Simulation and Analysis of the Multipath Environment of Mars

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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. Elements of the network have a short transmission range, low power requirements, low cost, and a relatively short-life span. The performance of any such wireless network depends fundamentally on the radio frequency (RF) environment. In wireless communication systems, communication engineers are generally concerned with two main radio channel issues: link budget and multipath. We have already reported results concerning the link budget at selected sites on Mars. These results were based on a 2.4 GHz proximity wireless network and simulated RF coverage patterns using high-resolution (11 m/pixel) DEMs of the Gusev Crater and Meridiani Planum regions. This paper presents our current research results regarding the multipath environment at the same selected sites on Mars. Our simulations compute the PDP between an access point and a node taking into account environmental parameters including terrain. With these PDPs, we are able to predict and analyze delay spread statistics which could be used in designing wireless network receivers for use on Mars' surface.

TABLE OF CONTENTS

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 *fundamen-*

tally 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 (PDP) 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.

Our earlier results concerned the link budget at selected sites on Mars and were presented in [3]. These simulations were based on a 2.4 GHz proximity wireless network and computed RF coverage patterns using high-resolution (11 m/pixel) digital elevation maps (DEMs) of specific areas in the Gusev Crater and Meridiani Planum regions. In order to develop the simulations, we utilized ATDI's HertzMapper software with Mars-specific modifications to the Irregular Terrain Model (ITM) propagation model codes. The modifications took into account differences from Earth such as planetary radius and atmospheric effects.

This paper presents our current research results regarding the multipath environment within hypothetical 1 km microcells inside these same regions. In this work, we have utilized a commercial RF propagation modeling software, ATDI's ICSTelecom [4], together with topographic data from the Mars Orbiter Laser Altimeter (MOLA) and composite data from the United States Geological Survey (USGS), to compute PDPs for a variety of access point and node locations within the sites of interest [5], [6]. The software, which

uses ray-tracing techniques to compute propagation paths, takes into account antenna heights and types, radiated power, topographic information, image data, and surface features and clutter. This approach can be more revealing regarding physical details and is often more accurate that conventional statistics-based approaches [2].

This paper is organized as follows. In Section 2, we provide information regarding the location of the selected sites, required DEMs, and access point/node arrangements within the microcell. In Section 3, we discuss the multipath characterization and its importance in a wireless channel. In Section 4, we present background information regarding how we conducted the simulations as well as the metrics used in evaluating the results. In Section 5, we present the simulation results including cumulative distribution plots of rms delay spread values. Our simulation results are analyzed and the effect of representative multipath on IEEE 802.11b at selected locations on Mars is discussed. Finally, we summarize the main results and conclude the article.

2. SELECTION OF SIMULATION SITE LOCATIONS

Mars Sites for RF Simulations

The Gusev Crater and Meridiani Planum (Hematite) regions were chosen as the landing sites for the 2004 MER mission because of the evidence that water may once have existed in these regions [7]. The Gusev Crater appeared to have been a lake fed by a river which flowed through the Ma'adim Vallis at one time. The Meridiani Planum region showed the chemical signature of Hematite minerals associated with liquid water locations. Recent findings from this mission have since confirmed that water did exist on Mars [8].

For both the Gusev Crater and Meridiani Planum regions, the RF simulations focus at specific sites within each of the 2004 MER 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 [9]. 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. 1 – 3 where the red discs in the left-most picture indicate the simulated network access point positions.

The multipath simulation points around each access point are selected as shown in Fig. 4. The simulation points are selected such that the first two points are 100m, next four points are 500m and next two points are 1000m away from the access point. For all the access points shown in Figs. 1 – 3 the simulation points are chosen as described above.

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
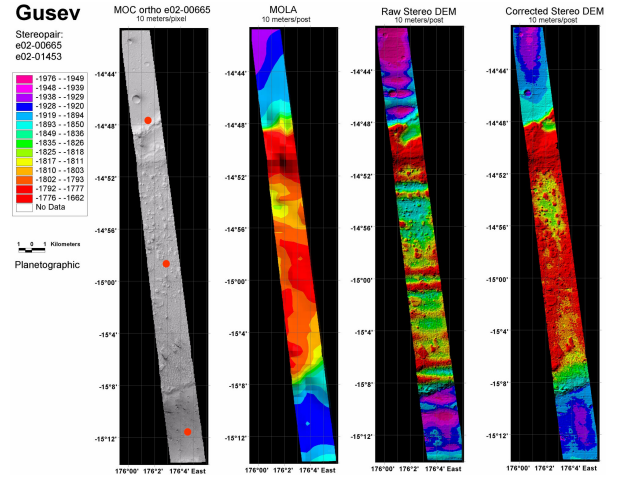

Figure 1. Gusev Crater region, near the center of the landing ellipse. Red discs in left-most picture indicate approximate locations for simulated network access points.
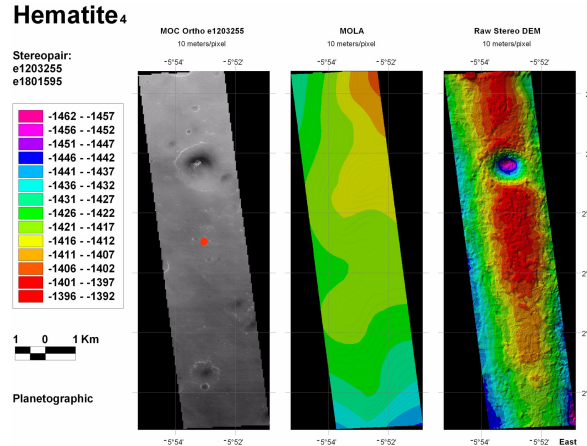

Figure 2. Meridiani Planum region, near the center of the landing ellipse. Red discs in left-most picture indicate approximate locations for simulated network access points.

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.
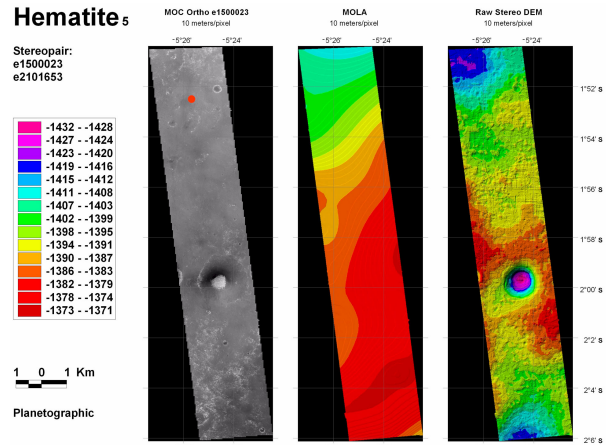
Table 1. Sites for Multipath Simulations.

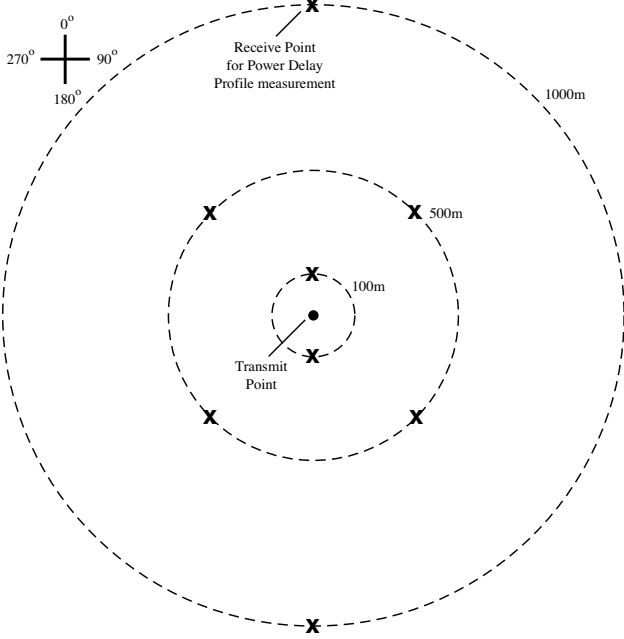| Site	Mars Latitude	Mars Longitude
Gusev1 - Site 1	14° 47′ 39.35″ S	176° 1′ 29.18″ E
Gusev1 - Site 2	14° 58′ 41.95″ S	176° 2′ 53.51″ E
Gusev1 - Site 3	15° 11′ 35.66″ S	176° 4′ 31.23″ E
Hematite4 - Site 1	2° 11′ 0.69″ S	−5° 53′ 5.16″ E
Hematite5 - Site 1	1° 52′ 29.16″ S	−5° 25′ 39.59″ E

Figure 4. Locations of network access point (transmit point) and nodes (receive points) used in calculating power delay profiles.

[5]. However, these data sets have a relatively coarse resolution (∼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 [10]. 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 ICSTelecom.

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

3. MULTIPATH CHARACTERIZATION

The mechanisms which govern radio propagation are complex and diverse, and they can generally be attributed to three basic propagation mechanisms: reflection, diffraction, and scattering [2]. These propagation mechanisms have an impact on the instantaneous received signal in different ways for a wireless receiver. When the receiver has a clear line-of-sight (LOS) path from the transmitter, the propagation is dominated by direct and ground reflected rays. However, in the case when a receiver has no clear LOS from the transmitter, diffraction and scattering will most likely dominate the propagation. Therefore if the receiver moves (as in the case for a mobile rover), the received signal strength will fluctuate rapidly because the field is a sum of many ray contributions coming from different directions with random phases. This rapid fluctuation is referred to as *small-scale fading*. As the receiver moves away from the transmitter over larger distances, the local average received signal power will gradually decrease and this is referred to as *large-scale fading*. Multipath which arises due the reflections from nearby objects is one of the main contributors to small scale fading. In general, small-scale fading limits the data rate and large scale fading limits the coverage area.

In order to determine the effect of small-scale fading on data rates, the multipath structure of the channel should be quantified. Usually the multipath structure of the channel is expressed with a PDP, i.e. received power as a function of excess delay with respect to a fixed time delay reference. Power delay profiles are found by averaging instantaneous PDP measurements over a local area in order to determine an average small-scale PDP.

Many multipath channel parameters are derived from the PDP. Time dispersion caused by multipath is commonly described by two statistical moments: mean delay and rms delay spread [12]. Mean delay is the first moment of PDP given by

$$\overline{\tau} = \frac{\sum P(\tau_k)\tau_k}{\sum P(\tau_k)} \tag{1}$$

where τ is the time delay and P is the average receiver power. The rms delay spread is the square root of the second central moment of the PDP and is defined to be

$$\sigma_\tau = \sqrt{\overline{\tau^2} - (\overline{\tau})^2} \tag{2}$$

where $\overline{\tau^2}$ is given by

$$\overline{\tau^2} = \frac{\sum P(\tau_k)\tau_k^2}{\sum P(\tau_k^2)}. \tag{3}$$

For several modulation types, such as BPSK, QPSK, OQPSK,

and MSK, average irreducible BERs have been shown to become larger than 10^{-3} when the rms delay spread exceeds 10% of the symbol period and equalization is not used [13]. Therefore, as a general rule, the maximum data rate with acceptable BER performance is limited to $0.1/\sigma_\tau$ when using a receiver which does not employ an equalizer to combat the effects of frequency selective fading. The shape of delay profile will not be important when symbol duration is more than ten times the rms delay spread. However, when the symbol period is less than or equal to the rms delay spread, the shape of the delay profile will be a factor in determining the performance [13].

Another measurement of time dispersion is maximum excess delay defined to be the time delay during which multipath energy falls to a predetermined level, x below the maximum. In other words, the maximum excess delay is defined as $\tau_x - \tau_o$, where τ_o is the first arriving signal and τ_x is the maximum delay at which a multipath component is within the predetermined level of the strongest arriving signal (which does not necessarily arrive at τ_o). Table 2 shows the typical rms delay spread values for different regions on Earth [14]. RMS delay spreads such as those listed in Table 2 allow designers to estimate data rates. For example, using the rms delay spread value for mountain terrain, the maximum data rate with acceptable BER performance is probably limited to $0.1/(3.8 \times 10^{-6}) = 26$ kbps.

Table 2. RMS delay spread values derived form CDF's

Terrain	Area (Reference)	$\sigma_\tau (\mu s)$
Urban	4 US cities (Rappaport [12])	1.9
	Manhattan (Cox [15])	1.1
	Toronto (Sousa [16])	0.7
	Denver (Wepman [17])	0.7
	Red Bank micro cells (Devasirvatham [18])	0.2
Suburban	Toronto (Sousa [16])	0.3
	The Hague (Van Rees [19])	0.3
Rural	Colorado (Wepman [17])	0.13
	Netherlands (van Rees [19])	0.08
Mountain	Vevey (de Weck [20])	3.8
	Kofu (Tanaka [21])	1.8

4. SIMULATIONS

The system parameters for the assumed transmitter and receiver used in computing the PDPs for the sites on Mars are listed in Table 3. Simulations are conducted using ATDI's IC-STelecom on a standard PC. DEM files (converted to ATDI's format) for the Mars sites (11m/pixel resolution) are first loaded into the software. Multipath simulation begins with RF coverage calculations at the selected site. The ITM is chosen as the propagation model with Mars-specific modifications [3]. Environmental parameters are specified in the ITM. For example, the reflectivity of rocks at the sites is selected as 0.23 [10]. Finally, transmitter and receiver locations

are specified (see Fig. 4) and the PDP is computed.

Table 3. System Parameters

TX Parameters	Transmitted Power	1 Watt
	Frequency	2400 MHz
	Antenna Height	1 m
	Antenna Type	Omni Directional
	Polarization	Vertical
RX Parameters	Frequency	2400 MHz
	Antenna height	1m
	Antenna Type	Omni Directional
	Polarization	Vertical

5. RESULTS

Figs. 5 – 7 illustrate the Cumulative Distribution Function (CDF) of rms delay spread values simulated for all receiver points. Fig. 5 shows that 92% of the rms delay spread values calculated for the 100 m points have less than 0.72 μs delay spread. The maximum delay spread value calculated for this case was found to be 0.7565 μs. For the 500 m points, 70% of rms delay spread values calculated have less than 0.72 μs delay spread and the maximum rms delay spread value was found to be 3.1257 μs. Fig. 8 shows the PDP corresponding to this maximum rms delay spread value. Finally, for the 1000 m points, 72% of the rms delay spread values are less than 0.72 μs and the maximum rms delay spread was found to be 3.0825 μs.

As a short example for how these PDP calculations and rms delay spread statistics can be utilized, we consider an IEEE 802.11b link operating at 11 Mbps. For this link, the symbol duration is $0.72\mu s$ [23]. Noting from Figs. 5 – 7 that a large proportion of the PDPs have delay spread values which exceed the 10% of the symbol duration, we can conclude (based on the discussion in Section 3) that average BERs may become significantly larger than 10^{-3} if equalization is not used.

6. CONCLUSIONS

In this paper, we have simulated the multipath environment at selected sites on Mars using actual terrain data. Assuming a 1 m high access point antenna, radiating 1W at 2.4GHz, we have computed actual power delay profiles for a number of access point and node locations. The results show that the terrain can induce large rms delay spread values which in some cases exceed $3\mu s$ or more than 10% of the symbol duration for an IEEE 802.11b 11 Mbps link. The multipath results presented in this paper combined with previously reported RF coverage patterns provide a sophisticated model of the wireless channel for Gusev and Hematite regions on Mars. The coverage and multipath statistics could be used to very accurately simulate and predict the communication system performance in these or other regions of interest on Mars.
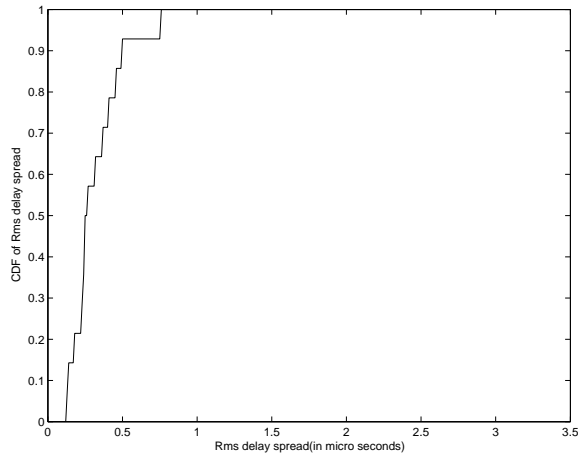
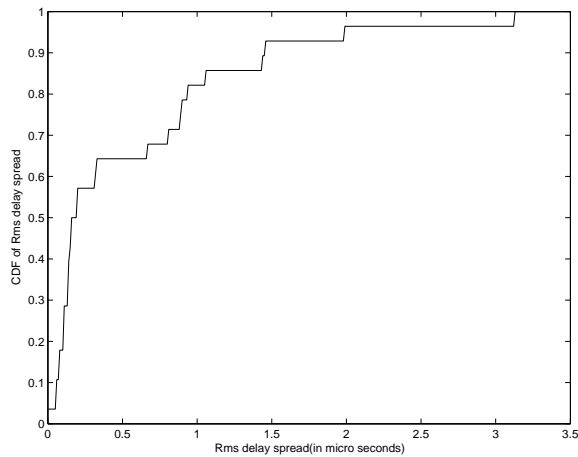**Figure 5**. The CDF of rms delay spread at 100 m receiver points.

Figure 6. The CDF of rms delay spread at 500 m receiver points.
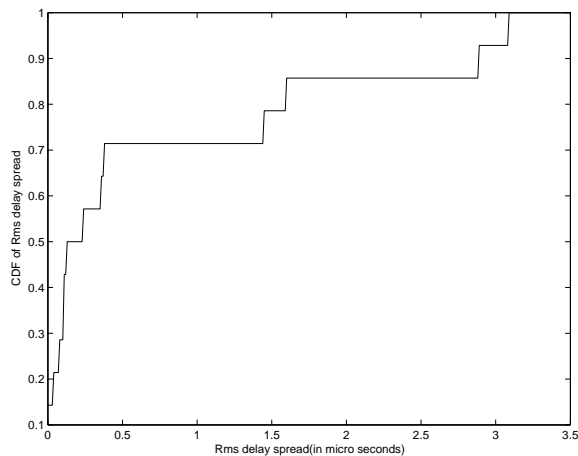

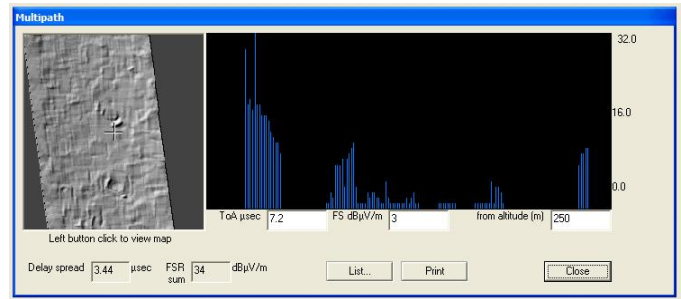**Figure 7**. The CDF of rms delay spread at 1000 m receiver points.

Figure 8. Power delay profile corresponding to the worst observed rms delay spread (node located 500 m away from access point in Gusev region.

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BIOGRAPHIES

Vishwanath Chukkala *received the B.Tech. Electronics and Communications Engineering from the Jawaharlal Nehru Technological University,India, in 2001 and the M.S. degree in Electrical Engineering from New Mexico State University at Las Cruces in 2004. He currently is employed as a software applications engineer with HME in San Diego, CA. His research interests are in Wireless Communiations and Real Time DSP.*
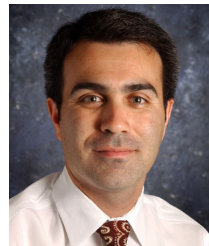
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