QAM), and assesses their suitability for achieving higher data rates and reliable communication. Security Considerations in FSO Satellite Communication: Security is a critical aspect of satellite communication, and discuss the security considerations associated with FSO technology[8-10]. The review encompasses encryption techniques, vulnerability assessments, and countermeasures against potential attacks, providing insights into securing FSO communication in satellite networks. Quantum Communication and FSO in Future Satellite Networks: The future of satellite communication may involve the integration of quantum communication. The study discusses the potential synergy between FSO and quantum communication technologies, paving the way for highly secure and efficient satellite communication systems.

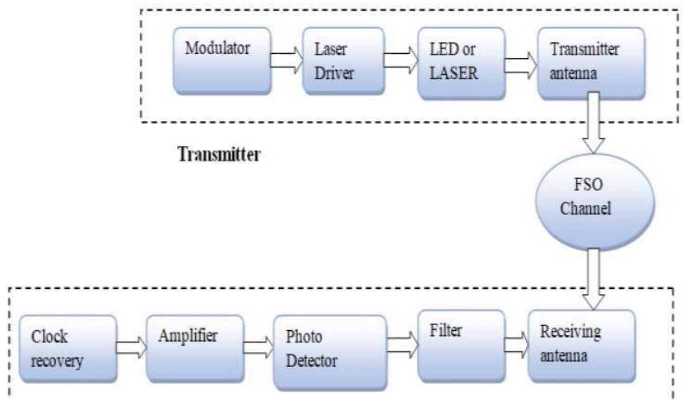

Fig. 4 FSO BLOCK DIAGRAM

3. PROBLEM STATEMENT

The problem Statement for this project is to achieve control over the data transfer rate instead of depending on the modulation scheme and channel parameters and reduce the size of data for reducing data traffic and send the large chunk of data with small parameters to over some free space optics challenges which involves the channel parameter which effects the data sending through the signal.

Atmospheric Interference and Signal Degradation:

Atmospheric conditions, including fog, rain, and turbulence, pose significant challenges to FSO communication in satellite links. These conditions can lead to signal attenuation, scattering, and fluctuations in signal intensity, affecting the overall performance and reliability of the communication link.

System Robustness and Error Correction:

While FSO systems offer high data rates, they are susceptible to errors introduced by atmospheric disturbances, pointing inaccuracies, and other environmental factors. Developing effective error correction techniques, such as advanced coding and modulation schemes, is crucial to enhance the robustness of FSO communication in satellite links.

Practical Implementation and Simulation:

While theoretical studies provide valuable insights, practical implementation and simulation of FSO communication systems in satellite links are essential for a comprehensive understanding of their performance. Leveraging tools like MATLAB Simulink, there is a need to develop realistic models that consider various components such as random integer generators, modulation schemes, and error correction techniques to validate theoretical findings.

Future-Proofing with Quantum Communication:

The evolution of satellite communication networks requires a forward-looking approach. Investigating the integration of FSO with quantum communication technologies is an emerging area that demands exploration. Ensuring the security and efficiency of future satellite networks through this integration is a challenge that requires careful consideration. Addressing these challenges will contribute to unlocking the full potential of FSO communication in satellite links, enabling the development of robust, high- performance systems that can meet the ever-growing demands of modern space- based communication applications.

4. OBJECTIVES OF THE PROPOSED SYSTEM:

The objective of the proposed system is through simulation and algorithms reduce the raw data into smaller but lossless version of data which will also handle encoding part of the data and convert that data into binary and send the signal. This system aims to reduce the data loss in transmission and speed of transmission and send the big chunk of data in smaller part and store that data in fractal images as the pair of complex numbers which can be retrieved back through iterations.

5. PROPOSED SYSTEM

Converting Raw data into 0 to 16 numbers: Generally, in every communication system the data in converted into integers and that integer data is converted into binary data for transmission and mostly they are encoded at binary level. ASCII (American Standard Code for Information Interchange) has given the code numbers to all letters and basically these standards are used in communication model of various systems. And these codes given by ASCII cover the standard data from 0 to 255 (there are till 256 numbers assigned to the letters as ASCII code) so for a prototype if we are able to transfer the data between 0 to 255 then it can be applicable to further data transfer systems. To make this data small in size we can use division algorithm. So basically, if you divide the given integer data from 0 to 255 by 16, your quotient and remainder would not exceed the value of 16. And as we know the division formula which is "Dividend = (Quotient + Remainder) X Divisor" with this formula we can decode the encoded data of raw integer from 0 to 16 to raw integer. So basically, we are splitting the raw integer data into the pairs of 0 to 16 numbers[13].

Converting 0 to 16 data into Equation parameters: Now we have all the data into even number of pairs of encoded raw data from 0 to 16 so it is easy to understand the sequence made by the data. Now to convert this massive data into small group of data or small data we need to convert this data into such equations which will give you the data back without any loss with some parameters of it. Now depending on the data sequence of pairs of numbers from 0 to 16 we can take the n optimal data sequence for compressing them into a equation and get those parameters from equation. Now the parameters of these equation will depend on the equation it uses. As for prototype we have used only linear and quadratic equation which will iterate and give us our pairs back. For further enhancement we can use many other types of equations like trigonometric, higher powers of polynomial equation etc. depending on the pattern formed by the 0 to 16 paired data and how much of data we can fix it in the equation sequentially. After this you are ready to transmit those equation parameters to the receiver as the equation will derive the 0 to 16 sequence that we need in lossless manner[9-12].

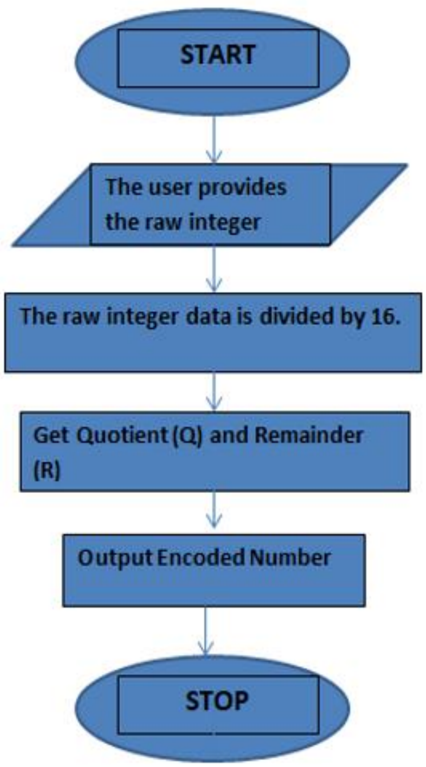

Fig. 5 Encoding flowchart for converting raw data into 0 to 16 integers

Converting those parameters into complex numbers: Now to store that data in another iterating equation or fractal we need to provide the complex value of "C" in the equation of Mandelbrot set which is "$Z(n) = Z^2(n+1) + C$" since the quadratic/linear equation has already values stored in it, we can use those parameters for storing it in the Mandelbrot set. As Mandelbrot set has infinite number of Julia sets stored in it we can access those through our quadratic equation or linear equation which you will use according to the equation and the sequence.

Storing those complex number values in Mandelbrot set: Storing the complex number derived from pairing the sequence or the equation parameters and converting it into complex number for giving that value into "C" in the equation of Mandelbrot set. In this Mandelbrot set equation "Z" is the between the range -2 to 2 evenly taken as per needed. "C" we can control and give any complex number which will be added in the iterations as the equation of Mandelbrot set is iterated. Iteration in this will act as the resolution of the image, the more the resolution the more values of "C" you can store in the Mandelbrot set. We can use Julia set here also but Julia set has limitation of retrieving back the data i.e. the data which is stored in the Julia set is hard to detect as the escape count of the image is same but in Mandelbrot set we can detect the numbers as it has different number of escape counts in the image. *Connecting equation parameters to m-QAM Modulator:* After converting the raw data from the integer generator into equation parameters we can connect that parametrical data to the 64-Qam modulation for modulating that digital data into analog signal. *m-QAM Modulator to Channel:* Generally, we would connect this to AWGN Channel for line of sight communication and it would be sufficient for normal parameters. And for satellite communication we can you Rayleigh or Rician channel for non-line of sight communication[14].

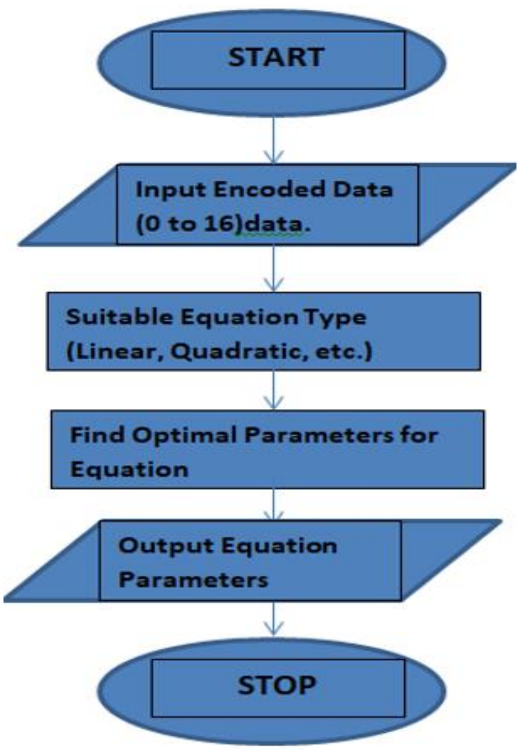

Fig. 6 Encoding flowchart for converting into 0 to 16 integers into equation

Channel to Demodulator and decoder: After going through channel, the analog wave is converted to the digital data through demodulator and we get the equation parameters at the receiver. From there we convert back those parameters into equation and after decoding that equation we get the sequence of those pairs of 0 to 16 number and the again we convert those pairs to the integer format through division formula "dividend = divisor X (quotient + remainder)". Hence in this way we get our integer data in lossless manner. And after that we can store that information into iterating equation of Mandelbrot set efficiently with the help of optimized iterations.

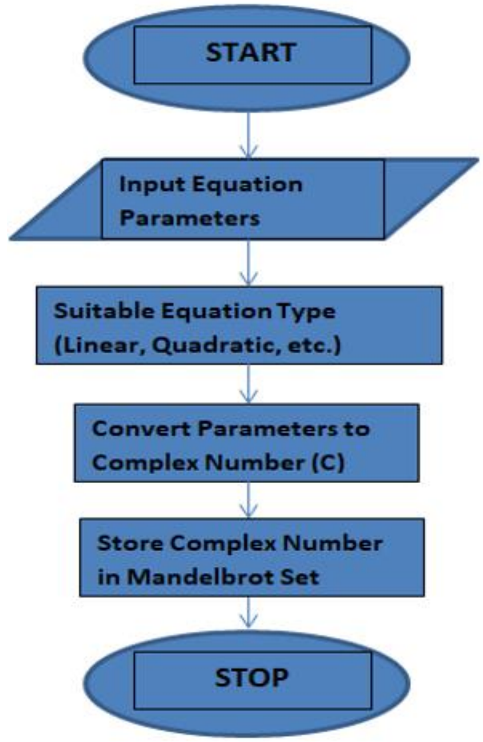

Fig. 7 Encoding flowchart for converting paired sequence to complex number

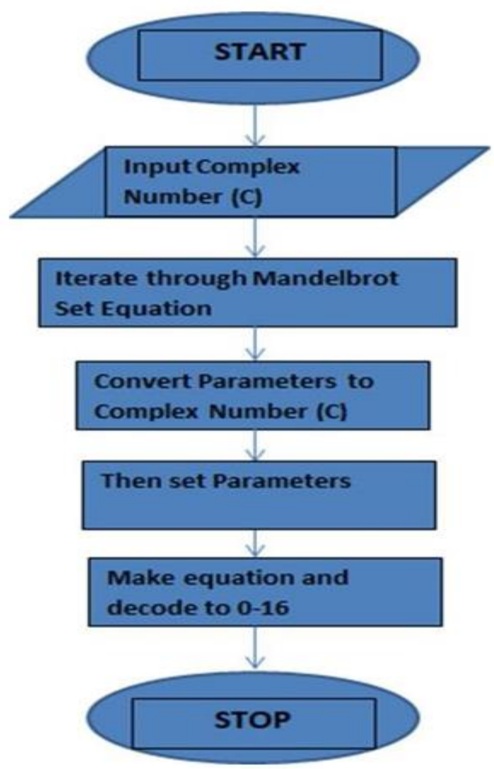

Fig. 8 Flowchart for converting from complex number to integer and for storing sequence in Mandelbrot set.

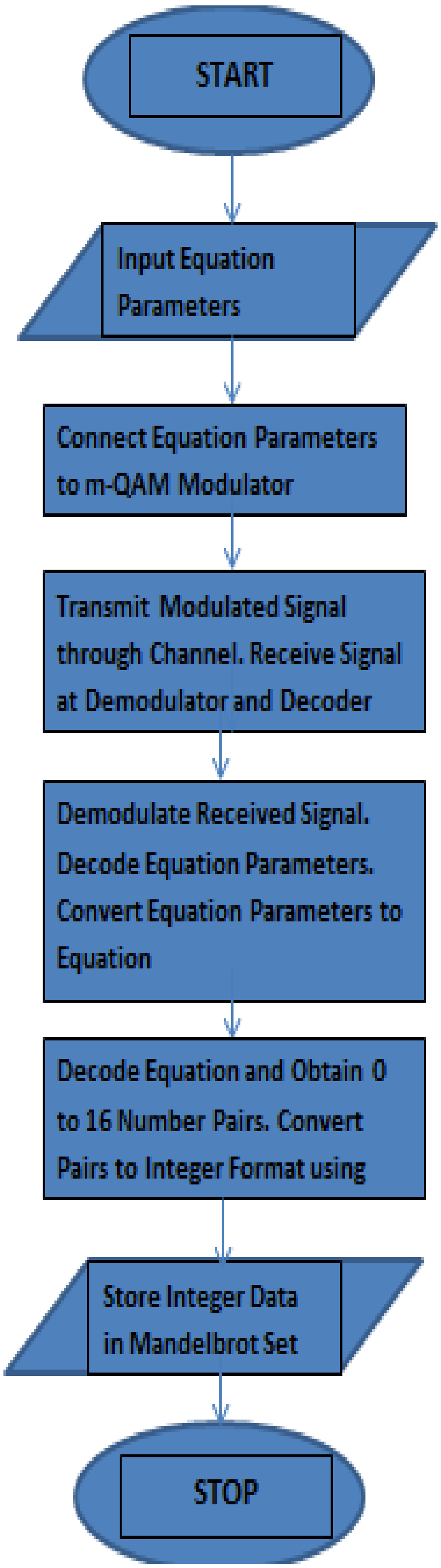

Fig. 9 Flowchart for converting into integer and for decoding from equation parameters to integer

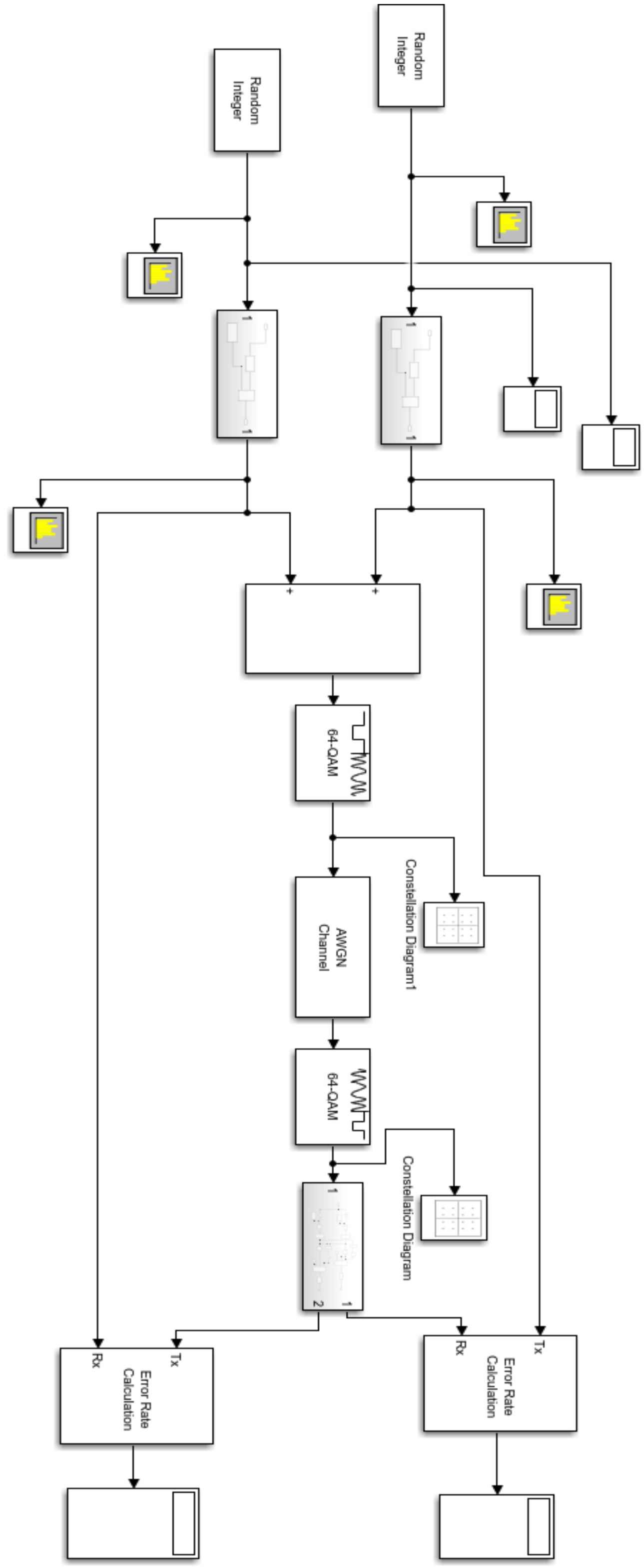

Fig.10 Simulink Diagram of FSO system

Simulation Parameters:

Random Integer Generator: The Random Generator block in Simulink is used to generate random numbers or sequences. In FSO communication simulation, the Random Generator block can be used to create a sequence of random symbols or bits that represent the input data to be transmitted. This helps assess the system's performance under various data conditions.

64QAM Modulation and Demodulation: The 64 QAM Modulator block in Simulink is used to modulate input data into a 64-QAM (Quadrature Amplitude Modulation) signal.64 QAM Modulator is applied to the random data generated by the Random Generator. It simulates the modulation process before transmitting the signal through the FSO channel. The demodulator is placed after the FSO channel, the 64 QAM Demodulator reverses the modulation process, recovering the transmitted data[15].

AWGN Channel Simulation: Placed after the 64 QAM Modulator, the AWGN Channel block adds noise to the modulated signal, replicating real- world conditions where communication signals are subject to impairments on the system's reliability.

Spectrum Analyzer: In FSO communication, the Spectrum Analyzer can be employed to examine the spectral components of the optical signal before and After modulation. This analysis is crucial for ensuring that the signal occupies the desired frequency band and meets regulatory requirements.

Constellation Diagram: In FSO communication, the Constellation Diagram is often used to analyze the modulation and demodulation processes. It allows for the assessment of signal quality, detection of potential impairments (e.g., noise, distortion), and optimization of modulation parameters for reliable communication.

Add Blocks: In FSO communication simulation, add blocks are useful for combining signals, such as adding the modulated signal with noise generated by an Additive White Gaussian Noise channel. This simulates the real-world scenario where the transmitted signal undergoes noise during propagate environmental noise.

Error Rate Calculation: The Error Rate Calculation block quantifies the performance of the FSO communication system by comparing the transmitted and received data. It helps assess the impact of noise. Implementation Method: System Design: Define the objectives and requirements of the FSO necessity in satellite communication. Use the data compression algorithm for converting 0 to 255 to 0 to 16 pairs.

Software Development: Using MATLAB and Simulink for the software basis and for writing algorithms and implementing it in Simulink model. Using MATAB for developing the code and Simulink for developing the FSO model.

Algorithm Development: Design and implement integer compression algorithms based on the raw data sequence. These algorithms may include integer to limited range value convertor, Mandelbrot set parameters saving code. Testing and Validation: Conduct thorough testing of the entire FSO system, the integer compression code, storing the data and getting that data back from Mandelbrot set. Deployment and Evaluation: Deploy the implemented FSO system in the targeted prototype environment. Monitor and evaluate its performance over an extended period, gathering data on it. Gather feedback and make necessary adjustments for optimization. It's important to note that the specific implementation method may vary depending on the system requirements, available resources, and the complexity of the raw data sequence. The steps provided above offer a general framework to guide the implementation process. Random Integer Generator the Random Integer Generator block is configured to produce a sequence of integers representing the data to be transmitted. Key parameters include: Set Size: 64 (for 64-QAM modulation) Source of Initial Seed: Dialog (manually set seed for reproducibility) Sample Time: 0.1 (adjust based on system requirements) Samples per Frame: 1 Output Data Type: double Rectangular QAM Modulator Baseband the Rectangular QAM Modulator block is employed for baseband modulation of the generated data. Configuration parameters include: Modulation Order (M): 64 (for 64-QAM) Symbol Mapping: Gray (or Binary, based on preference) Bit Input: Connected to the output of the Random Integer Generator Output Type: Inherit: Same as input AWGN Channel The AWGN Channel block introduces additive white Gaussian noise to simulate real-world channel conditions. Key parameters are configured as follows: Noise Power (dBW): Adjust based on desired SNR (Signal- to-Noise Ratio) Signal Power (dBW): Set to 'Input port' for dynamic signal power handling Signal Input: Connected to the output of the Rectangular QAM Modulator Output Type: Inherit: Same as input Simulation Procedure The simulation is executed by setting the appropriate simulation parameters, including the duration (Stop Time) and solver options in the Simulink environment. The simulation results are then analysed to evaluate the performance of the FSO communication system. *Data Analysis* Simulation results include visualizations such as constellation diagrams, Bit Error Rate (BER), or Symbol Error Rate (SER) plots. These visualizations provide insights into the impact of noise and modulation order on system performance[16].

6. RESULTS AND DISCUSSION

The implementation of this system has many advantages as it reduces the time to transfer the data and whole data is transferred in less bytes so unnecessary use of bandwidth is saved and data traffic is reduced. Here are some of the results that are derived from this project. Bulk data transfer: By implementing this system successfully, the large amount of data can be transferred using a smaller number of integers and transfer bytes but the whole data can be transferred few data and through computing it at receiver will give lossless and high- resolution images and high data can be obtained without

any data loss. And by using the basic values from equation we can get data with least amount of data loss in analog system.
Lossless data transfer: This data encoding and compression system will compress the data in lossless manner and its extraction is also lossless in digital calculations. It is easy and has few steps involved in the data compression and encoding. The sequence pattern identification and giving parameters and retrieving that information from those parameters is also in lossless manner so the whole transfers are in lossless manner digitally. Better data encoding: This system of data encoding has better security and as the sequence parameters are taken from the sequence so even if there is an unauthorized access would not understand the access data. For decoding parameters, you need the decoding code in the software and the type of sequence parameter like quadratic or linear etc. sequence type. So, the sequence is well protected. By getting the serial raw data and converting that into the small and complex data we get strong encoding for data protection. Data transfer dependents on computing power: The integration with the computing power of the system decreases the data transfer time and data access time. Now instead of depending on the better range and the serially transfer of bytes through antenna radiation pattern and many such factor we can be independent and our computing power will help access the large amount of data through the less amount of data. Efficient high-quality data transfer efficiency: The Considering the above advantage the high-quality images or high amount of data transfer happening in satellite communication the satellite information the data recorded by the satellite or the use of satellite will improve with this method and we can program a satellite even for connection lost phase.

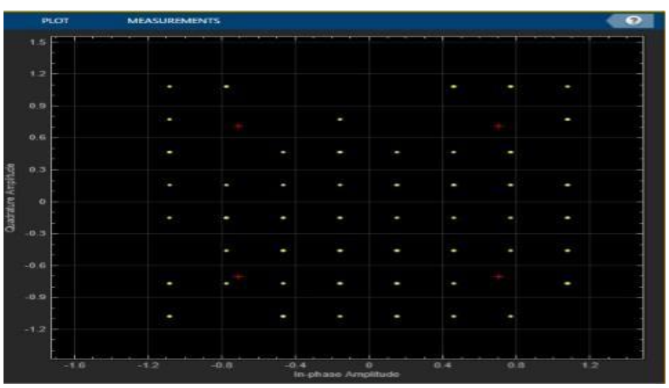

Fig. 11 Constellation at input

So basically, if the connection between the ground station and satellite is lost the data is stored in the satellite through fractal method we can get the data during that period so the data loss during that period is also acquired and because of the compression and encoding transmissions we can get the data as soon as the satellite is connected again to the ground station and for many such different space scenarios or weather phenomenon's we can acquire the bulk data by just the range and accessing the transmitting antenna or the transmissions. Hence this system has many advantages in implementing and this system will just take place of encoding.
Constellation Diagrams Two sets of constellation diagrams were generated for comparative analysis.

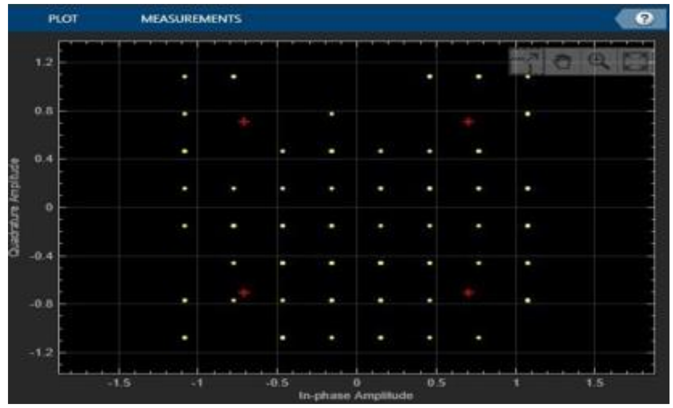

Fig. 12 Constellation at output

Figures 11 and 12 illustrate the constellation diagrams for the baseline configuration (Baseline) and an optimized configuration (Optimized) at a specific SNR. Baseline Constellation Diagram Constellation Diagram for Baseline Configuration at SNR = 10dB. Figure 12: Constellation Diagram for Optimized Configuration at SNR = 10dB. The simulation results demonstrate a notable enhancement in the performance of the optimized Free-Space Optical (FSO) communication system compared to the baseline configuration. Constellation diagrams at a specific Signal-to-Noise Ratio (SNR) reveal that the optimized system exhibits tighter and more distinct clusters of points, indicating improved resistance to noise. These results underscore the effectiveness of the optimization strategy in mitigating the impact of noise and improving the fidelity of transmitted data.

7. CONCLUSION AND FUTURE SCOPE

In conclusion, this research paper emphasizes the significance of the proposed Free-Space Optical (FSO) communication system and underscores its advantages in the communication sector. The system demonstrates the ability to handle a substantial amount of data efficiently, making it particularly well-suited for applications where secure communication is paramount. The encoding process ensures data security by concealing clues about the size of the raw data, mitigating vulnerabilities that could be exploited by unauthorized access. The prototype project showcases the feasibility of achieving high-speed data transfer within the FSO communication framework. Furthermore, the research identifies promising future scopes for enhancements, such as refining the sequence recognition code by incorporating additional equations, including trigonometric and other mathematical expressions, to improve sequence identification. There is potential for optimizing the sequence identifying code to handle larger datasets and compress them into more compact parameters. Additionally, the project can explore avenues for increasing the efficiency of fractal data storage, aiming for optimal output and enhancing the overall transfer data capacity. The continuous improvement in these aspects contributes to the system's reliability, scalability and adaptability in diverse communication scenarios. Overall, this research lays the groundwork for further advancements in FSO communication, providing a platform for future innovations and optimizations.

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