BYU MARS ROVER AT THE 2018 UNIVERSITY ROVER CHALLENGE

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ABSTRACT

This paper describes the design and performance of the BYU mars rover with an emphasis on the wireless communications system and the transmission and reception of data vital to the performance of the rover.

INTRODUCTION

The University Rover Challenge (URC) is a three day competition that takes place each year at the Mars Desert Research Station in Hanksville, Utah. The competition is hosted by the Mars Society and has been running for twelve consecutive years. The University Rover Challenge is organized into four separate tasks: science, autonomy, extreme retrieval and delivery, and equipment servicing. Each task features a variety of challenges, the completion of which comes with a certain amount of points. Participating teams are required to build a rover that can complete these challenges through teleoperation. Teams operating in the 900 MHz band are required to operate in specific channels that are 8 MHz wide and those operating in the 2.4 GHz band are to operate in channels that are 22 MHz wide. There are also two tasks in which in line-of-sight communication is not guaranteed.

BYU has competed in the URC since its conception. While team performance has fluctuated over the years, the 2017 group was rather successful, finishing fourth. There is very high turnover from year to year since the BYU Mars Rover team is almost entirely made up of seniors. This often comes as a disadvantage because each year we have to start off from scratch, inheriting all the problems of the previous year's rover without much of the background knowledge required to make design modifications.

This year's team consisted of 23 fulltime students with 8 volunteers. We were divided into 3 sub-teams: mechanical, electrical, and autonomy. Each sub-team was further divided down according to team goals and requirements. This paper will focus on the work of the wireless communications section of the electrical sub-team.

INHERITED CHALLENGES

Despite the success of the previous team, there were still a number of problems with the rover that needed to be addressed, particularly with the wireless communication system (last year's rover is shown in figure 1). The previous group of students utilized a 2.4 GHz communication link with ROS (Robot Operating System) used to handle communication between various parts of the system. While this system supplied good data throughput during challenges which were in line-of-sight, it was highly unreliable in out of line-of-sight terrain. For this reason 2 tasks were left uncompleted during the competition.

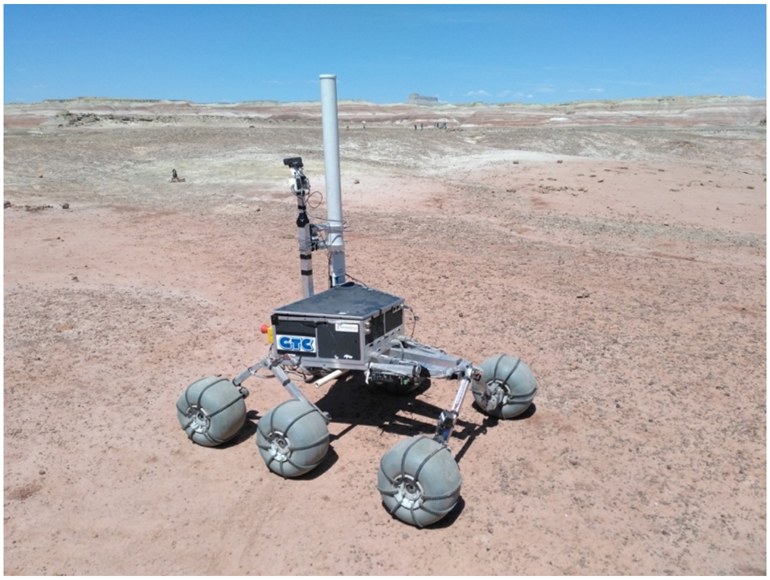

Figure 1: Previous year's rover at 2017 URC

Rover operators also experienced difficulty due to latency in the video feeds. Data throughput capability dropped with the rover in certain positions, this caused the network to be bogged down and led to lagging. This issue became especially prominent when trying to transmit more than two video feeds. This is problematic because situational awareness is extremely difficult with two video feeds and is nearly impossible with just one. The ability of the rover operators to receive feedback from more than two camera feeds is essential to successful navigation of the competition tasks.

REQUIREMENTS

We derived a requirements matrix based on the published URC rules, the feedback from the previous year's team, and the state of the rover when we received it. The electrical sub-team requirements matrix can be seen in figure 10. The specific requirements that were related to the communications system were: video quality of 10 frames per second at one kilometer from base station, receive a strong signal from the base station with the rover at a distance of 1.15 km, degrees out of line of sight while still maintaining a strong signal (see figure 2), and minimum throughput of 1 Mbit/s at 1 kilometer from the base station.

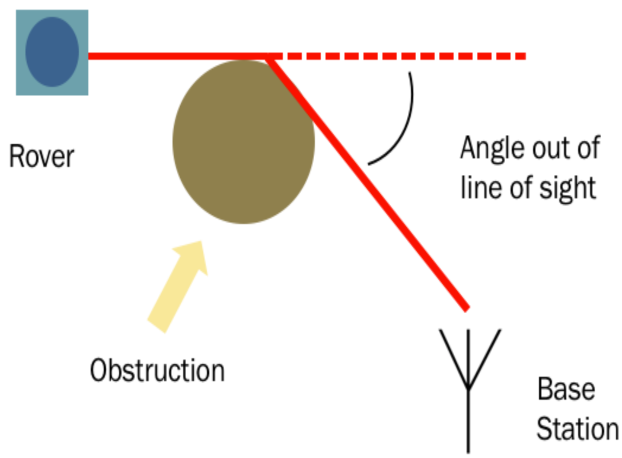

Figure 2: Diagram of angle out of line of sight

DESIGN CONCEPTS

We explored a variety of potential solutions to the rover communications issues. We wanted to strengthen out of line-of-sight communications without sacrificing too much of the throughput that 2.4 GHz afforded. We discussed employing a 433 MHz RC style communication system with a series of analog cameras, we explored implementing a repeater-dropping system that would allow 2.4 GHz signals to reach around corners and down valleys, and we looked at adding a 900 MHz link in addition to the 2.4 GHz that we already had. We compared our ideas in the controlled convergence chart shown in figure 3. Our final plan was to simply use a 900 MHz link: a Ubiquiti Airmax Yagi antenna at the base station, and an omnidirectional antenna for the rover, purchased from Data Alliance. Both antennas were connected to Ubiquiti Rocket M900's. The radiation patterns of our chosen antennas are shown in figure 4 and figure 5.

Market Requirements	2.4 GHz Ubiquiti Network	900 MHz Ubiquiti Network	433 MHz RC Communication	900 MHz in conjunction with 2.4 GHz	2.4 GHz with repeaters dropped
VGA quality frames per second at one kilometer	S	-	-	S	+
Max weight of on rover antenna	S	+	+	-	-
Minimum throughput at one kilometer out of line of sight	S	+	+	+	+
Max distance that the base station receives a signal from the rover	S	+	+	+	+
Ease of implementation	S	S	-	-	-
Minimum throughput at one kilometer	S	-	-	+	+
Sum S	6	1	0	1	0
Sum +	0	3	3	3	4
Sum -	0	2	3	2	2
Total Entries	6	6	6	6	6
Disposition	Discard	Keep	Discard	Discard	Discard

Figure 3: Controlled convergence table

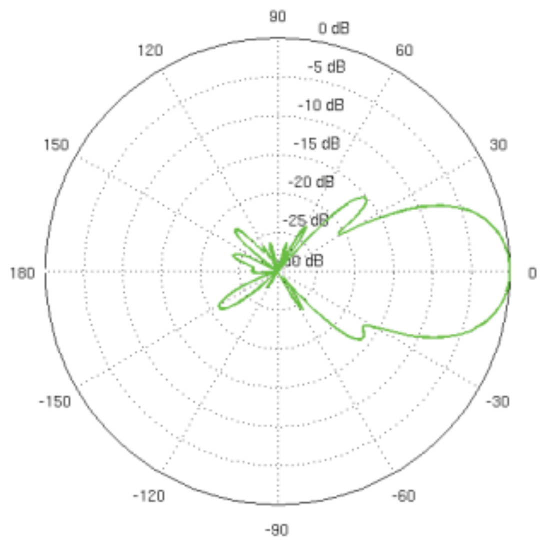

Figure 4: Horizontal radiation pattern of base station antenna [1]

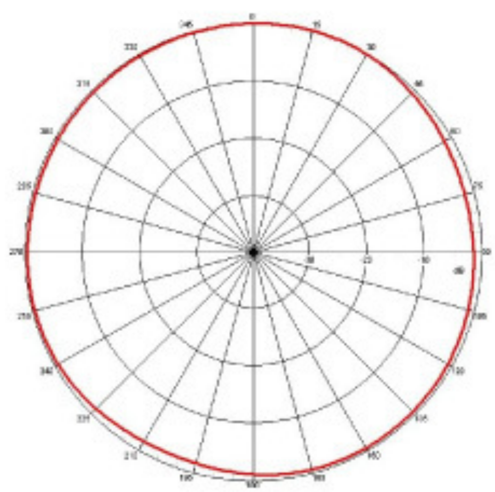

Figure 5: Horizontal radiation pattern for rover antenna [2]

DESIGN TESTING

We first wanted to get a sense of what kind of throughputs we could achieve with our 900 MHz link. Using the built in speed test feature of Ubiquiti's AirOs (already installed on the rocket) we were able to acquire throughput readings of our link at various distances and different degrees out of line-of-sight. A view of the speed test GUI can be seen in figure 6. Figure 2 also details our method for testing out of line-of-sight and what degrees out of line-of-sight means. At one kilometer in line-of-sight we recorded an average throughput of 2.53 Mbps and at 60 degrees out of line of sight we recorded an average of 1.4 Mbps.

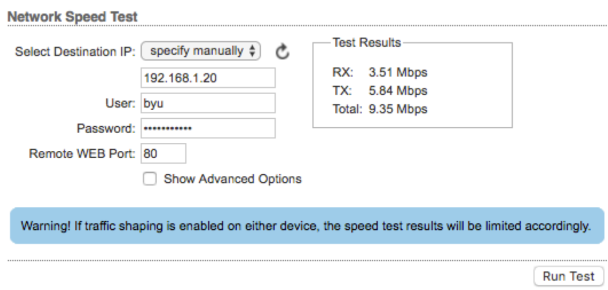

Figure 6: View of speed test GUI

These recorded values were well within our requirements, however, we wanted to confirm that they could transmit multiple video feeds without a significant amount of latency. We discovered that by using the theora video compression package, and at a resolution of 480x640, the transmission rate of one video feed was no more than 80 Mbps. This would mean that theoretically we could transmit up to 17 video feeds from the rover without overloading our network and causing latency. This calculation proved to be consistent with our experience in operating the rover. Publishing a significant number of video feeds from the rover never seemed to cause latency in the video transmission as long as theora compression was used.

DIRECTIONALITY OF BASE STATION ANTENNA

As evidenced in figure 4, the Ubiquiti yagi antenna that we elected to use at our base station was highly directional. This was not acceptable for our purposes since the rover is constantly changing position with respect to the base station. In addition, we are never guaranteed a foreknowledge of where the task is going to be performed with respect to the base station. Thus it became necessary for us to design a rotation mechanism that could be automatically and manually adjusted so that the base station antenna's heading was always toward the current location of the rover.

We created an antenna mount that was bolted to the top of a Lazy Susan bearing. We then connected another mount to the bottom of the bearing that could easily connect to the top of a ten foot pole. The mounting hardware was custom made and the Lazy Susan bearing was purchased at Home Depot. We purchased a small stepper motor with a 100:1 gear ratio from StepperOnline, which was used to supply the mechanical force needed to rotate the antenna and withstand up to 40 mph winds. A photo of the hardware is shown in figure 7 and figure 8.

Figure 7: Antenna mounting hardware

Figure 8: View of antenna mount with antenna

We implemented two different methods for tracking the position of the rover with the base station antenna. The first was manual control. Since the competition regulations stipulate that the rover operators are not allowed to see the base station antenna during the operation, rover operators must rely on the signal strength obtained by querying the rocket using the ‘iwconfig ath0’ command. An example of the output of this command is shown in figure 9. Operators can monitor the ‘Link Quality’ field of the output as they control the antenna rotation to find the position of highest signal integrity. The second mode that we implemented was an automatic tracking algorithm that would follow the rover based on its GPS coordinates. The algorithm we designed calculates the new heading from the base station to the rover every ten seconds, and if the current heading is different from the new heading by more than five degrees, the antenna is rotated to the new heading.

```
XM.v5.6.2# iwconfig ath0
ath0      IEEE 802.11ng  ESSID:"ubnt"  Nickname:""
          Mode:Master  Frequency:907 MHz  Access Point: 68:72:51:6A:40:76
          Bit Rate:19.5 Mb/s   Tx-Power=28 dBm   Sensitivity:0/0
          Retry:off   RTS thr:off   Fragment thr:off
          Encryption key:off
          Power Management:off
          Link Quality=33/94  Signal level=-63 dBm  Noise level=-105 dBm
          Rx invalid nwid:0  Rx invalid crypt:0  Rx invalid frag:0
          Tx excessive retries:0  Invalid misc:0   Missed beacon:0
```

Figure 9: Example of output query from rocket

CONCLUSION

While our rover placed fifth, the changes that were made to the wireless communications system were extremely effective. Not once did the rover operators lose contact with the rover. We were able to compete in all legs of the ‘Extreme Retrieval and Delivery Task’ because of the robustness of our communications link. The rotating base antenna mechanism also proved essential as we used it to improve signal quality during crucial legs of the competition.

Electrical Subsystem Design Requirements

#	Electrical Subsystem Design Requirements	1	2	3	4	5	6	7	8	9	10	11	12	13	14	16
1	In-field rover set-up time	●	●													
2	Length of time the rover can operate at full battery usage			●												
3	Disance the rover can travel on a full battery charge			●												
4	Percent of electrical connections terminating in latching (secure) connectors				●											
5	Percent of 2m radius 2m tall cylinder around rover within camera field of view					●										
6	Number of camera views					●										
7	Percent successful startup attempts	●	●				●									
8	VGA quality frames per second at one kilometer							●								
9	Max weight in any competition configuration												●			
10	Max distance that the base station receives a signal from the rover								●					●		
11	Minimum throughput at one kilometer							●	●					●		
12	Interface is intuitive and reliable														●	
13	Rover design is well documented									●	●					
14	Maximum Jetson TX2 operating temperature											●				●
	Importance															

Importance	#	Performance Measures	Units	Lower Acceptable Limit (Ideal Values)	Ideal (Ideal Values)	Upper Acceptable Limit (Ideal Values)	Target (Real Values)	Predicted (Real Values)	Measured (Real Values)
	1	Base station to rover connection initialization time	seconds	-	10	180	40	15	37
	2	Rover software initialization time	minutes	-	0.5	4	2	1	0.52
	3	Length of time the limiting power supply can operate at worst case competition scenario	minutes	75	90	-	90	109	-
	4	Cables have working latching (secure) connectors	%	50	100	-	80	-	94
	5	Number of simultaneously publishing cameras possible	number	1	4	-	2	-	7
	6	Percent successful startup attempts	%	70	100	-	90	-	100
	7	Latency from rover to base	ms	-	250	4000	1000	-	500
	8	Minimum throughput at 1 km	Mbps	0.1	5	-	2	-	2.3
	9	Percent of Code Commented	%	10	50	-	30	-	15.9
	10	Percent of Electrical Systems Documented	%	50	100	-	80	-	67
	11	Maximum Operating Temperature	Celsius	-	70	80	80	70	70
	12	Max weight of on rover antenna	kg	-	1	5	2	-	1.94
	13	Minimum throughput at 1 km 60 degrees out of line of sight	Mbps	0.1	1	-	0.7	-	1
	14	Percentage of operators that think interface is intuitive/reliable	%	40	100	-	80	-	71
	16	Percent electrical subsystems insulated	%	20	100	-	60	-	97.5

Figure 10: Electrical sub-team requirements matrix

REFERENCES

[1] Ubiquity Networks, Technical Information for airMAX 900 MHz Yagi Antenna, online: https://dl.ubnt.com/datasheets/airmaxyagi/airMAX_900MHz_YAGI_Antenna.pdf

[2] Data Alliance, Technical Information for 900 MHz 8dbi Omni-Directional Antenna, online: https://www.data-alliance.net/antenna-900mhz-8dbi-omni-directional-w-n-female-wifi-pole-mount-gsm-wifi/