International Journal of Trend in Research and Development, Volume 2(3), ISSN: 2394-9333
www.ijtrd.com

IMPULSE RESPONSE MODELING FOR SUBMARINE WIRELESS OPTICAL COMMUNICATION LINK

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Abstract **- Underwater wireless optical communications (UWOC) has attracted considerable attentions as an alternative technology to traditional acoustic approach. As a special type of free space optical (FSO) communications, UWOC systems employ the blue/green region of visible light spectrum to realize data transmission since this region of light suffers lowest attenuation in natural water. The multiple scattering effect may spread beam pulse both temporally and spatially, which plays a key role in beam propagation. The spatial beam spreading has been studied. More recently, the impulse response of underwater optical links has been studied. Most prior works have adopted Monte Carlo approach to model the impulse response of UWOC links. Instead of Monte Carlo method, Jaruwatanadilok developed an analytical model of impulse response based on the vector radiative transfer theory. Wei et al. have proposed an inverse Gaussian function to model the impulse response of UWOC links. Their work only focused on the half amplitude width extension between the transmit and receive pulses in time domain without comparing the theoretical shape of impulse response with that from either Monte Carlo simulations or experiment.**

Keyword: Monte carlo model; Double gamma model

I. INTRODUCTION

Underwater wireless communications has been proposed for submarine communications due to the felicity and scalability. Underwater acoustic communications which utilizes acoustic waves to transmit information has been widely studied. As the frequently activities of oceanic exploitation recently, the acoustic method is not able to meet the requirements of large data and high speed communications.

In recent years, underwater wireless optical communications (UWOC) has attracted considerable attentions as an alternative technology to traditional acoustic approach. As a special type of free space optical (FSO) communications, UWOC systems employ the blue/green region of visible light spectrum to realize data transmission since this region of light suffers lowest attenuation in natural water. Compared with acoustic communications, UWOC systems can provide high security, low time delay and a much higher data rate up to hundreds of Mbps in relatively short ranges (typically shorter than 100 meters). Due to these advantages, UWOC has numerous applications such as real-time video communications, remote sensing and navigation, imaging as well as high throughput sensor network.

In this paper, we analyze the optical characteristics of seawater and present a closed-form expression of double Gamma functions to model the channel impulse response. The double Gamma functions model fits well with Monte Carlo simulation results in turbid seawater such as coastal and harbor water. The bit-error-rate (BER) and channel bandwidth are further evaluated based on this model for various link ranges. Numerical results suggest that the temporal pulse spread strongly degrades the BER performance for high data rate UWOC systems with on-off keying (OOK) modulation and limits the channel bandwidth in turbid underwater environments.

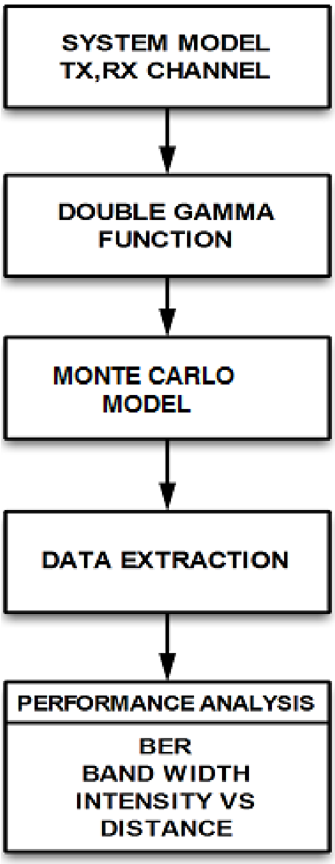

Figure 1.1 Block Diagram of Proposed System

II. LINK CHARACTERISTICS AND SYSTEM MODEL

A. Optical Characterization of Seawater

The interactions between eachphoton and seawater contain absorption and scattering through beam propagation. Absorp-tion is an irreversible process where the energy of photons lost thermally by interacting with water molecule and other particles. In scattering process, the transmit direction of each photon is changed by the interactions between photons and seawater, which may cause energy loss since less photons are captured by the receiver. The energy loss of the non-scattered light caused by absorption and scattering processes can be evaluated by absorption coefficient a (λ) and scattering coefficient b (λ), respectively. The extinction coefficient (also known as attenuation coefficient in ocean optics) c (λ)= a (λ)+b (λ) describes the total effects of absorption and scattering on energy loss. The values of a (λ), b (λ) and c (λ) vary with the water type and source wavelength λ.

Unlike the FSO links in atmosphere, the UWOC links encounter a large number of suspended particles such as dissolved salts, mineral components, organic matter and etc. in underwater environment. Then the scattering order of light is typically high in seawater especially in coastal and harbor water. There exist three types of scattering in water such as small scale scattering (≫λ) caused by density fluctuations due to random molecular motions (also known as pure seawater scattering), particle scattering by large suspended particles (>λ), and large scale scattering (≫λ) resulting from turbulence-induced refractive fluctuations. Note that the large scale scattering caused by turbulence has not been fully studied yet and is omitted by most prior works in UWOC.

In this paper, we therefore only consider the pure seawater scattering and particle scattering with coefficients b_{sw} (λ) and b_p (λ), respectively, which implies the total scattering coefficient b (λ)= b_{sw} (λ)+b_p (λ). To study the effects of multiple scattering, the scattering phase function (SPF) β (θ,λ) is introduced to describe the energy distribution of scattering light versus scattering angle θ with

$$1 = 2\pi \int_0^\pi \beta(\theta,\lambda)\sin\theta d\theta$$

Since we mainly focus on the propagation of blue/green region of visible light, we simply omit the parameter λ for brevity hereafter. Taking into account the particle scattering caused by large suspended organic or inorganic particles, seawater SPF is strongly peaked in small forward angles and measured by Petzold for selected water types. Several closed-form expressions have been adopted to represent the SPF of seawater such as HG function and two terms HG (TTHG) function.

The HG function is typically used to describe the SPF of dispersive medium such as clouds with the expression as

$$\beta_{\mathrm{HG}}(\theta) = \frac{1-g^2}{4\pi(1+g^2-2g\cos\theta)^{\frac{3}{2}}}$$

Where θ is the scattered angle and g is the average cosine of θ . Mobley averaged the measurement based on Petzold’s results for different water types and subtracted the effects of pure seawater to obtain the SFP for particle scattering which is also referred to as particle phase function (PPF). To release the restriction of limited data points of measured PPF, Mobley then proposed a scheme by utilizing linear interpolation for $\theta \geq 0.1^\circ$ and the assumption that the PPF is proportional to $\theta^{-1.346}$ for $\theta < 0.1^\circ$, and also confirmed the validity. By this means, the PPF can be added more data points, which is referred to as linear interpolated PPF hereafter for simplicity. The results obtained based on the rules above are adopted in this paper to represent the PPF denoted as $\beta_p(\theta)$.

The total SPF β (θ) including the effects of pure seawater and particles is given by,

$$\beta(\theta) = \frac{b_{sw}}{b}\beta_{sw}(\theta) + \frac{b_p}{b}\beta_p(\theta)$$

In this paper, we mainly focus on the temporal pulse spread in turbid environments such as coastal and harbor water with channel parameters summarized. Generally, the processes of absorption and multiple scat-tering of light propagation in seawater can be described theoretically by the radiative transfer equation (RTE), which can be solved both numerically and analytically.

B. System Model

In this section, we present the system model for UWOC links as well as the general link geometry. As shown, we consider a UWOC system with a precisely aligned line-of-sight (LOS) link and receiver locating on the plane perpendicular to the beam axis. The beam pulse emitted from the source is deteriorated temporally through the underwater channel, and then corrupted by the noise in the receiver reception. which can be approximated and modeled as additive white Gaussian noise (AWGN). In this paper, with the assumption of AWGN at the receiver, the UWOC system can be modeled as

$$y(t) = h(t) * x(t) + n(t),$$

where x(t) and y (t) are the transmit and receive signal, respectively, h (t) is the impulse response of UWOC links, n (t) is the AWGN, and ∗ denotes the convolution operator. The receive current noise in our work takes into account the effects of background radiation, dark current, shot noise and thermal noise, which can be estimated based on prior studies with the noise variances given by

$$\begin{aligned} \sigma_0^2 &= \sigma_b^2 + \sigma_d^2 + \sigma_t^2 \\ \sigma_1^2 &= \sigma_b^2 + \sigma_d^2 + \sigma_s^2 + \sigma_t^2 \end{aligned}$$

where σ^2_0 and σ^2_1 represent the variance of the noise for empty and pulse slots, respectively.σ^2_b, σ^2_d, σ^2_t and σ^2_s are the variances of background radiation, dark current, thermal noise and shot noise, respectively. The exact noise distribution can be found for the realistic devices such as avalanche photodiode (APD), which is out of the scope of this paper.

Each photon may interact with the medium when propagating Δs distance, which can be determined by $\Delta s = -\ln \xi_s/c$ with ξ_s as an uniform distributed random variable in the interval of [0 , 1] . After the distance between two interactions Δs being determined, the spatial position and propagation time can be updated accordingly. The photon weight can be updated by

$$W^{i+1} = \left(1 - \frac{a}{c}\right) W^i$$

where W^i is the photon weight after the i th interaction with medium. The scattering may also affect the direction of photon trajectory which changes with the scattering zenith angle θ_s as

$$\xi_\theta = 2\pi \int_0^{\theta_s} \beta(\theta) \sin\theta d\theta$$

Then the scattering azimuth angle φ_s can be computed by

$$\phi_s = 2\pi \xi_\phi$$

The root mean square errors (RMSE) of impulse response by double Gamma functions for each scenario with 180◦ FOV are summarized. We have also verified that the RMSE for each scenario with other FOVs such as 20° and40° are still less than 5%. Hence we can conclude that the double Gamma functions can well model the impulse response of UWOC LOS links, which benefits the system design and performance evaluation of UWOC systems.

As mentioned earlier, has implied the dependence of the transition between non-scatte ring and multiple scattering light dominant regions on water types and system configurations such as source divergence, receiver aperture and FOV are referred to as wide configuration systems while the UWOC systems with relatively small divergence of source, compact receiver and narrow FOV are referred to as narrow configuration systems. Therefore may dominate even at relatively small τ . For wide configuration systems, however, the double Gamma functions model will not break down even for relatively small τ and be valid obviously for large τ. unfortunately, the exact relationship among transition, water types and system configurations still remains unknown to the best of our knowledge.

III. SIMULATION RESULT

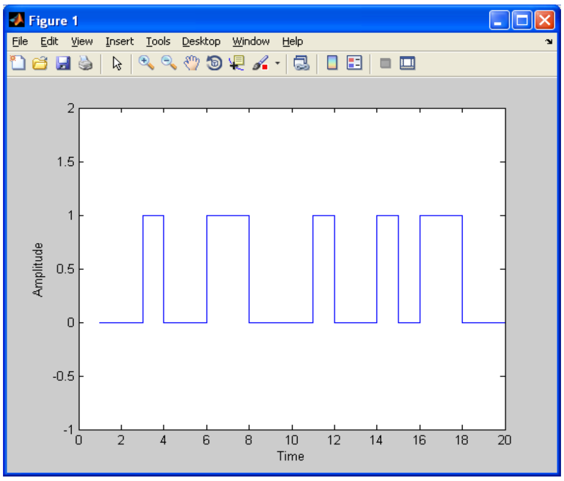

Figure 3.1 Random binary Data

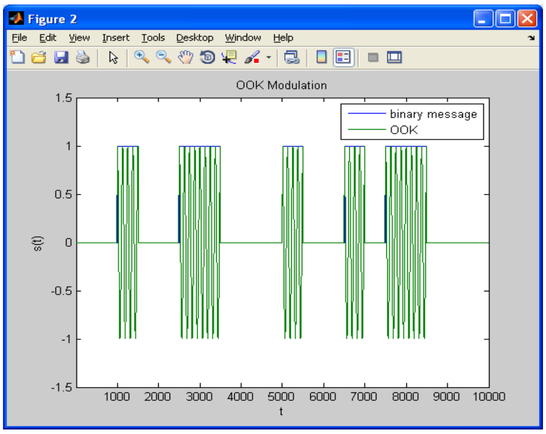

Figure 3.2 OOK Modulated Data

Blue color indicate Binary Data Green clolor Indicate After On-off key modulation.

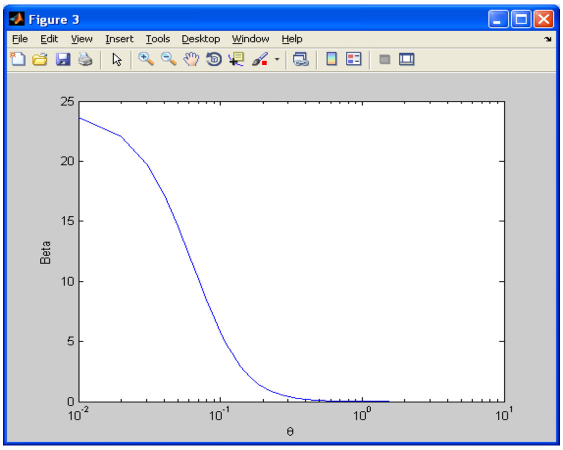

Figure 3.3 Light Incident angle vs Scattering

If incident angle increases the scattering value decreases rapidly,it’s used for Channel modeling.

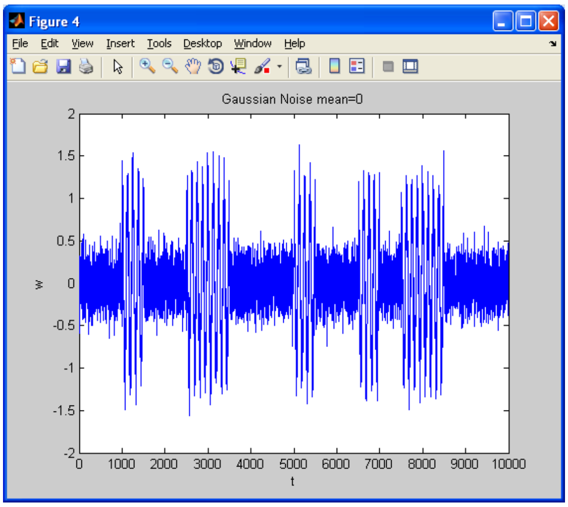

Figure 3.4 Add Noise and channel scattering in modulated signal

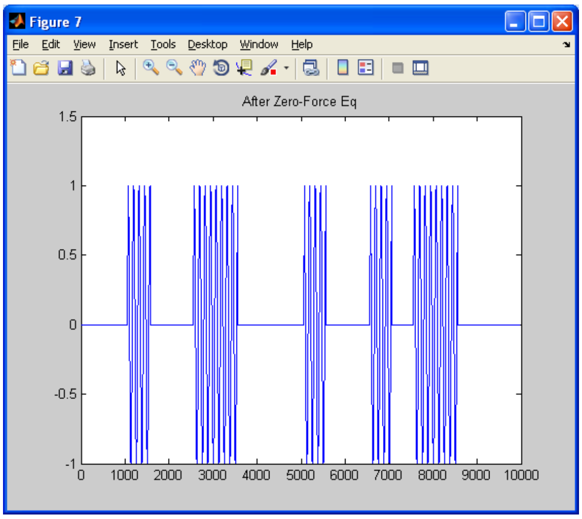

Figure 3.5 After apply zero-force Equalization

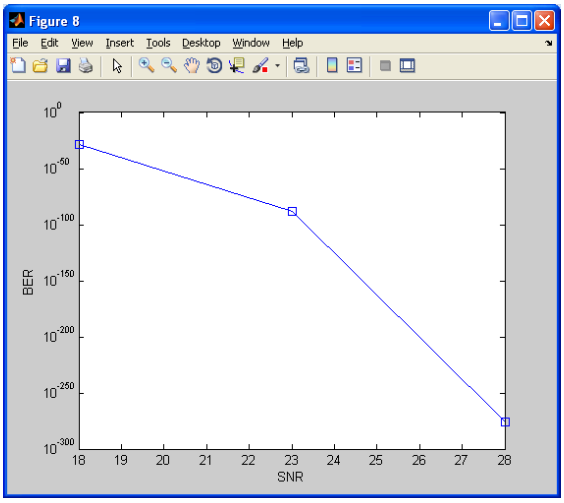

Figure 3.6 Signal to Noise Ratio

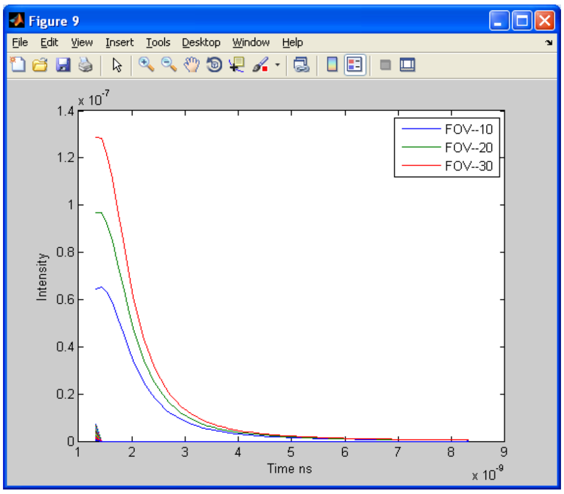

Figure 3.7 Impulse Response of Channel with different Field of View

IV. CONCLUSION

In this paper, we have investigated the temporal dispersion of UWOC links due to the multiple scattering effect in turbid environments. A closed-form expression of double Gamma functions is presented to model the channel impulse response, which fits well with the Monte Carlo simulations using actual SPF for various link ranges in coastal and harbor water. This provides a plausible and convenient way to evaluate the system performance such as BER and bandwidth based on this simple closed-form model of impulse response. Numerical results suggest that the 3-dB channel bandwidth decreases for large attenuation lengths where light suffers much temporal spread-ing, meanwhile the ISI degrad es BER performance heavily for high bit rates system without equalization.

V. FUTURE WORK:

As future work to this project we shall apply Optimization based on Particle swarm optimization, by applying this optimization method we shall have minimum BER and low time convergence.

VI. REFERENCES

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