Path-loss measurement system for design of in-vehicle short range communication

Hiroya Tanaka^{a)}, Junya Muramatsu, Toshiaki Watanabe,
and Yoshiyuki Hattori

*Toyota Central Research & Development Labs., Inc.,
41-1 Yokomichi, Nagakute, Aichi 480-1192, Japan*

a) tanak@mosk.tytlabs.co.jp

Abstract: A compact path-loss measurement system for design of in-vehicle short range communication is proposed. The system is composed of sensor network modules for data transmission and a transceiver for the sounding signal. The channel is measured in an engine compartment of a hybrid vehicle using the developed system. As a result, it is clarified that the engine compartment has a severe fading channel.

Keywords: path-loss, fading, propagation, in-vehicle communication

Classification: Microwave and millimeter wave devices, circuits, and systems

References

- [1] H.-M. Tsai, O. K. Tonguz, C. Saraydar, T. Talty, M. Ames and A. Macdonald: IEEE Wireless Comm. Mag. **14** [6] (2007) 67.
- [2] A. R. Moghimi, H. Tsai, C. U. Saraydar and O. K. Tonguz: IEEE Trans. Veh. Technol. **58** [9] (2009) 5299.
- [3] S. Horiuchi, K. Yamada, S. Tanaka, Y. Yamada and N. Michishita: IEICE Trans. Commun. **E90-B** [9] (2007) 2408.
- [4] M. Heddebaut, V. Deniau and K. Adouane: IEEE Trans. Intell. Transp. Syst. **5** [2] (2004) 114.
- [5] T. Kobayashi: IEICE Trans. Fundamentals **E89-A** [11] (2006) 3089.
- [6] S. Velupillai and L. Guvenç: IEEE Control Syst. Mag. **27** [6] (2007) 22.
- [7] S. Wyne, A. P. Singh, F. Tufvesson and A. F. Molisch: IEEE Trans. Wireless Commun. **8** [8] (2009) 4154.
- [8] H. Akaike: IEEE Trans. Autom. Control **AC-19** [6] (1974) 716.

1 Introduction

A lot of sensors have been mounted in a vehicle to realize advanced controls that can provide safe driving. The sensing data are processed in electrical control unit. Thus, sensors and electrical control units are connected through not only a wired network but also wireless one. The wireless short

range communication is used in case when the wired network is unfeasible. Wireless vehicle networks have received a considerable amount of attention recently [1]. The propagation characteristics should be investigated in order to design wireless devices that provide an appropriate data rate and outage. A unique characteristic was observed in the in-vehicle propagation channel. The propagation mechanism was investigated in the passenger compartment [2, 3]. The channel measurements were carried out for a Zigbee-based sensor network and ultra wide band system [4, 5].

A conventional channel sounding system has difficulty in measuring the channel characteristics in vehicles for the following reasons: The in-vehicle sensors are usually mounted in the inside of car, which are spatially bounded by the car body and various assemblies. Therefore, a compact and wireless propagation measurement system is necessary.

In this letter, a compact path loss measurement system in the vehicle is proposed. The system is composed of sensor network modules for data transmission and a transceiver for the sounding signal. The channel is measured in the engine compartment of a hybrid vehicle using the developed system. The sounded frequency is 316 MHz, which is used for in-vehicle short range communication [6]. The specifications of the developed system are described in Section 2. The test scenario and measurement results in an engine compartment are presented in Section 3. This letter is then concluded in Section 4.

2 Architecture and protocol

Outage is the most important factor for in-vehicle short range communication that must ensure faultless operation. Also, the baud rate of the in-vehicle sensor network is not so high. This letter focuses on the path loss measurement of narrow band wireless communication. Figure 1 and 2 show overview and architecture of a developed measurement system. The system is composed of a PC and three wireless modules, measurement controller (MC), sounding signal transmitter (SST), and sounding signal receiver (SSR). PC and MC are connected by a serial signal data transmission line. SST and SSR include (1) a controller and (2) a transmitter or receiver in 300 MHz band. The wireless data communication between the modules is conducted by Zigbee-based data transceiver in 2.4 GHz band. Measurement request, synchronization signal, and RSSI data are communicated between modules. Sounding signal is a monotone frequency in 300 MHz band, which is generated by crystal oscillator and phase-locked loop (PLL) synthesizer in SST. The sounding frequency can be arbitrarily tuned by the design of PLL synthesizer. Small loop antennas are used in 300 MHz band. The transmission timing of sounding signal is controlled by the RF switch. The received signal in the SSR is converted to intermediate frequency, the RSSI is observed by the image rejection filter. Resolution of RSSI is 0.5 dB. RSSI detection range of image rejection filter is -110 dBm to -70 dBm. The appropriate transmitted power is set by tuning the attenuator in SST. SST and SSR are powered by a battery. The modules are placed in a small resin box (Depth: 85 mm, Width: 45 mm, Height: 55 mm). The proposed system is capable of measurement in a small space such as the inside of car.

Figure 3 shows the protocol of the data transfer between modules. The PC requests MC to start the channel measurement [arrow (1)]. Next, MC

Fig. 1. Overview of developed path-loss measurement system.

Fig. 2. Architecture of developed path-loss measurement system. The arrows indicate the flow of the measurement information. The dotted lines represent wireless data communication by Zigbee (2.4 GHz). The dashed line represents the sounding signal.

transmits measurement request signals to SST and SSR [arrow (2)]. The request signals are transmitted every 0.13 sec. The controllers in SST and SSR repeat a sleep and wake-up mode before receiving the measurement request. The sleep and wake-up time is 2.5 sec and 0.26 sec, respectively.

The ratio of wake-up and sleep time is 0.1 ($= 0.26/2.5$). This implies that the reduction of 91% ($= 0.26/[2.5+0.26]*100$) in stand-by power consumption can be obtained in SST and SSR. When the controllers of SST and SSR receive the measurement request in the wake-up mode, they start to operate constantly. Then the channel measurements are conducted every 0.13 sec following the measurement requests from MC [arrow (2)]. The controller in SST turns on the RF switch and then the monotone sounding signal is transmitted [arrow (3)]. The sounding signal is degraded by the path-loss of channel. The path-loss can be calculated using the received power in SSR. The received signal strength is measured by the IF limiting amplifier in SSR. A received signal strength index (RSSI) is sent to the microcomputer and this data are transmitted to MC by the sensor network module in 2.4 GHz band [arrow (4)]. Finally, the RSSI is converted to the amplitude of signal by a calibration table and stored in the PC. The measurement stops by a request from the PC [arrow (5)].

Fig. 3. Protocol of the data transfer between modules.

3 Measurement in engine compartment

A measurement was conducted in the engine compartment of the hybrid vehicle depicted in Fig. 4. This measurement scenario was determined to study a propagation characteristic and feasibility of “network by wireless” in the hybrid system. SST was attached on the side of the power control unit (PCU), where the inverters and DC-DC converters are assembled. SSR was moved at an interval of 5 cm along the dashed arrows. In order to simulate the operating state of the short range communication system, the hood of the vehicle was closed during the measurement.

Figure 5 shows the cumulative distribution functions (CDF) of the measured signal amplitude. The amplitude is normalized with the square of the mean signal power. The amplitude of the received signal in fading channels under stationary conditions is often characterized with a

Fig. 4. Engine compartment of a hybrid vehicle. The engine, motors, harness, power control unit, and equipment are assembled. SSR is moved through the narrow gaps between the assemblies. The number of observation points is 48.

statistical channel model in wireless communication [7]. It is expected that the channel inside the engine compartment can also be described by statistical models. The Rician and Nakagami distributions are considered as candidate models. Table I summarizes the distributions and estimated parameters. Note that I_0 is the modified Bessel function of the first kind with order zero. Γ is the gamma function. a and b are parameters that characterize the distributions. The distribution parameters were obtained using the maximum likelihood estimation. The fact that $a = 0$ in the Rician distribution indicates Rayleigh fading. The range of $0.5 < a < 1$ in the Nakagami distribution implies more severe fading than Rayleigh fading due to the traversed signal.

Fig. 5. Cumulative distribution function (circle: measured amplitude, solid: Rician, dashed: Nakagami). The amplitude is normalized with the square of the mean signal power.

Table I. Distribution function and estimated parameters.

Distribution	$F(x)$	a	b	AIC
Rician	$\frac{x}{b^2} I_0\left(\frac{ax}{b^2}\right) \exp\left(-\frac{x^2 + a^2}{2b}\right)$	0.00	0.71	68.5
Nakagami	$\frac{2a^a x}{\Gamma(a)b^a} x^{2a-1} \exp\left(-\frac{ax^2}{b}\right)$	0.78	1.00	66.5

$N=48$ and $k=2$ are used in the calculation of AIC.

Better model was selected by the Akaike information criterion (AIC) [8], which is defined by the following equation:

$$AIC = -2 \sum_{n=1}^N \log F_{\theta_0}(x_n) + 2k, \quad (1)$$

where θ_0 is the maximum likelihood vector obtained from N independent identically distributed observations x_n , and k is the dimensionality of the model. AIC is a relative measure to evaluate the fit of the models and is summarized in Table I. A model giving the smaller AIC is better matched than others. One or more differences between the AICs imply statistical significance. It is clearly seen that the Nakagami distribution is better matched model than the Rician. This result indicates that the severe fluctuation of the signal amplitude occurs in the engine compartment due to the fading.

These results are accepted because SST and SSR are not in the line of sight and various metallic components are present in the engine compartment, i.e., the engine, motors, harness, electrical devices, and vehicle body. Reflection and diffraction occur in such an environment, which give rise to severe fading. This result indicates that the degradation should be considered in the design for the robust wireless networks in the engine compartment.

4 Conclusion

A compact path loss measurement system for in-vehicle short range communication has been proposed. The amplitude of the received signal was measured in the engine compartment of a vehicle by using the developed system. As a result, it was revealed that severe fluctuation of the signal amplitude occurs in the engine compartment due to the fading. This result indicates that the degradation should to be considered to design the robust wireless networks in the engine compartment.

Acknowledgments

The authors are grateful to Mr. Hironori Ohshima for his support in the measurements. The authors also appreciate the fruitful discussions with Prof. Jun-ichi Takada of the Tokyo Institute of Technology.