3D Ray-Tracing for Intra-vehicle Environments

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Introduction

In order to develop a wireless communication system that could be used for all types of aircraft sensor networks, the severe multipath channel found inside aircrafts must be well defined. This multipath channel is much more complex than usual outdoor/indoor channels and thus far, research has been limited to a basic stochastic model for the aircraft environment called hyper-Rayleigh [3]. This model has been useful for a general understanding of the aircraft environment; however, in preliminary simulations this model was not accurate enough to describe MIMO performance for a range of fading channels [7]. The next level of accuracy in modeling is site-specific modeling, also known as ray-tracing. Due to the 3-dimensional (3D) reflective surface of the fuselage, ray-tracing must be implemented in a 3D simulation in order to fully describe the aircraft environment.

This paper discusses a 3D ray-tracing modeler [1] that has been adapted to simulate the reflections that occur inside an aircraft fuselage, which is closely related to the environment in a bus or tunnel. Preliminary research has shown that MIMO systems take advantage of extreme multipath environments found in aircraft and provide more consistent channel capacity than SISO systems. Thus the software is extendable to simulate both SISO and MIMO antennas. To validate and calibrate the ray-tracing software, it was compared with preliminary measurements taken in a tunnel, and other measurements from a bus and aircraft. The MIMO output of the simulation software will be used in future research to create the channel matrix that is needed for previously developed MIMO optimization software [6].

Quantification of the Aircraft Vehicle Environment

In order to characterize the intra-aircraft channel, SISO measurements were taken in varying environments, then fit to curves for a range of Ricean K factors, and finally compared to simulation results [7]. The best fit K factors for each measured location are listed in Table 1 [5]. Simulation software written to evaluate MIMO performance in various channels [6], was adapted to the aircraft channel using the hyper-Rayleigh model detailed in [3] to create a channel matrix, H. A 2x2 MIMO channel with $.5\lambda$ spacing was then simulated over 500 trials at varying K factors to compare against the best fit curves for actual measurements that were taken in [5]. Capacity values are given in Figure 1.

For the MIMO system, the lowest capacities were seen with the highest K values, such as K = 150 dB. Capacity had little variation for decreasing K values until a noticeable increase in capacity occurred around K = 25 dB, and capacity continued to increase until it maxed out at 5.5 bits/Hz/antenna for 50% abscissa and K = 8 dB and stayed close to that capacity for decreasing K values. This shows that varying the K value to match the range of values measured in intra-vehicle channels (from 8 to -150 dB, as seen in Table

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1) seems to have little effect on the capacity of each antenna of a MIMO system using the hyper-Rayleigh channel model. [7]

Table 1: Measured Ricean K Values for Environments with Various Levels of Multipath [5]

Location	**K (dB)**	**Multipath Level**
Anechoic Chamber	200	Low
Aircraft Bay 2 to Bay 3	8	Moderate
Hallway	6	Moderate
Car Passenger Compartment	3	Moderate
Aircraft Cockpit to Wing	0	Moderate
Car Engine Compartment	-70	Extreme
Aircraft Left to Right Wing	-150	Extreme

Figure 1: Matlab Simulation of MIMO performance using the Hyper-Rayleigh channel [7]

Due to this limitation of the hyper-Rayleigh model, it was determined that a more site-specific H matrix would be needed to properly analyze the performance of MIMO in the intra-aircraft environment. This matrix could be easily created using a site-specific 3-D ray tracing model.

Measurement, Validation, and Calibration

There are several ray tracing models available, but the model chosen was selected for its minimal processing time and its ease of adaptation to new environments. This software is based on a ray-tracing method where the antenna radiation pattern at the transmitter is multiplied with E-fields in the incident plane to find the contributions of each ray trajectory to the total received power. This ray-tracing method was already validated in [1], and thus in this paper, the focus is more on using measurements to calibrate since initial comparisons showed the simulation followed the trend of the measured data with about a 5-15 dB shift, as seen in the plots in Figure 2. This shift is likely due to the extra loss in the bus channel due to absorption of the signal by the seats, whereas the simulation was of an empty fuselage with no loss factors.

Figure 2: Average receive power at distances 1 through 8 meters for 3D ray-tracing simulation of fuselage without seats (solid line) compared with measurement data from a bus (dotted lines) at 2.40083 GHz (top) and 2.483 GHz (bottom).

Extension to MIMO

Extending the 3-D software to MIMO requires running the software for a set of SISO antenna locations to represent MIMO, and then processing the channel data in Matlab to calculate the additive channel matrix effects from all antennas. This channel matrix can then be loaded into the MIMO optimization software [6] which is also in Matlab, to determine the best system parameters.

Conclusions

In order to more accurately simulate MIMO in an intra-vehicle environment such as aircraft, it was necessary to acquire a more site-specific H matrix than was attainable with the mathematical model for the hyper-Rayleigh environment. This was accomplished by adapting a ray-tracing software method to a new 3D environment—an aircraft fuselage. This method was validated in [1] and the software was then calibrated using measurements in various environments, including a bus, a tunnel and a small aircraft. The MIMO output of the simulation software will be used in future research to create the channel matrix needed for previously developed MIMO optimization software [6].

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