Performance improvements of photonic lantern based coherent receivers

Ibrahim Ozdur[1,2], Paul Toliver[1] and T. K. Woodward[1]
[1] *Applied Communication Sciences, 331 Newman Springs Road, Red Bank, New Jersey 07701, USA*
[2] *Abdullah Gül University, Erkilet Boulevard, Melikgazi, Kayseri 38080, Turkey*
ibrahim.ozdur@agu.edu.tr

Abstract: In this work, the signal-to-noise ratio improvement of photonic lantern-based coherent receivers over single-mode coherent receivers is demonstrated. The signal-to-noise ratio is improved by a factor of 2.8 when other parameters kept constant.

1. Introduction

Free space coherent optical systems suffer from target or channel-induced speckle, collection efficiency, and multimode effects that degrade the mode matching of the local oscillator (LO) and the signal during signal detection. To overcome the mode matching penalty for free-space coherent optical systems, single-mode fibers are often used at the collection optic in place of free-space detection because the LO is also a single-mode and the mixing efficiency is nearly perfect [1]. A drawback of single-mode detection is the poor free-space-to-fiber collection efficiency due to the single-mode design of the fiber and smaller core size when compared to the multi-mode fiber. The photonic lantern has been introduced recently to effectively collect light in a large core multimode fiber and convert to an ensemble of single-mode fibers [2]. Because of its mode transforming properties, the photonic lantern can be anticipated to have an impact on coherent free-space optical detection systems, such as light detection and ranging (LIDAR) or free-space optical communication (FSOC). Previously, the single-mode collection efficiency enhancement for free-space optical systems using a photonic lantern to collect scattered light at near-field distances was investigated, and a single-mode collection efficiency improvement of ~8 dB was demonstrated relative to standard single-mode fiber [3]. This manuscript is a continuation of our previous work [3] and demonstrates the signal-to-noise ratio (SNR) improvements of a photonic lantern-based free-space coherent detection system. The photonic lantern-based coherent LIDAR system presented here has 2.8 times higher SNR compared to a single-mode fiber-based system.

2. Experimental setup

The essential elements of our coherent LIDAR system setup are shown in Figure 1a. The system starts with a narrow line width (1 kHz) CW laser at 1550 nm. The optical frequency is shifted by 4 GHz in the upper arm using a DQPSK modulator, which is driven at single-side band suppressed-carrier mode. The intensity modulator is driven by a pattern generator that sends 2 ns digital pulses at a 1 MHz repetition rate. The transmitter and receiver lenses are used to send and collect the modulated optical signal, respectively. In order to test the photonic lantern-based coherent detection system, the modulated optical signal is directly sent to the coherent detection system after passing through an attenuator which adds the free-space link loss for near field distances.

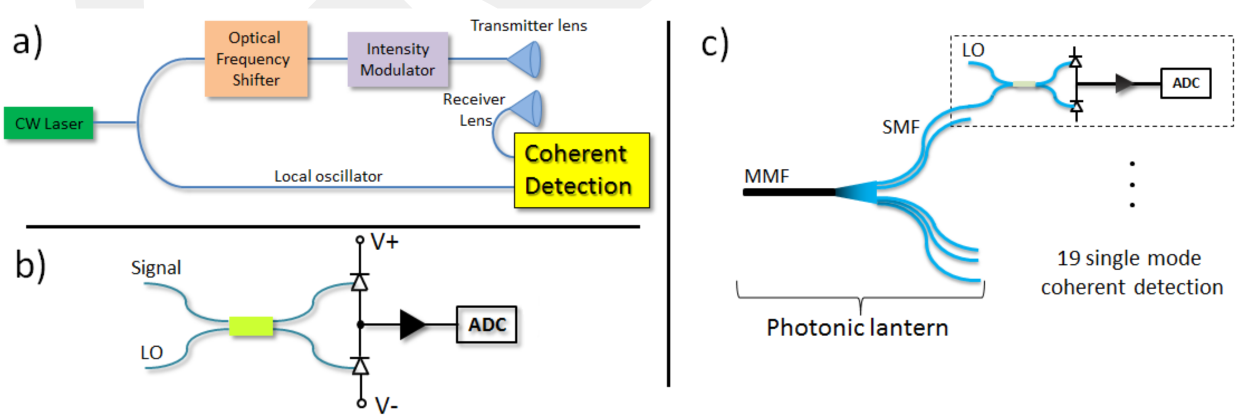

Fig. 1. (a) A coherent light detection and ranging system (LIDAR). The optical polarizers, couplers, RF drivers, etc. are not shown in the figure. (b) Single-mode fiber based coherent detection with balanced photo detector. (c) Proposed photonic lantern-based coherent detection with 19 single-mode detections.

The coherent detection system shown in Figure 1a has two different configurations. The first one uses a single-mode fiber to collect the reflected modulated optical signal after the receiver lens. The modulated signal is mixed with a local oscillator, which is also single-mode and sent to a balanced photo detector (Figure 1b). This configuration represents a typical coherent LIDAR system. The second coherent detection system configuration uses the photonic lantern for collection, as shown in Figure 1c. The multi-mode section of the photonic lantern is placed behind the receiver lens to collect the reflected modulated optical signal. A 19 port photonic lantern with 50 μm multimode core diameters is used in the experiment, which is the same as the one used in Reference [3]. Each single-mode fiber of the photonic lantern is combined with single mode local oscillator using an optical coupler and sent to a balanced photo detector. This process is repeated for each single-mode section one by one and the results are averaged. During the process, the multi-mode section of the photonic lantern is kept stationary to prevent optical power fluctuations due to randomized coupling into the 19 single mode fibers.

2. Results

The return signal with the single-mode fiber-based coherent detection is shown in Figure 1a. The 2 ns pulse and the 4 GHz carrier frequency can be seen in the figure. The small graph is the noise distribution histogram. The signal amplitude is 41.8 mV, and the standard deviation of the noise is 2.64 mV, which results in a SNR of 15.8. In the photonic lantern-based coherent detection configuration, 8 dB higher modulated optical signal is sent to the photonic lantern as the free-space to fiber collection efficiency is 8 dB higher [3]. The plot in Figure 2b is divided into 19 sections, each having a time span of 2 ns. The number at each section indicates the single-mode fiber from which the signal is obtained. The detected signal amplitudes are different as the output power distribution is not equal among all the 19 single mode fibers due to the optical power distribution inside the multi-mode fiber and single-mode core position. The averaged signal and noise amplitude of the 19 single mode coherent detections are 23.7 mV and 0.53mV respectively, which results in a SNR of 44.7. The inset small graphs in both of the figures are the noise distribution histograms and show the noise reduction after averaging the noise of 19 single mode fibers from the photonic lantern-based coherent detection.

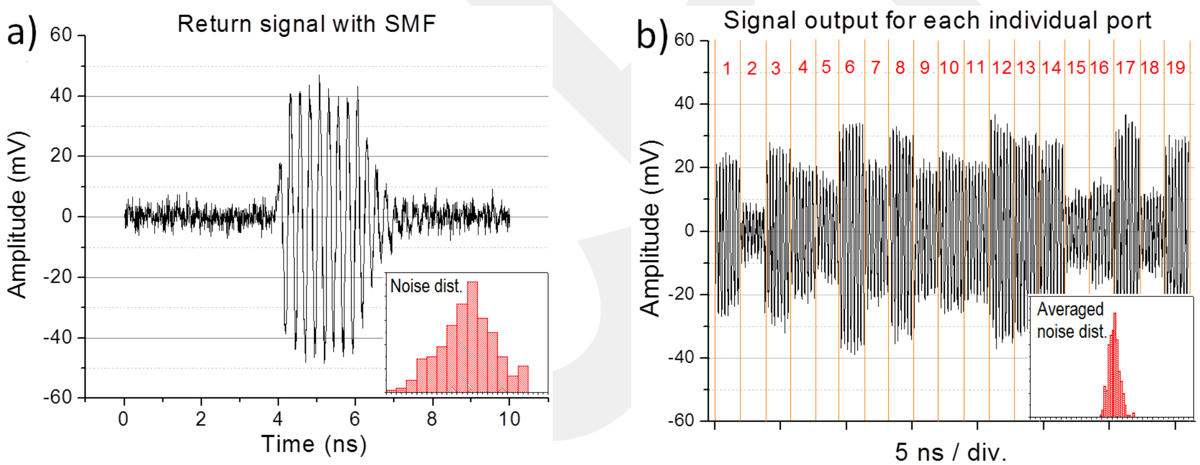

Fig. 2. (a) The detected signal with the single mode fiber based coherent detection and the noise histogram (inset). (b) The signal output for each single mode fiber of the photonic lantern is shown in the figure. The inset noise histogram is the averaged noise distribution of the 19 single mode coherent detections. The inset noise distributions in (a) and (b) are same scale.

3. Conclusion and discussion

In this work, signal-to-noise ratio improvement of photonic lantern-based coherent receivers over single-mode fiber based coherent receivers is demonstrated. The SNR is improved by a factor of 2.8 (from 15.8 to 44.7). This improvement is achieved without increasing the lens size or transmitted optical power.

This paper describes the most straightforward means of using photonic lantern for SNR enhancement, and other methods remain under study. Photonic lantern based coherent detection systems can increase the system performance of LIDAR and FSOC systems for demanding applications. The performance improvement can also be traded with lower size weight, and power (SWaP) systems for micro/nano UAVs and space platforms.

[1] M. B. Mark, in Proceedings of the IEEE 1992 National Aerospace and Electronics Conference (NAECON), Vol. 3, p. 1256.
[2] J. Bland-Hawthorn, S. C. Ellis, S. G. Leon-Saval, R. Haynes, M. M. Roth, H.-G. Löhmannsröben, A. J. Horton, J.-G. Cuby, T. A. Birks, J. S. Lawrence, P. Gillingham, S. D. Ryder, and C. Trinh, Nat. Commun. 2, 581 (2011).
[3] I. Ozdur, P. Toliver, A. Agarwal, and T. Woodward, "Free-space to single-mode collection efficiency enhancement using photonic lanterns," Opt. Lett. 38, 3554-3557 (2013).