Electromagnetic Propagation Prediction Inside Aircraft Cabins

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Abstract—**Electromagnetic propagation models for signal strength prediction within aircraft cabins are essential for evaluating and designing a wireless communication system to be implemented onboard aircraft. A model was developed using Wireless Valley's SitePlanner; which is commercial grade software intended for predictions within office buildings. The performance of the model was evaluated through a comparison with test data measurements taken on several aircraft. The comparison concluded that the model can accurately predict power propagation within the cabin. This model can enhance researchers' understanding of power propagation within aircraft cabins and will aid in future research.**

I. Introduction

The shape, material, and conditions within aircraft cabins create a complex environment for electromagnetic propagation. This complexity makes predictions difficult and leads to extensive field tests. Thus, there is a desire to develop an accurate model for electromagnetic wave propagation within an aircraft cabin. Currently there are several software packages available that are designed for modeling and simulating wireless communication networks in office buildings and institutions. These could be used as a foundation to design a model of an aircraft cabin. SitePlanner, a registered product of Wireless Valley Communications, Incorporated, was selected for the present effort.

The model created was to replicate an experimental study conducted in the spring of 2003, which examined 802.11 wireless communication network performance onboard several aircraft. This experimental study was completed onboard four airplanes: B747-400, B767-300, B777-200 and A320-200. Three different access points were tested, each of which used various 802.11 standards. The parameters of this study were thoroughly examined in order to accurately compare the predicted data with the experimental data [1].

II. Methods

SitePlanner is a program used for engineering, managing, and planning wireless communication networks. It is powered by AutoDesk technology, allowing a 3D model of the test area to be created or imported. SitePlanner combines AutoCAD, a tool used widely in the engineering field, with wireless communication capabilities, therefore making it simple to operate. The wireless communication capabilities are divided into four software modules. They consist of: Building Database Manipulator (BDM), Predictor, InFielder, and Optimatic [2].

Utilizing the AutoCAD features of SitePlanner combined with components of the BDM module, eight drawing (.dwg) files were created for the simulation. Two drawings for each aircraft were created with the exception of the B747-400. A half-cylinder shape with the same dimensions as the cabin was needed to represent the cabin. However, the prediction and drawing capabilities of SitePlanner did not support a half-cylinder drawing. This problem was resolved by creating a multi-floor building, where each floor had a slightly different width than the floor beneath it. When viewed in 3D, the object approximated the shape of the cabin. Fig. 1 illustrates the different geometries used in the simulation. Additionally, a rectangular prism with the same cross-sectional area as the cabin under examination was created for comparison purposes. Neither representation contained windows, doors or any other internal components, to simplify model construction and prediction calculations.

The drawings in Fig. 1 were constructed by drawing the basic shapes (rectangles) in 2D then using

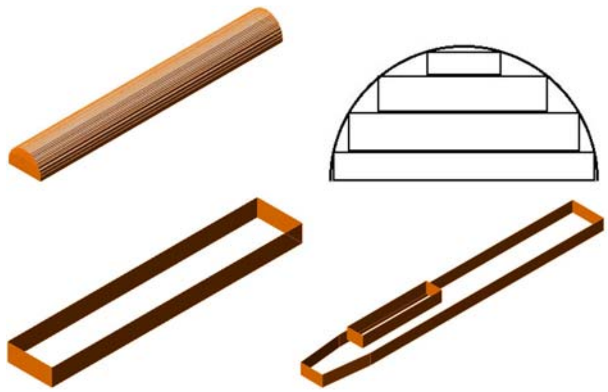

Fig. 1. Top: Half-Cylinder drawing and an example of how it was created. Below: Rectangular drawings; to the right is the drawing used for the two level B747-400.

the formatting features of SitePlanner to set the ceiling height. Several other settings are required for SitePlanner to make predictions. This procedure is referred to as formatting an image. It consists of using the BDM module to set ceiling heights, wall widths, and material. The material for the walls in both models was set to "Elevators-Metal Partitions" which has a path loss similar to what is expected of the cabin walls and ceilings. The path loss for each material can be adjusted for any frequency; the default value for "Elevators-Metal Partitions" is 10 dB at 900 MHz. Verifying a drawing checks that the drawing has been completely formatted, scaled, and that all floors have been aligned. A verified drawing is the final product of the BDM module; without a verified drawing other modules could not be used [2].

After the drawings were formatted and verified, the Predictor module was used to place the base stations and antennas. In SitePlanner, the access point is the combination of the base station and the antenna. Each access point and wireless standard required a new base station and antenna. There are several parameters of the access point that Predictor must have. The parameters for the base station are entered when it is placed in the drawing and include the output power, wireless standard and channel set. Next, an antenna is added to complete the access point. SitePlanner had

TABLE I
SUMMARY OF ACCESS POINTS PARAMETERS

Access Points	ORiNOCO AP 2000	LinkSys WAP51AB	NetGear WG-602
Standard	802.11a & 802.11b	802.11a & 802.11b	802.11b & 802.11g
Antenna Type	Two omnidirectional	Single linear dipole	½ wave dipole
Antenna Gain	5.0 dBi	1.0 dBi	2.0 dBi
Output Power	802.11a: 17dBm	802.11a: 14.653 dBm	802.11b: 10.530 dBm
	802.11b: 18dBm	802.11b: 10.530 dBm	802.11g: 10.530 dBm
Polarization	Vertical	Vertical	Vertical

many antennas (along with their corresponding antenna patterns) to choose from in the software database. With the exception of the ORiNOCO 802.11a, all of the access points were modeled with "Generic" antennas due to their simple characteristics. The ORiNOCO 802.11a access point, which utilizes two omni-directional antennas, was modeled by altering an omni-directional antenna already stored in the SitePlanner database to the proper frequency and antenna gain. An important parameter, not specified with the experimental data, was the height at which the access point and receiver were placed. These values were approximated for each aircraft based on the description of the locations from the report *802.11 Wireless Network Performance within Aircraft Cabins* [1].

Power propagation predictions are easily obtained after the base station and antenna have been placed. Nine different models exist for determining the path loss of a signal. These models are divided into three main categories: Distance Dependent, Wall/Floor Attenuation, and True Point-to-Point. The Distance Dependent and the Wall/Floor Attenuation models are the simpler models. The True Point-to-Point models are the most comprehensive, they account for every obstruction (walls or floors) regardless of transmitter and receiver locations. For each of the three categories a type of path loss exponent is selected for the calculation. There are three different exponent models: Single Path Loss Exponent, Multiple Path Loss Exponent, and Multiple Breakpoint Path Loss Exponent. The Single Path Loss Exponent Model uses one exponent for the entire building (plane) and the Multiple Path Loss Exponent Model uses a different exponent based on the number of floors separating the transmitter and receiver. Lastly, the Multiple Breakpoint Path Loss Exponent Model uses up to five different exponents that are based on the distance between the transmitter and receiver. The True Point-to-Point, Multiple Breakpoint Path Loss Exponent Model was the most applicable for calculating the power propagation within the cabin because it was the most comprehensive and used several path loss exponents. The expression used for this model, in dB, is shown below:

$$PL(d_0) + 10n(d)\log\left(\frac{d}{d_0}\right) + \sum_i [(P_i)(AF_i)] + FAF \qquad (1)$$

where the variable *d* is the transmitter-receiver separation distance and the variable *n* is the path loss exponent (determined as a function of T-R separation or of the number of floors separations). *FAF* is the value of the attenuation based on the number of floor separations (an input parameter). The summation term represents the loss sustained from the signal when it intersects a partition, which is known as the Partition Attenuation Factor. In the summation, P_i is the number of partitions intersected of type *i* and AF_i is the attenuation factor of the partition type *i* [2].

With the Path Loss Model set and the access point positioned, seven different prediction modes can be used. Of the seven modes only four are useful for the power propagation measurements. Three of the prediction modes, Contour Coverage Mode, 3D Contour Coverage, and Grid Coverage Mode, display the power measurements as either a color grid or contour across the test area. This gives an illustration of how the power propagated through any part or all of the test area. However, the measured data results were obtained at specific locations and the power at these locations was not easily obtained from any of these modes. The Instant Point Mode was used to obtain the values needed to compare the measured data directly. In this mode the cursor acts as a mobile receiver. When the mode is initialized, the mobile receiver parameters are entered; such as power, antenna gain, body loss and the height above the floor. In addition, other values (besides power) can be displayed next to the cursor. This includes the Signal to Noise Ratio (SNR), Signal Interference Ratio (SIR), relative power and power density; however, only the received power or Received Signal Strength Intensity (RSSI) was needed for this experiment. After the mobile receiver parameters are entered and additional measurements selected, the cursor can be moved to any location in the test area to display the RSSI value. This mode allows the cursor to be moved to each location to record the measurement. The measurements were entered into Excel and were compared to the measured data [1].

III. Results

The predicted results were graphed with the measured data for comparison. In addition, the standard deviation was calculated. Earlier papers written on simulation results indicate that an acceptable data set can range from 6 to 8 dBm above or below the measured data. Figure 2 and Tables 2 and 3 are comparisons between simulated test data and measured data collected in a previous study with two different devices. The client card result is from the wireless receiver and the Spectrum Analyzer result is from spectrum analyzer measured through an uncalibrated antenna. The differences between the two measurements can be attributed to the differences in measurement techniques of the two devices. The client card uses spread spectrum technology whereas the spectrum analyzer measures power at each discrete frequency. Additionally, the

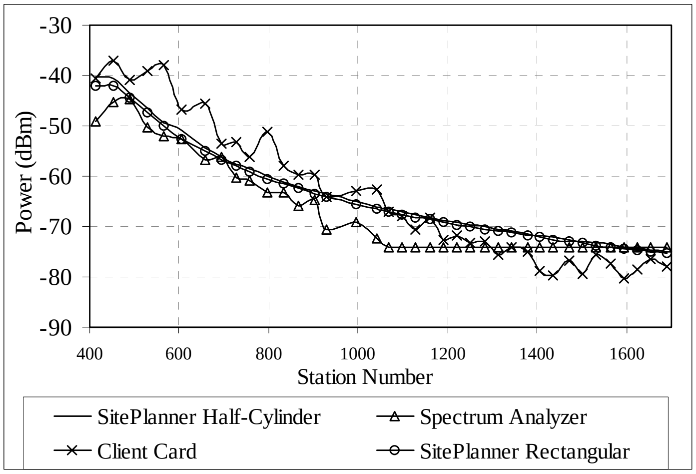

Fig. 2. 802.11a power propagation in the B767-300. The station number is the location of the test point in the cabin.

uncalibrated antennas used with the spectrum analyzer are another error source. All of the results shown are for the ORiNOCO access point because the results of the other access points were not available. The differences between the rectangular model and the half-cylinder model in Fig. 2 appear slight however their variations become more evident when examining the standard deviations.

TABLE 2
STANDARD DEVIATIONS OF 802.11A TEST DATA

Aircraft	Rectangle	Half-Cylinder	Experimental Data
B747	5.61	N/A	Client Card
B747	4.37	N/A	Spectrum Analyzer
B767	4.84	4.68	Client Card
B767	3.5	3.95	Spectrum Analyzer
B777	4.17	3.91	Client Card
B777	1.96	2.05	Spectrum Analyzer
A320	4.05	3.69	Client Card

TABLE 3
STANDARD DEVIATIONS OF 802.11B TEST DATA

Aircraft	Rectangle	Half-Cylinder	Experimental Data
B747	4.8	N/A	Client Card
B747	4.8	N/A	Spectrum Analyzer
B767	3.6	3.93	Client Card
B767	7.63	7.56	Spectrum Analyzer
B777	7.12	7.19	Client Card
B777	6.32	6.28	Spectrum Analyzer
A320	4.05	3.69	Client Card

In most cases the results using the half-cylinder model were slightly more accurate than the rectangular model. As stated previously, the half-cylinder model created for this experiment was not a true half-cylinder; therefore, it is likely to have similar results as the rectangular model. Despite either model not being a true cylinder the results were conclusive. As shown in Fig. 2, the results measured with the client card and the spectrum analyzer differed greatly as well.

IV. Conclusion

The results show that SitePlanner is comparable to the measured data despite the absence of internal components. The simulated graphs follow the general trend of the power propagation found experimentally, which is significant. The experimental data varies due to the effects of the cabins shape and material. Thus, having a model that follows the trend of the measured data is all that can be expected of the simple models in the present study. The low standard deviation concludes that SitePlanner generated results within an appropriate range for SitePlanner to be considered an effective model. Most of the standard deviation values are within 4-5 dBm, which is acceptable. Additionally, the peaks and valleys present in the experimental data can be attributed to the obstructions in the cabin that were not modeled in this effort.

References

[1] F. Whetten, A. Soroker, and D. Whetten, “802.11 Wireless Network Performances within Aircraft Cabins,” Embry-Riddle Aeronautical University: 2003.

[2] *SitePlanner 7.0 User’s Manual,* Wireless Valley Communications Inc., Austin, TX, 2003, pp 123-169.