

Performance Analysis of Modulation Schemes in Intra Vehicle Communications (IVC) Channel

Gulmira Khuandaga*, Asif Iqbal*, Kyung Sup Kwak*

* UWB Wireless Communications Research Center (INHA UWB-ITRC),
Inha University, Korea

gulmira08@yahoo.com, asifsoul@gmail.com, kskwak2006@inha.ac.kr

Abstract—Recently Intra Vehicle Communication received great interest from the automotive industry and Ultra Wideband (UWB) technology considered as one of the potential candidate for this system. Goal of this paper is to compare UWB pulse modulation schemes like time hopping pulse position modulation (TH-PPM), direct sequence pulse amplitude modulation (DS-PAM) and multi-band orthogonal frequency division multiplexing (MB-OFDM) under intra vehicle communication (IVC) channel environment and find best suited modulation scheme for in-vehicle communication system. Vehicular channel model which is used for this paper was developed on the basis of IEEE 802.15.3a indoor channel model with modification in propagation environment. Through simulation BER performance of modulation schemes are evaluated.

Keywords— UWB, IVC, PAM, PPM, bit error performance

I. INTRODUCTION

Recently there has been tremendous growth for in-vehicle electronics technology, for example, in-vehicular LAN and air-bag sensors for the safety of passengers. UWB systems have been extensively studied in indoor environments; very little attention has been paid to the study of applying UWB in commercial vehicles. There are two main types of applications of UWB systems in vehicles. The first one is on-board high-speed wireless networks and wireless intra-vehicle communications: Wireless IVC, which is used for passengers to access the Internet and other applications. The second is wireless network control systems (wireless NCS), which are suggested to replace the conventional wired controller area networks (CAN). Mobile phones, MP3 players and video games inside a car are expected to be essential services especially in luxury cars. The weight of the communications cables to handle these services cannot be neglected, which results in degrading the fuel and engine efficiency.

In order to provide above mentioned wireless services in vehicle, reliable high speed wireless data transmission up to 100Mbps is required. Thus UWB can be seen as a promising transmission technology to meet these requirements. UWB

provides short-range wireless communications at a low power have been carried out [8]. UWB system has been investigated in many works for in-vehicle wireless scenario. In [1]-[3], UWB propagation characteristics have been experimentally defined from the viewpoint of the delay profile as well as the propagation loss. As we can imagine, in a vehicular environment the clusters and rays are exceedingly overlaid each other and hard to be distinguished. The modelling of the UWB channels within vehicles is implemented separately by many authors since that the IEEE 802.15.3a indoor channel model was not suitable to represent the characteristics of UWB vehicular channels. Selection of a proper physical layer radio technology is crucial in the intra-vehicle environment.

This paper is organized as follows. In Section II, we introduce system model including modulation types. In Section III, IVC channel model is described and in Section IV we demonstrate the simulation results. Finally, conclusion is drawn in Section V.

II. SYSTEM MODEL

In UWB systems there are several basic methods of modulation. By far the most common modulation in literature is pulse position modulation (PPM), where each pulse is delayed or sent in advance of regular time scale. Pulse amplitude modulation (PAM) is a technique where the amplitude of the pulse varies to contain digital information. As an alternative scheme to conventional UWB systems, multi-band orthogonal frequency division multiplexing (MB-OFDM) approach can be seen as a promising transmission technology for IVC. In the MB-OFDM systems, available frequency band is divided into five band groups and each band group is composed of three sub-bands that are set to be 528MHz and OFDM symbols are transmitted according to the FH pattern.

A. TH-PPM

The data modulation is typically based on PPM using TH-UWB as the basis for a communication system. The PPM signal can be presented as follows [6]:

$$x(t) = w_{tr}(t - \delta t_j) \quad (1)$$

where d_j takes 2 values 0 and 1 depending on the bit transmitted and δ indicates shift by given modulation. The concept of TH-PPM is that only one monocycle per data symbol is used. The time hopping randomizes the signal in both time and frequency domains. The TH time shift and PPM time shift combine to determine the transmission instant of the pulse in the case of PPM. The information signal $s(t)$ for m -th user can be analytically described for PPM modulation as:

$$s^{(m)}(t) = \sum_{k=-\infty}^{\infty} \sum \left(t - kT_d - jT_f - (c_w)_j^{(m)} T_c - \delta d_k^{(m)} \right) \quad (2)$$

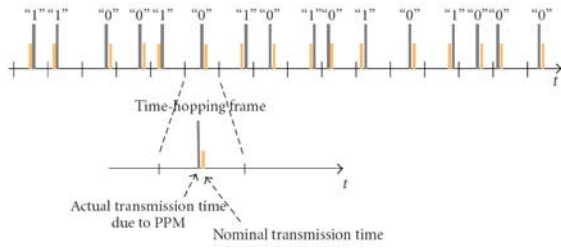


Figure 1. Time-hopping pulse position modulation technique.

where δd_k is data sequence modulated by PPM, $(c_w)_j$ is j -th pseudorandom code with chip duration T_c , T_f is the frame duration, N is the number of pulses per data bit and T_d is bit length which defined by $T_d = NT_c$.

B. DS-PAM

The transmitted binary base-band PAM modulated signals can be presented as [6]:

$$x(t) = d_j w_r(t) \quad (3)$$

where $w_r(t)$ represents pulse waveform, j represents the bit transmitted (0 or 1), and

$$d_j = \begin{cases} -1, & j = 0, \\ 1 & j = 1, \end{cases} \quad (4)$$

DS -PAM employs train of high-duty-cycle pulses whose polarities follow pseudo-random code sequence. Specifically, each user in the system assigned a pseudo-random sequence that controls pseudorandom inversions of the UWB pulse train. After that data bit is used to modulate sequence of UWB pulses. The PAM data signal $s(t)$ for user m is given by:

$$s^m(t) = \sum_{k=-\infty}^{\infty} \sum_{j=1}^N w(t - kT_d - jT_c) (c_p)_j^{(m)} d_k^{(m)}, \quad (5)$$

where d_k is the k -th data bit, $(c_p)_j$ is the j -th chip of the PR code, $(c_w)_j$ is the j -th code phase defined by the PR code, $w(t)$ is the pulse waveform, T_c is the chip length, and N is the number of pulses per data bit. The pseudorandom sequence takes values $\{-1, +1\}$ and the bit length is $T_d = NT_c$.

C. MB-OFDM

One approach for designing a UWB system based on OFDM is to combine the modulation technique with a multibanding approach, which divides the spectrum into several sub-bands, whose bandwidth is approximately 500 MHz. MB-OFDM has been adopted by many industry alliances and standardized by ECMA as high-rate UWB PHY and MAC standard.

In the MB-OFDM systems, $c_m = a_m + jb_m$ indicates the point in the constellation associated with symbol d_m , the OFDM signal of modulated is denoted as [7]:

$$x(t) = g_T(t) \sum_{m=0}^{N-1} (a_m \cos(2\pi(f_p + f_m)t + \phi) - b_m \sin(2\pi(f_p + f_m)t + \phi)) \quad (6)$$

in which

$$g_T(t) = \begin{cases} \sqrt{1/T}, & -T_G = T_0 - T \leq t \leq T_0 \\ 0, & elsewhere \end{cases} \quad (7)$$

All the modulators use the same rectangular shape $g_T(t)$ of finite duration T . while the corresponding complex envelope is:

$$\begin{aligned} \underline{x}(t) &= g_T(t) \sum_{m=0}^{N-1} c_m e^{j2\pi f_m t} \equiv \\ &\equiv \sum_{m=0}^{N-1} c_m \varphi_m(t) = g_T(t) S(t) \end{aligned} \quad (8)$$

where $\varphi_m(t) = g_T(t) e^{j2\pi f_m t}$, $S(t)$ is a periodic function of period T_0 .

The simplest way of implementing OFDM modulator is to adopt a digital structure by using the Discrete Fourier Transform (DFT). The transmitted OFDM signal can be written like:

$$\underline{x}[n] = x(nt_c) = g_T(nt_c) \sum_{m=0}^{N-1} c_m e^{j2\pi f_m nt_c} \quad (9)$$

In which t_c is sampling period, so the complex envelope of the OFDM signal can be expressed by samples taken a multiples of $t_c = T_0 / N$:

$$\underline{x}[n] = g_T(nt_c) \sum_{m=0}^{N-1} c_m e^{j \frac{2\pi f_m n T_0}{N}} \quad (10)$$

We assume that:

$$f_m = m\Delta f - (N/2), \Delta f = m/T_0 - N/(2T_0), \quad (11)$$

Leading to:

$$\begin{aligned} \underline{x}[n] &= g_T(nt_c) \sum_{m=0}^{N-1} c_m e^{j \frac{2\pi f_m n T_0}{N}} e^{-j m n} \\ &= g_T(nt_c) (-1)^n \sum_{m=0}^{N-1} c_m e^{j \frac{2\pi m n}{N}} \end{aligned} \quad (12)$$

The summation in Eq.(12) corresponds to the n -th element of vector c denoting the Inverse Discrete Fourier Transform (IDFT) of the vector $\{c_0, \dots, c_n, \dots, c_{N-1}\}$:

$$\underline{x}[n] = g_T(nt_c) (-1)^n c_n \quad (13)$$

Equation (13) indicates that the samples of the complex envelope of Equation (4) can be obtained by computing the IDFT of the set of points of the coefficients $\{c_0, \dots, c_n, \dots, c_{N-1}\}$, which produces the IDFT sequence $\{C_0, \dots, C_n, \dots, C_{N-1}\}$. IFFT is often exploited for faster and more efficient in practical UWB OFDM systems. Modulation scheme for MB-OFDM are QPSK and DCM according to the proposal.

III. INTRA VEHICLE CHANNEL MODEL

UWB technology takes extremely wide transmission bandwidth, so it provides fine delay resolution in time domain, which results in the lack of significant multipath fading. Also, UWB signals demonstrate strong resistance to narrowband interference. These features make UWB promising technique for implementing the intra-vehicle wireless network. We adopted the IVC channel model that was specified in [1]. Channel measurement was implemented in engine compartment of the commercial vehicle, and multipath propagation was described by classical S-V model. The model covers evaluation statistical path loss, excess delay profile and channel impulse response etc. Empirical channel model parameters for intra vehicle environment are shown in Table 1.

The classical S-V channel model to account for clustering of MPCs in engine compartment of car expressed as:

$$h(t) = \sum_{l=0}^L \sum_{k=0}^K \alpha_{kl} \exp(j\theta_{kl}) \delta(t - T_l - \tau_{k,l}), \quad (14)$$

where L is the number of clusters, K is the number of MPCs within cluster, α_{kl} is the multipath gain of the k -th path in the l -th cluster, that is the arrival time of the first path within the l -th cluster, assuming that the first path in the first cluster arrives at time zero, $\tau_{k,l}$ is the delay of the k -th path within the l -th cluster, relative to the arrival time of the cluster, and θ_{kl} is the phase shift of the k -th path within l -th cluster which takes values between 0 and π . Arrival of clusters and the arrival of the paths within a cluster described as two Poisson processes. Accordingly, the cluster interarrival time and the path

interarrival time within a cluster complies exponential distribution described following 2 distribution functions [1],[4]:

$$\begin{aligned} p(T_l | T_{l-1}) &= \Lambda \exp[-\Lambda(T_l - T_{l-1})], \quad l > 0, \\ p(\tau_l | \tau_{(k-l)l}) &= \lambda \exp[-\lambda(\tau_{kl} - \tau_{(k-l)l})], \quad k > 0, \end{aligned} \quad (15)$$

where Λ is the cluster arrival rate, and λ is the path arrival rate in clusters.

Furthermore, S-V model assumes that the average power of both the clusters and the paths within the clusters decay exponentially as follows:

$$\overline{\alpha_{kl}^2} = \overline{\alpha_{00}^2} \exp\left(-\frac{T_l}{\Gamma}\right) \exp\left(-\frac{\tau_{kl}}{\gamma}\right), \quad (16)$$

Where $\overline{\alpha_{00}^2}$ is the expected power of the first path in the first cluster, and Γ and γ are the power decay constants for the clusters and paths within clusters, respectively.

Root mean square delay spread is standard deviation value of the delay of paths, weighted proportional to the path power. It is defined as:

$$\tau_{rms} = \sqrt{\frac{\sum_k (t_k - t_1 - \tau_m)^2 \alpha_k^2}{\sum_k \alpha_k^2}}, \quad (17)$$

where t_k and t_1 are the arrival time of the k -th path and the first path, respectively, α_k is the amplitude of the k -th path, and τ_m is the mean excess delay defined as:

$$\tau_m = \frac{\sum_k (t_k - t_1) \alpha_k^2}{\sum_k \alpha_k^2} \quad (18)$$

TABLE 1. IVC CHANNEL MODEL PARAMETERS

Channel characteristics	IVC channel
RMS delay (τ_{rms}) [ns]	1.5918
Interpath arrival time ($1/\lambda$) [ns]	0.2452
Intercluster arrival time ($1/\Lambda$) [ns]	3.0791
Path amplitude	11.0571
Cluster amplitude	5.19993
Attenuation of first path (χ)	0.9452
Path power decay factor (γ) [ns]	1.084
Cluster power decay factor (Γ) [ns]	3.0978
Speed of PDP increases to peak	0.224
Path Loss	4.86
Path Loss coefficient	1.21

Channel impulse response and discrete time impulse response of IVC channel defined by implementing CLEAN

algorithm on measurement results is demonstrated in Figure.2 and Figure.3 respectively.

Compared to UWB channel model defined in 802.15.3a standard, in intra-vehicle environment, the path or cluster arrival rates are greatly larger than those reported for indoor or outdoor environments while the path or cluster power decay constants are smaller. The reason for the faster arrival rates is due to the much shorter range of the UWB propagation in the intra vehicle environment. The measurements of RMS are also less than those reported for the indoor UWB propagation. When the distance between the transmitter and receiver decreases, the delay spread decreases.

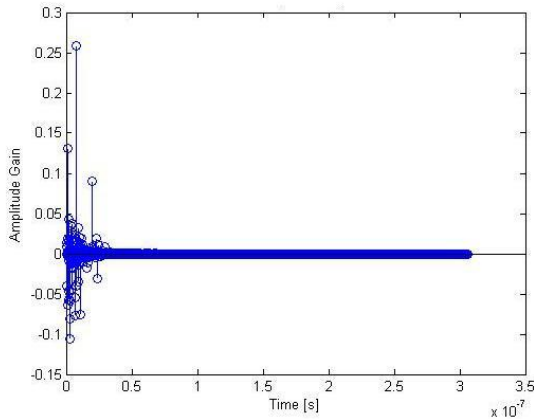


Figure 2. IVC Channel impulse response

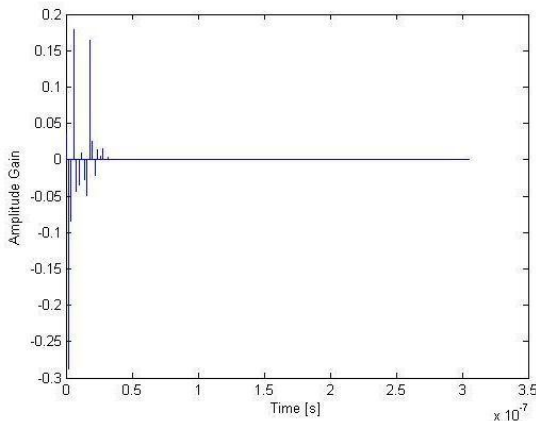


Figure 3. Discrete time impulse response

IV. SYSTEM SIMULATION

In this paper BER performance of data modulations (TH-PPM, DS-PAM and MB-OFDM) investigated in IVC channel environment. Monte Carlo simulation used for all modulation types for evaluating the BER performance of system. Figure 4 shows the BER performance of 3 types of systems in case of IVC channel. We can see from Figure 4 that TH-PPM is out performing MB-OFDM and DS-PAM. For providing BER equal to 10^{-3} DS-PAM requires 1dB more than that of TH-PPM while MB-OFDM requires 2dB more than that TH-PPM. But in point of complexity issue MB-OFDM has advantages over impulse radio (IR) modulation schemes in which

complexity depends on number of rake fingers for efficiently collecting multipath energy. MB-OFDM complexity is defined by the number of FFT point.

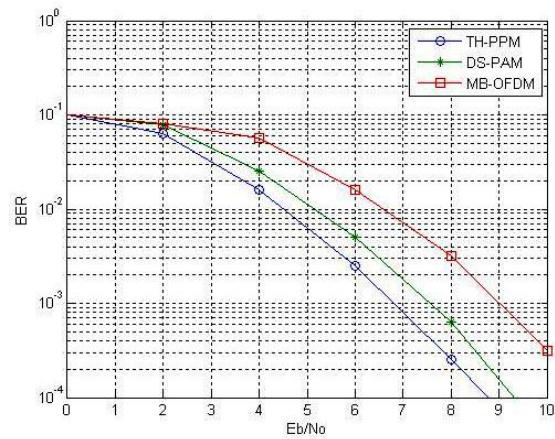


Figure 4. BER performance in IVC channel

V. CONCLUSIONS

In this paper we determined the performance of modulation schemes as a preliminary analysis on physical layer technology for IVC channel environment.

TH-PPM showed best performance in term of BER performance. For further research we will investigate physical layer techniques based on channel capacity and data rate performance in intra vehicle channel environment.

ACKNOWLEDGMENT

This research was supported by the MKE (The Ministry of knowledge Economy), Korea, under the ITRC (Information Technology Research Center) support program supervised by the NIPA (National IT Industry Promotion Agency (NIPA-2010-C1090-1011-0007)).

REFERENCES

- [1] W.Niu, J.Li, T.Tslyt, "Ultra-Wideband Channel Modelling for Intravehicle Environment," EURASIP Journal on Wireless Communications and Networking, vol.2009.
- [2] M.Shack, J.Jemai, R.Piesiewicz, R.Geise, I.Schmidt, T.Kurner, "Measurements and analysis of an in-car UWB channel," Proc.IEEE VTC 2008 Spring, pp.459-463, May 2008.
- [3] W.Xaing, "A Vehicular ultra-wideband channel model for future wireless intra-vehicle communications (IVC) systems, Proc.IEEE VTC 2007 Fall, pp.2159-2163, October 2007.
- [4] A.Saleh and R.Valenzuela, "A statistical model for indoor multipath propagation," IEEE Journal on Selected Areas in Communications, vol.5 issue 2, pp.128-137, Feb.1987.
- [5] Y.Li, Y.Wang, J.Lu "Performance analysis of multi-user uwb wireless communication systems" Proc.IEEE Wireless VITAE 2009, pp 152-155.
- [6] A. Batra, J. Balakrishnan, G.R.Aiello, J.R.Foerster, A.Dabak, "Design of a multiband OFDM system for realistic UWB channel environments", IEEE Transactions on Microwave theory and techniques, vol. 52, September 2004.
- [7] M.Di Bencdetto, G.Giancola, Understanding ultra-wide band radio fundamentals. New Jersey, Prentice Hall Professional Technical reference.

- [8] W. P. Siriwongpairat, K.J Ray Liu *Ultra Ultra -wideband communications systems Multiband OFDM approach*, IEEE Press, A John WILEY & SONS, INC., publication
- [9] Y.Zhang, J.Zhao, "Performance simulation of fixed point for MB-OFDM UWB system", Proc.IEEE. Wireless Communications,
- [10] .Kaneko, A.Yamakita, F.Maehara, "Coverage area prediction method for extremely reliable In-car mb-ofdm UWB communication", Proc.IEEE VTC 2010-Spring, pp.1-5,May 2010