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LoRa High Altitude Balloon Remote Control Protocol for Up to 30 Miles

Harun Adiyaman, SP25-20-ECE 4806

Abstract— High Altitude Balloons (HABs) tend to burst at high altitudes due to a large pressure difference. As a result, time spent at a high altitude is limited for data collection. This article highlights part of a solution to create a venting system on a high-altitude balloon in order to achieve near neutral buoyancy that can be remotely controlled via a ground station which is stationed downrange of the balloon launch. LoRa will be used as the radio modulation technique, which calls for a trade off between range and data rate. Having a greater range decreases the data rate meaning control commands must be small in size. This will be discussed as part of the custom communication protocol. In regard to transmission regulations, without violating FCC regulations, without needing an amateur radio license or needing amplification, and powered by three point three volts our main challenge is obtaining a communication range of 30 miles with a clear line of sight. To which correct antenna choice is crucial.

***Index Terms*— Antennas, chirp spread spectrum modulation, control command, directional antenna, LoRa, patch antenna, remote control**

I. INTRODUCTION

THE High Altitude Ballooning (HAB) team at Virginia Tech regularly launches high altitude balloons in order to collect data. Most notably, as part of the NASA Nationwide Eclipse Ballooning Project the HAB team released a balloon with a camera payload which took the picture found in Fig. 1.

Fig. 1. Image of the shadow of the moon on the earth during the 2024 solar eclipse. Source: Adapted from [1].

This work was supported and funded by the Virginia Tech ECE department under ECE 4806 - Major Design Experience. This work was also supported by this project's customer and subject matter expert: Kevin Sterne (Faculty Advisor for the High-Altitude Ballooning team at Virginia Tech)

Harun A. is a Senior at Virginia Tech in Computer Engineering, Blacksburg, VA (e-mail: haruna@vt.edu)

However, this balloon burst soon after and was unable to capture more images. To find a solution a team of five computer engineering students (including the author) were tasked with designing and implementing a remote-controlled venting system.

The primary method of achieving long distance communication was to use LoRa, which is a modulation technology that can achieve long range communication with low power while sacrificing data rate. In designing the communication protocol, the limitations of LoRa have to be considered. Such as low data rate and half-duplex communication. LoRa alone will not be able to achieve a range of 30 miles. Meaning, antenna choice is crucial to be able to propagate a signal over 30 miles with a clear line of sight (since the balloon will be in the sky). On the ground, a high-gain directional antenna will be used to transmit control commands. On the balloon, an omni-directional antenna (or a better option: patch antenna) will be used to obtain the control command and transmit an acknowledgement back. More details on the protocol will be discussed later.

II. LORA BACKGROUND

LoRa is a proprietary spread spectrum modulation scheme that is derivative of Chirp Spread Spectrum modulation (CSS) and which trades data rate for sensitivity within a fixed channel bandwidth [2]. LoRa is sometimes confused with the LoRa WAN protocol. LoRa is a physical layer implementation, whereas LoRa WAN is a communications protocol used to create a network of LoRa devices. In this application LoRa WAN has a very high overhead and is unnecessary since there are only two nodes in this application.

An important thing to note about LoRa is that it is half-duplex meaning it can only transmit or receive at any given time.

A. Shannon – Hartley Theorem

The reason LoRa can achieve much longer ranges is because it can detect symbols[1] with a very low signal to noise ratio (SNR). This can be seen using the Shannon – Hartley Theorem (1) in Fig. 2 which establishes that a channel's capacity for a communication link and defines the maximum data rate that can be transmitted within a specified bandwidth in the presence of noise interference [2]. This means C is the data rate in which data can receive error free.

[1]Symbol – The smallest amount of data a channel can carry. Ex. One Bit or Byte

$$C = B * \log\left(1 + \frac{S}{N}\right) \quad (1)$$

$$\frac{N}{S} \approx \frac{B}{C} \quad (2)$$

Fig. 2. Shannon – Hartley Theorem for Channel Capacity.
C = Channel Capacity (bits/s)
B = Channel Bandwidth (Hz)
S = Average Received Signal Power (Watts)
N = Average Noise or Interference Power (Watts)

Assuming a SNR much below 1, (1) in Fig. 2 can be rewritten as seen in (2) to form a proportional relationship. The inverse SNR is proportional to the channel bandwidth and capacity ratio. Keeping the SNR constant, we can see that increasing bandwidth allows for more reliable transmission under very low SNR conditions. This fact reinforces the idea that CSS can achieve reliable long-distance communication despite a very low SNR.

B. Spreading Factor

The final concept that is relevant to LoRa and this paper is Spreading Factor (SF). SF is essentially the amount of time a symbol is *spread* over. This can be visualized in Fig. 3 where a symbol is transmitted with increasing SF. It is fairly obvious from this figure how much the SF would decrease the data rate. As a consequence, increasing the SF, can decrease the symbol error rate as the SNR decreases as seen in Fig. 4. While an SF of 7 experiences a 100% symbol error rate at an SNR of -18dB, an SF of 12 experiences a symbol error rate of 0.001 at an SNR of -22db which is outstanding.

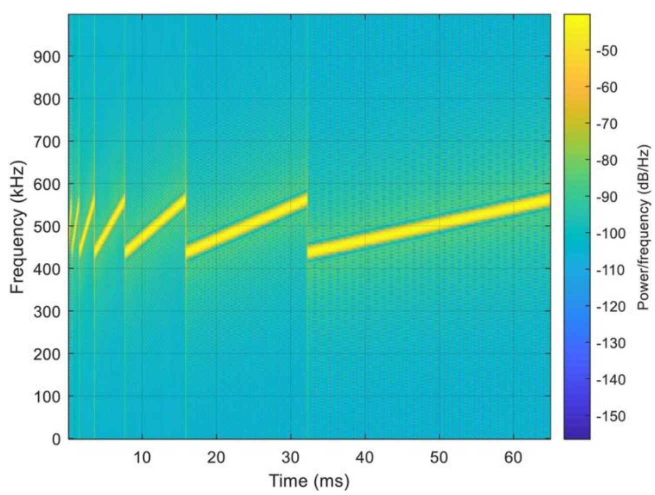


Fig. 3. Visualization of SF from 7 to 12 (left to right). Source: Adapted from [4].

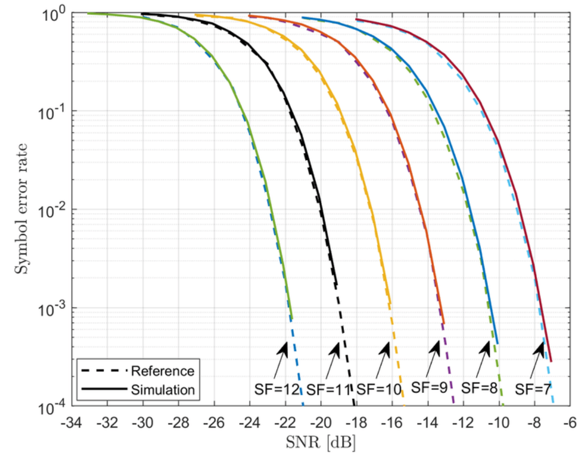


Fig. 4. SNR vs Symbol Error Rate for SF 7-12. Source: Adapted from [3].

III. Solution

A. High Level Solution

The proposed solution is implemented on both balloon-side (Fig 6) and ground station side (Fig 5). The ground station will be positioned down range of the balloon launch. And a high gain directional antenna will point at the balloon and transmit a control command packet. On the balloon side an omni-directional antenna will pick up this packet and process the command to execute. The balloon also has a logging subsystem used for testing purposes which will be mentioned later.

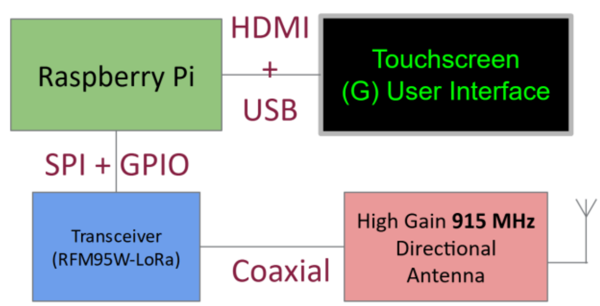


Fig. 5. Ground Station High Level (HL) Block Diagram

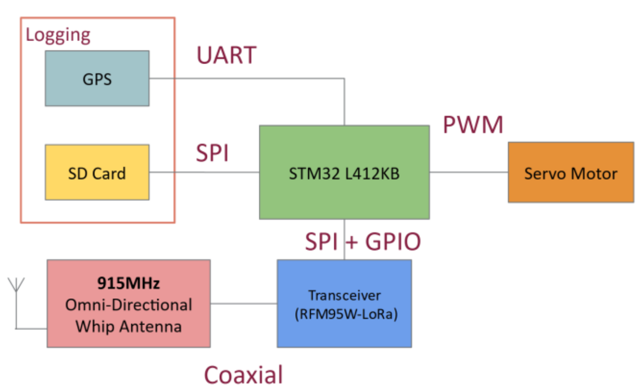


Fig. 6. Balloon Venting System HL Block Diagram

It is worth mentioning that the RFM95W will act as the LoRa transceiver module, which utilizes the Semtech SX127x transceiver chip. This chip has one of the lowest sensitivities at over -148dBm [5].

In the application of LoRa to this project, an SF of 12 will be used extensively in order to reliably detect weak and noisy signals and meet range requirements.

B. Protocol

With all the relevant background information from LoRa, an appropriate communication protocol can be developed. This protocol must support the half-duplex nature of LoRa along with its low-data rate (especially at higher SF). In addition to designing the protocol around the design of LoRa, it has an added benefit to include acknowledgements such that a human will be able to confirm the receipt of a control command. This is, however, a sufficient but not necessary condition in verifying that the balloon received the control command.

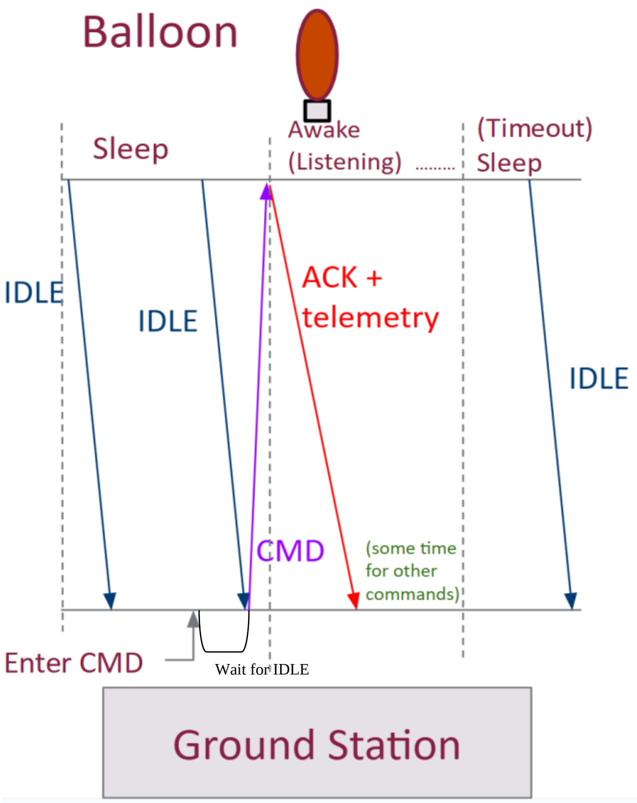
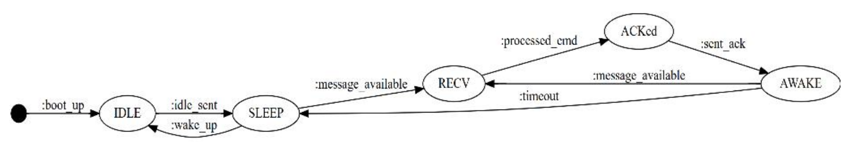


Fig. 7. Communication Protocol Behavior Diagram

The protocol behaves as follows (Fig. 7): The balloon periodically broadcasts *IDLE* commands and then goes into sleep mode to save power. The RFM95W will trigger an interrupt in the event a message is available, which will pull it out of sleep mode. On the ground station side, an *IDLE* command will appear when the balloon is in range. The user will select a command and send it. However, it will not be transmitted immediately, it will wait for the next *IDLE* command to be received and will then send it immediately afterwards. This is done to solve the half-duplex problem. By ensuring turn-taking we can be relatively certain that when the control command arrives at the balloon it will not be in a transmitting state (*IDLE*). But to ensure this the sleep duration must be long enough to compensate for propagation delay. In addition, increasing sleep duration decreases power consumption, thus increasing battery life. On the other hand, increasing sleep duration can also significantly increase initial latency. This process is only done with initial communications. Once the balloon has received a control command, it will enter an *AWAKE* state where it will no longer broadcast *IDLE* commands but will be constantly listening for new control commands. Once it receives a control command, it will send an acknowledgement back down to the ground station (with the option of telemetry: to be decided later). As mentioned previously, this is a sufficient but not a necessary condition in verifying the receipt of the control command. After a significant timeout, the balloon will once again enter the sleep-*IDLE* cycle.

[2]Sensitivity – lowest signal strength a receiver can detect and decode accurately.

Fig. 8. Finite State Machine on Balloon



C. Packet Format

In addition, a custom packet format must be developed to be as small as possible while supporting the protocol. Table I represents the current packet format with a 4-byte header. The header consists of Sequence number, Acknowledgement number, the Command, and Length of payload data each being 1 byte. The data can theoretically be 255 bytes long although this is not recommended to keep the packet small. However, the option is made available if it is necessary.

TABLE I
Packet Format

Packet Format (4-byte width)			
Seq #	Ack #	CMD	Len
Data (*len* bytes)			

Some examples of control commands are *IDLE*, *CUTDOWN*, and *OPEN*. The CMD field supports up to 255 commands with 0x00 reserved as a default. This means that the command set is expandable for fit future use cases. The value of each command has a purpose. The value the command has dictates how the payload data is to be processed. For example, the lowest values of commands are commands that have no payload data meaning further parsing is not required. Commands in the middle range around 0xB to 0xC1 hex (11 to 193 decimal) are reserved for commands with their payload data encoded as a binary coded decimal (BCD). This will reduce the data length as sending digits as characters will parse each digit as its own byte. Instead using BCD allows for one byte to represent a number up to 255. The rest of the values can be implemented and defined as needed.

D. Command Set

The current command set includes the following:
(Format: *Name* – Value (hex) – Description)

- *IDLE* – 0x01 – Idle command sent by the balloon
- *CUTDOWN* – 0x02 – Cuts down the balloon
- *OPENs* – 0x40 – Opens the vent for 'x' seconds
- *OPENm* – 0x41 – Opens the vent for 'x' minutes

V. Conclusion

In conclusion, this work proposes a solution to achieving remote control of a HAB with a range of up to 30 miles. This remote control will allow Virginia Tech's HAB team to remotely control the venting mechanism on a HAB in order to achieve near neutral buoyancy and lengthen the data collection period before bursting or cutting down.

The solution involves LoRa and careful antenna choice. It also takes useability and expandability into account. As this project is handed over to the customer, detailed documentation will be provided which documents the creation of the product as well as instructions on how to use it or expand on it.

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Harun Adiyaman (VT CPE Undergraduate)
From Aldie, Virginia, Harun was born in Rockville, Maryland and spent much of his childhood in the DMV area. For his undergraduate education, he attended Virginia Tech in Blacksburg, Virginia. Following his Graduation in May 2025 he is looking to work full-time while completing his Master's education part-time.