Table 1 Mission architecture comparison

Parameter	DRM 2011 ERV cargo flight	DRM 2014 crew flight	Swingby abort option (crew and ERV combined)
TMI payload mass, MT	74.1	60.8	140.45
TMI date	11/8/11	1/20/14	1/02/14
TMI delta V including velocity losses	3.695	4.019 km/s	3.77 km/s
Outbound transit time (days)	297	161	184
Mars atmospheric entry speed	5.65	8.7 km/s	8.3 km/s
Mars swingby delta V including velocity loss	N/A	N/A	1.30 km/s
Venus swingby date (delta V)	N/A	N/A	2/8/15 (0.0038)
Earth return date, return transit time	N/A	6/26/16 (154)	7/23/15 (383)
Earth atmospheric entry speed	N/A	14.22	12.34 km/s
Total stack mass, MT	147.5	137.5	
Total mission duration, days		888	567
IMLEO, MT	285		286

crew. In case of a solar proton event (the most dangerous and unpredictable source of potential radiation exposure), the crew could enter a radiation storm shelter, a section of the vehicle that would be heavily shielded by consumables and other materials.

The rapid interplanetary transits recommended in the DRM are based on radiation exposure guidelines for low Earth orbit (LEO) missions established to limit the risk of fatal cancer to levels comparable to the risk of fatal accidents for terrestrial workers in occupations such as agriculture or construction. These recommendations are largely based on work[7,8] partly carried by one of the authors of this Note. We assert that it is not reasonable to completely eliminate the option of a mission abort because of such stringent guidelines regarding radiation exposure risks, especially when radiation exposure guidelines for a Mars mission are currently nonexistent. Our proposed modification provides a swingby abort option in exchange for a 23-day increase in the outbound crew transit time without increasing the total mission mass or the re-entry G loads on the crew. Such a minimal increase in transit time will result in only a small (<20%) increase in galactic cosmic ray exposure for the transit to Mars. The possible increase in lifetime cancer mortality for the crew from the increased radiation exposure resulting from such an change in transit time is likely to be negligible.

Conclusion

Although the data presented here do not reflect a comprehensive analysis throughout the several mission opportunities in the Earth–Mars synodic cycle, we believe they support our primary point: that undue concern over crew radiation exposure has inappropriately restricted architectural options in the DRM.

Acknowledgment

The authors would like to thank Larry Kos of the NASA Marshall Space Flight Center for providing the data shown in Table 1 on the Design Reference Mission payloads, transit times, and stack masses for comparison.

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J. A. Martin
Associate Editor

Performance Analysis for International Space Station Wireless Local Area Network

Shian U. Hwu,* John P. Boster,† and Yin-Chung Loh‡
Lockheed Martin Space Mission Systems and Services, Houston, Texas 77258

Introduction

THE International Space Station (ISS) will use a wireless local area network (WLAN) to provide continuous local area network (LAN) services to mobile astronauts carrying portable computers. Wiring a space vehicle with a traditional LAN can be very expensive, especially if vehicle structural changes are required. The WLAN is very flexible; astronauts carrying portable computers are not tied to a particular desk or wiring outlet. Thus, the WLAN is very attractive in the space station zero-gravity environment.

An understanding of the wave propagation and coverage performance of rf signals is important for the development and evaluation of the WLAN system. The signal propagation is greatly affected by the structures along the propagation paths. Multipath effects must be characterized, especially in regions where line of sight is unavailable. There are concerns about the multipath effects (signal interference due to reflections and diffractions) on the WLAN rf signals. The purpose of this study is to analyze whether the ISS WLAN can provide adequate signal strengths to achieve an adequate file transfer data rate over the required coverage areas. Both experimental and computational analyses were performed to investigate the WLAN performance in the ISS environment and to verify the acceptability of the proposed WLAN access point location.

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*Electronic Engineering Specialist, Communication Systems Analysis and Test Section, 2400 NASA Road 1. Senior Member AIAA.

†Electronic Engineer, Communication Systems Analysis and Test Section.

‡Electronic Engineering Specialist and Project Manager, Communication Systems Analysis and Test Section.

Computational Investigations

Computational investigations were performed using the electromagnetic modeling technique. The uniform geometrical theory of diffraction (UTD) technique was applied to model and to compute the signal strength for various configuration setups in which the multipath effects are taken into account. The UTD technique provides a high-frequency approximate solution to the electromagnetic fields, including incident, reflected, and diffracted fields, and their interactions.[1,2] In the field computation, the reflected and diffracted fields are determined by the field incident on the reflection or diffraction point multiplied by a dyadic reflection or diffraction coefficient, a spreading factor, and a phase term.[1,2]

The proposed WLAN system will provide two-way transmission of data between a remote portable laptop computer and the ISS file server computer. The WLAN access point, connected to the file server computer, will be located in the U.S. laboratory module (LAB). Astronauts may carry laptop computers in the service module (SM), Russian FGB module, node 1 module, and LAB module (Fig. 1). This study is to determine whether the proposed locations and quantity of access points can provide adequate coverage performance for the WLAN system aboard the ISS.

Two proposed access point locations were tested separately. These were an aft location and a forward location in the LAB module. Vertical and horizontal astronaut translation paths and different access point and laptop computer antenna orientations were evaluated. Both the laptop computer and the WLAN access point use standard quarter-wavelength monopole antennas. Two different antenna orientations were analyzed. The aligned orientation has the access point antenna and the laptop computer antenna pointing in the same direction (parallel to each other). The orthogonal orientation has the access point antenna and the laptop computer antenna oriented at right angles to each other (perpendicular to each other).

The ISS WLAN is a frequency hopping system, the system continuously hopping between different channels to overcome poor link due to multipath. The transmitter and receiver constantly change channels, ensuring that any interference received lasts for only a short duration (while the units are tuned to the channel where the interference is). Data lost during those short periods are retransmitted at a different frequency (channel) so that no information is lost. A good representation of the operating characteristics can be developed by testing the high, middle, and low frequencies of the hopping range from 2.4 to 2.48 GHz.

Experimental Verification

A series of WLAN signal strength measurements was conducted in the NASA Marshall Space Flight Center LAB module facility.[3] A test configuration in the LAB module is shown in Fig. 2. Data obtained from the measurements were compared to the UTD computed results. As shown in Fig. 3, good agreement between the computed and measured data was obtained.

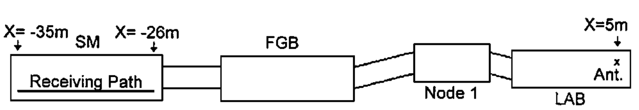

Fig. 1 ISS module model and transmitting/receiving antenna locations.

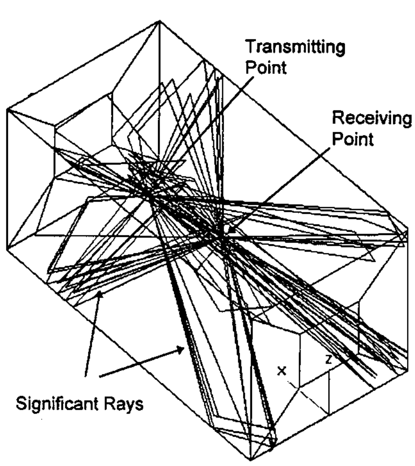

Fig. 2 LAB model and significant rays between transmitting and receiving antennas.

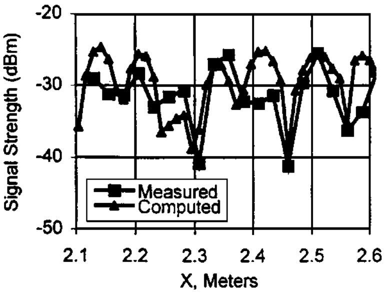

Fig. 3 Comparison of measured and computed signal strengths.

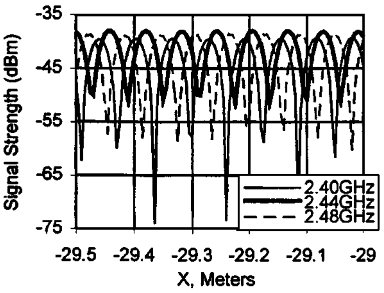

Fig. 4 Signal strength along a receiving path in SM.

Results and Discussion

For each access point location, various translation paths and antenna orientations were analyzed in each module. A complete set of results is given in the technical report.[4] The signal strength threshold used in this study is −71 dB (1 mW), which includes the 6-dB margin to vendor's specification of −77 dB (1 mW). This represents the signal level where the data transmission would drop from a high data rate to a low data rate.

For the LAB and node 1, there is adequate signal strength for either access point location. Signal levels in the FGB and SM are lower than the levels in the LAB and node 1. It is in these two modules that the orientation of the antennas becomes important. Figure 4 shows the signal strength for aligned antennas along a horizontal path in the SM. The standing wave phenomenon is observed. The peaks and valleys are shifted for different frequencies. The frequency hopping system overcomes a poor link spot by hopping to a different channel.

Analyzing the SM data, the aligned antenna case has a few dropouts [lower than minimum required −71 dB (1 mW)], but the average signal level is about 20 dB above the threshold. When compared with the orthogonal antenna orientation, a drop of approximately 15–20 dB is observed. The signal level for the orthogonal antennas becomes marginal as there are many drops below −71 dB (1 mW). The orthogonal orientation (90-deg angle between the access point antenna and the laptop computer antenna) is the worst case. By changing the orientation to 80 deg, the average signal level increases by 5–10 dB. When the orientation is changed to 70 deg, the average signal level increases by an additional 5–10 dB with fewer dropouts. Antenna orientation is important in the space station environment. The user should move to a better orientation if experiencing a poor link.

Another possible concern is the presence of the cupola, which will be installed on the port side of node 1 during ISS assembly flight 14A. Computed data show that the cupola will have very little effect on the signal level received. Interference from outside sources may enter the ISS through the cupola, but ample margins exist to handle this interference.

Conclusions

Two locations for the access point antenna, located in the LAB module, were evaluated. One location is 1 m from the aft bulkhead and the other is 1 m from the forward bulkhead. It was observed that both access point locations provide acceptable signal strength throughout the ISS. The worst signal strength is in the SM. For the

SM, the forward access point antenna location is better and is the preferred location. The approximate location of the access point antenna will be $x = 5.0$ m, $y = 0.0$ m, and $z = 5.5$ m in space station coordinates.

Based on the measured and computed data obtained from this study, the proposed WLAN system will provide adequate coverage using one access point located in the forward portion of the LAB module. Signal level and link performance will be affected by antenna orientation. Better signal level and link performance can be achieved by arranging the access point antenna and the laptop computer antenna pointing in the same direction (parallel to each other).

Acknowledgments

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A. C. Tribble
Associate Editor

Multipath Effects on International Space Station Global Positioning System Performance

Shian U. Hwu*
Lockheed Martin Space Mission Systems and Services, Houston, Texas 77258
and
Susan F. Gomez† and Robert J. Panneton‡
NASA Johnson Space Center, Houston, Texas 77258

Introduction

THE International Space Station (ISS) will use the global positioning system (GPS) for providing position, velocity, attitude determination, and time reference. There are concerns about the multipath effects (signal interference due to reflections and diffractions) of the surrounding structure, as shown in Fig. 1, on the GPS performance. Multipath from the surrounding structures may degrade the accuracy of the GPS attitude determination.[1] To investigate the multipath effects on the space station GPS measurement accuracy, experimental and computational investigations were performed to estimate the carrier phase errors due to multipath. A series of GPS multipath tests using the ISS GPS hardware were conducted in the NASA Johnson Space Center GPS test facilities.[2,3] Computational investigations were also performed using the electromagnetic modeling technique.[4,5] Measured and computed data were analyzed and compared.

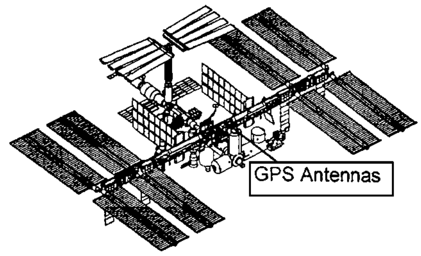

Fig. 1 ISS GPS antenna locations.

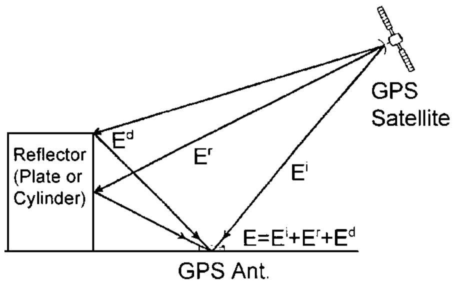

Fig. 2 GPS multipath ground-test configuration.

Experimental Investigations

A series of GPS multipath ground tests that simulated the ISS GPS multipath environment were performed.[2,3] Figure 2 shows the test setup. Each GPS receiver had a laptop computer to record the data. Data were collected with no intentional multipath producers and with intentional multipath producers (plate and cylinder) in place. Only selected data are presented here. A complete technical report with all configurations investigated and detailed calibration procedures can be found in Ref. 3. For Julian day (JD) 059, a 4×12 ft aluminum plate (multipath producer) was placed near the GPS antennas. For JD074, a 3-ft-diam, 4-ft-tall cylinder was placed vertically near the GPS antennas.

The multipath effects from the multipath producers were measured as differential carrier phase errors, which are the differences between the differential carrier phases measured by the GPS receivers with and without the multipath producers in place. The differential carrier phase errors are presented in millimeters as a function of time, given in GPS time of week in hours. The 190.5-mm wavelength λ, at the GPS L1 frequency of 1.575 GHz, corresponds to a 360-deg phase error.

Computational Investigations

The uniform geometrical theory of diffraction (UTD) technique was applied to compute the GPS carrier phase errors due to multipath from surrounding plate and cylinder structures.[3–5] In the field computation, the reflected and diffracted fields are determined by the field incident on the reflection or diffraction point multiplied by a dyadic reflection or diffraction coefficient, a spreading factor, and a phase term.[4] The reflected and diffracted field at a field point r', $\boldsymbol{E}^{r,d}(r')$, in general have the following form:

$$\boldsymbol{E}^{r,d}(r') = \boldsymbol{E}^i(r)\boldsymbol{D}^{r,d}\boldsymbol{A}^{r,d}(s)e^{-jks} \quad (1)$$

where $E^i(r)$ is the field incident on the reflection or diffraction point r, $\boldsymbol{D}^{r,d}$ is a dyadic reflection or diffraction coefficient, $\boldsymbol{A}^{r,d}(s)$ is a spreading factor, and s is the distance from the reflection or diffraction point r to the field point r'. $\boldsymbol{D}^{r,d}$ and $\boldsymbol{A}^{r,d}$ can be found from the geometry of the structure at reflection or diffraction point

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*Electronic Engineering Specialist, Communication Systems Analysis and Test Section, 2400 NASA Road 1. Senior Member AIAA.

†Project Engineer, Guidance and Navigation Branch, MC: EG2.

‡Chief Engineer, Avionics Test and Analysis Branch, MC: EV413.