



ANALYSIS OF OUTAGE PROBABILITY IN COHERENT OFDM AND FAST-OFDM SYSTEMS IN TERRESTRIAL AND UNDERWATER WIRELESS OPTICAL COMMUNICATION LINKS

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ABSTRACT

A model for a coherent orthogonal frequency division multiplexing (OFDM) system as well as Fast-OFDM system in both terrestrial and underwater wireless optical communication, has been proposed, that can be tuned with the virtual local oscillator, under the Gamma-Gamma atmospheric turbulence channel. Not only just considering the intensity scintillation but also considering the phase noise caused by atmospheric turbulence effect on the performance of the system. Analysis will be done under the premise of the different number of subcarriers, the influence of each parameter of atmospheric channel on the bit error, and the communication interrupt performance of the OFDM-FSO and F-OFDM-FSO systems, respectively. The result will confirm that the Fast-OFDM in both terrestrial and underwater wireless optical system may obtain higher sensitivity and hence overcome the bad atmosphere influence to obtain good performance of the system, even after the subcarrier spacing is reduced to half of that in the conventional OFDM systems.

Keywords: OFDM, F-OFDM, FSO, underwater.

1. INTRODUCTION

Free-space optical communication (FSO) is an optical communication technology that uses light propagating in free space to transmit data for telecommunications or computer networking. "Free space" means air, outer space, vacuum, or something similar. This contrasts with using solids such as optical fiber cable or an optical transmission line. The technology is useful where the physical connections are impractical due to high costs or other considerations.

A. Motivation

Recently, there has been a resurgence of research interest in this technique, due to its benefits including higher data transmission rates, greater bandwidth, lower power consumption and better security over radio frequency (RF) communications. However, atmospheric attenuation and turbulence due to atmospheric stochastic volatility may lead directly to intensity scintillation and phase fluctuation, which seriously affects stability and reliability when the optical signal of an FSO communication system is transmitted through an atmospheric channel. Orthogonal frequency division multiplexing (OFDM) technology can not only produce higher data transmission rates, but also can effectively suppress inter symbol interference (ISI), due to its increased robustness against frequency selective fading and narrow-band interference, and high utilization of the frequency spectrum, which can prevent the random fading effect caused by the atmospheric channel, which gradually appears within FSO systems.

B. Background

Recent research on OFDM technology in the FSO communication field has mainly focused on the direct detection method. There are two main areas of research. The first area of research is the BER performance of the

OFDM FSO system in the Gamma-Gamma channel or logarithmic channel, which is affected by the subcarrier modulation method and modulation order at different turbulence intensity levels. The second area focuses on introduction of technologies that can optimize the performance of OFDM-FSO systems.

2. SIMULATION DESCRIPTION

The primary goal of the simulation is to analyze the performance of OFDM and F-OFDM system in terrestrial as well as underwater wireless optical communication links. A detailed comparison will be drawn out so as to select the system that gives us better results and is more efficient than the other, considering the turbulent conditions present in both the channels. The analogy between the free space optics and underwater wireless optics helps us in giving an idea about the various factors responsible for underwater optical turbulence.

A. Free space optics

FSO is a complementary technology to the RF technology and optical fibre networks. The theory of FSO is essentially the same as that for fiber optic transmission. The difference is that the energy beam is collimated and sent through clear air or space from the source to the destination, rather than guiding it through an optical fiber.

Some of the major advantages of using this technology are:

- License-free long-range operation. (in contrast with radio communication)
- Installation cost is very low as compared to laying Fiber. (FSO costs are as low as 1/5 of fiber network costs)
- Immunity from electromagnetic interference.



- Invisible and eye safe, no health hazards so even a butterfly can fly unscathed through the beam.
- Highly secure transmission possible as it cannot be detected with RF meter or spectrum analyzer due to very narrow and directional beams.
- Deployment of FSO systems is quite easily and quickly.
- High data rates, upto 2.5 Gbps at present and 10 Gbps in the near future.

B. Atmospheric turbulence

In free-space optical communication links, atmospheric turbulence causes fluctuations in both the intensity and the phase of the received light signal, impairing link performance. Atmospheric turbulence can degrade the performance of free-space optical links, particularly over ranges of the order of 1 km or longer. Inhomogeneities in the temperature and pressure of the atmosphere lead to variations of the refractive index along the transmission path, which deteriorate the quality of the received signal and can cause fluctuations in both the intensity and the phase of the received signal. These fluctuations can lead to an increase in the link error probability, limiting the performance of the OFDM as well as F-OFDM-FSO system.

Some of the key signal propagation impairment factors in free space are:

- a) Fog
- b) Absorption
- c) Scattering
- d) Scintillation
- e) Physical Obstruction

C. Underwater optics

Radio waves suffers high attenuation in water and acoustic communication systems are relatively low data rates, we need to develop an optical communication system that is capable of supporting underwater wireless communication in a high data rate. In this simulation, a new and simple analytical method based on the atmospheric turbulence model is developed to evaluate the capacity of underwater optical links with the effects of scattering and absorption in realistic ocean water. Limited communication bandwidth presents a considerable challenge to underwater wireless optical communication application.

The factors and the turbulence parameters that are responsible for the interruption in the communication are required to be mitigated as to get a reliable optical communication system that helps in the underwater communication.

D. Underwater optical turbulence

Applying FSO underwater is not a trivial matter. The underwater environment is far more challenging than air, not only due to increased channel attenuation, but also significant variability and more sources of communication

disruption. Natural oceans are rich in dissolved and particulate matter, leading to a large range of conditions that an underwater communication system must satisfy.

The sources of noise that are responsible for underwater optical turbulence are discussed below:

- a) Absorption
- b) Phytoplankton
- c) Scattering
- d) Sunlight

E. Orthogonal frequency division multiplexing (OFDM)

Orthogonal Frequency Division Multiplexing (OFDM) is a method of encoding digital data on multiple carrier frequencies. A large number of closely spaced orthogonal sub-carrier signals are used to carry data on several low speed parallel data streams or channels.

Each sub-carrier is modulated with a conventional modulation scheme (i.e. quadrature amplitude modulation) at a low symbol rate, maintaining total data rates similar to conventional single-carrier modulation schemes in the same bandwidth.

F. Fast- orthogonal frequency division multiplexing

Reducing the spacing between subcarriers in OFDM system, results in improved bandwidth efficiency. Fast-OFDM is based on the OFDM principle with the advantage of having twice the bandwidth efficiency when compared to conventional OFDM, where the frequency separation of the subcarriers is $(1/2T)$ Hz, and T is the time interval.

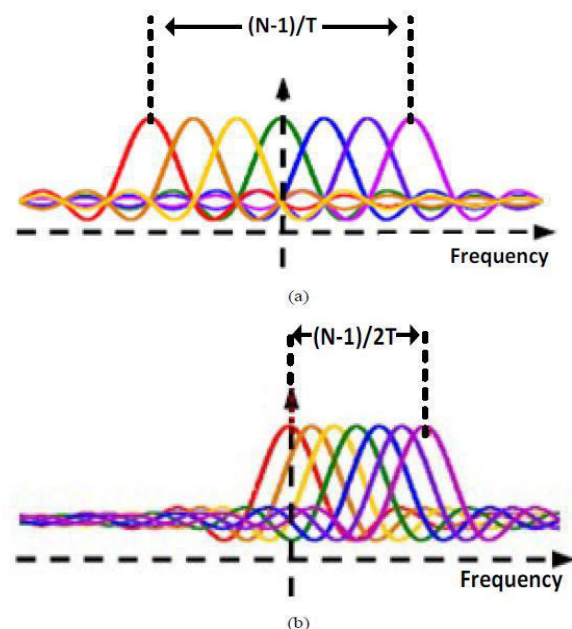


Figure-1. Frequency spectrum: (a) OFDM (b) F-OFDM.



3. DESIGN APPROACH

A. Atmospheric turbulence model

The Gamma-Gamma model describes the atmospheric fluctuation phenomena including the inner scale and outer scale, and is the product of two independent random processes, each of which has a gamma probability density function. The probability density function of light intensity fluctuation is given as:

$$f(I) = \frac{2(\alpha\beta)^{\frac{(\alpha+\beta)}{2}}}{\Gamma(\alpha)\Gamma(\beta)} I^{\frac{(\alpha+\beta-2)}{2}} K_{\alpha-\beta}(2\sqrt{\alpha\beta}I), \quad I > 0 \quad (1)$$

Where $Kn(.)$ is the modified Bessel function of second kind of order n . Also α and β are the large-scale and small-scale optical wave intensity scintillation.

$$\alpha = \left\{ \exp \left[\frac{0.49k_R^2}{\left(1 + 1.11k_R^{\frac{12}{5}}\right)^{\frac{5}{6}}} \right] - 1 \right\}^{-1}, \quad \beta = \left\{ \exp \left[\frac{0.51k_R^2}{\left(1 + 0.69k_R^{\frac{12}{5}}\right)^{\frac{5}{6}}} \right] - 1 \right\}^{-1} \quad (2)$$

$k_R^2 = 1.23C_n^2 k^7/6 L^{11/6}$ is the Rytov variance

When $\bar{\sigma}R^2 < 1$, this indicates weak turbulence, and when $\bar{\sigma}R^2 \approx 1$ this indicates medium turbulence, and when $\bar{\sigma}R^2 > 1$ this indicates strong turbulence.

B. Outage probability

The transmission reliability of the OFDM system can be verified from calculation of the outage probability. The probability that the instantaneous system SNR is either above or below the target SNR threshold value.

Closed form expression:

$$P_{\text{out}} = \Pr\left(\frac{E_s}{N_0} \leq \mu\right) = \Pr\left(\frac{\rho P_0 I^2 \delta^2 T}{2qBN} \leq \mu\right) = \int_0^{\frac{1}{\delta} \sqrt{\frac{2\rho qBN}{\rho P_0 T}}} f(I) dI \quad (3)$$

Let $x = \sqrt{2\rho qBN}/\rho P_0$ for the normalized threshold value

Outage Probability for OFDM system:-

$$P_{\text{out}} = \frac{(\alpha\beta)^{\frac{(\alpha+\beta)}{2}}}{\Gamma(\alpha)\Gamma(\beta)} \left(\frac{x}{\delta} \sqrt{\frac{N}{T}}\right)^{\frac{\alpha+\beta}{2}-1} G_{1,3}^{2,1} \left[\alpha\beta \frac{x}{\delta} \sqrt{\frac{N}{T}} \left| \frac{1-\frac{\alpha+\beta}{2}}{\frac{\alpha-\beta}{2}, \frac{\beta-\alpha}{2}, -\frac{\alpha-\beta}{2}} \right. \right]$$

Outage Probability for Fast-OFDM system:-

$$P_{\text{out}} = \frac{(\alpha\beta)^{\frac{(\alpha+\beta)}{2}}}{\Gamma(\alpha)\Gamma(\beta)} \left(\frac{x}{\delta} \sqrt{\frac{N}{2T}}\right)^{\frac{\alpha+\beta}{2}-1} G_{1,3}^{2,1} \left[\alpha\beta \frac{x}{\delta} \sqrt{\frac{N}{2T}} \left| \frac{1-\frac{\alpha+\beta}{2}}{\frac{\alpha-\beta}{2}, \frac{\beta-\alpha}{2}, -\frac{\alpha-\beta}{2}} \right. \right] \quad (4)$$

The above two expressions (1) & (2) will be used to find the large scale and small scale scintillation parameters.

C. Calculations

The values of the large scale and small scale scintillation parameters as well as the flicker factor are determined using the equation (1).

Table-1. Values of the scintillation parameters for free space optics.

Free space optics	α	β	SI
Weak Turbulence	6.05	4.47	0.43
Medium Turbulence	4.19	2.26	0.79
Strong Turbulence	4.34	1.31	1.17

Table-2. Values of the scintillation parameters for underwater wireless optics.

Underwater wireless optics	α	β	SI
Pure Sea Water	0.179	0.219	35.6623
Clean Ocean Water	0.114	0.037	272.8781
Deep Ocean Water	0.0405	0.0025	10301.2457

4. SIMULATION AND ANALYSIS

Figure 2(a) & (b) represent the communication in free space optics for $N = 128$ subcarriers.

- Function 1 & 4 both represent weak turbulent regions for the same value of α and β . Hence, they are the most stable and occupy the bottom-most position in the graph. The value of SI for weak turbulence being the lowest amongst all, $SI = 0.42598$.
- Function 2 & 5 both represent medium turbulent regions for the same value of α and β . Hence, they are the almost stable and occupy the middle position in the graph. The value of SI for medium turbulence being second in number, $SI = 0.786744$.
- Function 3 & 6 both represent strong turbulent regions for the same value of α and β . Hence, they are the least stable and occupy the top-most position in the graph. The value of SI for strong turbulence being the highest amongst all, $SI = 1.16966$.

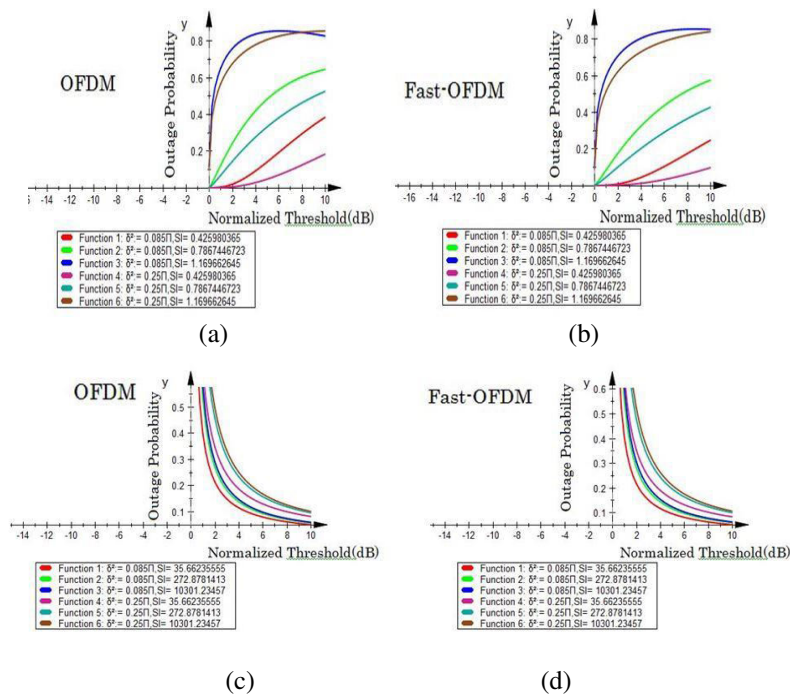


Figure-2. Outage probability of the coherent OFDM & F-OFDM system as a function of normalized threshold for $N=128$ numbers of subcarrier: (a) OFDM-FSO, (b) F-OFDM-FSO, (c) OFDM-UO, (d) F-OFDM-UO.

Figure 2(a) & (b) represent the communication in free space optics for $N = 128$ subcarriers.

- Function 1 and 4 both represent pure sea water sample for the same value of α and β . Hence, they are the most stable and occupy the left-most position in the graph. The value of SI for pure sea water sample being the lowest amongst all, $SI = 35.6623$.
- Function 2 and 5 both represent clean ocean water sample for the same value of α and β . Hence, they are the almost stable and occupy the middle position in the graph. The value of SI for clean ocean water sample being second in number, $SI = 272.8781$.
- Function 3 and 6 both represent coastal ocean water sample for the same value of α and β . Hence, they are the least stable and occupy the right-most position in the graph. The value of SI for coastal ocean water sample being the highest amongst all, $SI = 10301.23457$.

5. CONCLUSIONS

Raising the intensity scintillation and phase fluctuation will cause a significantly increased outage probability. The outage probability decreases while reducing the normalized threshold value.

The more the number of subcarriers, the faster the outage probability of the system increases with the increase of the normalized threshold values. The stability of the system can be improved by preferably controlling the threshold value.

Comparison between the three different types of graphs, shows that under the same conditions, the system

communication interruption probability increases as the number of subcarriers increases, because when the total transmission rate and required bandwidth of OFDM system are approximately constant, the adjacent subcarrier spacing becomes small as the number of subcarriers increases, which will exacerbate the interference between adjacent subcarriers and, thus, increase the communication interruption probability.

The simulation also indicates that the Fast-OFDM is a promising technique for providing a cost-effective, robust, high-speed solution, with half the bandwidth efficiency compared to conventional OFDM.

By analyzing the graphs of Fast-OFDM closely, we can see with half the bandwidth efficiency to that of coherent OFDM, we are getting approximately the same values for the outage probability, under the same conditions.

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