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Atmospheric effects on Quaternary polarization encoding for free space communication

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ABSTRACT

We have simulated atmospheric effects such as fog and smoke in laboratory environment to simulate depolarization due to atmospheric effects during a free space optical communication. This has been used to study noise in two components of Quaternary encoding for polarization shift keying. Individual components of a Quaternary encoding, such as vertical and horizontal as well as 45° and 135°, are tested separately and indicates that the depolarization effects are different for these two situation. However, due to a differential method used to extract information bits, the protocol shows extremely low bit error rates. The information obtained is useful during deployment of a fully functional Quaternary encoded PolSK scheme in free space.

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1. Introduction

Two-binary, one-quaternary (2B1Q) encoding is a method of mapping a pair of bits (DiBIT) to single encoding of a 4-level scheme. Such methods of encoding multiple bits to each level of the encoding scheme allows increase in transmission density, although most of the times requires hardware with better precision. Several schemes for such multiple encoding have been proposed and studied earlier [1–3] and their robustness have been discussed. Some of them are optical methods involving light, wherein different polarization or phase states of light are mapped to DiBITs [2,3]. However, when such methods are operated in free space communication protocols, concern has to be taken about the fact that atmospheric phenomena such as fog and smoke cause multiple scattering of the light, leading to a depolarization [4,7–10]. In addition, as we show in this communication, the depolarization behaviour is different for different encodings, adding additional difficulty, which is peculiar to M-ary encodings. But our method of differential measurement, as shown earlier [11], will allow us to extract information with a near zero bit error rate despite a significant depolarization.

The paper is organized as follows. We first briefly describe our experimental setup, which is same as the one used in [11]. We then present the results for errors due to depolarization, first for vertical and horizontal encoding and then independently for 45° and 135°. The present study is not a complete and proper Quaternary scheme, but instead a depolarization study of individual components. But this will help us understand whether or not the atmospheric effects such as fog and smoke affect these states differently, and if so, whether that information can be incorporated into the communication scheme for better detection.

We also explain the differential method of measurement based on State of Polarization, which allows us a higher tolerance for depolarization. Finally we show an analysis of this technique in terms of the Muller matrix method, which incorporates

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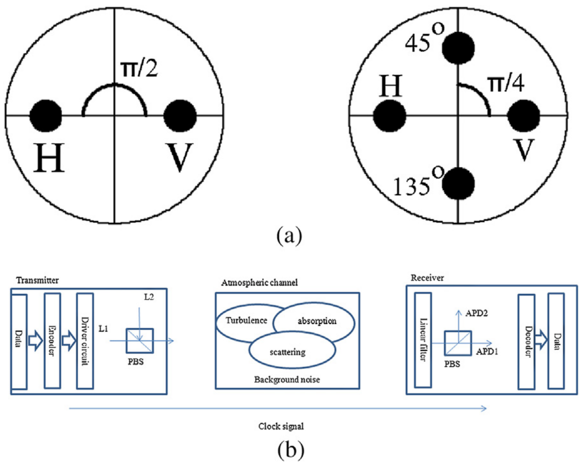

Fig. 1. (a) Constellation diagrams for Binary (left) and Quaternary encoding (right). (b) Schematic of the experimental setup. See text for details.

Table 1
Quaternary encoding of bit pairs to polarization.

Bit pairs	Polarization
00	Vertical
01	45°
10	135°
11	Horizontal

the depolarization effects. This allows us to represent the depolarized light as a Stokes vector with partial polarization. The mathematical analysis for the differential method of measurement shows that the final measure is a value whose sign can be used to identify and map to the information bit.

2. Experiment

We consider a specific Quaternary encoding consisting of two pairs of mutually orthogonal polarizations – viz Horizontal and Vertical, as well as 45° and 135°. These can be represented on a standard constellation diagram as shown in Fig. 1(a). On the left is only the Binary encoding using only Horizontal and Vertical polarizations, while the right side shows the Quaternary encoding, indicating the angle between them. When finally deployed, we should be able to use this as an encoding for pair of bits as given in Table 1.

The experimental setup is briefly explained below. It is similar to that of our earlier work [11]. It consists of two lasers L1 and L2, both VCSEL's operating at 780 nm. The choice of the wavelength is due to the fact that atmospheric attenuation has a clear window in this region [12]. Light from lasers L1 and L2 is split into two polarized components by the polarizing beamsplitter PBS and vertical part of light from L1 and horizontal part of light from L2 goes into the communication channel. A LabVIEW software controls the lasers through the driver circuit, such that bit '0' results in a pulse from L1 and bit '1' results in a pulse from L2. The Halfwave plate, indicated by $\lambda/2$ in figure, is used to rotate the polarization whenever required. This is used to choose between vertical/horizontal scheme or 45°/135° scheme as required.

A glass chamber placed in the communication channel is filled with fog or smoke to simulate the atmospheric conditions. Smoke is created in the chamber by burning household incense powder. Fog is achieved by sprinkling water onto a sample dry ice kept within. Both smoke and fog cause depolarization of the light due to multiple scattering by smoke particles or water droplets. This results in loss of information.

The amount of smoke or fog is quantified by measuring the attenuation of the laser after passing through and characterized by optical density in dB, as given by [1]

$$\mathrm{OD}\ \ (\mathrm{dB}) = -10\log\left(\frac{\mathrm{Transmitted\ \ intensity}}{\mathrm{Incident\ \ intensity}}\right).$$

The receiver consists of another polarizing beamsplitter, labelled PBS2 and two Avalanche Photodiodes (labeled APD1 and APD2, both PCD Mini 0020 module from SensL with 20 μm sensor and peltier cooler). The TTL pulses produced by the

[1] An alternative definition of Optical density is in terms of Beer - Lambert law, as $\alpha = \ln I/I_0$, which serves the function equally well. In this manuscript, we continue to use the definition as in attenuation.

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