

ELECTROMAGNETIC PROPAGATION PREDICTION INSIDE AIRPLANE FUSELAGES AND AIRPORT TERMINALS

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Abstract

The focus of this effort is to evaluate the effectiveness of using commercial grade software - intended for electromagnetic predictions within office buildings- to develop models to analyze propagation inside airplane fuselages and airport terminals. The project goal is to verify that the Wireless XGTD and Insite software can accurately predict power propagation within airport terminals and airplane fuselages. Additionally, electromagnetic coupling between the interior and the exterior of an airport terminal, adjacent buildings and objects will be examined. Previous propagation models tested proved to be accurate predictors inside empty airplane fuselages. Current work uses fuselage models which containing additional internal components. The methodology used for airplanes will be extended to airport terminals. Results from airport terminals currently being examined are expected by the end of the semester.

Introduction

In today's industrialized world wireless computer networking is becoming more prevalent. Wireless computer networks are becoming of significant interest to aviation industry for enhanced passenger connectivity. It is clear that airport terminals across the globe will eventually be equipped with wireless networks to provide information access and services to passengers. However, airport terminals are also vulnerable to electromagnetic attack. Therefore, electromagnetic propagation models for signal strength prediction within airport terminals are essential for evaluating and designing wireless communication systems and to evaluate the effectiveness of radio frequency (RF) attack inside airport terminals. The focus of this proposed effort is to evaluate the effectiveness of using commercial grade software intended for electromagnetic predictions within office buildings to develop models to analyze propagation inside airport terminals. Various propagation scenarios will be analyzed, such as transmitter located inside the building and transmitter located outside the

terminal at various locations. If these models are developed successfully, they can enhance researchers' understanding of power propagation within airport terminals, and they will aid in future research to provide a means to design airport terminal wireless networks and to evaluate attack scenarios due to hostile RF or high power microwave (HPM) transmitters.

Creating the Simulation Environment

Software

The foundation of the simulation highly depends on the accuracy put forth in recreating the environment that is to be simulated. The first fundamental step is to create the fuselage for Wireless Insite. Wireless Insite (WI) and XGTD are an electromagnetic wave propagation prediction software created by Remcom; they use various ray-tracing models as a method of calculation. The programs are mainly used to predict how signal strength is affected by other parameters in system such as material properties and shape.

WI also provides various propagation methods for the user. Three different methods of propagation were considered for simulation (Urban Canyon, Fast 3D & Full 3D). All three methods were used to predict data. Two of the three methods use approximations to produce data; the third method is expected to be the most accurate, but takes longer to run. We must determine if the approximations made by the methods are adequate for our geometries. Only one of the methods is recommended for indoor use. But since the cabin has a unique shape, the indoor method may not be the most accurate [2].

Upon completion of the parameter assignments, study areas were constructed to simulate. WI provides many propagation methods. Three methods were used for multiple reasons. First, the fuselage system created fits the requirements of the three systems. Secondly, it is uncertain which method can give the most accurate results based

on statement one. Lastly, there is a time constraint. Two of the three methods use approximations to produce data; the third method is expected to be the most accurate, but takes longer to run. It has to be determined whether the approximations made by the model are adequate for our system. Only one of the models is recommended for indoor use. But since the fuselage has a unique shape, the indoor model may not be the most accurate.

The method of propagation used is the shooting and bouncing ray method (SBR). SBR uses geometrical optics to trace the rays. Numerous rays are shot at an object, and then their movement traced according to geometrical optics. When the SBR paths have been traced, a path is recorded. [2]

The first model is the Urban Canyon Model (UCM). It is to be used when transmitters and receivers are close to the ground in height as compared to the height of other objects. The UCM model uses the shooting and bouncing ray method (SBR) to determine the propagation paths of the transmitters. The ray tracing method uses SBR for horizontal plane and an image method for ground reflections. Since the UCM employs mostly 2D approximations. It assumes that if the heights of other objects around the transmitter and receiver are high, then the ray paths that are diffracted of the top of the objects are negligible compared to the rays that are bouncing between objects. The run time is significantly decreased due to this factor and multiple assumptions. The first assumption is that path length is larger than the receiver and transmitter height difference. This statement allows the UCM to neglect using the multiple reflection and diffraction coefficients. The second assumption made is that vertically polarized components are almost perpendicular to the plane of propagation and that horizontal components are parallel to the plane. The depolarization of the field is ignored with this assumption. [2]

Fast 3D Urban Model (FUM) is the second model tested. This model uses the same method described above but in addition it also takes into account the tops of low lying objects around the transmitter and receivers. The FUM does not use a full 3D trace; Fast 3D means that the vertical components of some objects are considered in the calculations. FUM incorporates the heights of

other objects when making calculations. Basically it is used if there are many objects of varying heights that could possibly have ray paths that affect the calculations. To account for the effects, SBR and multiple image methods in 3D geometry are used. The SBR is used for calculation in the horizontal plane; image method is used for ground reflection and ray path with less than 2 interactions. SBR main purpose is to find the paths of the ray. The program then calculates whether the rays have diffracted, passed over or intersected a boundary object. Depending on the situation above, paths are constructed and the most probable is obtained. FUM incorporates the heights of other objects when making calculations. It is generally used if there are many objects of varying heights that could possibly have ray paths to affect the calculations. [2]

For the FUM to be acceptable, two assumptions must be made. The first assumption is that the distance that the path is shifted vertically is small compared to the path length. This will be valid when the horizontal distance between the transmitter and receiver is greater than the vertical distance. The second assumption made is that shape of an object is not intricate. Since the vertical plane calculation is simplified, a complex shaped would take more paths, which would not be accounted for. [2]

The final model used is the Full 3D Method (FM). Of the three models, FM is recommended for indoor simulation and places no constraint on the object shape. It is the only model that allows for transmission through surfaces. Thus is most applicable for indoor environments. The FM combines SBR and MI ray tracing. MI is used when a path has three or fewer interactions. Paths with more than three interactions are found with SBR method. The thorough use of both methods produces a 3D model that takes into account many parameters. It is expected to deliver the most accurate results of the three models.

Fuselage Models

To validate EM power propagation predictions inside aircraft cabins, it was necessary to compare the simulation to an experimental study. Embry-Riddle Aeronautical University tested WLAN (Wireless Local Area Networks) performance in four airplanes (B747-400, B767-300, B777-200, &

Airbus A320-200) The fuselages examined are from the Boeing family, the Airbus model was not included in this study.

Two fuselage models were created for each plane; they will then be compared. The first model was used in previous research; it an empty hollow fuselage. The second model includes seats, galley, lavatories, windows, doors, and luggage compartments. The empty models were created using AutoCAD whereas the second set were created in Solidworks®. Solidworks® provides an easier venue for drawing and modeling accurately. The models are shown below in the WI program:

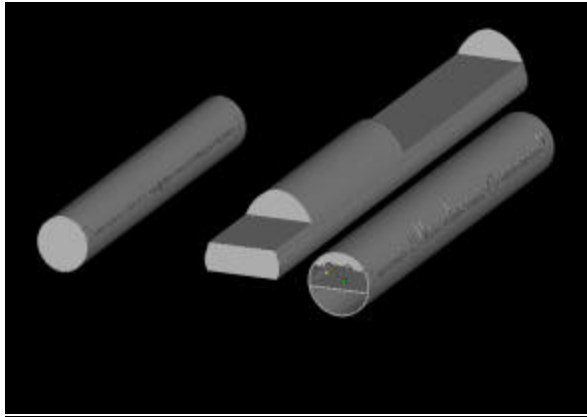


Figure 1: Boeing Models



Figure 2: Internal Boeing Model of B767

Network Components Representation

After the Solidworks® drawings were imported, they are assigned material properties. For simulation purposes it was assumed that the fuselage metal was a Perfect Electrical Conductor (PEC). Various coefficient types such as roughness, conductivity, permittivity, and thickness

are also incorporated. Reflection may play a role when collecting results. [2]

The waveform for each antenna was also created. The program offers two choices of waveforms, wideband and narrowband. Narrowband was chosen because the bandwidth is less than the frequency of operation. The specifications of the waveforms are included in the appendix. Four different antennas were needed to model the 11a and 11b standards. Each antenna is associated with a waveform. For the transmitters, a linear dipole antenna was used for both standards with the individualized waveform, antenna length, gain, polarization, and transmission line loss. The WI database provided the antenna basics for the transmitter. WI also generates the antenna patterns (visual depiction of the E-plane and the H-plane on different axes). The receiver antennas were not generated by the WI database since they are integrated antennas. An antenna format file that designates gain, polarization, and transmission line loss was created from the antenna pattern of the receiver that was obtained from the FCC Website. The antenna was then imported and assigned to the receiver. Again each system antenna had the same specifics. [2]

Transmitter and receiver creation and placement was the next step. To determine the accuracy of the data compared to experimental results, it was important to place the transmitters and receiver in the same location and orientation as the experimental setup. Transmitters needed the following properties to operate, coordinate system elevation type, rotation, waveform, antenna type, radiated power, and rotation about each plane in the xyz system. The height, rotation about the axis, and orientation differed for each plane. Receivers were easier to place. The receivers were laid as a strip on the left portion of the fuselage. The receiver ran from the transmitter to the end of the fuselage. Two different receiver heights were also used as a precaution. Ideally the receiver can be placed on the airplane tray or the seat. Thus two heights were collected to determine whether slight height changes allowed better reception. The heights of the receivers were 0.5m and 0.75m.

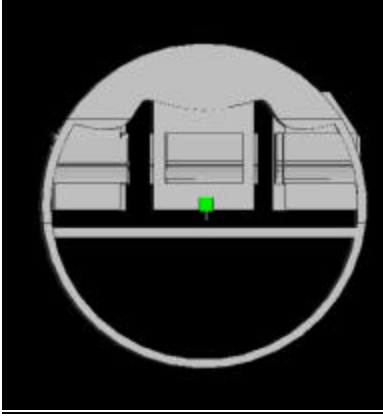


Figure 3: Transmitter placements in the fuselage

TABLE 1: SUMMARY OF ACCESS POINT PARAMETERS

Access Points	ORINOCO AP 2000
Standard	802.11a & 802.11b
Antenna Type	Two omnidirectional (11a) Linear dipole (11b)
Antenna Gain	5.0 dBi (11a) 2.0dbi (11b)
Output Power	802.11a:17dBm 802.11b: 18dBm
Polarization	Vertical

Power Calculation

Power calculations differed in each environment. The received power is defined as the total power received by the receiver antenna. It is measured in units of dBm, which is a measure of decibels relative to 1mW of power (0 dBm = 1mW).

The time averaged received power for Wireless Insite (P_R) is calculated by the following relationships. The received power is calculated by summing the individual power in the electric field without the phase information. [2]

$$P_R = \sum_{i=1}^{N_p} P_i$$

where N_p = number of paths, P_i = time averaged power (in watts) of the i th path.

$$P_i = \frac{l^2 b}{8p^2 h_0} |E_{q,i} g_q(\mathbf{q}_i, \mathbf{f}_i) + E_{f,i} g_f(\mathbf{q}_i, \mathbf{f}_i)|^2$$

where l = wavelength, h_0 = impedance of free space, b = overlap of frequency spectrum of the transmitted waveform. $E_{q,i}$ and $E_{f,i}$ are the \mathbf{q} - and \mathbf{f} - components of the electric field of the i th path at the receiver path. \mathbf{q}_i and \mathbf{f}_i is the arrival direction, $g_q(\mathbf{q}_i, \mathbf{f}_i) = |G_q(\mathbf{q}_i, \mathbf{f}_i)|^{1/2} e^{j\gamma}$ where G_q is the \mathbf{q} - component of the receiver antenna gain and γ the relative phase of the \mathbf{q} - component of the far zone electric field. Similarly for g_f with $\mathbf{q} \leftrightarrow \mathbf{f}$. b is defined as

$$b = \frac{\int_{f_T - B_T/2}^{f_T + B_T/2} S_T(f) S_R(f) df}{\int_{f_T - B_T/2}^{f_T + B_T/2} S_R(f) df}$$

where f_T and B_T are the center frequency and bandwidth of the transmitted waveform, $S_T(f)$ is the frequency spectrum of the transmitted waveform and $S_R(f)$ is that for the received waveform.

Results

The predicted results were graphed with the measured data for comparison. The graphs for the 802.11a standard are shown below. In addition, the Mean Absolute Error (MAE) and Root Mean-Squared Error (RMSE) were calculated for both sets of data. The equations for the MAE and RMSE are shown below. Where P_M is the measured power, P_P is the predicted power, and N is the number of data points collected.

$$MAE = \frac{\sum |P_M - P_P|}{N}$$

$$RMSE = \sqrt{\frac{\sum (P_M - P_P)^2}{N}}$$

The tables are shown below:

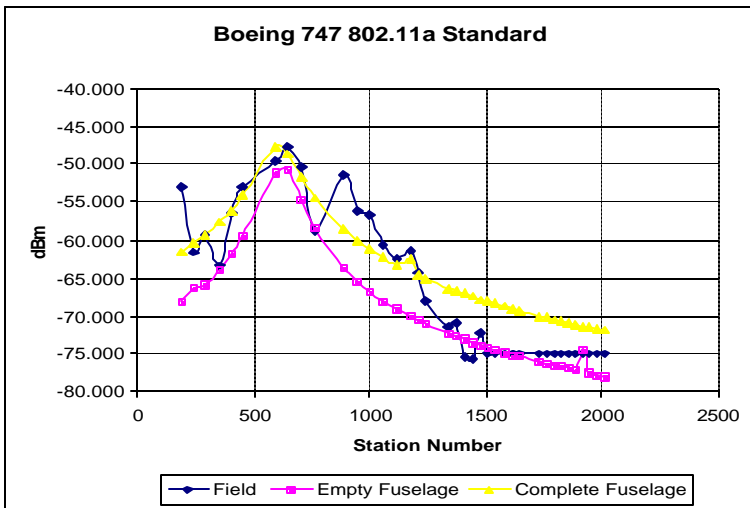
TABLE 2
Empty Fuselage

Aircraft	Standard	[MAE]	[RMSE]
B747	802.11a	3.619	5.096
B747	802.11b	3.985	5.569
B767	802.11a	5.358	6.564
B767	802.11b	4.344	4.893
B777	802.11a	1.804	2.1454
B777	802.11b	5.818	6.753

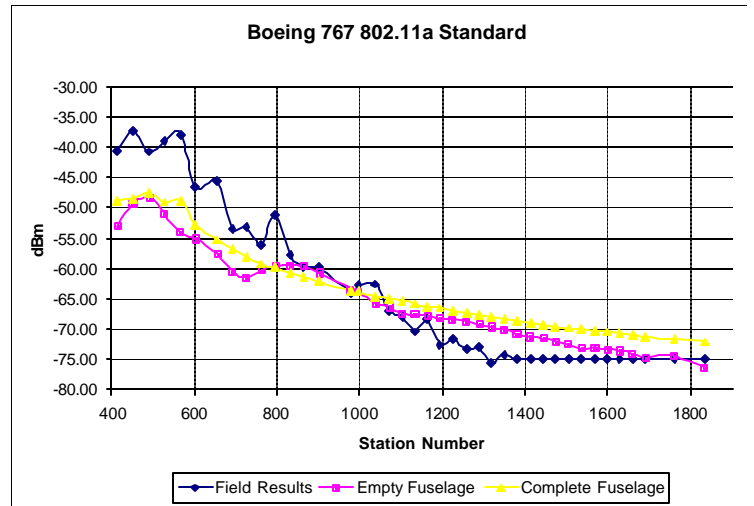
TABLE 3
Complete Fuselage

Aircraft	Standard	[MAE]	[RMSE]
B747	802.11a	3.981	4.619
B747	802.11b	3.782	5.032
B767	802.11a	5.062	5.678
B767	802.11b	4.125	4.558
B777	802.11a	2.562	3.177
B777	802.11b	4.189	4.445

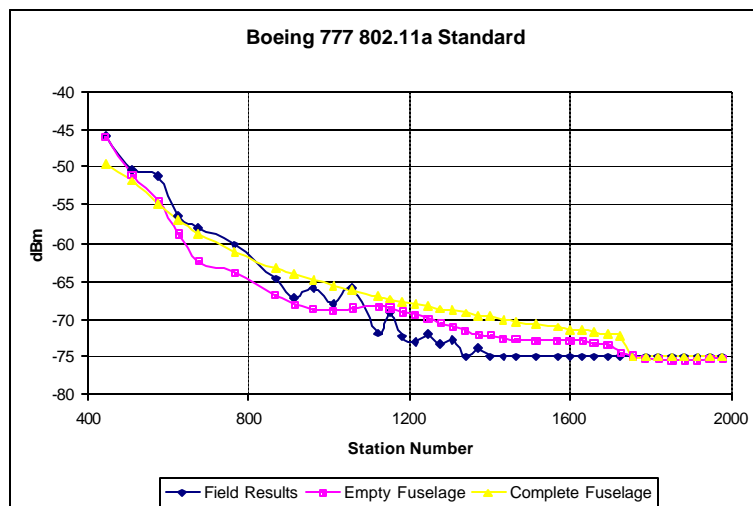
Graph of 802.11a Results



Graph 1: Boeing 747 802.11a Standard



Graph 2: Boeing 767 802.11a Standard



Graph 3: Boeing 777 802.11a Standard

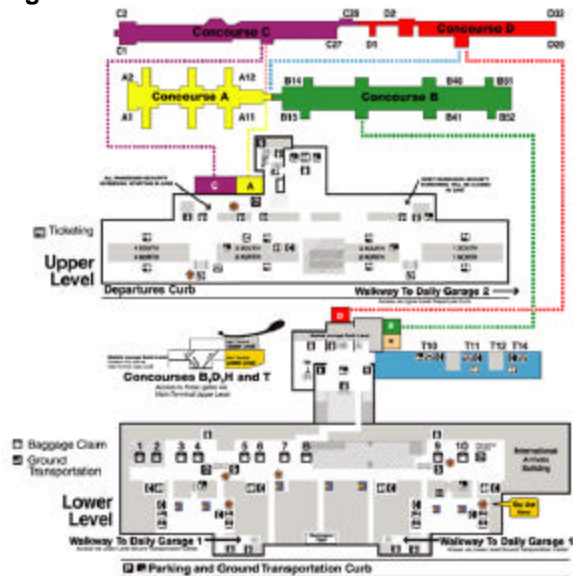
Discussion

Graph 1 is shows that the power levels observed have followed the same general trend. The three observed results peak at nearly the same point. This can be due to the power coupling that occurs due to the second level on the B747. The complete fuselage also has an overall higher power level on Graphs 1,2, and 3. This can be attributed to the reflection that occurs due to the galleys, seats, and other objects. Relatively low MAE and RMSE can be noted above by looking at Tables 2 and 3. Thus it can be concluded that the WI can accurately predict the power propagation in airplane fuselages.

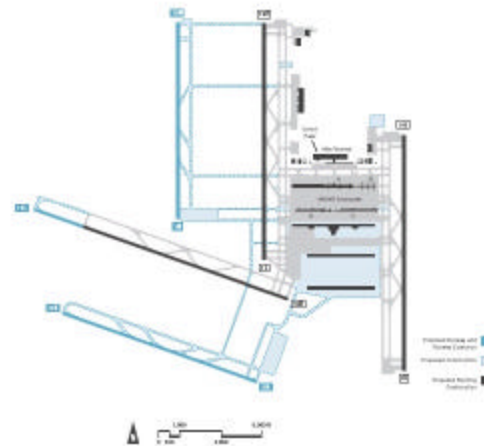
Application to Airport Terminals

The above research can be extended to airport terminals. The model above provides insight into the modeling environment. As mention previously RF propagation in airport terminals is of significant interest. Using the same components, RF propagation can be examined and the results evaluated. Currently a model is being built of the Washington Dulles Airport. The model and the results will be available. Internal components such as chairs, tables, and counters have already been built. Below is the Washington Dulles Airport layout.

Figure 4:



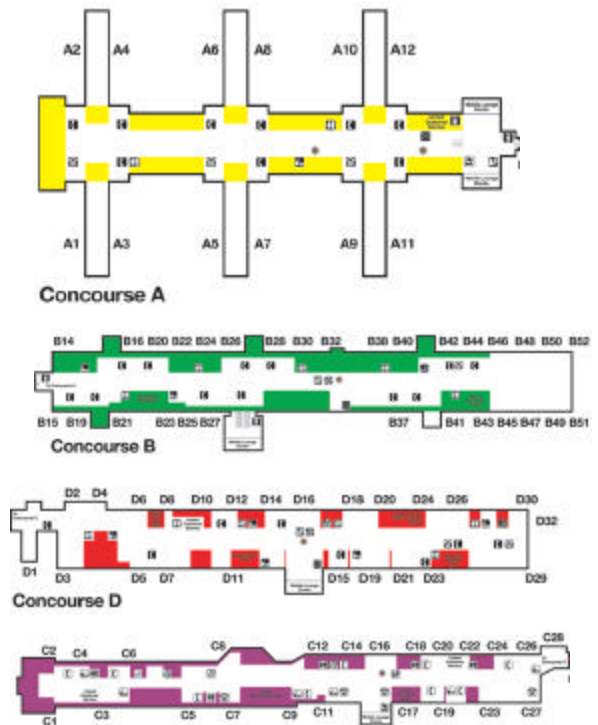
(a) Internal Airport Layout



(b) External Airport layout

The concourses are also very detailed. The details are taken into account when placing objects in and around the airport. The concourses are shown below.

Figure 5: Concourses



Results from the airport terminals are expected by the end of the semester.

Conclusion

The development of an electromagnetic model of an actual airport terminal can aid to analyze electromagnetic propagation both interior and exterior to the terminal. This type of analysis is crucial to be able to design a wireless network for the airport terminal, but this analysis is also crucial to understand and evaluate electromagnetic attack scenarios on airport terminals. The computing, communications, security and other electronic equipment inside an airport terminal are unshielded and particularly susceptible to electromagnetic attack. A successful electromagnetic attack on a large regional airport would create severe delays, chaos, passenger disruption and it would have widespread economic damage. The research conducted will provide valuable information on RF propagation in this sensitive environment.

References

1. Whetten, F.; Soroker, A.; Whetten, D. 802.11 Wireless Network Performances within Aircraft Cabins. Embry-Riddle Aeronautical University: 2003.
2. Remcom Incorporated. Wireless Insite User's Manual 1.5.0 October 2003