ODSB and OSSB Error Performance Analysis of MMoF Systems in Rician Fading Channel

Chang-Ho Yun, Tae-Sik Cho, and Kiseon Kim
Department of Information and Communications, Kwang-Ju Institute of Science and Technology
Tel: 062-970-2252 / Fax: 062-970-2274 / E-mail: sgn0178@kjist.ac.kr

Abstract-Error performance of two modulation schemes of millimeter-wave over fiber (MMoF) system i.e., optical double side band (ODSB) and optical single side band (OSSB) modulations is analyzed under Rician fading. Bit error rates (BER) of two detection techniques i.e., coherent and noncoherent detection are also compared in Rician fading. In aspect of error performance, ODSB modulation scheme has better BER than OSSB modulation scheme has under Rician fading. On the other hand, OSSB modulation scheme is advantageous in case of considering high bandwidth efficiency and small power degradation. Coherent detection technique is proper in Rician fading, because coherent detection provides more SNR gain whether fading is serious or not. Noncoherent detection can be applied when we need a simple receiver structure.

I. Introduction

MMoF system is one of the popular solutions to provide multimedia services through optical fiber links, which guarantees large bandwidth, low loss, and immunity to electro-magnetic interference (EMI) [1]. The system can distribute MMoF signals to various users such as fixed wireless access (FWA), portable wireless, or mobile terminals. Several papers were reported to analyze behaviors of MMoF signals in fiber-wireless system, where considering modulation techniques and optical characteristics like optical fiber loss, dispersion and non-linearity [1], [2]. Also, previous papers focused on improving the optical tolerance of MMoF system components such as the laser line-width, or the fiber characteristics.

However, nowadays, MMoF system performance analysis under fading channel or MMoF user management such as data scheduling under noisy surroundings becomes important due to the growth of interests with wireless channel environments. Especially, fading is a consequential factor to be considered, because MMoF system is mostly applied in urban areas where buildings, trees, and other obstacles, which result in multi-path scattering, exist.

Also, most millimeter-wave signals are studied under fading channel, but millimeter-wave signals which is transmitted through optical fiber are not researched with considering fading channel. Thus, we simplify the wireless channel under Rician fading, and show error performance of the MMoF system, because a line-of-sight (LOS) and scattered components of MMoF signals exist together in the urban areas.

In following sections, we derive BER of ODSB and OSSB modulation schemes under Rician fading, and BER for each detection technique. From numerical results, two modulation schemes are compared in order to choose a proper modulation scheme by analyzing error performance of MMoF system according to Rician parameter K and millimeter-wave frequency. Also, two detection techniques are compared by analyzing BER of MMoF system.

II. MMoF System Model and Environment

2.1 MMoF System Structure and ODSB and OSSB Signals

MMoF system which we are considering is depicted in Fig. 1. At central office (CO), we transmit the millimeter-wave signals, which are modulated by the Mach-zehnder modulator (MZM) in order to pass through optical fiber. In optical fiber, the signals are propagated, and they are detected by photo-diode (PD) at base station (BS). Also, the signals are radiated into wireless channel, and transmitted to user terminal (UT) under Rician fading.

The millimeter-wave signals, which are phase shifted and modulated by the MZM with an optical frequency f_c, can be expressed as [1]

$$E_{MZM}(t) = \frac{A}{2}[cos[w_c t + \gamma\pi + \alpha\pi cos(w_{mm} t + \phi_i(t))] + cos w_c t + \alpha\pi cos[w_{mm} t + \epsilon + \phi_i(t)]] \quad (1)$$

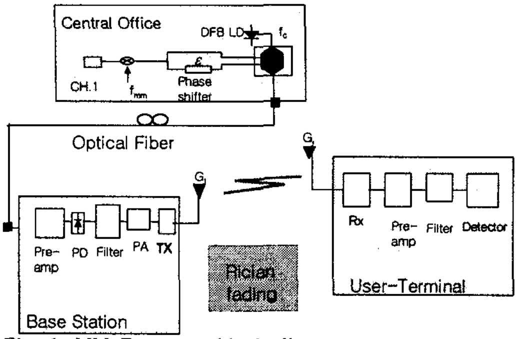

Fig. 1. MMoF system block diagram

where $w_{mm}=2\pi f_{mm}$ is the millimeter-wave frequency, $\phi_i(t)=\pi i/2\ (i=0.1)$ is the phase term for binary orthogonal signals, and $w_c=2\pi f_c$ is the optical frequency. ϵ is the phase shift of the MZM, A is the amplitude of the optical carrier, $\gamma=V_{dc}/V_\pi$ is the normalized bias voltage of the MZM, V_π is the switching voltage of the MZM, V_{dc} is the dc-bias voltage of the MZM, α is the normalized amplitude and V_{ac} is the voltage of the signals.

In case of ODSB modulation scheme, eq. (1) can be expanded in terms of Bessel functions as [1]

$$E_{MZMdsb}(t)=\frac{A}{\sqrt{2}}\cos(w_c t+\pi/4)[J_0(\alpha\pi) - 2J_1(\alpha\pi)\cos(w_{mm}t+\phi_i(t))] \quad (2)$$

where its phase shift ϵ is π. The millimeter-wave signals can be expanded in case of OSSB modulation as [1]

$$E_{MZMssb}(t)=\frac{A}{\sqrt{2}}\{[\cos(w_c t+\pi/4)J_0(\alpha\pi)] - \sqrt{2}[J_1(\alpha\pi)\cos(w_c-w_{mm})t+\phi_i(t)]\} \quad (3)$$

where the phase shift ϵ is $\pi/2$.

2.2 Optical Fiber Transfer Function and Received ODSB and OSSB Signals under Rician Fading

Considering the dispersion and loss of the optical fiber, the transfer function of optical fiber channel is represented as [3]

$$H(f)=exp[-j\pi LD\lambda_c^2 f^2/c]\cdot 10^{-\sigma L/20} \quad (4)$$

where D, L, c, σ and λ_c are dispersion parameter, the optical fiber length, light velocity, the loss of the optical fiber and the optical carrier wavelength respectively.

ODSB signals can be modeled to be adapted to the optical fiber transfer function as follows [2]

$$E_{dsb}(t)=\eta[A_{dsb}+B_{dsb}\cos(w_{mm}t+\phi_i(t))] \quad (5)$$

where $A_{dsb}=AJ_0(\alpha\pi)/2$, $B_{dsb}=-AJ_1(\alpha\pi)$ and η is coupling efficiency. Also, OSSB signals are represented by [2]

$$E_{ssb}(t)=\eta\{A_{ssb}+B_{ssb}exp[j(w_{mm}t+\phi_i(t))]\} \quad (6)$$

where $A_{ssb}=AJ_0(\alpha\pi)/2$ and $B_{ssb}=-AJ_1(\alpha\pi)/\sqrt{2}$. The output after propagating through the optical fiber for ODSB modulation is [2]

$$E_{out}(t)=\eta\int_{-\infty}^{\infty}E_{dsb}(f)H(f)exp(j2\pi ft)df \quad (7)$$

where $E_{dsb}(f)$ is fourier transform of $E_{dsb}(t)$.

Detected by the PD at BS, MMoF signals for ODSB modulation are represented by [2]

$$I_{dsb}(t)=\eta^2\sqrt{G_{pre-amp}}R\cdot 10^{-\sigma L/10}\cdot[2A_{dsb}B_{dsb}\cos\theta\cos(w_{mm}t+\phi_i(t))] \quad (8)$$

where $\theta=\frac{\pi LD\lambda_c^2 f_{mm}^2}{c}$, R is the responsivity of PD and $G_{pre-amp}$ is the gain of pre-amplifier at BS.

At UT under Rician fading, MMoF signals can be expressed as [4]

$$I_{receivedDSB}(t)=r_c\cos(w_{mm}t+\phi_i(t))+r_s\sin(w_{mm}t+\phi_i(t))+n(t) \quad (9)$$

where r_c is a random variable of which expectation is vU, variance is $v^2\delta^2$ and U is a specular component. r_s is a random variable whose expectation is 0 and variance is $v^2\delta^2$. From eq. (9), v is

$$v=A\cdot B \quad (10)$$

where

$$A=RA_{dsb}B_{dsb}\cos\theta\cdot 10^{-\sigma L/10}\eta^2,$$

$$B=\sqrt{\frac{2G_tG_rG_{pre-amp}G_{UTpre-amp}G_{BSPA}}{L_sF_{BSPA}F_{pre-amp}F_{UTpre-amp}L_{BSfilter}L_{UTfilter}M_{BS}M_{UT}}}$$

G_t is the transmitter antenna gain, G_r is the receiver antenna gain, $G_{UTpre-amp}$ is the UT pre-amplifier gain and G_{BSPA} is the BS power gain. L_s is the line loss of wireless channel, F_{BSPA} is the noise figure in BS power amplifier, $F_{pre-amp}$ is the noise figure in BS pre-amplifier and $F_{UTpre-amp}$ is the noise figure in UT pre-amplifier. $L_{BSfilter}$ is the BS filter loss, $L_{UTfilter}$ is the UT filter loss, M_{BS} is the BS gain margin and M_{UT} is the gain margin in UT.

By shortening above steps from eq. (7) to (8) and using a similar technique with ODSB modulation, the received MMoF signals of OSSB modulation can also be expressed as

$$I_{receivedSSB}(t)=r'_c\cos(w_{mm}t+\phi_i(t))+r_s'\sin(w_{mm}t+\phi_i(t))+n(t) \quad (11)$$

where r'_c is a random variable of which expectation is $v'U\cos\theta$ and variance is $v'^2\delta^2$. r'_s is a random variable whose expectation is $v'U\sin\theta$ and variance is $v'^2\delta'^2$.

Ⅲ. Receiver Structure and BER Analysis

The term 'coherent' refers to the phase of the fixed component only. When there is no specular component, the receiver reduces to the noncoherent receiver [4]. As shown Fig. 2, the specular components which are pointed by dashed line are added in the coherent receiver. Furthermore, the added parameters are different between ODSB and OSSB modulation. In ODSB modulation scheme, A and C are $U/2v\delta^2$, B and D are zero. In OSSB modulation scheme, A and C are $\cos\theta \cdot (U/2v\delta^2)$, B and D are $\sin\theta \cdot (U/2v\delta^2)$.

From the received MMoF signals, we derive error performance of ODSB and OSSB modulation scheme. Using coherent detection, BER of ODSB modulation scheme is expressed as [4]

$$P_{dsb}(E) = Q(\sqrt{a}, \sqrt{b}) - \left(\frac{\delta_0^2}{\delta_0^2+\delta_1^2}\right) \cdot \exp\left(-\frac{a+b}{2}\right) I_0(\sqrt{ab}) \qquad (12)$$

where $a = \frac{s_1^2}{\delta_0^2+\delta_1^2}$, $b = \frac{s_0^2}{\delta_0^2+\delta_1^2}$, $s_0^2 = \left(\frac{vU}{2\delta^2} + \frac{E_s v U}{N_0}\right)^2$, $s_1^2 = \left(\frac{U}{2v\delta^2}\right)^2$, $\delta_0^2 = \frac{1}{N_0^2}\left(E_s^2 v^2 \delta^2 + \frac{N_0 E_s}{2}\right)$, $\delta_1^2 = \frac{1}{N_0^2}\frac{N_0 E_s}{2}$,

E_s and N_0 are symbol energy and power spectrum density (PSD) of additive white Gaussian noise (AWGN), respectively. $Q(\sqrt{a}, \sqrt{b})$ is a Marcum Q function. Also, error performance of OSSB modulation scheme in coherent detection is represented by [4]

$$P_{ssb}(E) = Q(\sqrt{a'}, \sqrt{b'}) - \left(\frac{\delta_0'^2}{\delta_0^2+\delta_1^2}\right) \cdot \exp\left(-\frac{a'+b'}{2}\right) I_0(\sqrt{a'b'}) \qquad (13)$$

where $a' = \frac{s_1'^2}{\delta_0'^2+\delta_1'^2}$, $b' = \frac{s_0'^2}{\delta_0'^2+\delta_1'^2}$,

$$s_0'^2 = \left(\frac{U}{2v'\delta^2}\cos\theta + \frac{E_s'v'U}{N_0}\cos\theta\right)^2 + \left(\frac{U}{2v'\delta^2}\sin\theta + \frac{E_s'v'U}{N_0}\sin\theta\right)^2,$$

$$s_1'^2 = \left(\frac{U}{2v'\delta^2}\cos\theta\right)^2 + \left(\frac{U}{2v'\delta^2}\sin\theta\right)^2, \delta_0'^2 = \frac{1}{N_0^2}\left(E_s'^2 v'^2 \delta^{2\prime} + \frac{N_0 E_s'}{2}\right),$$

$$\delta_1^{2\prime} = \frac{1}{N_0^2}\frac{N_0 E_s'}{2}.$$

In noncoherent detection, error performance of ODSB and OSSB modulation schemes are [4]

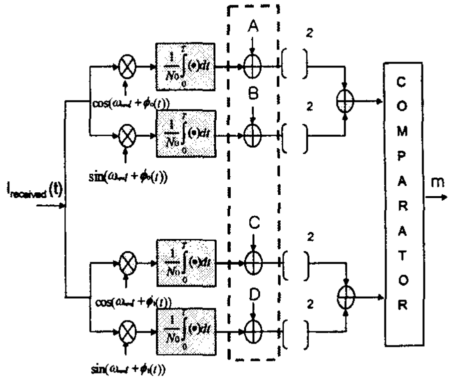

Fig. 2. Coherent and noncoherent detection receiver

$$P_{noncoherent}(E) = \frac{1}{v^2\beta+1}\exp\left[-\frac{2Kv^2\beta}{2(\beta+2)}\right] \qquad (14)$$

where $\beta = \frac{2v^2U^2E_s}{N_0}$, $K = \frac{U^2}{2\delta^2}$ for ODSB modulation scheme and $\beta = \frac{2v'^2E_s'}{N_0}$, $K = \frac{U^2}{2\delta^2}$ for OSSB modulation scheme.

Ⅳ. Numerical Results

To show proper modulation scheme and detection scheme of MMoF system, error performance of two modulation schemes and detection schemes are compared at Rician parameter K = 0 dB (Rayleigh), 8 dB (Rician), and 12 dB (Gaussin). We evaluate BER versus SNR when the millimeter-wave frequency is 26.5 GHz, and coherent detection is used. Also, BER vs. SNR is evaluated when the millimeter-wave frequency is 26.5 GHz, and ODSB modulation scheme is used.

4.1 Error performance according to Rician parameter and millimeter-wave frequency

We plot BER vs. SNR performance of two modulation schemes by varying Rician parameter K. As shown Fig. 3, We plot BER at K=0 dB, 8 dB, and 12 dB. The dashed line is corresponded to OSSB modulation and the solid line is corresponed to ODSB modulation.

In Fig. 3, as K is increasing, the error performance is improving, and BER of ODSB modulation is better than that of OSSB modulation. When BER is 10^{-2}, SNR differences of two modulation schemes at those Rician parameters are all over 5 dB. From these results, ODSB modulation scheme of MMoF system has better error performance than OSSB modulation scheme has, whether fading is serious or not.

Thus,

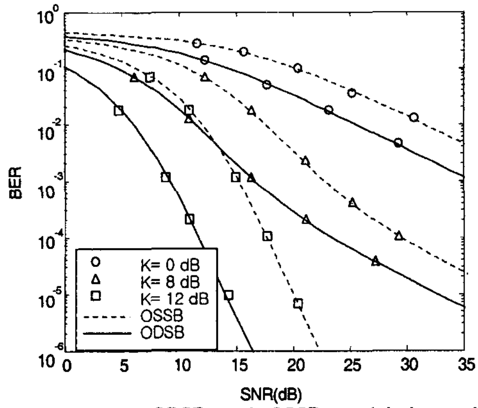

Fig. 3. BER of ODSB and OSSB modulation schemes using 26.5 GHz millimeter-wave frequency and coherent detection

it is advantageous to use ODSB modulation scheme for good error performance and easy implementation, but OSSB modulation scheme can also be applied when we obtain good bandwidth efficiency and small power degradation.

Furthermore, error performance of two modulation schemes are compared by varying millimeter-wave frequencies at coherent detection. While BER of ODSB modulation scheme has a minimum value at specific frequencies such as 17 GHz, 23 GHz and 26 GHz because of a characteristic of the MZM, error performance of OSSB modulation scheme has no change according to millimeter-wave frequencies. When SNR is 20 dB, ODSB modulation scheme has much better error performance than OSSB modulation scheme has at above frequencies.

4.2 Coherent and Noncoherent Detection in MMoF System

As shown Fig. 4, we plot BER vs. SNR of two detection techniques, when Rician parameter K is 0 dB, 8 dB, and 12 dB. The dashed line is corresponded to noncoherent detection, and the solid line is corresponded to coherent detection.

When K is increasing, BER is improving. Also, BER of coherent detection is better than that of noncoherent detection. When Rician parameter K=0 dB, SNR gain difference of the two detection techniques is 3 dB at BER of 10^{-2} as shown in Fig. 4. When K increases to 12 dB, SNR gain difference becomes more than 15 dB. Thus, as Rician parameter K is increasing, we can significantly improve error performance. Noncoherent detection can also be implemented, when we need the receiver structures as simple as possible.

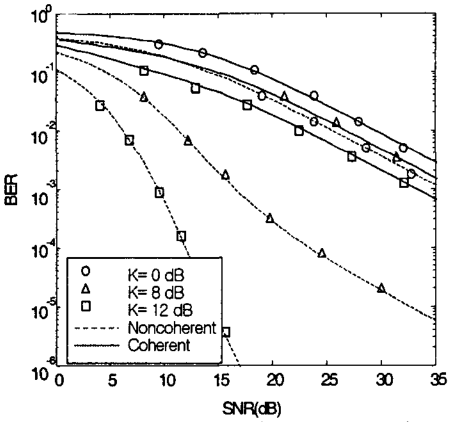

Fig. 4. BER of coherent and noncoherent detection using ODSB modulation scheme at 26.5 GHz millimeter-wave frequency

V. Conclusion

We have analyzed error performance between ODSB and OSSB modulation schemes of MMoF system under Rician fading. Also, error performance of two detection techniques of MMoF system was compared in Rician fading. As Rician parameter K increases, BER of both modulation schemes are improved. Whether fading is serious or not, ODSB modulation scheme has better error performance. Furthermore, when Rician parameter K increases, error performance of two detection techniques are improved, too. Thus, ODSB modulation scheme and coherent detection technique are proper choices in MMoF system in aspect of error performance under Rician fading.

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