Predicted MIMO Performance in Intra-Vehicle Channels

Alyssa Magleby*(1) and Cynthia Furse (2)
(1) University of Utah, Salt Lake City, USA
(2) University of Utah, Salt Lake City, USA
E-mail: aly.magleby@gmail.com

Introduction

Wireless sensor networks inside vehicles face particularly harsh multipath and shadowing constraints. The closed or semi-closed metallic structure functions much like a reverberation chamber, but with some regions shielded from other regions. Vehicles (particularly aircraft) often have extremely high electromagnetic interference across broad frequency bands. This EMI also reverberates within the shell of the vehicle, creating a strong multipath noise environment. This poses unique challenges and unique opportunities.

Increasing interest in wireless sensor networks on aircraft has led to the research and evaluation of this harsh wireless environment. Limited simulations and measurements are available to describe this complex channel. However, it has been established that special attention will have to be given to the types of signals used in wireless transmission in order to overcome the severe multipath affects that have been measured in aircraft cabins [1],[2] and to avoid interference with present aircraft systems [3]. The severe multipath effects found in vehicles are modeled by a hyper-Rayleigh channel, which is a mathematical model created specifically for aircraft environments. This represents the measurements of wireless signals in aircraft and other vehicles which exhibit fading worse than the previous worst-case Rayleigh channel fading [2].

There are several options for wireless communication between sensors in aircraft. The first is to operate wirelessly only on the ground, thus avoiding interference with and from on-board aircraft systems and avoiding emissions from personal electronic devices (PEDs) brought on by passengers. This option reduces the noise in the system, but does not reduce the multipath or shielding effects on the signal itself. There are several methods that could potentially be used to overcome the severe fading and multipath effects of the aircraft environment. Ultra wideband (UWB) and multiple input, multiple output (MIMO) technologies have been widely used in severe fading outdoor environments, but limited research has been conducted to evaluate how they perform in the vehicular environment. Due to a study that found electromagnetic interference from UWB systems caused interference with essential aircraft systems [5], MIMO was chosen for further exploration. MIMO takes advantage of multipath delay spread, spatial diversity, and random fading to turn multipath propagation losses into a benefit [7].

This paper predicts and evaluates MIMO performance for intra-vehicular communication in aircraft and cars with a focus on low data rates typical of sensors for temperature, pressure, vibration, wire fault location, fluid level, etc. The feasibility of using MIMO, including establishing sufficient multipath channels, evaluating miniature antenna array configurations near the metallic structure, and estimating potential loss from passengers and load is considered

978-1-4244-2042-1/08/$25.00 ©2008 IEEE

Vehicular Environment

To better understand the wireless channel in the vehicular environment and how it relates to other wireless channels, several measurements were taken and compared between several areas with varying K values and multipath levels. This was accomplished using 915 MHz monopole antennas to transmit and receive at 433, 915, and 2450 MHz. The transmitting antenna was connected to an Agilent E4438C ESG Vector Signal Generator, and the receiving antenna was connected to an Agilent E4404B ESA-E Series Spectrum Analyzer. These antennas were placed in a variety of locations, including an anechoic chamber, the hallway of a building, and numerous locations in a passenger car and small aircraft. Measured data at each frequency and location was fit to a Ricean curve with varying K values. Some of the results for K values are found in Table 1. Weak multipath, or low fade depth (around -5 dB), is expressed by a high K value, say above K=150 dB. Moderate multipath (fade depth around -20 dB) is expressed in K values between 0 and 10 dB. Extreme multipath (fade depth below -40 dB) occurs at K values below -70 dB [4]. This data shows that a wide range of K values, associated with moderate to extreme multipath, can be found on intra-vehicle channels. Shielding effects also come into play in these measurements.

Table 1: K Values for Environments with Various Levels of Multipath [4]

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

These severe hyper-Rayleigh multipath effects found in vehicles occur when the received signal is dominated by two constant amplitude signal components which are uniformly distributed over [0, 2π). This is also referred to as two-wave with diffuse power (TWDP), and is described by equation (1), with Δ and K values defined by equation (2) and equation (3). [2]. Common channel models and their associated K and Δ values are listed in Table 2.

$$V_{received} = \underbrace{V_1 \exp(j\varphi_1) + V_2 \exp(j\varphi_2)}_{specular\ \ components} + \underbrace{\sum_{i=3}^{L} V_i \exp(j\varphi_i)}_{diffuse\ \ component} \qquad (1)$$

$$\Delta = \frac{Peak\,specular\,power}{Average\,specular\,power} - 1 = \frac{2V_1V_2}{V_1^2 + V_2^2} \qquad (2)$$

$$K = \frac{Average\,specular\,power}{Diffuse\,power} = \frac{V_1^2 + V_2^2}{2\sigma^2} \qquad (3)$$

Table 2: K and Δ Values for Channel Models [2]

Model	**K**	**Δ**
Rayleigh	K = 0	NA
Ricean	K > 0	Δ = 0
One-wave	K → ∞	Δ = 0
Two-wave	K → ∞	Δ = 1

MIMO Communication in Aircraft Environment

Simulation software from [8] was simplified to ignore antenna correlation effects and then used to evaluate MIMO performance in various channels. These channels were modeled based on K values from Table 1. The software implemented a waterfilling method over 500 channel realizations. A channel matrix was computed similar to the method in [9], but used path gains based on the hyper-Rayleigh channel model [2]. A 2x2 MIMO channel consisting of monopole antennas with .5λ spacing was simulated to compare against actual measurements that were taken from [4]. Widely varying K values seem to have little effect on the capacity of each antenna of a MIMO system in hyper-Rayleigh channels, as shown by Figure 1.

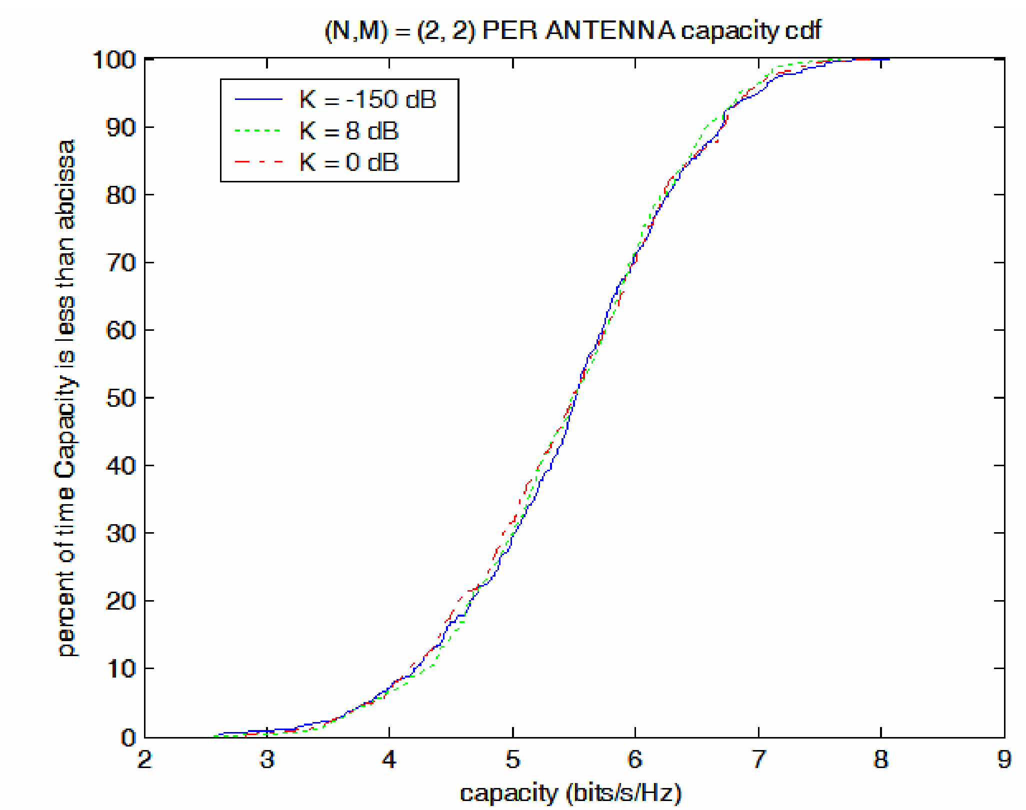

Figure 1: Matlab Simulation of MIMO performance using the hyper-Rayleigh channel

Conclusion

Intra-vehicle channels experience moderate to extreme multipath fading, which is best modeled by the hyper-Rayleigh channel. Using this model, MIMO transmission was simulated over the ranges of K values that were measured in vehicles, from 8 dB to -150 dB. MIMO simulations resulted in consistent channel capacity regardless of varying K values, which predicts that MIMO provides consistent channel behavior over the wide range of fading experienced in vehicles, potentially allowing for robust and reliable intra-vehicle communication.

References

[1] Fitzhugh, C. and J. Frolik, J. Covell, R. Ketcham and T. Meyer. "2.4 GHz Multipath Environments in Airframes." Wireless and Microwave Technology Conference. Clearwater, FL. April 7-8, 2005

[2] Frolik, J. "A Case for Considering Hyper-Rayleigh Fading." In press, IEEE Transactions Wireless Communications, submitted: August 2005, accepted: October 2006

[3] Mennatoallah Youssef, Linda Vahala, John H. Beggs. "Wireless Network Simulation in Aircraft Cabins." 2004 IEEE

[4] Tom T Evans, Personal Communication, Nov 2007.

[5] Aitan Ameti, Robert J. Fontana, EJ. Knight & Edward Richley. "Ultra Wideband Technology for Aircraft Wireless Intercommunications Systems (AWICS) Design" IEEE *A&E SYSTEMS* MAGAZINE, JULY 2004

[6] Jay J. Ely, Gerald L. Fuller, Timothy W. Shaver. "Ultrawideband Electromagnetic Interference to Aircraft Radios." NASA 2002. available online: http://techreports.larc.nasa.gov/ltrs/PDF/2002/mtg/NASA-2002-21dasc-jje2.pdf

[7] David Gesbert, et al. "From Theory to Practice: An Overview of MIMO Space–Time Coded Wireless Systems." IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS, VOL. 21, NO. 3, APRIL 2003

[8] David Landon. PhD Dissertation. University of Utah. Nov. 2007.

[9] J. W. Wallace, M. A. Jensen, A. L. Swindlehurst, B. D. Jeffs, "Experimental characterization of the MIMO wireless channel: Data acquisition and analysis," IEEE Trans. on Wireless Communications, 2(2)(2003), 335-343