An Application of LoRa in a Mars Rover Model

Noam Cohen

Abstract— **This paper evaluates the feasibility of using a LoRa communication scheme for long-distance communication in a Mars Rover. Due to the extreme conditions on Mars, reliable communication between a rover and a base station is critical for successful exploration and data transmission. However, traditional communication methods are often limited by their high-power consumption and susceptibility to interference. A series of experiments were conducted to determine whether LoRa could be used on Mars. The results show that LoRa communication using a spreading factor of 7 and bandwidth of 31.25kHz is a reliable way to establish long-distance communication on Mars, with a data rate of 1.669 kilobytes per second with a transmission gain of 0dB. This research demonstrates the potential of LoRa communication for future Mars missions, enabling low-power, long-range communication.**

Index Terms—**LoRa, Mars Rover, Spreading Factor.**

I. Introduction

The objective of this paper is to investigate the feasibility of using a LoRa communication system for a Mars rover, with the aim of improving power efficiency and enabling more data collection. As the demands for scientific data from Mars increase, the power required for rovers to operate effectively also increases. However, the available power in the form of a Radioisotope Thermoelectric Generator[1] is limited, and traditional communication systems often require high power consumption. A low-power communication system such as LoRa could potentially address this challenge. LoRa is a wireless communication scheme that is well-suited for long-range, low-power applications. It is known for its robustness and ability to function in low signal-to-noise ratio (SNR) environments. This paper proposes a spreading factor and bandwidth of a LoRa communication system for a Mars rover scale model and investigates the theoretical limits of the system. In this paper the results of an experiment testing the system's performance in an emulation of Mars' environment, as well as a test on Earth for comparison are presented.

II. The Communication Channel

Traditionally, a rover's communication channel back to earth can be established in two main ways, the first is a direct link from the rover to earth, in figure 1 it can be seen as a direct connection from (1) to (4), where the rover would transmit a signal through an antenna onboard directly to NASA's "Deep Space Network" (DSN) which is essentially a big antenna with a high gain capabilities. However, the direct link approach is limited as it requires a direct line of sight (LOS) with earth and significant power to transmit information directly to Earth[2].

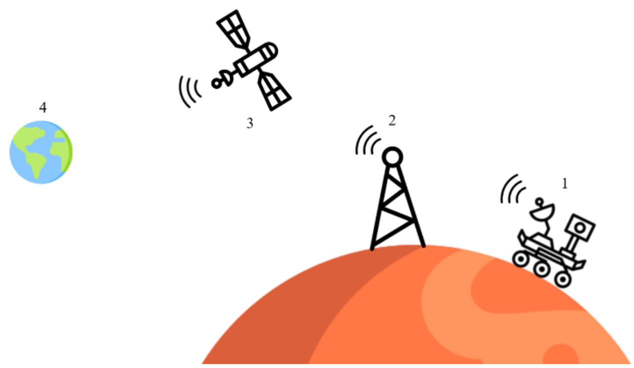


Fig. 1. Mars to earth communication channel; 1) Mars Rover; 2) Mars base station; 3) Mars Orbiter; 4) Earth

These requirements both limit the amount of data that can be sent and require significant power from the rover. The second approach is indirect link using NASA's Mars orbiters, these satellites are 400 kilometers away from the surface of mars and can transmit information back to Earth using their larger antennas, the second approach is favorable as it allows the rover to conserve much needed power that can be used to other scientific experiments. In this paper the indirect link is chosen as the favorable channel. The rover will use a mounted LoRa module and a small antenna to communicate with the base station, in figure 1 is shown as (1) – (2) which then will amplify the signal and transmit it to a Mars orbiter (2) – (3) and from there the signal will be further amplified and sent back to DSN (3) – (4).

III. Model Rover Design

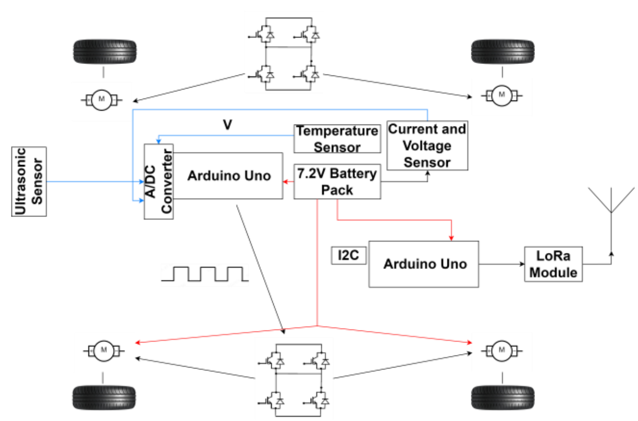


Fig. 2. Block diagram of the Mars rover scale model.

The rover model was designed to replicate the most basic actions that a real Mars rover performs daily on Mars, and thus provide an approximation of the power consumption of a real Mars rover. As shown in figure 2 the scale model consists of 4 permanent magnet DC motors which provide maneuverability, ultrasonic sensor that allows the rover basic obstacle detection, two microprocessors that will act as the brain of the rover. The only power source of the rover is a 7.2V battery pack. The rover can send its health status by reporting back the drawn current and the supplied voltage using Arduino Uno's analogue to digital converter. The commands that can be sent to the rover include drive forward, backward, rotate, and report obstacle distance.

IV. LoRa Configuration Parameters

To maximize power efficiency, and to maximize data sending rate, LoRa's parameters must be chosen carefully. Two key parameters must be determined: 1) Spreading factor (SF) which determines the symbol size and the robustness of the channel; 2) The bandwidth (BW) of the channel; These parameters will determine the maximum distance which communication is possible, the power consumption of the communication, and the data rate.

A. Simulation of LoRa under various SNRs

A simulation of LoRa communication was conducted using Matlab, the simulation generated a LoRa symbol and then introduced noise of different SNRs, for each SNR, 100 samples were taken, and the error rate was computed.

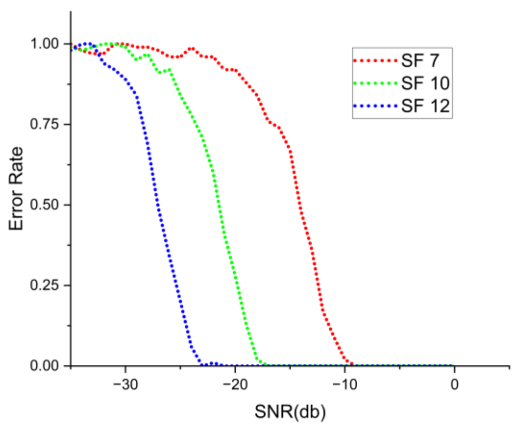


Fig. 3. Error rate vs SNR for: 1) SF of 7; 2) SF of 10; 3) SF of 12.

As can be seen in figure 3, even when the SNR is -23db the error rate for SF of 12 is negligible while for SF of 10 and SF 7 it is significant. However, increasing the SF does increase the power consumption significantly, thus an estimation of the SNR of the channel is needed to determine the lowest SF that can be used reliably. As was discussed earlier, SF determines the symbol length of LoRa.

The number of possible values in a symbol are given by the equation:

$$\textbf{(1)}\ \boldsymbol{Possibilites} = \mathbf{2}^{\boldsymbol{SF}}$$

It is then useful to treat the spreading factor as the number of bits per symbol. The time on air (ToA) of a symbol is given by the following equation:

$$\textbf{(2)}\ \boldsymbol{ToA} = \frac{\mathbf{2}^{\boldsymbol{SF}}}{\boldsymbol{BW}}$$

TABLE I
ToA in seconds of varying spreading factors and bandwidths.

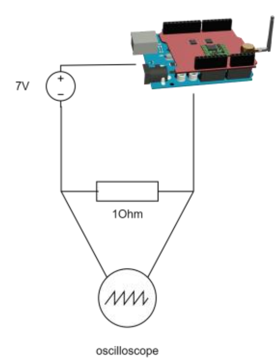
SF \ BW	31.25 kHz	125 kHz	500kHz
7	0.004096	0.001024	0.000256
10	0.032768	0.008192	0.002048
12	0.131072	0.032768	0.008192

B. Power Consumption of LoRa

ToA of the LoRa symbol essentially dictates the data rate and thus sets the power consumption, data rate increases as ToA decreases. The theoretical data rate in bits per second of a given SF and BW is given by the following equation:

$$\textbf{(3)}\ \boldsymbol{Data\ Rate} = \boldsymbol{SF} * \frac{\mathbf{1}}{\boldsymbol{ToA}}$$

To verify these assumptions, an experiment was conducted. As part of the experiment an Arduino Uno was used with a SX127x Shield attached[3], which enabled the Arduino to send LoRa packets. The setup is shown in the figure below.



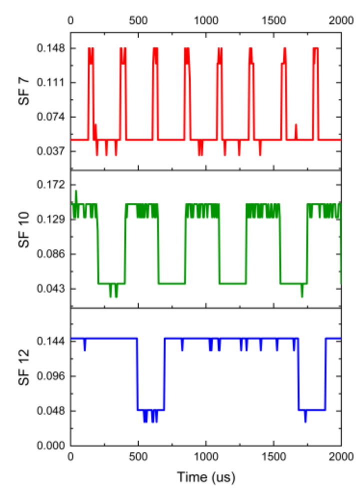


Fig. 4. ToA experiment setup

Fig. 5. ToA experiment results

The voltage across the resistor was recorded in an oscilloscope and since a 1Ohm resister was used, the voltage across the resistor equals to the current through, and thus the power consumption during a transmission can be recorded, during the experiment the Arduino sent continuously identical packets of 1 byte each. The experiment was conducted for each SF. The bandwidth was 125kHz for each test. As can be seen in figure 5, the results are as expected, using SF 7, the Arduino was able to send the largest number of packets. The theoretical data rate is not the data rate that can be seen in figure 5 and this caused by the preamble of the communication and the header of the LoRa packets that SX127x introduces as part of its implementation of LoRa communication. However, this is a good indication that reducing the ToA, increases the data rate and thus decreases the power consumption. Another important aspect that the SF and BW of the channel influences is the receiver sensitivity, which determines the threshold RSSI for the receiver, hence it is desirable to keep the receiver sensitivity as low as possible to ensure the maximum achievable range of transmission. The receiver sensitivity is given by:

$$\textbf{(4)}\ \boldsymbol{Sens = -174 + 10\log(BW) + NF + SNR}$$

Where NF is the noise floor of the given hardware, and the resultant sensitivity is in dBm. The sensitivity range for the SX127x shield that was used is between -111 and -141. The sensitivity equation shows that increasing the bandwidth, noise floor, or noise in the signal will decrease the sensitivity.

C. Range Test of LoRa in Free Space

To establish LoRa's performance on a Mars Rover transmitting to a Mars orbiter, a free space transmission experiment was conducted, in the experiment 2 SX127x modules were used. However, the modules' antennas were not used, instead the modules were connected by a coaxial cable and a programmable attenuator. This setup allowed to test various attenuations that simulate different distances in free space. To calculate the required free space attenuation, the "free space path loss" equation was used:

$$\textbf{(5)}\ \boldsymbol{F = 20\log_{10} d + 20\log_{10} f - 147.55 + G_{Tx} + G_{Rx}}$$

Where d is the desired distance between the nodes, f is the base frequency which in this experiment was 868MHz, G_{Tx} is the gain of the transmitter antenna, which in this case was set to 0, and G_{Rx} which is the gain of the receiver antenna, set to 0 as both antennas were not used in this experiment.

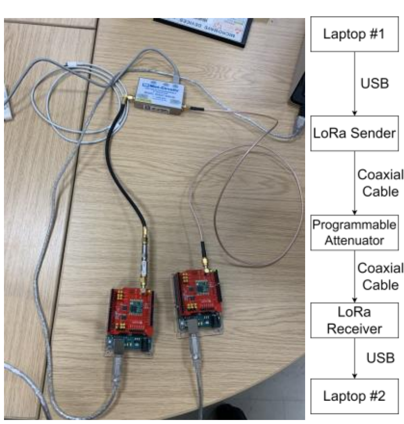


Fig. 6. FSPL Experiment Setup

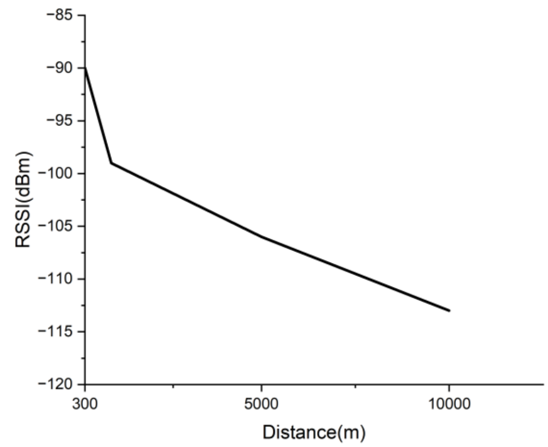


Fig. 7. FSPL experiment results

For each distance, 20 packets were sent from the sender to the receiver, then the RSSI were recorded and averaged using Radiohead's RF95 library for Arduino[4], The bandwidth was set to 31.25kHz and the coding rate was 4/8. SF 7 was used.

```
#include <RH_RF95.h>
RH_RF95 rf95;

void setup() {
   rf95.init();
}

void loop() {
   // Receive packet
   rf95.lastRssi(); // RSSI of the last transmission
   rf95.lastSNR(); // SNR of the last transmission
}
```

Fig. 8. Arduino code for RSSI and SNR recording

The FSPL range was limited by the available range of attenuators in the experiment. However, as it can be seen in figure 7, the estimated RSSI when the distance is 10km is about -113 dbm which according to the datasheet of SX127x[5] is well within the range of the acceptable sensitivity, thus communication is possible within the node.

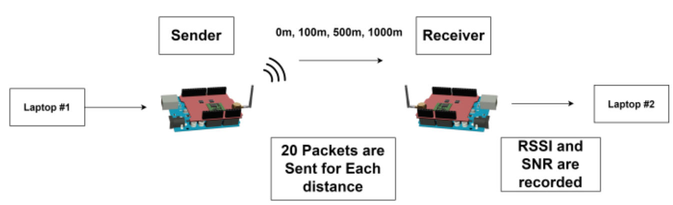


Fig. 9. LoS on Earth Experiment Setup

Fig. 10. The experiment point of interest in Cardbiff bay, sender is shown as a red dot: 100m; 500m; 1000; The blue dot represents the receiver.

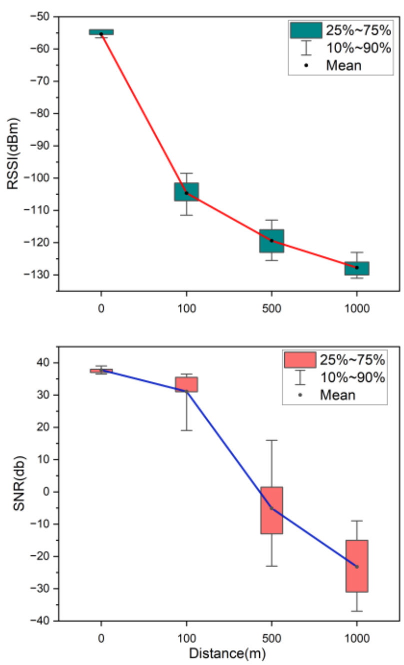


Fig. 11. RSSI and SNR plot under varying distances with LoS for SF 7, experiment on earth, mean line is presented

The final experiment that is covered in this paper was a range test on earth as shown in figures 10 and 11. Using Radiohead's RF95 Arduino library, the RSSI and SNR were recorded for various distances. In contrast to the FSPL experiment, in this experiment, the antennas on the SX127x modules were used. As it can be seen in figure 11, communication between 2 nodes was still possible even with an RSSI of -130dbm and SNR of -23dB. Only SF 7 was plotted since it is the most promising spreading factor in terms of data rate and power consumption.

V. Discussion

From the results of the experiments, it is apparent that a spreading factor of 7 is desirable for a Mars rover. It provides a data rate of 1.669kb/s when the bandwidth is 31.25kHz or 26.7kb/s when the bandwidth is 500kHz. These data rates are significantly smaller than the current range of NASA's Curiosity data rate to the Mars orbiter which ranges between 125kb/s and 250kb/s[2], however, if the power consumption is the most important aspect then LoRa can be used. The projected RSSI of a LoRa symbol on Mars when the receiver and sender are distanced 10km away is estimated to be about -123dBm (figure 11) when the signal is not amplified, while the theoretical receiving sensitivity is estimated to be -123dBm as well when the BW is 31.25kHz, the noise floor set to be 6dB, and the SNR set to 0 which can vary (equation 4). This further solidifies the estimation that LoRa can be used on the surface of Mars. Additionally, the experiment on Earth with a direct line of sight showed promising results as even with an off the shelf LoRa module, communication in a channel with RSSI of -123dBm and SNR of -23db was possible. Perhaps an additional experiment with an unconventional bandwidth can be conducted to test whether the data rate can be increased without decreasing the sensitivity significantly, as the sensitivity only decreases by a log of the bandwidth.

VI. Conclusion

In conclusion, this paper discussed the theoretical limits of LoRa, it showed that communication on Mars using LoRa is theoretically achievable with a SF of 7 and BW of 31.25kHz. The paper showed the results of 3 experiments that were conducted to simulate the channel of communication on Mars. While further research is required to examine whether a lower spreading factor can be used, or what signal gain is needed before the transmission of the LoRa message, the results are promising as the data rate is relatively on par with the existing data rate. Therefore, LoRa is an attractive communication scheme for a Mars rover as it provides a sufficient data rate with a low power consumption.

VII. Acknowledgment

Figure 1 had been created using images from Flaticon.com, and from thenounproject.com.

VIII. References

[1] "Multi-mission radioisotope thermoelectric generator (MMRTG)." [Online]. Available: https://mars.nasa.gov/internal_resources/788/. [Accessed: 21-Apr-2023].

[2] "Communications with Earth," NASA, 08-Aug-2019. [Online]. Available: https://mars.nasa.gov/msl/mission/communications/. [Accessed: 21-Apr-2023].

[3] "Arduino Shield featuring Lora® Technology," Dragino. [Online]. Available: https://www.dragino.com/products/lora/item/102-lora-shield.html. [Accessed: 21-Apr-2023].

[4] Radiohead: Rh_rf95 class reference. [Online]. Available: https://www.airspayce.com/mikem/arduino/RadioHead/classRH__RF95.html. [Accessed: 21-Apr-2023].

[5] "Adafruit Industries," SX1276/77/78/79 - 137 MHz to 1020 MHz Low Power Long Range Transceiver. [Online]. Available: https://cdn-shop.adafruit.com/product-files/3179/sx1276_77_78_79.pdf. [Accessed: 21-Apr-2023].