Image and Video Transmission in Wildlife Sanctuaries using LoRa Technology

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Abstract- The proposed project explores image and video transmission in wildlife sanctuaries using LoRa technology, addressing the challenge of interference among multiple nodes in dense deployments. Traditional time-division methods face latency issues, prompting the adoption of Frequency Division Multiplexing (FDM). Each node operates on unique frequencies, ensuring simultaneous, interference-free transmission. Compression algorithms and efficient hardware design enhance data handling within LoRa's bandwidth constraints. Findings demonstrate robust, low-power communication, enabling scalable and cost-effective wildlife monitoring systems. The impact lies in real-time data accessibility, aiding conservation efforts and ecological research.

Keywords: LoRa Technology, Frequency Division Multiplexing, Packetization, Serial Communication, Video Transmission.

I. Introduction

The ability to transmit image and video data swiftly and effectively within wildlife sanctuaries using LoRa technology will surely enhance the monitoring and conservation work carried out effectively. Frequency Division Multiplexing (FDM) will help curb the issue of interferences faced in such applications that have a large network of sensors dispersed over a region while maintaining its low power loRa connectivity. Wildlife monitoring systems have become very important for the conservationists as a means of helping them comprehend and safeguard biodiversity. In the recent years, camera trap monitoring systems have become a significant trend, allowing for collection of vital information on animals, including their behaviors, movement and the ecology. Though useful, such systems have unique drawbacks when employed in the field of wildlife conservancies for example the remoteness and inaccessibility to power and communication networks. These environments have also made LoRa technology, which is characterized by wide range and low power, a necessity for communication. Nevertheless, the narrow bandwidth of LoRa coupled innumerable nodes transmitting concurrently leads to intolerable interference which undermine the efficiency and reliability of the system. Most of the existing solutions for wildlife monitoring systems are built on wired networks and/or employ high-power conventional wireless protocols such as Wi-Fi and cellular networks which are unsuitable for these remote dormitories. LoRa technology is an optimization but it's still based in Time Division Multiplexing (TDM) control of different nodes operations. The technique allows for effective communication, however, there is a drawback as the latency is high since all the nodes will have to wait for their time slots, TDM is therefore not appropriate for systems where data transmission is required frequently or simultaneously.

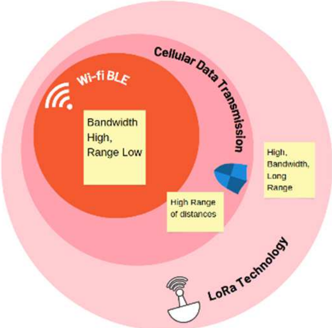

Fig.1 Comparison of data transfer technologies(Wifi, Cellular data transmission, LoRa)

As per Fig.1, the comparative analysis summarizes that among Wifi (BW=2.4 to 2.48 GHz,range=30 meters), Cellular Data Network (BW>20 Gbps,range=8.0 Km), LoRa(BW=125 KHz, 3Km<range<100Km), LoRa supports best transmission qualities in case of wildlife sanctuaries. The lack is filled in the present research by incorporating and implementing Frequency Division Multiplexing (FDM) in a

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‘LoRa-based wildlife monitoring system’. Since FDM allows data to be transmitted at the same time and its associated channels without the need of waiting to transmit as in TDM where a time segment needs to be allocated to each node, FDM assigns unique frequency channels to each node. This revolutionizes the way the system is designed increasing its scalability greatly allowing real time data access even with huge population of the monitored nodes..

II. METHODOLOGY

The process of transmission of image and video using LoRa technology is starting from data acquisition with cameras which can be an image or a video that is relayed to the ESP32 via a UART communication. JPEG is the format that is used to compress still images while H.264 format is used for compressing moving images by the ESP32 so that better use of the narrow band LoRa’s transmission capabilities is utilized. Further, compressed data is broken off into several chunks (max 256 bytes) that have basic information like node id, sequence number and CRC in order to aid in error checking and data restatement.

These data packets are then sent to the LoRa module using SPI for sending the packet wirelessly. In this case of multiple nodes, Frequency Division Multiplexing (FDM) is employed whereby each node is ascribed its own frequency and thus avoids interference. In essence, the LoRa gateway is multi-channels so the data is accepted and then sequence numbers applied to correct any errors before lost packets are retrieved. After this, the reconstructed signal is sent to an analyzing machine for analysis.

Frequency Division Multiplexing:

To overcome interference when many nodes are deployed, Frequency Division Multiplexing (FDM) is utilized. Each LoRa node is given a distinct frequency channel within the bandwidth, thereby forbidding simultaneous transmission within the same frequency, which in turn lowers the chances of collisions. The gateway has multi-channel receivers that track several frequency channels, providing the possibility of multiple nodes speaking at the same time without any clear lapse for speech. This FDM based method increases performance of the network by eliminating interference allowing for data transmissions that do not compromise the quality of the signals even when done simultaneously.

The link budget equation is used to ensure robust communication by calculating the received power Pr from the transmission power Pt and the path loss L, along with antenna gains Gt and Gr at the transmitting and receiving ends, respectively. This equation helps optimize signal strength over long distances:

$$P_r = P_t + G_t + G_r - L \qquad ....(1)$$

The quality of communication is determined by computing the Signal-to-Noise Ratio (SNR) given as:

$$SNR = P_r - P_n \qquad ....(2)$$

In this equation, Pn refers to the noise power. In LoRa quality networks, a minimum SNR of -20 dB is always needed for effective communication. The transmission rate (R), which is a function of the spreading factor SF, the bandwidth BW, and the coding rate CR, is given by the following relation:

$$R = \frac{BW}{2^{SF}} \times CR \qquad ....(3)$$

Where $CR = \frac{4}{4+N}$ and N represents the quantity of error correction bits. This equation assists in configuring the maximum data rate depending on the conditions of the network, allowing the system to be used in different types of transmission environments. To achieve effective frequency allocation while reducing interference, the total utilization of bandwidth is expressed as:

$$BW_{Total} = N \times BW_{Node} \qquad ......(4)$$

Where BW_{Node} is the bandwidth given to each node, whereas N signifies the number of the nodes present. This equation is used to make sure that the bandwidth is efficiently used and there is no issuing of congestion especially in cases where there is high usage of the nodes engaging in data transmission simultaneously. T, the transmission time for each packet, is influenced by different parameters such as packet size P, spreading factor SF, and bandwidth BW as indicated in the following equation:

$$□ = \frac{□ \times 2^{□□}}{□□} \qquad ....(5)$$

This ensures that the time taken to transmit a packet is within the limits set by LoRa, paving the way for effective communication of information between various nodes of the network. After the data has been sent to the gateway via LoRa, the multi-channel receivers at the gateway gather packets from the designated channels. The gateway then reconstitutes packets using the sequence numbers and requests retransmission for any lost or damaged packets. Upon the completion of receipt of all freaking packets, the provided image or video is reconstructed ready for processing/display.

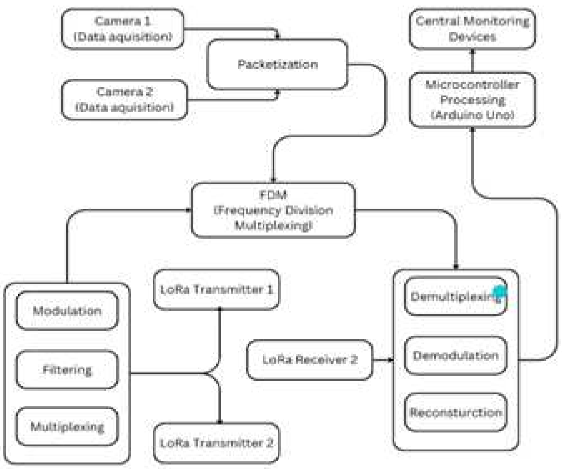

Fig.2 Detailed Flow of LoRa Image and video transmission in wildlife sanctuaries

As per Fig.2, the proposed approach incorporates Frequency Division Multiplexing (FDM) in order to eliminate interference and adds packetization, data rate optimization to guarantee and effective transmission. the proposed approach leverages Frequency Division Multiplexing (FDM) to ensure interference-free communication by assigning distinct frequency bands to each data source. Additionally, it integrates packetization for structured data handling and data rate optimization to maximize transmission efficiency and reliability over the LoRa network.

Algorithm: Image and Video Transmission Using Lora

1. Initialize all devices: camera, Arduino Uno and LoRa modules.
2. Capture image or video frames using the camera.
3. Divide compressed data into packets.
4. Send packets to the LoRa module.
5. If multiple nodes are present:
Assign a unique frequency band to each node.
Else:
Use a single frequency band.
6. Use a multi-channel LoRa gateway to receive packets from all nodes.
7. Reassemble packets in the correct order based on sequence numbers.
8. Forward the reconstructed data to an analysis unit for further processing or display.

III. RESULTS AND DISCUSSIONS

Fig.3 Camera 1 and Camera 2 hardware implementation along with LoRa Transmitters

Fig 3 shows the hardware setup of Camera 1 and Camera 2 integrated with LoRa transmitters for wireless image and video data transmission.

Fig.4 Implementation of LoRa Receiver

Fig. 4 shows the setup and working components of the LoRa receiver, responsible for receiving, verifying, and reconstructing transmitted data packets.

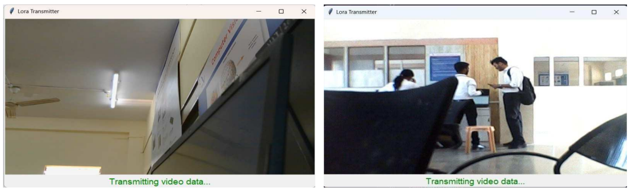

Fig.5 Video Data Transmission through cam 1 and cam 2.

Fig.5: Real-time video streams recorded by two separate camera modules, Cam 1 and Cam 2, are shown in this picture. The modules are actively sending data via LoRa-based transmitters. Successful encoding and wireless transmission over the LoRa network are confirmed by the on-screen notification "Transmitting video data." The configuration demonstrates the system's capacity to manage many sources of simultaneous video feed delivery via low-power long-range communication.

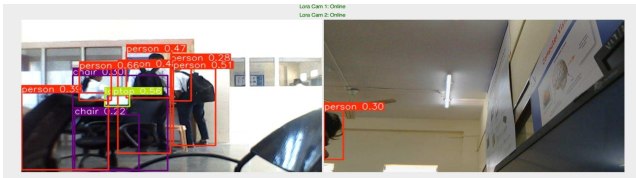

Fig.6 Video Data Received from transmitter 1 and transmitter 2 and applied machine learning algorithm

The Fig.6 shows two different LoRa-enabled transmitters sending video streams. Following transmission, the frames are processed by a machine learning-based object detection algorithm that effectively identifies and tags items like laptops, seats, and people. This demonstrates the system's ability to support the transmission of video data over LoRa and to intelligently analyze the content that is received.

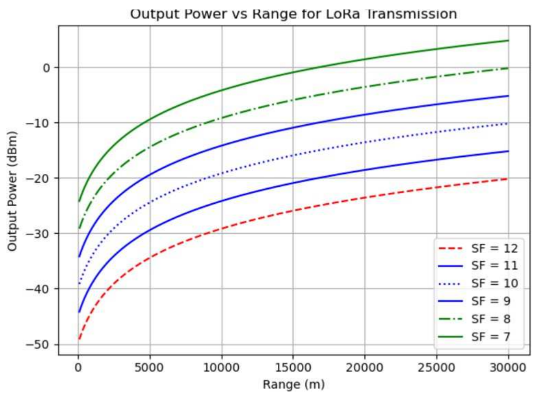

Fig.7 Output Power vs Transmission Range in LoRa Communication.

Fig.7. Shows that for a range of Spreading Factor (SF) values, from SF 7 to SF 12, the figure shows the relationship between transmission distance and the output power required for LoRa communication. While lower SF values (green lines) offer faster data rates but are only viable at shorter distances, higher SF values (blue and red lines) increase communication range at the cost of increased power consumption and lower data throughput. This trade-off is essential for configuring LoRa systems for efficient image and video transmission over varying distances.

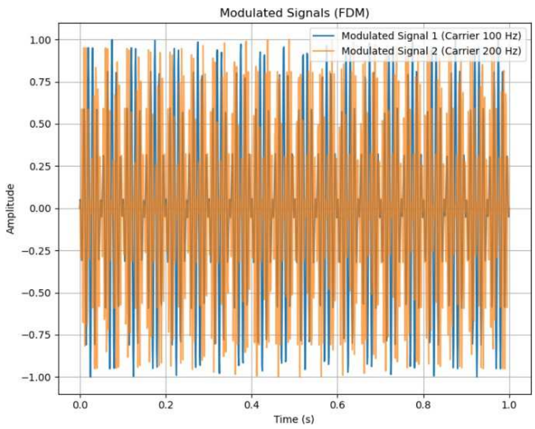

Fig.8. Combined output of two modulated signals.

This Fig.8 illustrates the combined signal resulting from the frequency division multiplexing (FDM) of two modulated signals. Each signal is modulated onto a distinct carrier frequency to enable simultaneous transmission over a shared communication channel. The combined signal shows the superposition of both modulated signals, maintaining their individual frequency bands without interference, demonstrating the effectiveness of FDM in separating and preserving signal integrity for transmission.

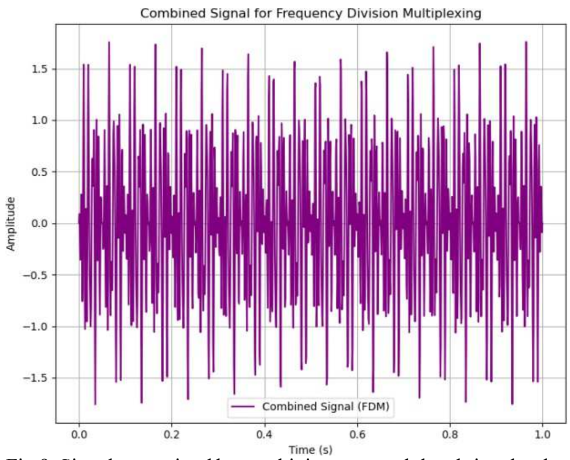

Fig.9. Signal transmitted by combining two modulated signals taken from two transmitters.

This Fig.9. shows the transmitted signal formed by combining two modulated signals, each originating from a separate transmitter. The signals, modulated at distinct carrier frequencies, are superimposed to create a single composite waveform for transmission. This demonstrates the utilization of frequency division multiplexing (FDM) to enable simultaneous data transmission from multiple sources over a shared medium.

IV. CONCLUSION

The idea put forth LoRa technology with Frequency Division Multiple Access, FDM, to achieve flawless, reliable, scalable image and video transmission, especially in enclosed spaces like wildlife areas. The extended range and low power characteristics of LoRa, combined with the ability of FDM to mitigate interference, make it possible to connect multiple video recording devices without any data loss. Packet creation, signal to noise ratio SNR enhancement, and sophisticated error correction techniques make it possible for data to be of high quality even though LoRa has low bandwidth. This technique is economical, consumes less energy, and is suitable for widespread application to overcome the issues posed by remote observation systems while providing consistent voice services even in poorly resourced environments.

V. FUTURE SCOPE

The vision for the system is based on improving the performance of the transmission part by adding advanced compression methods such as HEVC for video and adjusting LoRa parameters in relation to the surroundings. It is possible to integrate machine learning to learn the interference patterns and manage the frequencies in real time, hence increasing the reliability of the system. The system can have enhancements such that it will be able to process and accommodate high-definition images and videos, hence finding use in advanced applications such as tracking endangered species, monitoring catastrophes or natural disasters, and precision farming.

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