Investigating the Feasibility of 5G in a Lunar Environment

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FINAL REPORT

The final report and project are submitted to the advisor with following comments.

Comments: The team performed a comprehensive review of relevant wireless technologies, and identified key differences between generations for consideration in the lunar environment. They conducted some prototyping activities, and when technical issues arose were able to adapt the project to deliver a functional design utilizing bidirectional communications and control across WiFi and the Internet, and constructed a graphical user interface.

Advisor Signature: Daniel Raible

Date: 4/28/2021

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Abstract:

The goal of this project is to examine the feasibility of implementing a 5G wireless network in a lunar environment. In order to do so, the ideas and technologies behind 5G should be explored, as well as how it relates to previous wireless technologies in terms of speed, coverage, latency, and other important factors for a successful lunar network. A simplified representation of the lunar network was created to observe how the system would function. Two Arduino Uno boards were used alongside a wifi shield to simulate a lunar rover taking in data through sensors, compiling the data, sending it through a 5G network to a station or satellite, and then the data being transmitted back to a terrestrial command station. We hoped to show with the design of our network that a lunar network utilizing 5G would be a feasible and worthwhile option for communication on and with the moon. Our group expected to see some limitations including range and coverage limitations for the different levels of 5G data transfer and potentially other limitations due to the conventions of AT commands for telephone communication. The study, testing, and implementation of a 5G lunar network would have far-reaching effects in the space exploration field. Once active, the network would allow for a base of operations to be built and communicated with effectively. This could open up the possibility of easier access to Mars and other planets in the future.

Terminology/ Definitions:

- Arduino: An open-source electronics platform based on easy-to-use hardware and software.
- AT Commands (AT): Instructions which control Modulator-Demodulators (MODEMS).
- Bandwidth: The amount of information or data that can be transferred over a network in a given time.
- Coverage: The area the wireless network reached given off from a broadcasting tower
- High Bands: A range of bandwidth typically between 3GHz and 300 GHz
- Low Bands: A range of bandwidth typically between 10MHz to 1GHz
- Latency: The time it takes for data to be transferred from one place to the next.
- IDE: Integrated Development Environment (IDE). Text editor software which allows the user to write Arduino coding for Arduino based electronics.
- LDR: Light Dependent Resistor (LDR). A sensor which detects light by changing its resistance based on light intensity.
- Wifi: A network which transmits and receives data over short distances.
- SIM Card: Subscriber Identification Module (SIM). An integrated circuit running a card operating system that securely stores numbers and its related key, which are used to identify and authenticate subscribers on mobile telephone devices
- 4G LTE Shield: An Adafruit product which is compatible with Arduino circuit boards and provides 4G LTE capabilities.
- Ethernet Shield: An Adafruit product which is compatible with Arduino circuit boards and provides an ethernet port to allow connection to the internet.

- LTE: Long-Term Evolution (LTE): A standard for wireless broadband communication for mobile devices.
- 5G: Term for 5th Generation of wireless communication.
- OLED: Organic Light Emitting Diode (OLED). A display screen that uses a light emitting diode (LED) to display light onto a screen.
- SPI: Serial Peripheral Interface (SPI). a synchronous serial communication interface specification used for short-distance communication, primarily in embedded systems.

Initial Research:

A lot of information is being projected about 5G and how much better it is than anything that has come before. However, in an effort to give an adequate idea of 5G, and its feasibility in a lunar environment, it shall be compared and contrasted against previous and other current networks. In order to understand 5G there are certain technologies behind it that require explanation. The biggest of which is the New Radio(NR) air interface it uses. This new technology was developed in 2017 and was designed specifically for 5G implementation. 5G New Radio is able to provide communications for high bands, as with streaming video, and low latency communications for remote control vehicles. It also can operate with low data rate, low bandwidth signals for machine communications. This broad spectrum of data rates and bandwidth allows it to be used in conjunction with 4G LTE systems if necessary, while also keeping its high speeds and low latency for higher priority situations. The diversity of the systems allows for an easy switch between sub-6 GHz networks, mid to low frequency bands, and much higher mmWave(24 - 40 GHz) networks. This also means that the speeds have increased as well. Peak Data Rates can come in around 10 Gbps, while latency is reduced to 1 ms. Compared to any of the past wireless networks this is a drastic improvement. Even the Average Data Rates for 5G fall between 200 - 400 Mbps.

There is a downside to these high speeds, however. Because the frequencies are so high, the coverage from a single tower is decreased dramatically. This also means that things like trees and walls can completely block signals if there is not sufficient coverage in an area. The lower the frequency of the network, the greater the area that can be covered. This is problematic in terms of lunar implementation. A vast array of towers would have to be set up to cover a base camp and any significant portion of the surrounding area. A possible fix to this could be the combination of a 4G LTE and 5G network so as to increase the range of the coverage, while also allowing for higher speeds where it would be most necessary for communication and data storage.

In terms of implementation, another aspect to consider is the surface of the moon itself. Depending on the terrain, a 5G tower will only be able to reach a distance of 1000 ft. On the southern pole of the moon, the topography is more mountainous and would prove difficult for a 5G antenna to cover any significant area close to the optimal range of 1000 ft. Even implementing a network on a flat portion of the moon's surface in order to optimize coverage, a satellite array would have to be used to keep communication with the towers from earth. This could be a considerable expense, both in terms of time and resources. Keeping restrictions on communication time between the moon and a terrestrial satellite may be an easier solution, but even still, it would require much more planning to coordinate any type of remote operated mission or calls between astronauts and ground control.

The table below compares the basic wireless networks throughout the different generations. It can be seen that 5G is by far the fastest and most reliable with peak data rates reaching 10Gb per second while keeping latency on transfers to less than 10ms. It is also shown to be the most versatile. The comparatively enormous bandwidth range allows for interaction with 4G towers, as well as allowing huge amounts of data to be transmitted simultaneously at different frequencies. Once again, the only downside seems to be the minimal range established with a 5G tower, especially considering how the previous generations have been able to cover a much larger area.

Table 1: Wireless Cellphone Communication Comparison					
	1G	2G	3G	4G	5G
Tech Standard		GSM/D-AMPS/IS-95 A	UMTS/CDMA2000	LTE	NR/mmWaves
Digital/Analog	Analog	Digital			
Services	Voice only	Voice + SMS + Data(Mobile Internet)			
Peak Data Rates	N/A	384 kbps	42 Mbps	1Gbps	10Gbps
Average Data Rates			144 kbps	25-50 Mbps	200-400 Mbps
Bandwidth		25 MHz	25MHz	100 MHz	6 GHz to 300 GHz
Latency			100-500 ms	20-30 ms	<10 ms
Range			45 mi	10 mi	1000 ft

Prototype Development and Testing:

- <u>Basic Arduino Labs:</u>

To begin the process of creating a prototype, the group needed to familiarize themselves with the basics of Arduino including how to physically build a system utilizing Arduino boards, and how to use the Arduino IDE environment to develop code for the system. A series of Arduino labs were completed in order to gain the skills needed. The fundamental labs involved simply connecting the board to the computer and writing a code that returns “Hello World” in the serial monitor, writing a code that blinks a light built into the Arduino Uno board, attaching a button and writing a code to receive the input from it, and attaching an LED and writing a code to fade the light on and off. These initial labs helped the group to understand where the basic elements of the Arduino IDE environment are located as well as how to connect simple components to the board to increase its functionality. The second set of more advanced labs involved implementing a Light-Dependent Resistor and plotting the data feed received by it, adding a filter using the IDE environment, using the LDR paired with an LED to create a basic analog PID controller, using Arduino's random number generator to change the colors on a multicolor LED, and creating an IR transmitter and receiver to send and receive signals. These labs showed some of the more powerful capabilities that the Arduino boards are capable of and were a very useful stepping stone on to very advanced components such as ethernet shields or the 4G shields for this project.

- <u>Data Map:</u>

The basic structure of communication in the proposed system is similar to today's current lunar communication map. Today's lunar communication system consists mostly of basic radio waves. The future for communications through space is using infrared lasers to transmit data much quicker, however this will still require a basic lunar network to connect to. The only change would be adding a final step utilizing a relay tower on the moon in between the lunar mission and satellite relay network. Below is a simple communication diagram demonstrating what steps the data would take.

- <u>Simulation:</u>

A scaled down, physical representation of a 5G network would help better understand the possibilities and limitations of the proposed system. The goal for this simulation is to run a wireless connection between two Arduino Uno boards. The first board would be connected to a series of sensors taking in information and data such as surrounding temperature pressure and light levels. This board would be attached to a 4G LTE shield, and using an active SIM card, it would package the information and send it to the second Arduino board also with a 4G shield. This would simulate a rover taking in sensor information while connected to the 5G network and passing the incoming information along to a data center or satellite. The second Arduino would then take the package bundle and send the information to a restricted web page where the information can be unpacked and displayed in real time. This would simulate the relay type connection from a rover to a lunar tower via a 5G connection, followed by a lunar satellite and a ground control station on Earth as can be seen in the diagram.

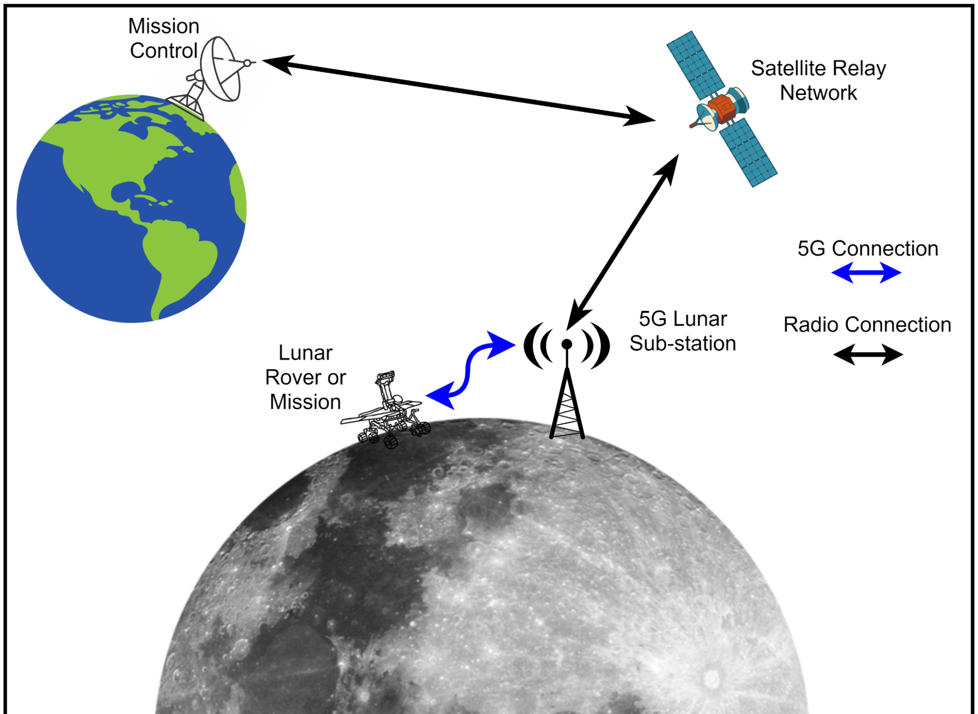

Figure 1: Lunar Space Communication Data Map

Unfortunately, some issues arose while attempting to complete this system. The 4G shields did not work as well with the Arduino as originally anticipated. After weeks of failure getting the 4G shield operational, it was determined that the amount of time and effort to get them to work together and operate effectively would not leave enough time to finish the project before the deadline. After realizing that the 4G would not be achievable for the time given for the project, the group decided to explore two alternative routes. The first alternative method explored was to swap the 4G shields on the Arduino Unos for Ethernet shields instead. Initially this option seemed promising as we were successful in connecting the ethernet shield to the internet to act as a server for basic chat communication and connecting the ethernet shield to upload live data from a sensor to a website. But we were unsuccessful in uploading data or instructions to the Arduino using the ethernet shields. We also could not send any information in either direction from one Arduino directly to another using the ethernet shields and using a router as an in between step would have required being able to upload data. This idea was abandoned in favor of a simpler connection using a wifi enabled Arduino Uno board connecting to the internet and the Adafruit IO web server for controls and visual data tracking. While we were successful in using the wifi enabled Arduino Uno board to connect to the internet, the sensors attached had to be changed as the barometric pressure and temperature sensor was not compatible with the wifi enabled Arduino Uno board. Before switching to the wifi enabled board, the group was successful in implementing the barometric pressure and temperature sensor, one light dependent resistor, and an OLED screen to display four different outputs from the sensors.

- Field Testing:

The final version of our prototype is composed of a series of sensors and outputs including: two light-dependant resistors, a potentiometer, an LED light, and an OLED screen, connected to a wifi enabled Arduino Uno board that interfaces with the adafruit

IO server through a wifi network. Below is a diagram depicting how each part is connected. The sensor array of the prototype was connected directly into some of the arduino's input pin array. The LED was wired in a similar way but connected to one of the output pins. Since the OLED screen is more complicated than the LED light, it requires more inputs. The 5 pins used are what is required for SPI wiring to send the data required to display on the screen. The arduino then connects through a wifi network to the internet and the Adafruit IO website.

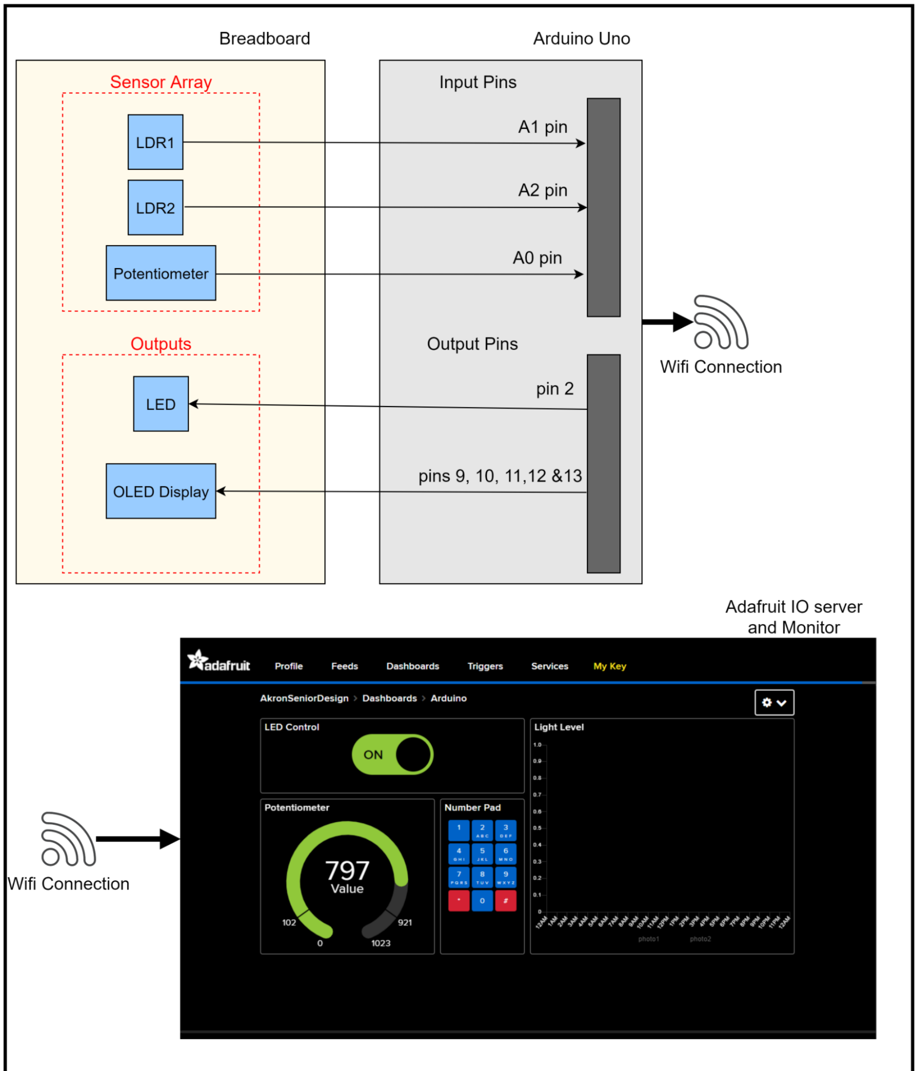

Figure 2: Prototype Configuration

The adafruit IO page has a control switch that turns the LED light on and off, a graphical display for what level the potentiometer is set at, a plot for the light levels sensed by each of the LDRs, and a keypad that sends a number to the Arduino board when pressed. The OLED screen is the only component in the final configuration that does not currently function as issues related to the limited memory of the Arduino board prevented its final implementation; however, the group wasn't able to get the OLED screen functioning when using a code with more free memory. The prototype demonstrated that it could both upload data over a wifi network to the adafruit IO server and receive data from the adafruit IO server sending controls to the LED or numerical values displayed on the serial monitor.

Conclusion:

As we come to the end of this project, we can take a look at what some of the next steps for this application could be in the future or if we had run into less roadblocks along the way. Firstly, working more closely with the 4G and 5G technologies would be the most important next step. Working with 4G and 5G network professionals would most likely solve some of the most significant obstacles faced when working with this technology. Transitioning the prototype build made during this project to transmit and receive data using 5G technology instead of the wifi signals would be another integral step towards the faster data rates and representative model we wanted to achieve. Understanding the lunar environment and its effects on a 5G communication network is another key step. To achieve this, figuring out the optimal coverage of the antennas to meet the desired data transfer rates on the lunar environment would be one of the first steps. Understanding the number of antennas and their location in a lunar area would be important for determining the use of 5G for specific missions. Once an operational 5G prototype is created then it could be field tested in lunar-like environments to better understand how 5G might function on the moon. While this project did not turn out exactly the way we originally intended, our group learned not only about many different modern technologies, but also about dealing with unforeseen difficulty and failures.

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