Performance Evaluation of the Physical Layer of the DSRC Operating in 5.8 GHz Frequency Band

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In this paper, the theoretical as well as experimental results of BER characteristics of three different modulation schemes, ASK, FSK and BPSK, in a multi-path Rician channel are addressed. These BER characteristics are analyzed as a function of E_b / N_o and the power ratio of the line of sight (LOS) component to the Rayleigh scattered component. The theoretical as well as computer simulation results shows the ASK is the most suitable modulation scheme for the dedicated short range communication (DSRC) in terms of implemental cost and system complexity. The decision feedback equalizer is proved to be very effective in canceling the multi-path interference in the DSRC channel environment. The simulation result of the equalized ASK, reveals the performance enhancement achievable with decision feedback (DFE) equalizer for the first generation DSRC system. The multi-ray DSRC channel model is also provided to predict the received carrier power and fluctuation, which are quite dependent on the surroundings of a cell.

I. INTRODUCTION

The intelligent transportation system (ITS) is in focus throughout the world as possible and unique measures to provide advanced and intelligent services to the drivers of various vehicles. Among the numerous services, the advanced traffic management and information service, automatic toll collection, automatic vehicle control, and the mobile computing and internet service are considered to be the most important services that will be provided in the near future [1], [2].

These ITS services will be based on the newly defined telecommunication infrastructure called the dedicated short range communication (DSRC) system. The DSRC system, consisting of roadside base stations and user terminals equipped on vehicles, is characterized by the extremely small cell size of 100 meters. Due to the small cell size, the condition of the line of sight (LOS) between the receiver and transmitter is normally assumed. However, besides the LOS component, there exists the scattered multi-path component, too, so the channel characteristic can be described by the Rician. The frequency allocated to the DSRC for the ITS is 5.8 GHz with bandwidth of 80 MHz, which is partially allocated for broadcasting.

In this paper, the theoretical as well as experimental results of BER characteristics of three different modulation schemes, ASK, FSK and BPSK, in a multi-path Rician channel are addressed. This BER characteristic is analyzed as a function of E_b / N_o and the value K (the power ratio of LOS component to the Rayleigh scattered component) to discriminate three different modulation schemes in terms of BER and system complexity.

To accommodate the higher data rate service of ITS, the equalizer may be necessary to compensate for distortion brought by the Rician fading channel. It is shown through

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computer simulation that the multi-path interference can be cancelled effectively by utilizing the decision feedback equalizer with feed forward and feed backward taps.

To predict the received carrier power level within a cell depending on the surroundings, the multi-ray channel model employing path loss and reflection coefficient is provided. The validity of the multi-ray channel model is certified by comparing it with the result of the theoretical link budget calculation.

II. SYSTEM MODEL

The BPSK, FSK, and ASK are considered as the possible modulation schemes for the DSRC system because their structures are simpler to implement than any other multi-level modulation scheme. The cost-effectiveness of the DSRC system, particularly the user terminal, is the most important factor, from economical as well as sociological point of view, for initiating and extending ITS service in its first phase. Among those three candidates the simplest one is the most preferable as long as it meets the BER requirement of ITS service.

To provide valid BER performance figures that are close to those in real situations, it is necessary to set up an adequate channel model of the communication system. The ITS services are based on the short range communication between the road side base station and the user terminal equipped on a vehicle, and the LOS condition can normally be assumed between the two apparatuses. However, along the dominant LOS component, the other numerous multi-path signals are expected to arrive at the receiver antenna, so the Rician fading channel model is adequate for the DSRC system.

1. Channel Model for BER Calculation

The mobile communication channel, faded by multi-path signals with the dominant LOS signal, can be represented by the Rician channel model of two ray components [3], [4]. The channel transfer function can be expressed as impulse response function $h(t)$, as in (1):

$$h(t) = \delta(t) + \alpha \exp(j\phi)\delta(t), \tag{1}$$

where the first term of the right side means the LOS component and the second term represents the sum of multi-path signals whose amplitude and phase are α and ϕ, respectively. The amplitude of the multi-path component has Rayleigh distribution with $E[\alpha^2] = 2\sigma^2$ and phase ϕ is assumed to have uniform distribution. Since the amplitude of the LOS component is normalized as unit, the ratio of LOS signal power to the reflected interference power can be expressed as

$$K = \frac{1}{E[\alpha^2]}. \tag{2}$$

2. The BER of ASK, FSK, and BPSK in Rician Channel

If the demodulator is assumed coherent to the LOS signal, then the sum of the reflected signals will be the interference with its power $E[\alpha^2]$. For the three different types of demodulator, the same signal power is assumed to be allocated to transmit the data symbol. This assumption is important for comparing the BER characteristics of different modulation schemes on an equal basis. With this assumption, ASK should be allocated two times greater power than FSK and BPSK because the carrier of ASK is on and off according to the data symbol 1 and 0, unlike the other modulation schemes which transmit continuous carrier regardless of its data symbol.

A. ASK

If the Average transmission power of the FSK- and the BPSK- modulated signals is assigned as P, then that of ASK should be $2P$. The signals representing its amplitude with transmission power $2P$ will be expressed as follows:

$$\begin{cases} s_1(t) = \mathrm{Re}\{\sqrt{4P}\exp[j(\omega_c t + \theta)]\} & 0 \le t \le T_b \\ s_2(t) = 0 & 0 \le t \le T_b \end{cases} \tag{3}$$

where ω_c, T_b mean carrier frequency and symbol duration, respectively. $s_1(t)$ is the signal for the symbol 1 and $s_2(t)$ for the symbol 0. The received signals in a Rician channel, when no propagation loss is assumed, can be expressed as

$$\begin{cases} r_1(t) = \mathrm{Re}\left(\sqrt{4P}\{\exp(j\theta) + \alpha\exp[j(\theta+\phi)]\}\exp(j\omega_c t)\right) \\ \qquad + n(t) \\ r_2(t) = n(t) \end{cases} \tag{4}$$

where $n(t)$ means AWGN with the two-sided power spectrum density $N_o/2$.

The decision variable Z obtained by integrating the low pass filtered component of the received signal, being multiplied by coherent carrier $2\cos(\omega_c t + \theta)$, during one symbol period can be expressed as

$$\begin{cases} Z_1 = \sqrt{4P}T_b + \sqrt{4P}T_b\alpha\cos\phi + N \\ Z_2 = N \end{cases} \tag{5}$$

where N is a Gaussian random variable with zero mean and variance N_oT_b.

Thus, σ_1^2 representing the noise plus interference power of the decision variable Z_1 is $4PT_b^2\sigma^2+N_oT_b$ and σ_2^2 of Z_2 is N_oT_b. So the BER of coherent ASK with its decision threshold κ can be expressed as follows [3], [5]:

$$\begin{aligned} P_b &= \frac{1}{2}\left[\int_{-\infty}^{\kappa} p\left(Z_1|s_1\right)dz + \int_{\kappa}^{\infty} p\left(Z_2|s_2\right)dz\right] \\ &= \frac{1}{2}\left[Q\left\{\frac{\sqrt{4PT_b}-\kappa}{\sigma_1}\right\}+Q\left\{\frac{\kappa}{\sigma_2}\right\}\right], \end{aligned} \tag{6}$$

where κ is just one half of the mean value of the decision variable Z_1, since the mean value of Z_2 is zero, and $Q(\cdot)$ is the complementary error function defined as

$$Q(x) \equiv \frac{1}{\sqrt{2\pi}}\int_x^{\infty}\exp\left(-\frac{y^2}{2}\right)dy \; .$$

B. FSK

The signal set for BFSK can be expressed as follows:

$$s_i(t)=\mathrm{Re}\{\sqrt{2P}\exp[j(\omega_i t+\theta)]\} \quad 0\le t\le T_b, \quad i=1,2 \; . \tag{7}$$

For coherent demodulation, signal $s_1(t)$ and $s_2(t)$ should be orthogonal. The minimum difference between two carrier frequencies being orthogonal to each other is half of the symbol frequency, *i.e.*, $|f_1-f_2|=1/2T_b$. To make the same condition in terms of average transmitted power, P is assigned to both FSK and BPSK, instead of assigning $2P$ to ASK.

Unlike coherent ASK demodulation, the coherent BFSK demodulator needs two independent branches coherent to f_1 and f_2, separately. Each branch needs the same functional block as the ASK except the common comparator which chooses the branch with the largest output as the estimated symbol it belongs to. When s_1 is sent, the decision variable will be as follows:

$$\left\{\begin{aligned} Z_1 &= \sqrt{2PT_b}+\sqrt{2PT_b}\alpha\cos\phi+N_1 \\ Z_2 &= N_2 \end{aligned}\right. \Bigg|_{s_1} \tag{8}$$

where $\mathrm{var}\{N_1\}=\mathrm{var}\{N_2\}=N_oT_b$ and the variance of the multi-path interference, $\sqrt{2PT_b}\alpha\cos\phi$, is $2PT_b^2\sigma^2$. When s_2 is sent, the values of Z_1 and Z_2 are simply reversed. Based on the decision strategy using the comparator, the BER can be written as

$$P_b=\Pr[\sqrt{2PT_b}+\sqrt{2PT_b}\alpha\cos\phi+N_1-N_2<0|\; s_1] \; . \tag{9}$$

where N_1, N_2 and the multi-path interference term are independent Gaussian random variables with its mean all zero. So, the mean and variance of the composite random variable of (9) are $\sqrt{2PT_b}$ and $2PT_b^2\sigma^2+2N_oT_b$, respectively. Thus, the BER equation can be written as

$$P_b=Q\left[\frac{\sqrt{2PT_b}}{\sqrt{2PT_b^2\sigma^2+2N_oT_b}}\right] \tag{10}$$

$$=Q\left[\sqrt{\frac{2K(E_b/N_o)}{2K+(E_b/N_o)}}\right] . \tag{11}$$

C. BPSK

In BPSK modulation, the transmitted signal can be expressed as follows: {}

$$s_i(t)=\mathrm{Re}\{D_i\sqrt{2P}\exp[j(2\pi f_c t+\theta)]\} \quad i=1,\; 2 \tag{12}$$

where $D_1=1$ and $D_2=-1$ depending on the symbol. The received signal in a Rician fading channel with AWGN can be expressed as follows:

$$\begin{aligned} r_i(t)=\mathrm{Re}\big(\sqrt{2P}D_i\{&\exp(j\theta)+\alpha\exp[j(\theta+\phi)]\} \\ &\times\exp(j2\pi f_c t)\big) \\ +n(t)& \end{aligned} \tag{13}$$

The coherent BPSK demodulator which tracts the LOS signal perfectly in phase has the decision variable as

$$Z_i=\int_{\mathrm{iT_b}}^{\mathrm{(i+1)T_b}} 2r_i(t)\cos(2\pi f_c t+\theta)dt \tag{14}$$

In the same manner, for the other modulation scheme, the BER of the BPSK can be obtained by

$$P_b=Q\left[\sqrt{\frac{2K(E_b/N_o)}{K+(E_b/N_o)}}\right] . \tag{15}$$

3. The Link Budget of the DSRC System

The BER equations derived in previous section appeared as a function of K, that is the LOS signal to multi-path interference power ratio, as well as E_b/N_o. To evaluate BER figures of various modulations of the DSRC, not only the value of K

but also the meaning of E_b / N_o, which can also be expressed in terms of C / N, should be clarified.

The important parameters of the DSRC system considered in this paper are summarized as follows: The EIRPs of the roadside station and the user terminal are set to 200mW and 10 mW, respectively. The carrier frequency and receiver bandwidth are 5.8 GHz and 5 MHz, respectively. The antenna gain of the roadside station and the user terminal is designed as 20 dBi and 3 dBi, respectively. The size of the cell is 100m in radius. Using these parameters, uplink and downlink C / N can be calculated. In the link budget calculation, the propagation loss can be approximated by free space loss since the propagation distance is extremely short.

From the calculated C / N, E_b / N_o can be obtained by [6]:

$$\frac{E_b}{N_o} = T_b B\left(\frac{C}{N}\right) \cong \left(\frac{C}{N}\right), \qquad (16)$$

where $T_b B$, bit-duration-bandwidth-product, can be approximated as 1 for ASK, FSK and BPSK. Thus, uplink and downlink E_b / N_o in a cell can be summarized as in Tables 1 and 2.

Table 1. Downlink parameters.

Distance (m)	10	50	100
E_b / N_o (dB)	65	51	45

Table 2. Uplink parameters.

Distance (m)	10	50	100
E_b / N_o (dB)	69	55	49

4. Numerical Analysis, Simulation and Measurement of BER

The range of the ratio of the LOS component power to Rayleigh scattered power, K, is expected to be from 10 to 20 dB depending on road environment [3], [7]. Figures 1 and 2 show BER characteristics of three different modulation schemes as a function of E_b / N_o when the K is fixed to 10dB and 13dB, respectively. As can be seen in both figures, BER is bounded by K rather than by E_b / N_o. In other words, once the BER is saturated by the ratio K, then E_b / N_o seldom contributes to the improvement of BER, whatever value it may have. In Fig. 1, 10^{-5} is thought to be the lower bound regardless of modulation scheme. In Fig. 2, 10^{-10} is the lower bound. In the region where E_b / N_o is around 20 dB, the BPSK shows the best performance in terms of BER. However, as can be seen in Tables 1 and 2, the operating point of E_b / N_o is much higher than 20 dB. Throughout the cell, the DSRC system operates in the range of E_b / N_o higher than 45 dB. In this region, those three different modulation schemes are saturated and show the same BER characteristics, so the ASK is thought to be the most suitable modulation scheme in terms of system complexity in normal operating range. Figure 3 shows the theoretical BER characteristic of ASK as a function of K as well as E_b / N_o. This theoretical BER characteristic well matches to the computer simulation

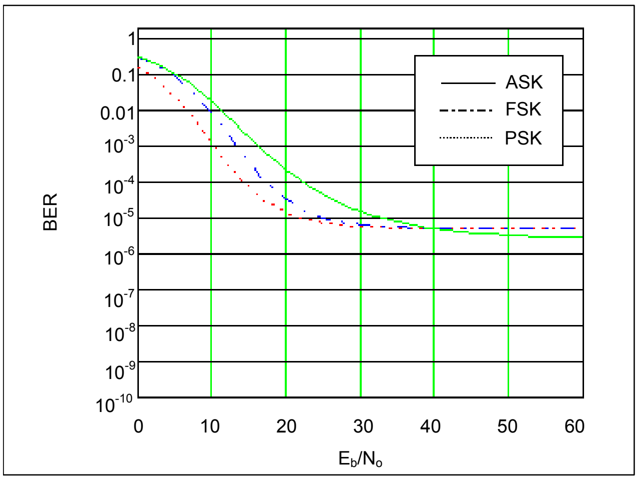

Fig. 1. BER characteristics of three different modulations with *K*= 10 dB.

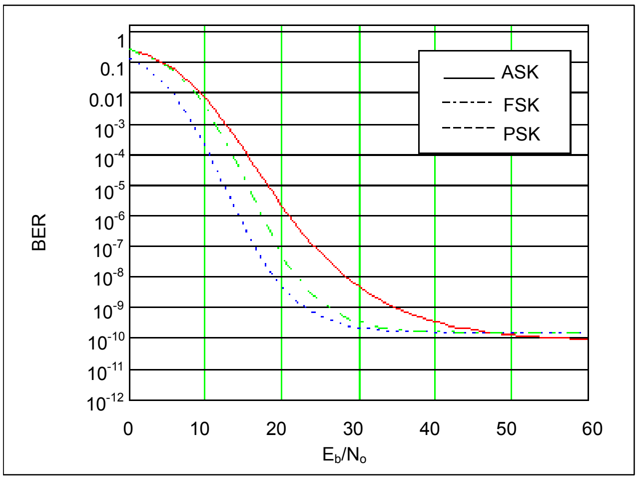

Fig. 2. BER characteristics of three different modulations with *K*= 13 dB.

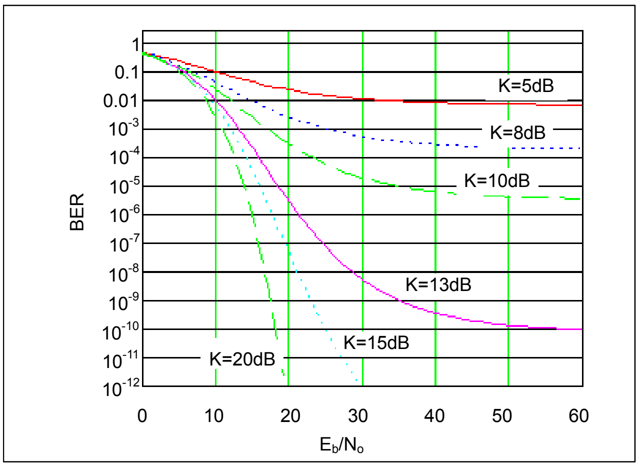

Fig. 3. Theoretical BER characteristic of ASK.

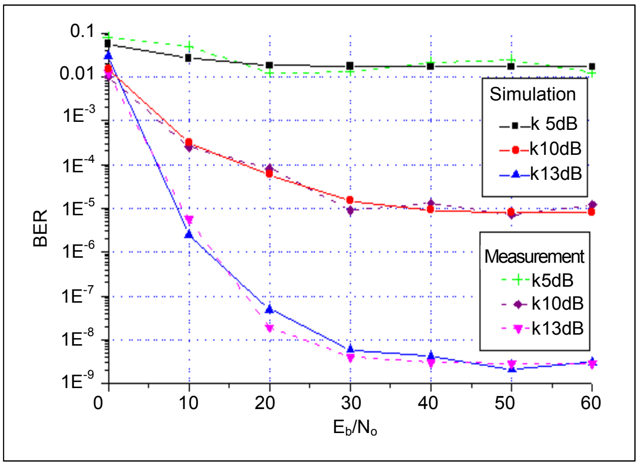

Fig. 4. Simulated and measured BER of ASK.

and measurement results of BER shown in Fig. 4. So it can be concluded that the two ray channel model is very effective and adequate for the DSRC channel.

III. PERFORMANCE IMPROVEMENT BY EQUALIZER

Through BER analysis in the previous section, the ASK is proven to be the most suitable modulation scheme among ASK, FSK and BPSK in terms of system complexity. However, when K falls below 10 dB, the lower bound of BER is greater than 10^{-5} which is the minimum requirement for acceptable DSRC communication. In this situation, some kind of measures to enhance the desired signal against harmful multi-path interference should be taken. In this paper, a decision feedback equalizer (DFE) consisting of feed forward and feed backward taps is used to compensate distortion brought by the faded channel [4].

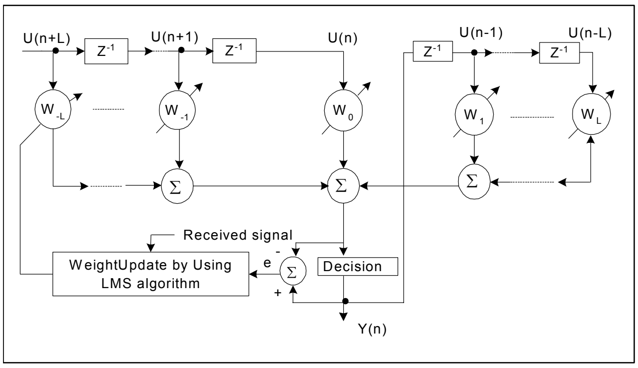

Fig. 5. DFE structure.

Figure 5 shows the structure of DFE. The received signal $r(t)$ distorted by a Rician channel can be expressed as follows:

$$r(t) = s(t) * h(t) + n(t)\ , \tag{17}$$

where the impulse response function of $h(t)$ is the same as that given in (1).

The signal appeared at the taps of the equalizer can be expressed in vector form as

$$\mathbf{y}(t) = \lfloor y(t+L_f), y(t+L_f-1), \cdots, y(t), \cdots y(t-L_b) \rfloor, \tag{18}$$

where L_f means the number of feed forward (FF) taps and L_b number of feed backward (FB) taps.

The weight of equalizer can also be expressed using vector notation as

$$\mathbf{w}(t) = \left[w_{f,-L_f}, w_{f,-L_f+1}, \cdots, w_{f,-1}, w_{f,0}, w_{b,1}, \cdots, w_{b,L_b}\right]^T . \tag{19}$$

To explain how the weights of the DFE are working to cancel interference in a multi-path faded channel, the phase component of channel transfer function of (1) is transformed to a relevant time delay τ ,

$$\begin{aligned} h(t) &= \delta(t)[1+\alpha \exp(j\phi)] \\ &= \delta(t)[1+\alpha \exp(j2\pi f_c \tau)]. \end{aligned} \tag{20}$$

The received signal is classified into two categories, depending on whether α is less than or greater than 1. When the condition of $\alpha < 1$ is met, the DFE is said to be under the minimum phase condition; otherwise, the non-minimum phase condition. To simplify the explanation, the DFE with single tap is considered. The signal at the equalizer input can be expressed as

$$\begin{aligned} y(t) &= s(t) + \alpha s(t-\tau) \\ &= s(t) + \alpha s'(t), \end{aligned} \tag{21}$$

where $s(t)$ is the LOS component received without any delay and $s'(t)$ is the signal transmitted τ time before but received at the same time as $s(t)$ due to the longer path delay. If the tap delay time of the DFE is set to τ, then same replica of signal $s'(t)$ is saved at the first FB tap. The equalizer output $z(t)$ is given by

$$z(t) = s(t) + \alpha s'(t) + w_{b,1} s'(t)\,. \tag{22}$$

So, if the $w_{b,1} = -\alpha$ condition is met, the equalizer output $z(t)$ will be recovered as original $s(t)$ without any multipath interference. The FF taps work in the same manner under the non-minimum phase condition.

In real situations, these tap weights are calculated and updated adaptively according to the variation of the received signal. In this paper, to minimize the implemental cost and complexity, the Least Mean Square (LMS) algorithm is used which can be summarized as follows [8]:

$$\begin{aligned} e(t) &= \hat{z}(t) - z(t) \\ &= \hat{z}(t) - \mathbf{w}^H y(t) \end{aligned} \tag{23}$$

$$\mathbf{w}(t+1) = \mathbf{w}(t) + \mu \mathbf{y}(t) e^*(t) \tag{24}$$

where $\mathbf{w}$ and μ, are weight vector and step size, respectively; while $[]^H$ and * mean conjugate transpose and conjugate operations, respectively.

The computer simulation result in Fig. 6 shows the BER characteristics of the ASK system adopting the DFE equalizer. As can be seen in Fig. 6, the value K no longer limits the lower bound of BER. From the simulation results, it is proved that the DFE equalizer can remove the scattered interference successfully. To accommodate higher data rate service using this DSRC system, similar kinds of equalizer may be necessary [9].

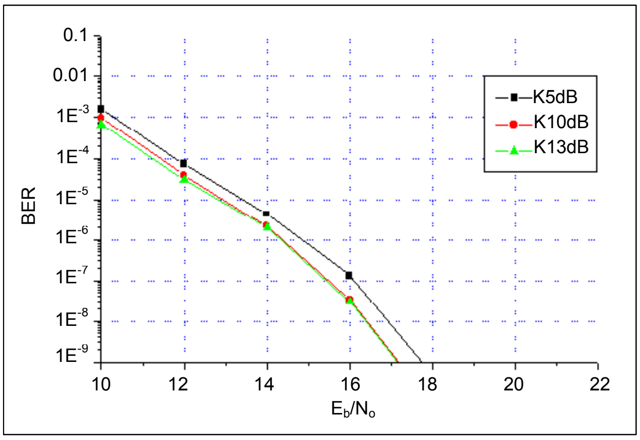

Fig. 6. BER performance with equalizer.

IV. MULTI-RAY CHANNEL MODELING

A simple two-ray channel model was introduced in the previous section to calculate the BER in a Rician channel [3]. However, this channel model is too simple to predict power level within a cell, which is very critical to designing an optimized cell depending on geographical and structural environment. Some sophisticated channel models with parameters of different paths and reflecting coefficient of surface can predict the power level depending on the surroundings within a cell. That is the multi-ray channel model employing the propagation loss and reflection coefficient of material [11]-[14]. With this model, not only the average power level but also the maximum fluctuation of the received signal can be predicted.

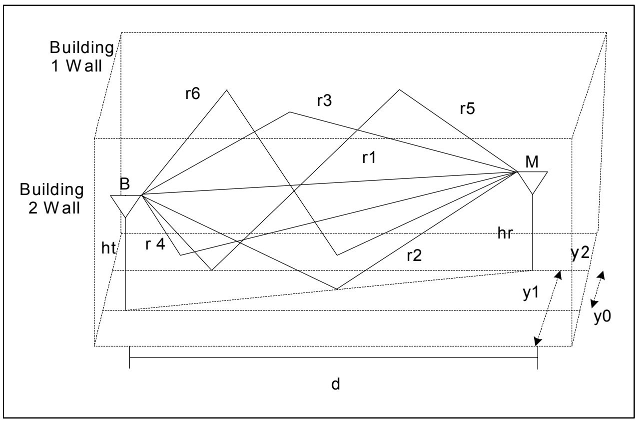

Fig. 7. Three-dimensional model of multi-rays.

In Fig. 7, the possible three-dimensional paths, along which the multi-rays propagate from transmitter to receiver, are shown. The channel transfer function of the multi ray model, $H(f)$, is simply the superposition of the transfer function of each ray, $H_i(f)$:

$$H(f) = H_1(f) + \sum_{i=2}^{M} H_i(f), \tag{25}$$

where $H_1(f)$ is the channel transfer function of the LOS component and H_i with $i \geq 2$ are the transfer function of reflected rays. These channel transfer functions can be expressed in detail as follows:

$$H_1(f) = \frac{\lambda \exp(-jkr_1)}{4\pi r_1} \tag{26}$$

$$H_i(f) = \frac{R_v(\xi_i)\lambda \exp(-jkr_i)}{4\pi r_i} \tag{27}$$

where λ, k mean wave length and wave number, r_i the absolute path lengths of propagation, and $R_v(\xi_i)$ the reflection coefficient of the surface of vertically polarized wave as a function of arrival angle ξ_i. Also, absolute path length of each propagation can be expressed in detail as follows:

$$r_{1,2} = \sqrt{d^2 + (h_t \mp h_t)^2 + y_0^2} \tag{28}$$

$$r_{3,4} = \sqrt{d^2 + (2y_{2,1} \mp y_0)^2 + \Delta h^2} \tag{29}$$

$$r_{5,6} = \sqrt{d^2 + (2(y_1 + y_2) \mp y_0)^2 + \Delta h^2} \tag{30}$$

where h means the parameters related to antenna height, and the parameters d, y are shown in Fig. 7. The reflection coefficient of the vertically polarized wave is given by

$$R_v(\xi_i) = \frac{\sin\xi_i - a_v\sqrt{\varepsilon - \cos^2\xi_i}}{\sin\xi_i + a_v\sqrt{\varepsilon - \cos^2\xi_i}} \tag{31}$$

where ε is the complex permittivity of the material and $a_v = 1/\varepsilon$.

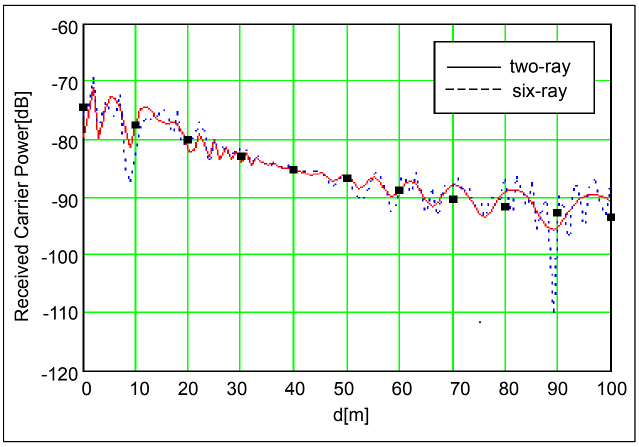

Fig. 8. Received carrier power of the two-ray and the six-ray mod model.

Figure 8 shows the computational results of the received carrier power on a downlink based on two-ray and six-ray channel models. The rectangular dot point is the theoretical value of carrier power based on link budget calculation. As shown in Fig. 8, the multi-ray channel model provides not only average carrier power received but also the level of the signal fluctuation. By using this model, the average receiver power level that is dependent on the surroundings can be easily predicted with its maximum deviation. The more sophisticated channel model which includes the Doppler frequency shift based on prediction [15], [16], is being studied for advanced ITS channel modeling.

V. CONCLUSION

In this paper, the BER of three different kinds of modulation schemes, ASK, FSK and BPSK, in a Rician multi-path channel is calculated with its relevant and supportive computer simulation and measurement. Since the implemental cost and complexity of the user terminal is very critical in the ITS service, these three basic modulation schemes are possible candidates for the DSRC system as long as they meet BER requirement. Theoretical analysis as well as computer simulation shows that BPSK is the best, FSK the second and ASK the worst in the BER characteristics in a Rician multi-path channel. The result is coincidental to the general theory of modulation in a noisy channel. However, this discrimination of BER only appears in the range of E_b/N_o up to 40dB. In the range of E_b/N_o, higher than 40 dB, the BER of the three different modulation is altogether saturated to lower bound that is supposed to be set by the value K. That means there is no difference between the three different modulation schemes in terms of BER in the range of E_b/N_o higher than 40 dB.

From the link budget analysis based on the system parameters of the DSRC system that is under development in Korea, the worst E_b/N_o is 45 dB in which the DSRC system is to operate at the boundary of a 100 m cell on the downlink. In this operating region, the three different modulation schemes do not show any difference in BER characteristics so the ASK is thought to be the most suitable modulation scheme in terms of implemental cost and complexity.

The other important aspect noticed in BER analysis of the DSRC system is that the Rayleigh scattered multi-path power dominates BER performance, so an equalizer may be necessary to cancel the multi-path interference to accommodate advanced ITS service with a higher bit rate.

To predict the received carrier power within a cell in a multi-path environment, the DSRC channel model with multi-ray is provided with its numerical analysis. From the numerical analysis, the multi-ray DSRC channel model can predict not only the average power but also the variance of the received carrier. This multi-ray channel model can be utilized to design an optimized cell considering the geographical and structural environment, and to simulate the multi-path fading channel of wireless communication using a computer.

For the next generation DSRC, more advanced modulation schemes, such as QPSK, QAM, GMSK and OFDM which can accommodate up to 10 Mbps, are being considered in ETRI [17].

REFERENCES

[1] R. Kohno, "ITS and Mobile Multi-Media Communication in Japan," *Proc. of Telecommunication Technique Workshop for ITS*,

May 2000.

[2] M. Yasunaga, "ITS Research and Development Activities in TAO, Japan," *Proc. Of Telecommunication Workshop for ITS*, May 2000.

[3] Andreas Polydoros, "Vehicle to Roadside Communications," *California PATH Research Report*, Southern California Univ., June 1993.

[4] D. Kwon, Y. Hahm, I. Jeong, and D. Im, "CDMA Mobile System Test-bed and Field Test," *ETRI Journal*, vol. 19, no.3, Oct. 1997, pp. 259-280.

[5] J. Proakis, *Digital Communication*, 3rd Ed., McGraw-Hill, 1999.

[6] Tri T. Ha, *Digital Satellite Communications*, 2nd Ed., McGraw-Hill,1990.

[7] C. Wietfeld, "Performance Evaluation of Vehicle–Roadside Communication Systems in Shadowing & Multipath Fading Environments," *IEEE Trans. Veh. Tech.*, vol. VT-45, 1995, pp. 947-952.

[8] B. Widrow and S.D. Stearns, *Adaptive Signal Processing*, Prentice-Hall Inc., 1985.

[9] S. Haykin, *Adaptive Filter Theory*, 2nd Ed., Prentice Hall,1991.

[10] W. Detlefsen, W. Grabow, U. Kersken, and R. Schmedding, "Reliability of 5.8GHz Short Range Links in Vehicle-Roadside Communication," *IEEE Vehicle Navigation &Information Systems Conference*, Otawa, 1993, pp. 300-303.

[11] R. Prasad, *Universal Wireless Personal Communications*, Artech-House, 1998.

[12] W. Zhang, "Physical Modeling of Wide-Band Propagation for Urban Line-Of-Sight Micro-Cellular Mobile and Personal Communication," *Journal of Electromagnetic Waves and Applications*, vol. 11, 1997, pp. 1633-1648.

[13] Richard Klukas and Michal Fattouche, "Line-of-Sight Angle of Arrival Estimation in the Outdoor Multipath Environment," *IEEE Trans. Veh. Tech.,* vol.47, no.4, Feb. 1998.

[14] A. Annamalai, C. Tellambura, "A general Approach for Evaluating the Outage Probability in Micro-cellular Mobile Radio Systems," *Proc, IEEE, International conference on communications*, vol. 3, June 1999, pp. 1836-1840.

[15] H. Shahram, H. Homayoun, "A Propagation Model for Microcellular Mobile and Personal Radio Communications," *Proc. IEEE., PIMRC.*, vol. l2, Sept. 1995, pp. 392-396.

[16] Moon-Hee You, Seong-Pal Lee, and Youngyeal Han, "Adaptive Compensation Method Using the prediction Algorithm for the Doppler Frequency Shift in the LEO Mobile Satellite Communication System," *ETRI Journal*, vol. 23, no.4, Dec. 2000.

[17] B.S. Lee, "Modulation Schemes for the Next Generation DSRC System," *Proc. of 2001 ITS Workshop and Exhibition,* Mar. 2001.

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