Propagation Characteristics of International Space Station Wireless Local Area Network

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Abstract

This paper describes the application of the Uniform Geometrical Theory of Diffraction (UTD) for Space Station Wireless Local Area Networks (WLANs) indoor propagation characteristics analysis. The verification results indicate good correlation between UTD computed and measured signal strength. It is observed that the propagation characteristics are quite different in the Space Station modules as compared with those in the typical indoor WLANs environment, such as an office building. The existing indoor propagation models are not readily applicable to the Space Station module environment. The Space Station modules can be regarded as oversized imperfect waveguides. Two distinct propagation regions separated by a breakpoint exist. The propagation exhibits the guided wave characteristics. The propagation loss in the Space Station, thus, is much smaller than that in the typical office building. The path loss model developed in this paper is applicable for Space Station WLAN RF coverage and link performance analysis.

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Index Terms — Wireless LANs; propagation model; space station; Uniform Geometrical Theory of Diffraction.

I. Introduction

The propagation characteristics are important for communication systems performance and interference analysis. Recent progress in mobile and personal communications services has developed intensive research in propagation characteristics for various Radio Frequency (RF) environments. The theoretical and experimental studies indicate the propagation characteristics are very dependent on the specific RF environment. For instance, the rural propagation mechanism is mainly determined by direct and ground-reflected waves. Urban propagation mechanism is more random in nature due to the presence of many reflected waves from surrounding buildings. The propagation characteristics of indoor environments such as in houses, office buildings, and factories are also very different based on the construction materials, furniture and partition setups.

The International Space Station (ISS) uses Wireless Local Area Networks (WLANs) to provide continuous LAN services to mobile astronauts carrying portable computers. Wireless LANs can provide a flexibility not offered by wired systems when astronauts carry portable computers in the Space Station zero gravity environment. The performance of wireless communication systems is greatly affected by the radio wave transmission path between the transmitter and the receiver. Unlike wired communications that are stationary, wireless radio propagations are extremely environment dependent. Therefore, it is necessary to thoroughly understand the propagation characteristics for system performance evaluation and verification.

The International Space Station consists of many modules, which are metallic cylindrical structures. The enclosed space and the one-dimensional extension make the Space Station modules a very unique propagation environment. The existing indoor propagation models are not readily applicable to the Space Station module environment. To characterize the propagation environment inside the Space Station modules, computer simulations were performed using the computational electromagnetic technique – Uniform Geometrical Theory of Diffraction (UTD). There is no universally applicable path loss model for all environments. The specific path loss model is typically obtained from intensive field measurements, which are expensive and time consuming. In this paper, the signal strength of the Wireless Local Area Network (WLAN) system inside the International Space Station is computed. The path loss exponent is determined from computed results.

II. Signal Strength Computations

A. Uniform Geometrical Theory of Diffraction (UTD)

The UTD computes the electromagnetic field for three types of rays: direct, reflected, and diffracted rays. The reflected and diffracted field at a field point r', $E^{r,d}(r')$, can be computed as

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

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

III. EXPERIMENTAL VERIFICATION

The measured data were used to assess the validity of the computer simulation model. The first comparison was made in an ISS LAB module. A series of the WLAN signal strength measurements were conducted in the Marshall Space Flight Center (MSFC) LAB module facility [1]. Data obtained from the measurements were compared to the UTD computed results. As shown in Reference [1], good agreement between the computed and measured data was obtained.

A comparison was made for a tunnel, 150 m long, with a rectangular cross-section 4.7 m high and 8 m width. The transmitting and receiving antennas are half-wave dipoles, vertically polarized and located in the middle of the tunnel. The conductivity is 0.01 S/m and the relative dielectric constant is 5 in the tunnel model. Curves in Fig. 1 show the measured and computed results of the variation of the signal strength versus the distance between the transmitter and the receiver at a frequency of 900 MHz. Good agreement between measured and computed results was observed.

The third verification case is for a smaller tunnel with 4.2 m width and 2.9 m high. The transmitting and receiving antennas are half-wave dipoles, horizontally polarized and located in the middle of the tunnel. The conductivity is 0.01 S/m and the relative dielectric constant is 10 in the tunnel model. Fig. 2 illustrates the measured and computed results of the variations of the received signal power levels versus the distance between the transmitter and the receiver at 900 MHz.

Again, the simulated propagation results agree well with the measured values. Fig. 2 shows that fluctuations of the received signals appear in the vicinity of the transmit antenna. In the short distance region, significant reflected rays cause large fluctuations, whereas in the long distance region as the reflected rays become less significant, the direct ray contributes the most to the received signal. Therefore, the magnitude of fluctuations diminishes as the receiver moves further away from the transmitter. Both measurements and predictions show the existence of a distinct break point along the line-of-sight path, before and after which the propagation has a different rate of attenuation. This propagation behavior was observed in other radio environments as well. By taking this break point into consideration, a good correlation between the propagation loss model and measurement data can be achieved.

IV. RESULTS AND DISCUSSIONS

As shown in Figures 3 and 4, linear regression analysis is employed to study the variation of signal strength over the distance from the transmitter to the receiver. It is observed that the propagation characteristics are quite different in the Space Station modules as compared with those in the office building. Two distinct propagation regions separated by a breakpoint exist in the Space Station modules. Thus, in order to have a more accurate fit, a two-slope regression fit is needed for the Space Station propagation model. The Space Station modules can be regarded as oversized waveguides. The propagation exhibits the guided wave characteristics. The propagation loss in the Space Station, thus, is smaller than that in the office building.

V. CONCLUSIONS

The obtained results illustrate the uniqueness of the Space Station module environment. The path loss is much less than a free space path loss due to the confined spaces of the modules and guided-wave phenomena. The multipath and multimode propagations have produced significant signal fluctuations. To verify our computational technique, we compare our computed results with the measurement results in two different tunnel environments, which are closer to the Space Station module environment. In both environments, the path loss is less than a free space path loss. The guided wave effects are confirmed by both measurements and simulations that the path loss is less than a free space path loss in 10 meter range. The Space Station modules act like oversized waveguides. The propagated waves consist of the fundamental mode, as well as an infinite number of higher order modes. However, the Space Station modules are made of metallic material. A subway or road tunnel is made of lossy dielectric material. The Space Station modules are shorter than the subway and road tunnels in length. The path loss for the Space Station modules are even smaller than the subway and road tunnels.

REFERENCES

[1] S. Hwu, J. Boster, Y. Loh, "Coverage Performance Analysis for International Space Station Wireless Local Area Network," Journal of spacecraft and Rockets, Vol. 35, No. 6, Nov. 1998.

[2] Marhefka, R. J., "Numerical Electromagnetics Code - Basic Scattering Code (NEC-BSC Version 4.0) Beta of User's Manual," ElectroScience Laboratory, The Ohio State University, Columbus, OH, Feb. 1996.

[3] Zhang et al., "Ray-Optical Prediction Of Radio-Wave Propagation Characteristics," pp.1339

[4] A. G. Emslie, R. L. Lagace, and P. F. Strong, "Theory of the propagation of UHF radio waves in coal mine tunnels," IEEE Trans. Antennas Propagat., vol. AP-23, pp. 192--205, Mar. 1975.

[5] T. Klemenschits and E. Bonek, "Radio coverage of road tunnels at 900 and 1800 MHz by discrete antennas," in Proc. Fifth IEEE Int. Symp. Personal, Indoor, and Mobile Radio Communications, vol. 2, the Hague, The Netherlands, Sept. 18--22, 1994, pp. 411--415.
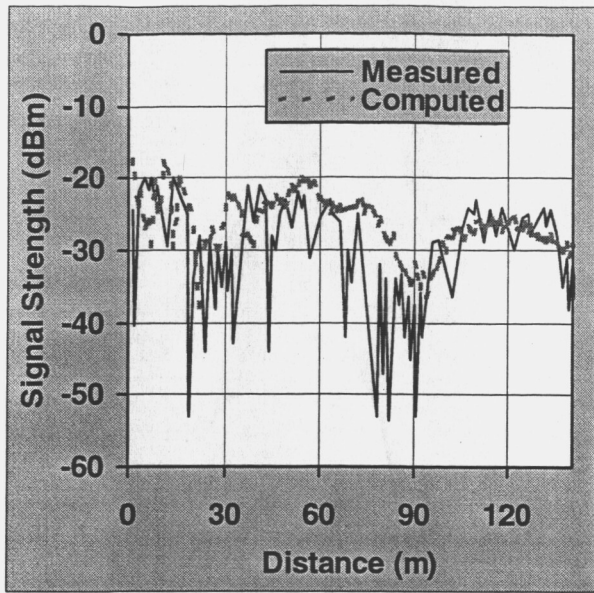
Fig. 1. Measured and computed results of the variation of the signal strength versus the distance between the transmitter and the receiver in a tunnel.
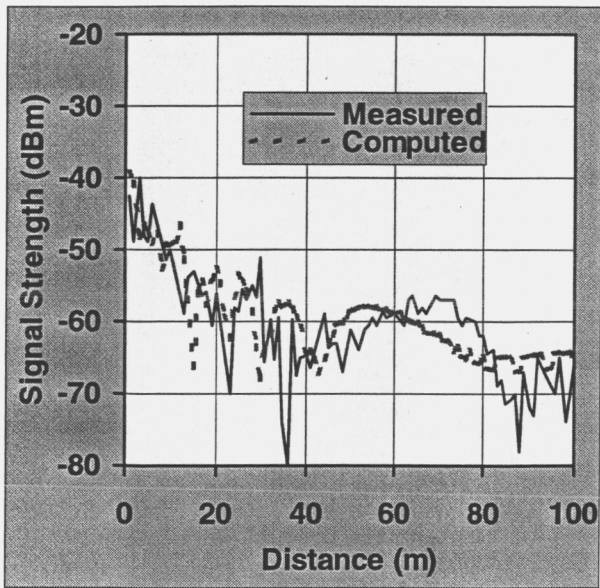

Fig. 3. Path loss versus the distance between the transmitter and the receiver in Space Station environment.

Fig. 2. Measured and computed results of the variation of the signal strength versus the distance between the transmitter and the receiver in a smaller tunnel.
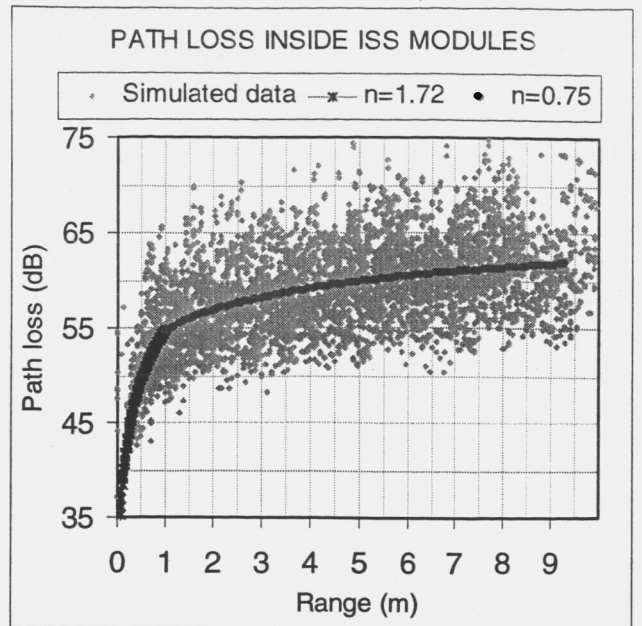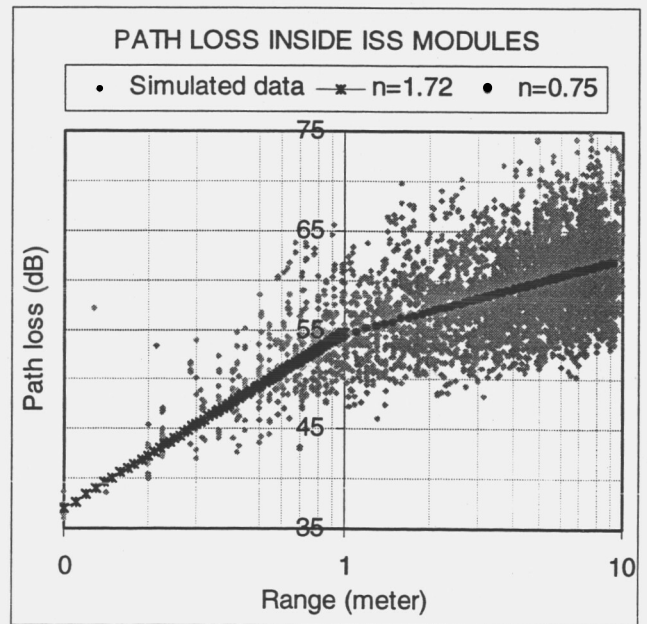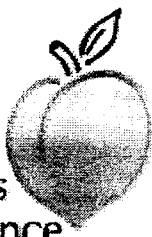

Fig. 4. Path loss versus the distance (in Log scale) between the transmitter and the receiver in Space Station environment.

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