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EXPERIMENTAL STUDY OF OPTICAL WIRELESS DATA TRANSMISSION IN CUBESATS

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Abstract - CubeSats, which are small satellites engineered to specifications, are increasingly adopting laser-based communication systems. Unlike RF based communication, laser grands higher data transmission rates due to shorter wavelengths and less energy spread. These systems capacitate new science missions at lower cost, including earth observations, planetary exploration and space science. Short comings include minimizing cost, improving pointing accuracy and ensuring attainability of earth-based laser stations. Furthermore, novel methods combining lens system and vertical cavity surface-emitting lasers (VCSELs) are being utilized for fine laser beam pointing in CubeSats. KIPP, it is a first Ku-band CubeSat with units of 3U. This paper discusses the use of laser-based communication system for CubeSats, integrated with techniques like low-density parity-check (LDPC) encoding and pulse position modulation (PPM), the research demonstrates improved data transmission efficiency and error correction capabilities. The data transmission rates at various atmospheric levels were compared and discussed for future advancements.

Key Words: CubeSat, Laser Communication, Ku band, Optical wireless communication, Low-density parity check, Pulse position modulation.

1.INTRODUCTION

CubeSats are miniscule satellites built in increments of 10x10x10 cubic centimeters, with each 10 cubic centimeters called as 1U (1 unit) these miniature satellites provide an optimum platform for universities and organization to perform space experiments. However, their dependence on conventional radio frequency (RF) communications faces short comings due to crowded spectrum and lack of data transmission capacity.

The first CubeSat idea came from a project at the Aerospace department of Stanford university collide with DARPA sought to launch a small satellite (picosat) about the size of klondike ice cream bars in 1998.but it was a major challenge of the graduate engineering students at Stanford university who had been working on microsatellites since 1995 to design and fabricate the launcher for this picosatellite. Then they came out with an idea of designing a deployer looks like a cartridge holder that could fit inside one of their existing microsatellites. When launching, the spring ejected the cartridge and release the picosat into earth orbit. The microsatellite fabricated for this purpose was named by Orbiting picosat Automated launchers (OPAL). In the year of 2000, OPAL was successfully launched and DAPRA Picosat performed as planned.

Figure -1: *CubeSat with laser technology*

The CubeSat was initially proposed to provide an opportunity for the students to design, fabricate, simulate and operate a miniature spacecraft similar to the first satellite, Sputnik. The first CubeSat was developed in 1999 by collaboration of professors Jordi Puig-Suari of California polytechnic state University and Bob Twiggs of Stanford University. CubeSat is a small satellite with a structure of cube and maximum size of 226.3cm*226.3cm and within the weight of less than 3kg.They can deploy from an international payload or launched as secondary payloads on other rockets. CubeSat can be launched by various forms like in a hot air balloon, small rockets, drones. It can only reach the altitude of low earth orbit (LEO). The first CubeSat was launched on 30 June 2003.It involves 6 CubeSats as a secondary payload. They used Rocket KS as launch vehicle from Eurockot launch service in Bremen, Germany. The launch site was Plesetsk, Russia. The secondary payload launched on that mission was XI-IV from the university of Tokyo (Japan), CUTE-1 from the Tokyo institute of technology (Japan), CanX-1 from the university of Toronto (Canada), AAUSat from Aalborg University (Denmark), Quakesat from the Stanford University (California, USA), DTUSat from the Technical University of Denmark (Denmark). These CubeSats are launched in a sun synchronous orbit. By 2012 approximately 75 CubeSats had entered orbit. Since 1999, more than 2300 CubeSats have been launched. In future, The Interplanetary Nano Spacecraft Pathfinder in Relevant Environment (INSPIRE) Project will demonstrate the revolutionary capability of deep space CubeSats by placing a nano spacecraft in Earth-escape orbit.

An impressive first experiments of basic optical communication containing a 1U CubeSat was performed by the FUKUOKA institute of technology {Japan} in assist with FITSAT -1, also known as Niwaka. It was deployed by the robotic arm of the international space station on October

2012. Niwaka had a neodymium magnet as a passive attitude control system that made the upper panel face the Fukuoka ground station. This panel contains 50 green 3-Watt LEDs, outputting 200-watt pulses, modulated with a 1-kHz morse-code signal. These signals were received by a photo multiplier coupled to 25 centimeters ground telescope.

Figure – 2*: FITSAT-1 (Niwaka)*

NICTs SOTA on board SOCRATES, which was launched in May 2014 into an approximately 600 km LEO orbit, and it was fully functional until November 2016. SOTA was to access gimbaled terminal with all capabilities to perform variety of laser com experiments in a compact 6kg package. The core experiment was the 10mbit/s links at 1549 nm. This capability utilizes main subsystems of Sota i.e., a coarsc pointing assembly to track the NICT OGS at Koganei (Japan). receiving lens is attached to tack the OGS 1 um deacon laser using a silicon quadrant detector, a fine pointing assembly to accurately transmit the 35 Mw laser through a 5cm Cassegrain telescope and an electronics unit to produce the stream of data, codify it using an error correcting codes and interleave the bits against signal fading.

2.LITERATURE REVIEW

Wenyi Fu (2022) Optical satellite communication involves in high-speed data transfer. It transfers information through light between satellite and ground control station with focus on low power consumption. In future optical satellite communication expected to integrate with 5G, focus on miniaturization of devices and space air ground integrated network. SAGIN, it integrates various satellite constellation to provide extensive coverage and support for communication service.

Vinod Kiran K et.al (2017) Optical wireless communication uses high -frequency light signals as a career for communication utilizes laser or optical signals. ISOWC plays a major role in advanced satellite communication and offers benefits over traditional RF methods optimizing IS-OWC involves considering system parameters such as distance between satellites, information bitrate, input, power and assessing Q-factor and bit error rate and then modelling the communication channel. QPSK modulation enhancing ISOWC system performance by providing robustness against noise and supporting high data rate.

Deva K Borah et.al (2012) Optical wireless communication system, it involves in both the short range (personal & indoor) and long range (outdoor & hybrid) communication. This system offers high speed data transmission but also have limitations in area coverage and user mobility compared to RF technologies. Indoor system focus on dispersion mitigation and visible light communication and the outdoor system deals with the atmospheric effects and employ mitigation techniques to extend link lengths and data transfer rate. Hybrid OW\RF system combines optical wireless with radio frequency links. It enhances reliability and its suitable for last mile communication and real time data transmission.

Rizwan muhal et.al (2012) ARAMIS is a nano satellite designed by polytecnico DI Torino. It is flexible and modular approach using panel bodies called tiles. Tiles consist of solar panels externally and data routing, power routing and subsystems internally. Housekeeping data communication within a tile and across tiles can be wireless. This process focuses on IR optical communication. Communication channel can be either free space or glass fibre. Each tile host two tile processors (MSP 430 Controller) responsible for communication. We use optical IR light communication for small satellites also.

Alberto Carrasco et.al (2017) In RF communication the data transfer rates are in order of 1-10 kbps and mbps with antenna length of 20m. It was already crowded & frequency allocation from ITU is longer. To overcome this X band communication has been introduced with data transfer rates of 100 to 200 mbps with antenna length of 5m but it was expensive and consumed high energy. In laser communication we can obtain data transfer rates of several Mbps to 1 Gbps. It can be used for inter satellite links which begins and the ends in space and for deep space missions. However, cube sat should be designed to sustain in deep space where the mission will last several years.

AMR Zeedan et.al (2017) This paper focus on the on-board transceiver and particularly highlighted on the base band architecture and their resulting performance. The future directions and challenges of CubeSat communication subsystems by improving higher data rates at lower cost, low power and high flexibility. This enhancement involves utilizing high frequency bands, implementing better modulation &coding techniques, enhanced base band algorithms, use of advanced antennas and efficient high-speed processors.

Harald haas et.al (2020) Optical wireless communication system uses signals from light – emitting diodes for wireless communication offers benefit like enormous bandwidth and minimal loses compared to conventional electro- optic networks. Techniques and technologies involve such as radio over fibre, fibre to the home, free space optics. OWC can enhance security in the physical layer, containing communication within secure-vetted areas. OWC can provide high speed secure and reliable access, making it suitable for 5G and future wireless networks.

Jaafar Elmirghani et.al (2020) Optical wireless communication involves some technologies such as free space optical (FSO) communication bridges the gap between optical fibre and wireless communication, visible light communication (VLC) utilizes white LEDs for wireless data transmissions, optical camera communication(OCC) enables its application in smart phones using digital camera sensors, LiFi (wireless networking with light) is for wireless networking using visible light as a communication medium. These innovations contribute to the evolution of wireless communication beyond traditional RF methods.

Basudev das et.al (2021) It aims to establish an optical wireless communication link operating a 10GHz frequency and achieving reliable communication using a low power C-band laser diode. Laser diodes are semiconductor devices that emits coherent light when current flow through them. In optical wireless communication system, LED serve as a transmitter. optical wireless communication finds applications in space communication for example NASA, Space X, Star link.

Jenila et.al (2021) This paper discusses optical wireless transmission (OWC) it offers high capacity of optic fibre and combines the advantage of radio and fibre optic network. It can be used for flexible broad band optical network and it analyses the sustainability of indoor OWC system. The performance of OWC system is measured in terms of data rate, spectral efficiency, reliability and energy efficiency. Lifi network utilizes light for wireless communication it offers high capacity compared to radio frequency system in the face of challenges like blocking and shadowing.

H Shakthi Murugan et.al (2019) In this paper optical wireless communication (OWC) channels for different optical fibre are analysed and discussed about Free space optics (FSO) is a new technology for high data rate and it reduce the difficulties while planting optical fibres with a key merit of simple installation, wide authorization free spectrum and transmission security. The OWC system has some limitations due to environmental factors like fog and smog.

Rizwan Abbas et.al (2024) Optical wireless sensor networks (OWSN) enable data collection, monitoring and controlling various applications by integrating optical communication with sensor nods. NOMA is a technique that enables multiple users to share the same source block. Designing efficient optical wireless sensors network by using NOMA techniques. It includes power-domain NOMA, code-domain NOMA and spartial-domain NOMA. Transforming the NOMA concept into the next generation through radio access technique.

Seshupriya Alluru et.al (2010) There are several advancements in laser communication, it offers benefits such as power efficiency, security and robustness. Optical crosslinks offer high precision and reduced transmission delays, making them attractive for inter-satellite communication. Key components of optical payload such as lenses, mirrors, sensors and cameras. The designing of an optical payload for a CubeSat focusing on laser types, operation and requirements for successful optical communication links. Design consideration is to meet the size, weight, power constraints of CubeSat.

Hayder S. Rashid Hujijo et.al (2018) This paper discusses the optical communication using 1550nm signal with rate of 350Mbps. The proposed system consists of a phase modulator which is operated by RF/mm wave signal of local oscillator for transmission the photodetector will receive the transmitted signal which produces voltage and can be converted back to the initial data using bit sequence regenerator. This paper also discusses the simulation of the proposed system.

Mrinmoyee Mukherjee (2016) This paper discusses the radio frequency communication and its merits, drawbacks, and applications and also provide the overview of optical wireless communication and its advantages, frequency bands, transmitter, and receiver module and the safety standards for eye. Wireless technology helps human to communicate using electromagnetic waves in open space at any moment through wireless media. Compares the optical wireless communication OWC and details the merits and features of OWC system benefits over RF, like license free spectrum, huge bandwidth, energy efficient components and safety standards and it can be carried out for both indoor and outdoor based application.

Ahmed Nabih Zaki Rashed et.al (2012) Optical wireless links offer high data rates and simplicity, their performance is affected by weather conditions such as fog, cloud. Optical wireless communication (OWC) is a line- of-sight wireless communication system that uses laser beams to transmit data. Maintaining a clear LOS between transmit and receive terminals is crucial for starting optical wireless links. The transmitted optical signal reacts to atmospheric effect based on particle physical parameters. OWC systems involve accuracy modulation, transmission through the atmospheric channel, and reliable reception. Understanding these elements is necessary for designing effective optical wireless links.

Francesco Sansone et.al (2020) This paper presents the design and testing of Laser Cube optical communication and its architecture has been defined for both downlink and intersatellite link version of the system. Laser Cube is a miniature, bi-directional optical communication system complaint to the CubeSat. It offers high bitrate communication, increased security. The dual stage pointing system of Laser Cube this system enables precise laser and pointing accuracy. This paper also takes a look at feasibility of integrating quantum key distribution to enhance the communication security.

Imam Uz Zaman et.al (2020) This paper discusses the use and optimization of systems in optical crosslinks for swarm of CubeSats. Optical data transfer is preferred over microwave technology due to their small size and increased data rates.

3. METHODOLOGY

3.1. Concept of optical wireless communication with CubeSat

In this communication laser technology is broadly used to transmit data wirelessly between satellite or ground stations. This technology can enhance communication capability specifically for small spacecrafts with limited power. Now, we use this laser technology as a replacement for the radio frequency communication. The exploitation of small satellites, especially CubeSats, for commercial applications has been continuously developing, in order to improve higher data transmission, the space agencies are working on optical wireless data transmission with laser technology.

3.2. Need for laser data transmission in space

As we traditionally used radio frequency waves for space communication, data are extracted at slower rate, in order to puzzle out this problem space agencies introduced optical communication which offers a higher frequency of around 200 terahertz compared to a few gigahertz for radio waves. Laser technology benefits in weight reduction which is crucial for spacecrafts impacting launch costs and mission flexibility. Optical communication helps in reduce power consumption by stemming directly from the physics of light. It mainly focuses on minimize power waste from spreading or absorption and offering greater efficiency. Optical communication is more secure than RF channels as laser beams are precise aiming along a narrow path.

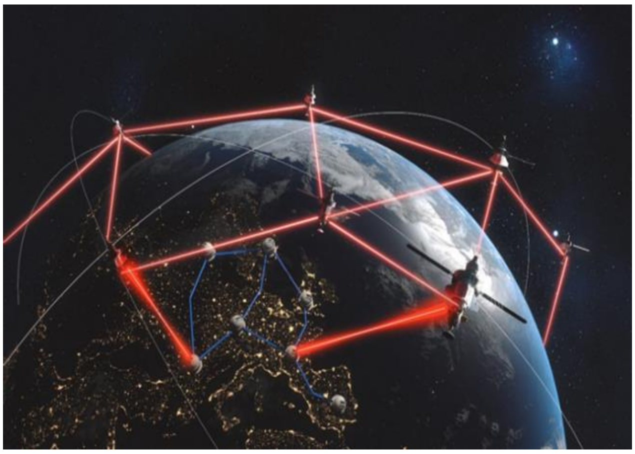

***Figure-3**: Satellites transmitting data with Laser communication.*

3.3. Encoding

LDPC (Low Density Parity Check) technique is used for encoding because it has better scalability, error correction capabilities and high communication rates. The LDPC code encodes the data by multiplying the data with a Sparse parity check matrix. The resulting encoded data will have additional redundant bits which helps to detect and correct the errors during decoding.

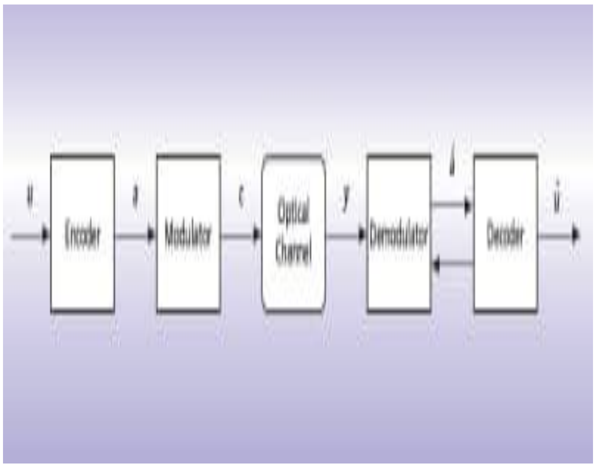

***Figure -4:** Datas are getting encoded and Decoded into Optical signals.*

The LDPC encoded data is converted into PPM format where each group of bits is represented by a pulse in specific time interval between the pulses. LDPC consumes more power so we use PPM with that, by combines these two for balanced power consumption and efficiency.

3.4. Transmission

The transmitted laser beam will reach the ground station or another spacecraft (other CubeSat's or satellites) via space. Effective long-distance communication is made possible by narrow laser beams, which minimizes spreading. Communication requires unobstructed line of sight.

3.5. Decoding

A photodetector will be placed at a receiver (ground station or spacecraft). The photodiode will act as photodetector. It converts optical signals into electrical signals. Lens system will be used to focus the incoming laser beams into the photodetector. To capture the weak signals from the CubeSat and direct them precisely into the photodetector.

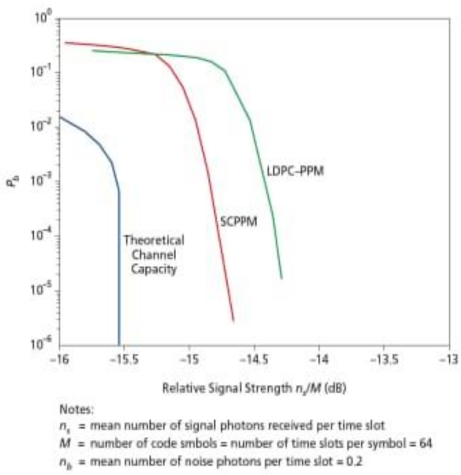

***Figure -5**: The Bit-Error Rate (P_b) was computed as a function of relative signal strength for two coding schemes.*

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When the laser beams strike the photodetector electric current will be generated proportional to the light intensity. The generated current will be small so it requires amplification. Transimpedance Amplifier (TIA) is used to convert the photodetector current into voltage signals and to amplify it. Then the electric filters are used to remove the noise and improve the signal quality. A low pass filter is used to remove high frequency noises and band pass filter will be used to isolate the signal frequency band.

The received signal will be demodulated to extract the LDPC encoded data. The amplified electric signal will be sampled to detect the presence of pulses with predefined time slots. For each time slot, the presence or absence of pulse is detected then the encoded data bits can be extracted.

The demodulated data will be decoded using LDPC decoding algorithms. The errors will be corrected if any. The encoded data transmitted from the CubeSat will be received by the ground station and modulated to the original format.

3.6. Applications

For example, there are two applications Temperature sensing and Distance measurement. Infrared cameras will be used to capture the hot and cold regions of the earth's surface on a heat map and this data will be converted into bits then transmitted. Lidar sensor is used to measure the distance of intersatellite. The measured distance and thermal image data are encoded and modulated by PPM then transmitted to the ground stations.

4. RESULT

This table describes the many scenarios of an optical wireless satellite communication together with their corresponding terminals, bitrates and distances.

When distance increases the data bitrate transmitted will get decreased. So, more distance less bitrate and less distance high bitrate will be transmitted.

FX Terminal – It act as Miniaturized laser terminal suited for long distance, high speed and bidirectional links.

ST Terminal – A more compact version of FX terminal designed for shorter distance communication.

LEO – Low Earth Orbit

GEO – Geostationary Earth Orbit

OGS – Optical Ground Stations

HAPS – High Altitude Platform Stations.

Scenario	Terminal	Distance	Bitrate	Comment
LEO-LEO	FX	5000 km	1 Gbit/s	Sparse const. (long distance)
LEO-LEO	FX	1000 km	10 Gbit/s	Dense const. (short distance)
LEO-GEO	FX	36,000 km	100 Mbit/s	Return link (LEO→GEO)
LEO-GEO	FX	36,000 km	1000 Gbit/s	Forward link (GEO→LEO)
LEO-HAPS	FX	1000 km	10 Gbit/s	Bidirectional (FX↔FX)
HAPS-HAPS	FX	200 km	2 Tbit/s	5 × 400G channels (WDM)
HAPS-OGS	FX	200 km	2 Tbit/s	5 × 400G channels (WDM)
LEO-OGS	FX	1000 km	400 Gbit/s	Downlink (LEO→OGS)
LEO-OGS	FX	1000 km	10 Gbit/s	Uplink (OGS→LEO)
LEO-LEO	ST	1000 km	100 Mbit/s	Dense const. (short distance)
LEO-OGS	ST	1000 km	10 Gbit/s	Downlink (LEO→OGS)
LEO-OGS	ST	1000 km	1 Gbit/s	Uplink (OGS→LEO)
LEO-HAPS	ST	1000 km	100 Mbit/s	Bidirectional (ST↔ST)
HAPS-HAPS	ST	200 km	100 Gbit/s	Bidirectional (ST↔ST)
HAPS-OGS	ST	200 km	100 Gbit/s	Bidirectional (ST↔ST)
Horizontal	FX/ST	20 km	5.6 Tbit/s	14 × 400G channels (WDM)

Table-1: *Simple Estimation of CubeSats Data transmission with distance and bitrate.*

5. DISCUSSION

The integration of laser-based communication systems in CubeSats represents an important leap forward in space technology. It offers enhanced data transmission rates, efficiency and scientific research opportunities. By utilizing lasers for communication, CubeSats can achieve faster and more reliable data exchange. It surpassing the limitations of traditional radio frequency methods. This development improves communication capabilities and also reduce power consumption and launch costs, making space missions more defendable and cost effective. With applications ranging from temperature sensing to intersatellite communication, laser technology in CubeSat unwraps new possibilities for earth observations, planetary exploration and space science missions. As optical communication technology continues to evolve, it will shape the future of space exploration and data exchange. Also, we can elaborate the dimensions of the CubeSat, like using 12U CubeSat offers excess space for various sensors, that improves the data reliability exchange. CubeSat can also be used as a mediator for transmitting data fastly. In order to transmit higher datas in low distance we use CubeSats that are linked from big satellites and ground station that can transmit higher datas easily from LEO as the distance get decreased.

6.CONCLUSION

In conclusion, this paper mainly focuses on optical wireless data transmission. CubeSats have transfigure space exploration due to their affordability and ease to access. RF waves, traditionally used for communication but it faces some limitations like transmit the data at slower rates. So, we use optical communication using laser technology. It offers better solution and minimizes the power consumption. Laser beams are more assured than RF channels due to precise aiming along narrow paths. LDPC technique is used for encoding for high communication rates and error correction. But LDPC consumes more power, so we use PPM with LDPC for balanced power consumption and efficiency.

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