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UNDERWATER WIRELESS OPTICAL COMMUNICATION USING MONTE CARLO SIMULATION

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Abstract- In Underwater Wireless Optical Communication (UWOC) links, multiple scattering may degrades the system performance in Single gamma function. In this project we analyze the optical characteristics of seawater and derived the closed form expression of double gamma function to model the channel impulse response. It is evaluated with Monte Carlo Simulation. Using this we analyze the performance of the system such as BER and channel bandwidth. It will give better performance than the conventional methods of UWOC systems.

Keywords: UWOC, Double gamma Function, Monte Carlo Simulation, Channel Bandwidth, BER.

I. INTRODUCTION

Underwater wireless communications has been proposed for submarine communications due to the flexility and scalability. Underwater acoustic communications which utilizes acoustic waves to transmit information has been widely studied and implemented in the past decades. However, the channel bandwidth of underwater acoustic links is typical limited to kHz since the sound is decayed in the ocean proportionally to its frequency. And the lower propagation speed typically 1500 m/s leads to a large time delay for acoustic system. Meanwhile, the multipath reflection of sound may cause signal fading and security issues. 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.

Prior studies have shown that the optical beam suffers absorption and scattering through propagation in the seawater. The absorption and scattering may introduce the effect of energy loss and direction changing for the optical beams, respectively. In turbid medium especially coastal and harbor water, the transmitted photons are scattered multiple times, which is referred to as multiple scattering. 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 in and exerts a positive impact on system performance. However the temporal beam spreading will introduce the temporal dispersion and therefore corrupt the receive signal especially for turbid water types.

II. EXISTING SYSTEM

Underwater acoustic communications which utilizes acoustic waves to transmit information has been widely studied and implemented in the past decades. However, the channel bandwidth of underwater acoustic links is typical limited to kHz since the sound is decayed in the ocean proportionally to its frequency. And the lower propagation speed typically 1500 m/s leads to a large time delay for acoustic system. Meanwhile, the multipath reflection of sound may cause signal fading and security issues.

Acoustic communication underwater remains a proven technique, optics stand poised to provide data transfer several orders of magnitude above current acoustic techniques.

Acoustic techniques have enjoyed success as an alternative to RF in this environment and many experimental and commercial systems have been reported both in the laboratory and in the field. The abundance of acoustic systems stems mainly from the fact that sound can propagate with minimum attenuation over long distances (hundreds of kilometers) underwater. Propagation however is highly dependent on frequency and acoustic systems.

A single Gamma function to model the impulse response for the non-line-of-sight (NLOS) link geometry or the links with τ . The light field may be too diffused in these scenarios, which can be treated as a special case of double Gamma functions model.

III. PROPOSED SYSTEM

A. Ook modulation

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.

B. Double gamma functions

We present the closed-form expression of the impulse response for UWOC links. Based on the measurement , the energy transportation in UWOC links can be divided into two regions where the non-scattering and multiple scattering light are dominant, respectively. For small values of the attenuation length (also known as optical thickness) τ defined as $\tau = cL$ [5] with c as the extinction coefficient and L as the physical link range, the non-scattering light dominates at the receiver side where the path loss versus τ follows the Beer's law . As τ increases.

The transition between these two regions occurs, after which the multiple scattering light dominates and the path loss deviates from Beer's law. Also implies negligible temporal dispersion of UWOC links in the non-scattering light dominating region, which is verified by simulating the impulse response in clean water, and increasing temporal dispersion in the multiple scattering light dominating region as τ increases.

In this work, we mainly focus on the impulse response modeling of UWOC links in coastal and harbor water environment where τ has relatively large values.

C. Closed form expression

The double Gamma functions has been firstly adopted to model the impulse response in clouds ,where τ is no less than 20. Although the channel properties of seawater differ from clouds , motivated by the dispersive nature of these two medium, we apply the double Gamma functions to model the impulse response in UWOC links with relatively large value of τ where multiple scattering light may dominate. The closed-form expression of the double Gamma functions is

$h(t) = C1\Delta te^{-C2\Delta t} + C3\Delta te^{-C4\Delta t}, \ (t \geq t_0)$

closed - form expression

IV. SYSTEM MODEL ANALYSIS

A. System model

We present the system model for UWOC links as well as the general link geometry. I 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. In our analysis, the underwater environment is assumed to be an ideal isotropic and homogeneous medium without flowing and turbulence. Therefore underwater wireless optical channel can be treated as a linear time-invariant system.

We consider the temporal correlation of irradiance caused by medium flowing as well as fading effects induced from both turbulence and random distribution of particles. The noise of UWOC systems depends on the type of receiver. For an ideal photon counting receiver where the number of detected photons in each slot follows the Poisson distribution, the receiver noise has sources mainly from the background radiation and dark current. For a more realistic receiver with the photon detector and load electronic devices, the receiver noise is a combination of background radiation noise, shot noise, dark current noise, and thermal noise.

B. Additive white Gaussian noise

Additive white Gaussian noise (AWGN). In this project, with the assumption of AWGN at the receiver, the UWOC system can be modeled

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

C. System model and link geometry of the uwoc link – block diagram

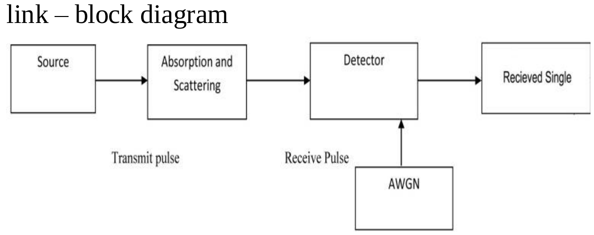

Fig. 1 System model and link geometry of the UWOClink

V. IMPULSE RESPONSE MODELING

A. Monte Carlo simulation

As a numerical solution of RTE, Monte Carlo approach employs the statistical method to evaluate the channel characteristics by generating numerous photons and then simulating the interactions of each photon with the medium. Compared with the analytical solutions of RTE, Monte Carlo approach is more flexible for various link geometry without restrictions on the scattering angles and therefore is widely employed in simulating the light propagation in dispersive medium, e.g., beam propagation in seawater.

We adopt the Monte Carlo approach similar with basic rules summarized as follows. Initially, a set of photons is emitted by the source with specific divergence angle. The interactions for each photon with the medium contain absorption and scattering and can be modeled by changing the basic attributes of each photon such as the position, transmit direction, propagation time and weight during the propagation. These attributes are recorded when the photon reaches the receiver. By collecting and analyzing the basic attributes for all received photons statistically.

I can obtain the channel characteristics such as impulse response and path loss. Detailed steps are provided in the following section. The basic attributes of each photon include the photon position in Cartesian coordinates (x, y, z), the direction of transmission described by zenith angle θ and azimuth angle φ1, propagation time t and weight w. For the source with narrow emission aperture, each photon is initialized at the position (0, 0, 0) with zero start time and unit weight. The emitted direction of each photon depends on both the divergence angle and angular intensity distribution of the source with details .

Each photon may interact with the medium when propagating Δs distance, which can be determined by $\Delta s = -\ln \xi s/c$ with ξs 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 Wi 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 θs as

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

where $\xi\theta$ is an uniform distributed random between 0 and 1 with $\beta(\theta)$ as the SPF. θs can be obtained by solving numerically. Then the scattering azimuth angle φs can be computed by

$$\varphi_s = 2\pi\xi_\varphi$$

where $\xi_\varphi$is also an uniformly distributed random variable in. Note that the scattering angles are the relative rotation angles to the direction before interactions. Hence, the next step is to transfer the direction of the photoninto the absolute coordinate system.

The tracking of each photon should be stopped either the photon reaches the receiver plane2 or its weight is lower than certain threshold. In the former case, the attributes including position, direction, propagation time and weight are recorded for each photon. In the latter case, the photon should be excluded from the simulation as suggested since the photons with lower weight than threshold have negligible contribution to the total receive photons.

When the photons reach the receiver plane, only the ones within the receiver aperture and with zenith angles less than the half angle of receiver FOV are selected as the detected photons.

B. Double gamma functions model

I will present the closed-form expression of the impulse response for UWOC links. Based on the measurement the energy transportation in UWOC links can be divided into two regions where the non-scattering and multiple scattering light are dominant, respectively. For small values of the attenuation length (also known as optical thickness) τ defined as $\tau = cL$ with c as the extinction coefficient and L as the physical link range, the non-scattering light dominates at the receiver side where the path loss versus τ follows the Beer's law.

As τ increases, the transition between these two regions occurs, after which the multiple scattering light dominates and the path loss deviates from Beer's law. Also implies negligible temporal dispersion of UWOC links in the non-scattering light dominating region, which is verified by simulating the impulse response in clean water, and increasing temporal dispersion in the multiple scattering light dominating region as τ increases.

In this project, we mainly focus on the impulse response modeling of UWOC links in coastal and harbor water environment where τ has relatively large values. The double Gamma functions has been firstly adopted to model the impulse response in clouds, where τ is no less than 20.

Although the channel properties of seawater differ from clouds, motivated by the dispersive nature of these two medium, we apply the double Gamma functions to model the impulse response in UWOC links with relatively large value of τ where multiple scattering light may dominate. The closed-form expression of the double Gamma functions is

$$h(t) = C1\Delta te^{-C2\Delta t} + C3\Delta te^{-C4\Delta t},\ (t \geq t_0)$$

- Where C1,C2,C3 and C4 are the four parameters to be solved.
- Δt = t-t_0.
- Where "t" represents (time scale).
- And "t_0" represent (propagation time).
- The ratio link range L over light speed *v in water.*

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The double Gamma functions model and $h_{mc}(t)$ is the Monte Carlo simulation results of impulse response. argmin(·) is the operator to return the argument of the minimum. Then can be solved by curve fitting approach using scientific computing software such as MATLAB.

The relationship between system configurations (such as source divergence, aperture size and FOV) and the validation of our model will be discussed in details later. The system geometry is a precisely aligned LOS link with receiver locating at the plane perpendicular to the beam axis. Based on these settings, we simulate the beam propagation of various link ranges and FOV in coastal and harbor water by the Monte Carlo method using at least 10^9 photons for each scenario.

The root mean square errors (RMSE) of impulse response by double Gamma functions for each scenario with 180◦ FOV. We have also verified that the RMSE for each scenario with other FOVs such as 20◦ and 40◦ 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.

By simulating the impulse response for narrow configuration systems, I have verified that the double Gamma functions will be valid only for relatively large τ corresponding to turbid water type.

Large link range where the temporal dispersion is in negligible and therefore the ideal delta function without ISI is no longer suitable to describe the system.

VI. CONCLUSION

We investigate the multiple scattering effect of UWOC. Then we designed the system model to create the impulse response using double gamma function and we used Monte Carlo simulation to analyze the channel characteristics.

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