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ON THE BER OF MULTIPLE-INPUT MULTIPLE OUTPUT UNDERWATERWIRELESS OPTICAL CDMA NETWORK: REVIEW

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ABSTRACT

Underwater Wireless Optical Communications is an arrivingexplanation to extend the demand for broadband links in oceans and seas. In this paper we examinethe Bit Error Rate (BER)attainment of multiple-input multiple-output of Underwater Wireless Optical Communication system (MIMO-UWOC). By using BER expressions, we also acquire an upper driven on the BER system. To estimate the BER expressions, we need quadrature formula of Gauss-Hermite as well as nearness to the addition of log-normal random variables.

Keywords: Multiple Input Multiple Output (MIMO), BER analysis, underwater wireless optical communications, log-normal turbulence-induced fading.

I. INTRODUCTION

Underwater wireless optical communication (UWOC) technology has been recently presented to suitablenecessity of high throughput and large data transmission of underwater communications. Acoustic communication systems had been examined and achievedin the past decades. UWOC systems have lower latency, high security of data and high range of bandwidth than acoustic communication systems These unique features propose UWOC system as anattractivesubstitute to acoustic communication systems.

UWOC systems are only appropriate for low range underwater communications, i.e., usuallybelow100 m. This occur due to underwater optical channelssevere turbulence, absorption and scattering effects. These effects of photons through propagation ofunderwater that causes attenuation and received optical signals timespreading[1]–[4]. Underwater optical turbulence effectoccur due to the unplanned variations of refractive index outcome in fading of the propagating optical signal [5], [6].

Previous works mainly targeted on the study of absorption and scattering effects of UWOC channels. In [1]–[3] the impulse response of channel turbulence has been pretended and designed using Monte Carlo simulation method. In [7], a cellular topology for UWOC network has been suggested and also the investigation of optical code division multiple access (OCDMA) technique uplink and downlink BERs.. For examples, in [6] by using Rytov methodthe scintillation index of optical plane and spherical waves schedule in weak oceanic turbulence channel has been evaluated and also investigate the average BER of an UWOC system with log-normal fading channel [8], [9]. Moreover, advantageous application of multi-hop transmission of underwater wireless OCDMA networks has been investigated [10].

In this paper we analytically study the BER performance of an UWOC system, with all effects of UWOC channels, include absorption, scattering and turbulence. In order to improve the system performance we use spatial diversity,.At receiver side we believe symbol-by-symbol processing and equal gain combining (EGC). In addition to evaluating the exact BER, we also decide an upper driven on the BER system from the inter-symbol interference (ISI) viewpoint. Moreover, to effectively compute the average BERs we use Gauss-Hermite quadrature formula and also approximate the addition of log-normal random variables with an equivalent random variable.

II. CHANNEL AND SYSTEM MODEL

A. Description of Channel

In underwater medium the propagation of light is under the power of three harm phenomena, namely absorption,turbulence and scattering. Absorption and scattering operationbecause loss, scattering of photons temporally spreads the received optical signals and limits the data transmission rate through activating ISI. In order to take into account absorption and scattering results of the underwater channel, we pretend the channel impulse response by Monte Carlo simulation method [1]–[3]. The turbulence-free impulse response of the UWOC channel between any two nodes, i^{th} and j^{th}, is denoted by $h_{0,\,ij}$ (t).

On the other hand, turbulence effects of the channel can be characterized by a multiplicative fading coefficient, $\tilde{h}_{ij}$[11] – [13]. For weak oceanic turbulence, the random variable with lognormal probability density function (PDF) forthe fading coefficient can be designed as a [8], [9] as;

$$f_{\tilde{h}_{ij}}(\tilde{h}_{ij}) = \frac{1}{2\tilde{h}_{ij}\sqrt{2\pi\sigma^2_{X_{ij}}}} \exp\left(-\frac{\left(\ln(\tilde{h}_{ij}) - 2\mu_{X_{ij}}\right)^2}{8\,\sigma^2_{X_{ij}}}\right) \quad (1)$$

Where$\mu_{Xij}$and $\sigma^2_{Xij}$are mean and variance of the Gaussian distributed log-amplitude factor $X_{ij} = \frac{1}{2}\ln(\tilde{h}_{ij})$. Therefore, the combined impulse response of the channel between any ith and jth nodes can be outline as $h_{i,j}(t) = \tilde{h}_{ij}\, h_{0,ij}(t)$. To protect that fading only makes fluctuations on the received optical signal, we should normalize fading coefficients as

$E[\tilde{h}_{ij}] = 1$, which implies that$\mu_{Xij} = -\sigma^2_{Xij}$.

.B. System Model

Consider an UWOC system with M number of transmitting lasers and N number of receiving apertures. We conclude on-off keying (OOK) modulation, i.e., the transmitter transmits each bit “1” with pulse shape P (t) and is off during transmission of data bit“0”. Therefore, the total transmitted signal can be defined as $S(t) = \sum_{k=-\infty}^{\infty} b_k P(t - kT_b)$, where $b_k \in \{0, 1\}$ is the k_{th}time slot transmitted data bit and $T_b$is the bit duration time.

In the case of transmitter diversity, all the transmitters transmit the same data bit b_k on their k_{th} time slot. Therefore, the transmitted signal of the ith transmitter can be characterized as$S_i(t) = \sum_{k=-\infty}^{\infty} b_k P_i(t - kT_b)$, where $\sum_{i=1}^{M} P_i(t) = P(t)$,for the sake of justice.

Each ith transmitter, TX_i is pointed to one of the receivers. The other receivers also capture the transmitted signal of TX_i due to multiple scattering of photons under water. In other words, the transmitted signal of TX_i,

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$S_i(t)$ signal passes through channel with impulse response of $h_{i,j}(t)$ to reach the jth receiver,R X_j. Therefore, the received optical signal from T X_i to thejth receiver can be determined as;

$$y_{i,j}(t) = S_i(t) * h_{i,j}(t) = \sum_{k=-\infty}^{\infty} b_k \tilde{h}_{ij} \Gamma_{i,j}(t - kT_b) \quad (2)$$

in which $\Gamma_{i,j}(t) = P_i(t) * h_{0,ij}(t)$ and $*$denotes convolution operation. Furthermore, RX_jreceives the transmitted signal of all the transmitters. Therefore, we can write the total received optical signal of RX_j as;

$$y_j(t) = \sum_{i=1}^{M} y_{i,j}(t) = \sum_{i=1}^{M} \sum_{k=-\infty}^{\infty} b_k \tilde{h}_{ij} \Gamma_{i,j}(t - kT_b) \quad (3)$$

At the receiver side various noise components, i.e., background light, dark current, thermal noise and signal-dependent shot noise all affect the system operation. As these components are supplement and independent of each other, we model them as an equivalent noise constituent with Gaussian distribution [13]. We also assume that the signal-dependent shot noise is negligible and therefore the noise variance is free of the received optical signal.

III. BER ANALYSIS

In this section we calculate the BER of UWOC system for single-input single-output (SISO) and MIMO (Multiple Input Multiple Output) configurations. We assume symbol-by-symbol deal with at the receiver side, which is insignificant in the presence of ISI[14]. In other words, the receiver merges its output current over each T_b seconds and then compares the result with an appropriate threshold to detect the received data bit. In thisdetection technique, the channel state information (CSI) is considered for threshold calculation [11].

A. SISO UWOC Link

In SISO scheme, the 0th time slot integrated current of thereceiver output can be expressed as:

$$\tau_{SISO}^{(bo)} = \mathbf{b_o} \tilde{\mathbf{h}}_{\gamma}^{(s)} + \tilde{h} \sum_{k=-L}^{-1} \mathbf{b_k}\, \gamma^{(k)} + \upsilon_{Tb} \quad (4)$$

Where $\tilde{h}$ is the channel fading coefficient , f is the optical source frequency $\gamma^{(s)} = R \int_0^{T_b} \Gamma(t)\,dt$,q = 1.602 × 10−19 C is electron charge, R= $\frac{\eta q}{hf}$ is the photo detector's responsivity, η is the photo detector'squantum efficiency, h = 6.626 × 10^{-34} J/s is Planck's constant, and L is the channel memory. Furthermore, $\gamma^{(k)} = R \int_0^{T_b} \Gamma(t - kT_b) = R \int_{-kT_b}^{-(k-1)T_b} \Gamma(t)\,dt$interprets the ISI effect and υ_{Tb} is the receiver integrated noise component, which has a Gaussian distribution with mean zero and variance $\sigma_{T_b}^2$[13].

Assuming the availability of CSI, the receiver compares itsintegrated current over each T_b seconds with an appropriatethreshold, i.e., with T h = $\tilde{h}_{\gamma}^{(s)}/2$ Therefore, the conditional probability of errors when bits "0" and "1" are transmitted,can be obtained respectively as;

$$P_{be|0,\tilde{h},b_k}^{(SISO)} = P_r(\tau_{SISO}^{(b_o)} \geq Th | b_o = 0)$$

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$$= Q\left(h \frac{[\frac{\gamma^{(s)}}{2} - \sum_{k=-L}^{-1} b_{k\gamma^{(k)}}]}{\sigma_{Tb}} \right) \quad (5)$$

$$P^{(SISO)}_{be|1,\tilde{h},b_k} = P_r(\tau^{(b_o)}_{SISO} \leq Th|b_o = 1)$$

$$= Q\left(h \frac{[\frac{\gamma^{(s)}}{2} + \sum_{k=-L}^{-1} b_{k\gamma^{(k)}}]}{\sigma_{Tb}} \right) \quad (6)$$

Where $Q(x) = (\frac{1}{\sqrt{2\pi}}) \int_x^{\infty} \exp(-y^2/2) dy$ is the Gaussian- Q function. The final BER can be obtained by averaging the

Conditional BER $P^{(SISO)}_{be|\tilde{h},b_k} = \frac{1}{2} P^{(SISO)}_{be|0,\tilde{h},b_k} + \frac{1}{2} P^{(SISO)}_{be|1,\tilde{h},b_k}$, over fading coefficient $\tilde{h}$ and all 2^L possible data sequences for b_ks, as follows;

$$P^{(SISO)}_{be} = \frac{1}{2^L} \sum_{b_k} \int_0^{\infty} P^{(SISO)}_{be|\tilde{h},b_k} f_{\tilde{h}}(\tilde{h}) d\tilde{h} \quad (7)$$

The form of Eqs. (5) and (6) suggests an upper bound on the system BER, from the ISI point of view. In other words, $b_k \neq_1$ maximizes Eq. (5), while Eq. (6) has its maximum value for $b_k \neq_0$. Indeed, when data bit "0" is sent the ill effect of ISI occurs when all the surrounding bits are "1" (i.e., when $b_k \neq_1$), and vice versa [14]. Concerning to these special sequences, the upper bound on the BER of SISO-UWOC system can be evaluated as;

$$P^{(SISO)}_{be,upper} = \frac{1}{2} \int_0^{\infty} [\, Q\left(\frac{\tilde{h}\left[\frac{\gamma^{(s)}}{2} - \sum_{k=-L}^{-1} \gamma^{(k)}\right]}{\sigma_{T_b}} \right) + Q\left(\frac{\tilde{h}\gamma^{(s)}}{2\sigma_{T_b}} \right)] f(\tilde{h}) d\tilde{h} \quad (8)$$

The averaging in Eqs. (7) and (8) over fading coefficient, involves integrals of the form $\int_0^{\infty} Q(C\tilde{h}) f_{\tilde{h}}(\tilde{h}) d\tilde{h}$, where C is a constant, e.g., $C = \gamma^{(s)}/2\sigma_{T_b}$ in second integral of Eq. (8).Such integrals can be calculated by Gauss-Hermite quadrature formula [15].

$$\int_0^{\infty} Q(C\tilde{h}) f_{\tilde{h}}(\tilde{h}) dh$$

$$= \int_{-\infty}^{\infty} Q(Ce^{2x}) \frac{1}{\sqrt{2\pi\sigma_X^2}} \exp\left(- \frac{(x-\mu_X)^2}{2\sigma_X^2} \right) dx$$

$$\approx \frac{1}{\sqrt{\pi}} \sum_{q=1}^{U} w_q Q(C \exp(2x_q \sqrt{2\sigma_X^2} + 2\mu_X)) \quad (9)$$

in which U is the order of approximation, w_q, q = 1, 2, ..., U,
are weights of U^{th} order approximation and x_q is the q^{th} zero of the Uth-order Hermite polynomial, $H_U(x)$ [11], [15].

B. MIMO UWOC Link

Assume a multiple-input multiple-output UWOC system with equal gain combiner (EGC). The integrated current of the receiver output can be expressed as;

$$\tau^{(b_o)}_{MIMO} = b_o \sum_{j=1}^{N} \sum_{i=1}^{M} \tilde{h}_{ij} \gamma^{(s)}_{i,j} + \sum_{j=1}^{N} \sum_{i=1}^{M} \tilde{h}_{ij} \sum_{k=-L_{ij}}^{-1} b_k \gamma^{(k)}_{i,j} + u^{(N)}_{T_b} \quad (10)$$

Where$\gamma_{i,j}^{(s)} = R \int_0^{T_b} \Gamma_{i,j}(t)dt, \gamma_{i,j}^{(k)} = R \int_0^{T_b} \Gamma_{i,j}(t - kT_b)dt = R\int_{-kT_b}^{-(k-1)T_b} \Gamma_{i,j}(t)dt$ and $\upsilon_{T_b}^{(N)}$is the integrated combinednoise component, which has a Gaussian distribution with meanzero and variance $N\sigma_{T_b}^2$.

Based on Eq. (10) and availability of CSI, in MIMO scheme the receiver selects the threshold value as $Th_{MIMO}=\sum_{j=1}^{N}\sum_{i=1}^{M}\tilde{h}_{ij}\gamma_{i,j}^{(s)}/2$. Following equation for conditionalBER.

$$P_{be|b_0,\tilde{H},b_k}^{(MIMO)} = Q\left(\frac{\sum_{j=1}^{N}\sum_{i=1}^{M}\tilde{h}_{ij}\gamma_{i,j}^{(s)} - (-1)^{b_0}\sum_{j=1}^{N}\sum_{i=1}^{M}\tilde{h}_{ij}\sum_{k=-L_{ij}}^{-1} 2b_k\gamma_{i,j}^{(k)}}{2\sqrt{N}\sigma_{T_b}}\right) (11)$$

in which $\tilde{H} = \{\tilde{h}_{11},\tilde{h}_{12}, ...,\tilde{h}_{MN}\}$ is the fading coefficients' vector. Assume the maximum channel memory to be $L_{max} = \max\{L_{11},L_{12}, ...,L_{MN}\}$, then the average BER of MIMO –UWOC system can be obtained by averaging over $\tilde{H}$ (through M × N-dimensional integral) as well as averaging over all $2^{L_{max}}$ sequences for b_ks;

$$P_{be}^{(MIMO)} = \frac{1}{2^{L_{max}}}\sum_{b_k}\int_{\tilde{H}}\frac{1}{2}\left[P_{be|1,\tilde{H},b_k}^{(MIMO)} + P_{be|0,\tilde{H},b_k}^{(MIMO)}\right]f_{\tilde{H}}(\tilde{H})d\tilde{H} (12)$$

Where $f_{\tilde{H}}(\tilde{H})$ is the joint PDF of fading coefficients in $\tilde{H}$.

Similar to Section III-A, the upper bound on the BER of MIMO-UWOC system can be evaluated by considering thetransmitted data sequences as $b_{k\neq 0}=1$ for $b_0 = 0$ and $b_{k\neq 1}= 0$ for $b_0 = 1$. Moreover, similar to Eq. (9) the M ×N-dimensional integral in Eq. (12) can be approximated byM×N-dimensional series, using Gauss-Hermite quadratureformula.

It's worth noting that the sum of random variables in Eq. (11) can be effectively approximated by an equivalent random variable, using moment matching method [16]. Inother words, we can reformulate the numerator of Eq. (11)as $\beta^{(b_0)} = \sum_{j=1}^{N}\sum_{i=1}^{M} G_{i,j}^{(b_0)}\tilde{h}_{ij}$ i.e., the weighted sum ofM ×N random variables. The weight coefficients are definedas $G_{i,j}^{(b_0)} = \gamma_{i,j}^{(s)} + (-1)^{b_0+1}\sum_{k=-L_{ij}}^{-1} 2b_k\gamma_{i,j}^{(k)}$. In the special case of log-normal distribution for fading coefficients, $\beta^{(b_0)}$can be approximated with an equivalent log-normal random variable as$\beta^{(b_0)}\approx\alpha^{(b_0)} = \exp(2z^{(b0)})$, with log-amplitude mean $\mu_{z^{(b_0)}}$and variance $\sigma_{z^{(b_0)}}^2$of [17];

$$\mu_{z^{(b_0)}} = \frac{1}{2}\ln\left(\sum_{j=1}^{N}\sum_{i=1}^{M} G_{i,j}^{(b_0)}\right) - \sigma_{z^{(b_0)}}^2 \qquad (13)$$

$$\sigma_{z^{(b_0)}}^2 = \frac{1}{4}\ln\left(1 + \frac{\sum_{j=1}^{N}\sum_{i=1}^{M}\left(G_{i,j}^{(b_0)}\right)^2\left(e^{4\sigma_{X_{ij}}^2} - 1\right)}{\left(\sum_{j=1}^{N}\sum_{i=1}^{M} G_{i,j}^{(b_0)}\right)^2}\right) \qquad (14)$$

Then averaging over fading coefficients reduces to one dimensional integral of

$$P_{be|b_0,b_k}^{(MIMO)} \approx \int_0^{\infty} Q\left(\frac{\alpha^{(b_0)}}{2\sqrt{N}\sigma_{T_b}}\right) f_{\alpha^{(b_0)}}\left(\alpha^{(b_0)}\right)d\alpha^{(b_0)} \qquad (15)$$

this can be effectively calculated using Eq. (9)

IV. CONCLUSION

In this paper we examine the calculated BER of a MIMO-UWOC system with equal gain addition and symbol by- symbol processing. Our analytical operation included all the annoying effects of the UWOC channels, i.e., absorption,scattering and fading. We obtained both the exact and upper driven BER expressions. We also use Gauss-Hermite quadrature formula to calculate more accurate averaging integrals with finite series. Moreover, we approximated the weighted sum of log-normal random variables with an equivalent log-normal random variable to reduce M × N- dimensional integrals of averaging to one-dimensional integrals. In addition, we recognize that MIMO transmission can introduce aimportant performance development in relatively high turbulent UWOC.

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