Modeling the Radio Frequency Environment of Mars for Future Wireless, Networked Rovers and Sensor Webs

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Abstract— NASA's long-term goals for the exploration of Mars include the use of rovers and sensors which intercommunicate through proximity wireless networks. The performance of any such wireless network depends fundamentally on the radio frequency (RF) environment. This paper presents our initial results concerning modeling the RF environment on Mars in support of determining the characteristics of potential in-situ networks. In this work, we have utilized commercial RF propagation modeling software, designed for cellular telephone system planning, together with recent topographic data for Mars to *deterministically* construct propagation path loss models. The software takes into account antenna heights and types, radiated power, topographic information, image data, and surface features and clutter. As we will show, the resulting models provide a powerful tool for determining potential coverage patterns and data rates for mission planners.

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1. INTRODUCTION

NASA's long-term goals for the exploration of Mars include the use of rovers and sensors which intercommunicate through proximity wireless networks. Elements of the network have a short transmission range, low power requirements, low cost, and a relatively short-life span [1]. The performance of any such wireless network depends *fundamentally* on the radio frequency (RF) environment. In order to evaluate and optimize the performance of a wireless network,

a basic understanding or model of the channel is important. With such a model, better choices for the modulation and coding schemes, equalizer design, and positioning of access point antennas can be made [2].

The two main communications issues with respect to evaluation of a channel are link budget and time dispersion. The link budget is determined by the propagation path loss or the average amount of received power (relative to transmitted power) at a particular distance or location from the transmitter. Time dispersion arises due to multipath propagation whereby replicas of the transmitted signal reach the receiver with different delays due to reflections and scattering. The time dispersion is often described with a power delay profile i.e., power received as a function of time. The time-dispersive nature of the channel is a major factor in determining the maximum data rate that may be transmitted. Power delay profiles may be averaged out over time (average rms) or expressed as worst-case values. Key statistics include maximum excess delay, mean excess delay, and rms delay spread.

This paper presents our initial results concerning modeling the RF environment on Mars. In this work, we have utilized a commercial RF propagation modeling software package from ATDI called *HertzMapper* [3]. This software is normally used in cellular telephone system planning. However, with the proper modifications, we are able to utilize this software together with high resolution Mars topographic data to *deterministically* simulate antenna coverage patterns [4]. The software takes into account antenna heights and types, radiated power, topographic information, image data, and surface features and clutter. This approach can be more revealing in terms of physical details and is often more accurate than statistics-based approaches [2]. For the Mars environment, the Irregular Terrain Model (ITM) codes are modified to also take into account differences from Earth such as planetary radius and atmospheric effects. The particular regions of interest for our study (based on prospects that they may have once had water) include the Gusev Crater and Meridiani Planum (Hematite) sites for which 10m/pixel resolution, Digital Elevation Models (DEMs) are readily available [5]. Within these regions we consider several sites within the landing ellipses for the Mars Exploration Rover (MER) missions which are currently underway.

This paper is organized as follows. In Section 2, we provide the source of the Mars topographic data and the selected sites for our simulations. We also detail the required conversions necessary to use the data in HertzMapper. In Section 3, we discuss the atmospheric composition of Mars and how its difference, as compared to Earth's, is taken into account with the ITM. In Section 4, we present the scenarios and assumptions for the simulations as well as metrics used in evaluating the results. Finally, in Section 5, we present the simulation results including antenna coverage patterns and received signal power. Our simulation results are analyzed and some initial conclusions regarding the use of commercial off-the-shelf networking hardware are made.

2. PREPARATION OF HIGH RESOLUTION DATA

Mars Sites for RF Simulations

The Mars exploration community initially developed a set of four candidate landing sites for rover missions to Mars. The final site decisions for the 2003 MER launches were made for the Gusev Crater and Meridiani Planum (Hematite) regions [5]. Both regions were chosen as a result of a selection process that considered both mission science and mission success criteria [5][6]. The mission science criteria included evidence of water on the Martian surface in the past. The Gusev Crater appears (see Fig. 1) to have been a lake fed by a river which flowed through the Ma'adim Vallis at one time. The Meridiani Planum region shows the chemical signature of Hematite minerals associated with ancient liquid water locations. For mission success, the sites were chosen "near the equator, low in elevation, not too steep, not too rocky, and not too dusty" in addition to other factors [5]. The topography of Gusev Crater region along with the target ellipse for the MER rover landing zones is also given in Fig. 1 [7].
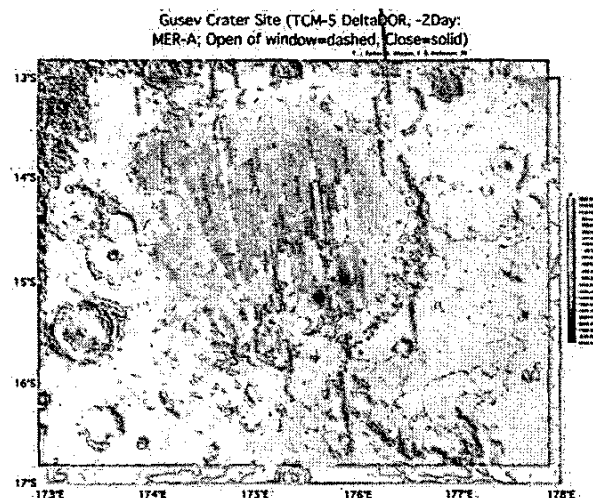

Figure 1. Gusev Crater site with landing ellipse.

For both the Gusev Crater and Meridiani Planum regions, the RF simulation will focus at specific sites within each of the

landing ellipses. The assumption is that a future Mars lander to these regions could serve as a network access point linking surface rovers and sensors to an orbiting relay station [8]. The specific sites for simulation were chosen to be near the center of the ellipse as well as at the outer edge of the ellipse and are given in Table 1. The selected sites are illustrated in Figs. 2 – 4 where the red discs in the left-most picture indicate the simulated network access point positions.
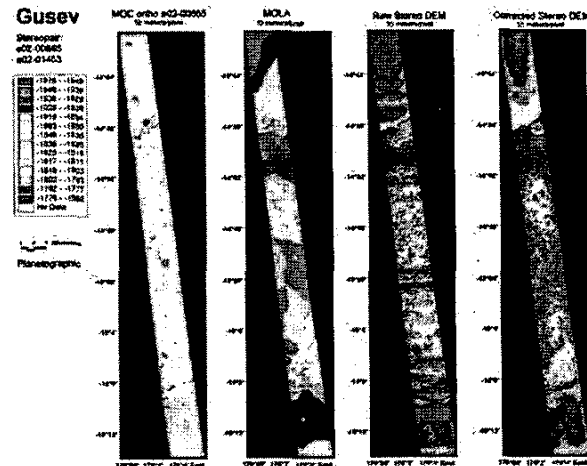

Figure 2. Gusev Crater region, near the center of the landing ellipse. Red discs in left-most picture indicate approximate locations for simulated network access points.
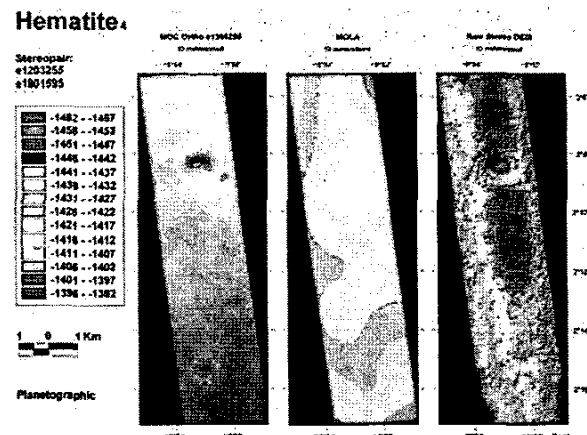
Figure 3. Meridiani Planum region, near the center of the landing ellipse. Red discs in left-most picture indicate approximate locations for simulated network access points.

Data Sources, Characteristics, and Conversions

The Gusev and Meridiani Planum regions cover a relatively large region on the Martian surface. The full region is covered in the Mars Orbiter Laser Altimeter (MOLA) data sets [9]. However, these data sets have a relatively coarse reso-

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Figure 4. Meridiani Planum region, near the center of the landing ellipse. Red discs in left-most picture indicate approximate locations for simulated network access points.
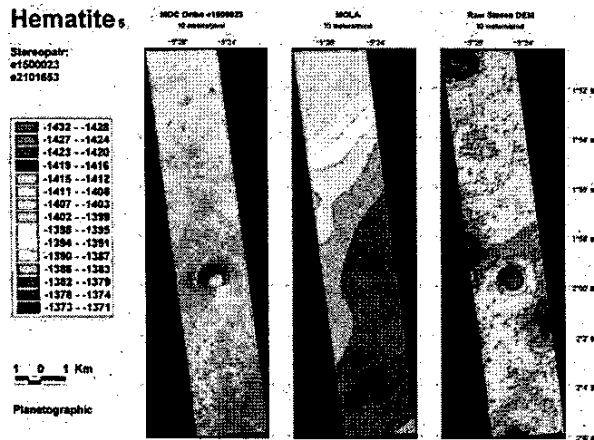
Table 1. Sites for RF Simulations.

Site	Mars Latitude	Mars Longitude
Gusev1 - Site 1	14° 47′ 39.35″ S	176° 1′ 29.18″ E
Gusev1 - Site 2	14° 58′ 41.95″ S	176° 2′ 53.51″ E
Gusev1 - Site 3	15° 11′ 35.66″ S	176° 4′ 31.23″ E
Hematite4 - Site 1	2° 11′ 0.69″ S	−5° 53′ 5.16″ E
Hematite5 - Site 1	1° 52′ 29.16″ S	−5° 25′ 39.59″ E

lution (~400m/pixel) and are not useful for this type of RF simulation. Instead, the narrow angle, high resolution Mars topographic data sets from the United States Geological Survey (USGS) covering portions of the expected MER landing regions were used [4]. The high resolution data are rendered into Arc/Info Grid files which have been processed to produce corrected data relative to the standard aeroid (Martian equivalent of "sea level"). The Arc/Info Grid data format is not in a format that is readily usable by most RF modelling software. Virtually all such software expect the topographic data to be in either the Band Interleaved by Line (BIL) or DEM formats used by the USGS. To make the files compatible, software was developed to make the necessary file conversions. With the data in BIL format, a final conversion to ATDI's proprietary format was required for use in HertzMapper.

In order to compensate for the different planetary radius (Mars vs. Earth), the data was first transformed to 10.4m/pixel. For compatibility with HertzMapper, the data was then subsampled to 11m/pixel (integer resolutions are required in HertzMapper). The subsampling does not have any significant effect on the accuracy due to the small areas under study.

3. MODIFICATIONS TO THE IRREGULAR TERRAIN MODEL FOR THE MARTIAN ATMOSPHERE

Within the HertzMapper software, we have selected the ITM (also known as Longley-Rice) propagation model. However, as implemented in HertzMapper, the ITM is configured to model RF propagation on Earth. This configuration includes among other things planetary radius and atmospheric effects. Thus Mars-specific variables must be accounted for and the ITM appropriately modified. ATDI made available their source codes for the ITM which interacts with HertzMapper as a Dynamically Link Library (DLL). In this section, we discuss the parameters within the ITM which must be modified for simulation of the Martian RF environment.

Irregular Terrain Model

The ITM is a general-purpose propagation model for frequencies between 20MHz – 20GHz. This model predicts the median attenuation of a radio signal as a function of distance and the variability of the signal in time and space. The predictions are based on electromagnetic theory and statistical analysis of both terrain features and radio measurements. Table 2 identifies the key parameters used in the ITM [10].

Table 2. Parameters used in the Irregular Terrain Model

Group	Parameter	Values
System	Frequency Distance Ant. Height Ant. Polarization	0.02 – 20 GHz 1 – 2000 km 0.5 – 3000 m Vert, Horiz, or Circular
Environment	Terrain Irregularity Elect Ground Const Permittivity Conductivity Surface Refractivity Radio Climate	
Deployment	Sitting Criteria	Random, Careful, or Very Careful
Statistics	Time, Location, and Situation Variability	0.1 – 99%

ITM Source Code Modifications

Of the parameters listed in Table 2, only the code defining the environmental parameters in the ITM needs modification for simulation of the Mars environment. The first modification is for the electrical ground constants for Mars. These are estimated as follows: permittivity is between 2.5 – 9 and conductivity is 10^{-8} siemens/m [11].

Next, modifications for the attenuation due to atmospheric effects are accounted for as follows. First, the surface pressure at Mars is approximately 6.1mbars which is only about

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0.6% of Earth's. Second, the Martian troposphere consists of almost entirely dry air and the surface atmospheric water content is $3000\times$ lower than on Earth. Hence the absorption and radiation by a hydrometeor is very low. No observation of rain on Mars has been made; however, even if it is observed in the future, due to very thin atmosphere in Mars, the rain would be so light that it would not cause any significant attenuation to radio waves. Third, the major constituents of the Martian atmosphere are given in Table 3 [12]. As can be seen, the Martian atmosphere is dominated by carbon dioxide and nitrogen gases. The physical properties of these components reveal that they do not have electric or magnetic dipoles and so do not absorb electromagnetic energy. Fourth, although, atmospheric particulates, such as dust or CO_2 ice might cause some attenuation, we do not believe that particulates that are light enough to be suspended in such a diffuse atmosphere could do much radio attenuation, unless they are highly electrically conductive [13].

Actual calculations of the attenuation due to the atmosphere for a horizontal path on Mars' surface, yields approximately 10^{-6} dB/Km at 2.5GHz [12]. Thus, we consider atmospheric attenuation to be negligible. Similar results can be found in [8].

Table 3. Composition of the Mars atmosphere

Carbon dioxide	95.32%
Nitrogen	2.7%
Argon	1.6%
Oxygen	0.13%
Carbon monoxide	0.08%

Finally, modifications for atmospheric refraction (bending of radio waves due to the atmosphere) are as follows. Given the fact that Mars' atmosphere is so diffuse, even at the planet's surface, it is for practical purposes, a vacuum compared to the Earth's. Thus we assume that any effects due to atmospheric refraction are also negligible in our study [12], [13]. The attenuation due to refraction from Earth's atmosphere is normally taken into account by introducing an "effective radius" multiplier. In the source code, this multiplier, K is set to 1.33 for all conditions, i.e., the effective radius for Earth is $K \times r_e$ where r_e is the Earth's radius. Since the attenuation due to refraction for Mars is negligible, we set $K = 1$ thus Mars' effective radius is equal to its physical radius, r_m. We note that in some implementations, an effective curvature (inverse of the effective radius) is used.

4. SIMULATIONS

For simulations of antenna coverage and RF propagation at the sites previously described, we make several assumptions. First, we assume an antenna height of 1m. This is based on the previous assumption that the lander would serve as a network access point with an antenna mounted near the top. Second, we assume an omni-directional antenna and con-

sider 1W radiated power at 2.4GHz. Third, on the receiver side (sensor or rover), we assume a minimum requirement of −93dBm received power for a 1Mbps link and a minimum of −84dBm for a 11Mbps link. These are figures normally provided by IEEE802.11b hardware designers [14]. For this study, antenna coverage patterns will be defined by these received power requirements.

In addition to the antenna coverage patterns, we provide two metrics to evaluate the results. These metrics are computed as follows. First, the *site coverage* (SC) is defined as

$$\mathrm{SC} \quad = \quad \frac{A_{-84}}{A_{\mathrm{CR}}} \qquad (1)$$

where A_{-84} is the area (in m^2) where RF power is −84dBm or greater and A_{CR} is the area (in m^2) of the *coverage region* (CR). For all sites, the CR is a 2000m × 2000m rhombus which fits inside the map "strips" of Figs. 2 − 4. Second, for the selected sites, the A_{CR} is approximately 3.966×10^6 m^2. The maximum coverage distance in the CR or d_{max} is defined as

$$d_{\mathrm{max}} \quad = \quad \max\left[d(x_{\mathrm{TX}}, y_{-84})\right] \qquad (2)$$

where $d(x, y)$ is defined as the distance (in m) from point x to point y, x_{TX} is the location of the transmitter, and y_{-84} is the location of the center of any 66m × 66m area where RF power is −84dBm or greater. The 66m × 66m or 6 pixel × 6 pixel square (at 11m/pixel) represents $0.1\% \times A_{\mathrm{CR}}$.

Simulations are conducted using ATDI's HertzMapper on a standard PC. DEM files (converted to ATDI's format) for the Mars sites (11m/pixel resolution) are first loaded into the software. Simulation parameters are then selected including both communication system parameters and parameters for the modified ITM. Finally, transmitter location is specified and simulation is started.

5. RESULTS

Figs. 5 − 9 illustrate the antenna coverage patterns for the selected sites. The grayscale areas indicate the Mars topography; the areas in red denote a received power between −85dBm and −93dBm and can (in theory) support a 1Mbps IEEE 802.11b link; the areas in green denote a received power greater than −84dBm and can (in theory) support a 11Mbps IEEE 802.11b link. All other areas do not have sufficient received power for an 802.11b link.

Table 4 below provides the percent site coverage, SC and maximum coverage distance, d_{max} metrics for each simulation as described in Section 4.

The results show that even with low radiated power (1W) and low antenna heights (1m) (standard assumptions for mission planners), coverage at 2.4GHz can (in some cases) extend outward several thousand meters in the actual Mars environment. Such a range suggests that a wireless microcell could

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Figure 6. Antenna coverage pattern for Gusev1, Site 2 (see Fig. 2). Red square with "A" indicates location of transmitter. Red areas denote 1Mbps, green areas denote 11Mbps.

Figure 5. Antenna coverage pattern for Gusev1, Site 1 (see Fig. 2). Red square with "A" indicates location of transmitter. Red areas denote 1Mbps, green areas denote 11Mbps.

Table 4. Metrics for RF coverage.

Site	Site Coverage (11Mbps link)	Maximum Coverage Distance, d_{max}
Gusev 1, Site 1	29.45%	3857.8m
Gusev 1, Site 2	22.78%	1888.5m
Gusev 1, Site 3	26.16%	4621.0m
Hematite 4, Site 1	46.87%	1435.6m
Hematite 5, Site 1	49.16%	2399.8m

be established on the Martian surface with the lander serving as a base/relay station and with rovers/sensors using low-cost, commercial IEEE 802.11b wireless networking technologies (with appropriate packaging for the space environment). The data rates could theoretically support not only measurement data but also images and possibly low-resolution video. Site coverage (as defined) ranges from 23% – 49% of a 2km × 2km region around the simulated base station thus providing a sizable area over which to deploy rovers or a sensor web and maintain a high-speed link. However, as can be seen in Figs. 5 – 9, coverage is not uniform due (no doubt) to the low antenna height in comparison with the Mars' surface feature sizes. Such non-uniform coverage may present a challenge to designers of wireless networks of rovers and sensor webs and especially ad-hoc networks.

6. FUTURE WORK

We are currently beginning simulation work of power delay profiles on the Mars sites. Such profiles together with the presented work will provide a fairly complete picture of the RF environment on Mars.
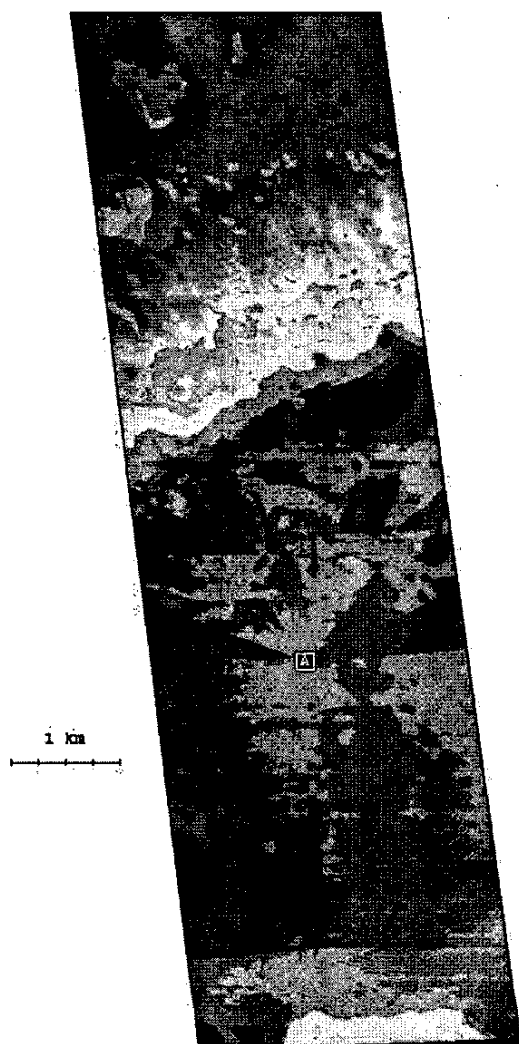
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Figure 7. Antenna coverage pattern for Gusev1, Site 3 (see Fig. 2). Red square with "A" indicates location of transmitter. Red areas denote 1Mbps, green areas denote 11Mbps.
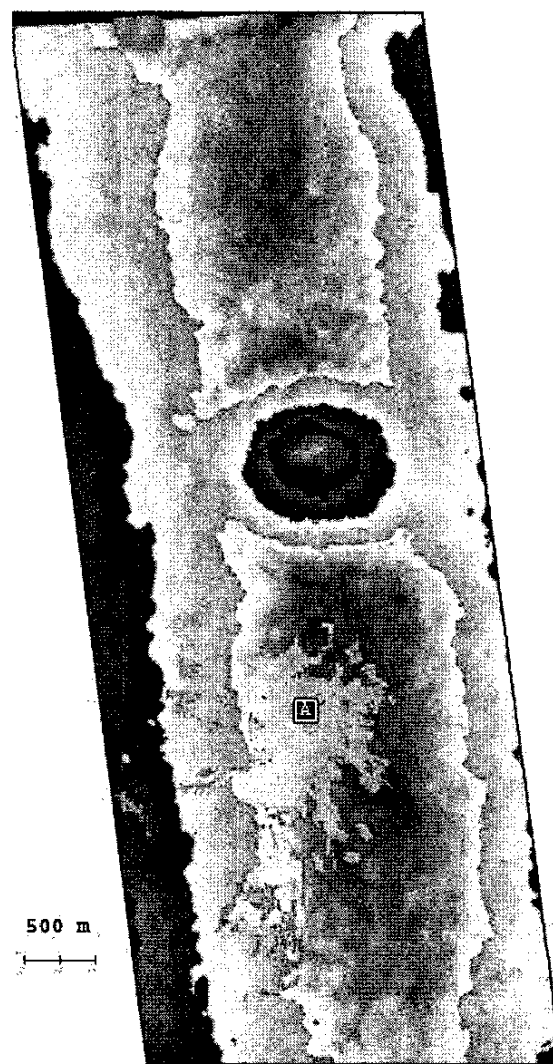

Figure 8. Antenna coverage pattern for Hematite4, Site 1 (see Fig. 3). Red square with "A" indicates location of transmitter. Red areas denote 1Mbps, green areas denote 11Mbps.

7. CONCLUSIONS

In this paper, we have demonstrated the potential for commercial, off-the-shelf wireless networking technologies like IEEE802.11b in the Mars environment. Specifically, we have simulated RF coverage patterns of a base station 1m in height, radiating 1W at 2.4GHz in the Gusev Crater and Meridiani Planum regions on Mars. Our simulations make use of commercial cellular telephone planning software (with some modifications specific to the Mars environment) together with actual topographic data of Mars. The results show RF coverage theoretically capable of supporting an 11Mbps IEEE 802.11b link (average received power greater than −84dBm) in 23% − 49% of a 2km × 2km region around the simulated base station. In addition, the results show some scattered areas thousands of meters away with sufficient received power for an 11Mbps link.

REFERENCES

[1] "NASA Space Communications Project," Jan. 2003. <http://scp.grc.nasa.gov/portfolio/pn/index.html>.

[2] J. Andersen, T. Rappaport, and S. Yoshida, "Propagation Measurements and Models for Wireless Communications Channels," *IEEE Communications Mag.*, pp. 42–49, Jan. 1995.

[3] "ATDI," May. 2003. <http://www.atdi.com>.

[4] M. Golombec, T. Parker, F. Anderson, and N. Bridges, "MOC Narrow Angle High Resolution Topography," Jan. 2003. <http://webgis.wr.usgs.gov/mer/moc_na_topography.htm>.
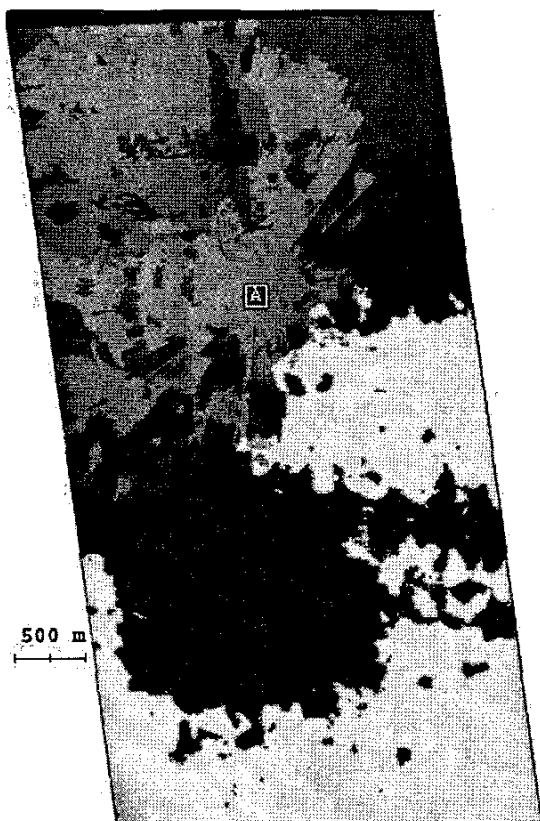
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Figure 9. Antenna coverage pattern for Hematite5, Site 1 (see Fig. 4). Red square with "A" indicates location of transmitter. Red areas denote 1Mbps, green areas denote 11Mbps.

[5] "NASA Rovers Slated To Examine Two Intriguing Sites On Mars," NASA News Release 03-137, Apr. 2003. <http://www.nasa.gov/home/hqnews/2003/mar/HP_news_03137.html>.

[6] A. Rayl, "NASA Announces Mars Exploration Rovers' Landing Sites," Apr. 2003. <http://www.planetary.org/html/news/articlearchive/headlines/2003/nasa_mer_sites.htm>.

[7] "NASA's Mars Exploration Program," Sep. 2003. <http://mars.jpl.nasa.gov/spotlight/images/merlandingGusev.jpg>.

[8] D. Hansen, M. Sue, C. Ho, M. Connally, T. Peng, R. Cesarone, and W. Horne, "Frequency Bands for Mars In-Situ Communications," *Proc. IEEE Aerospace Conf.*, 2001.

[9] D. Smith, G. Neumann, R. Arvidson, E. Guinness, and S. Slavney, "Mars Global Surveyor Laser Altimeter Mission Experiment Gridded Data Record," *NASA Planetary Data System*, no. MGS-M-MOLA-MEGDR-L3-V1.0, 2003.

[10] G. Hufford, A. Longley, and W. Kissick, "A Guide to the Use of the ITS Irregular Terrain model in the Area Prediction Mode," *NTIA Report No. 82-100*, Apr. 1982. NTIS Order No. PB82-217977.

[11] S. Cummer and W. Farrell, "Radio Atmospheric Propagation on Mars and Potential Remote Sensing Applications," *J. Geophysical Research*, pp. 104,14,149–14,157, Jun. 1999.

[12] C. Ho, S. Slobin, M. Sue, and E. Njoku, "Mars Background Noise Temperatures Received by Spacecraft Antennas," *The Interplanetary Network Progress Report*, vol. 42-149, May 2002. <http://ipnpr.jpl.nasa.gov/tmo/progress_report/42-149/149C.pdf>.

[13] P. McKenna. Private communication, Jul. 2003.

[14] "D-Link Technical Specifications for DWL-1750 AirPremier Outdoor 2,4GHz (802.11b) Wireless Bridge/Router," Sep. 2003. <http://www.dlink.com/products/resource.asp?pid=35&rid=179>.

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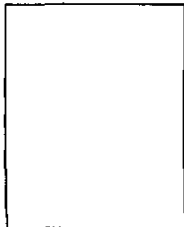
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