10 Gb/s Entanglement Assisted Communication over Free-Space Optical Link with Phase Conjugation on Idler Photons and Improvements from Adaptive Optics

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Abstract: We demonstrate record 10 Gb/s entanglement assisted communication over 1.5 km long turbulent free-space optical link in which optical phase-conjugation is performed on bright idler photons. To further improve the system performance adaptive optics is used.

Entanglement represents a unique feature [1] enabling communication above the Shannon limit [2], quantum sensors approaching Heisenberg limit [1], quantum radars operating in a very low signal-to-noise ratio regime [3], and secure communication with security guaranteed by the quantum mechanics laws [1], to mention few applications. Free-space optical (FSO) communication link represents a very challenging communication channel in which transmission is affected by various atmospheric effects including absorption, scattering, turbulence, and diffraction. In strong turbulence regime, in a desert environment, classical communication links exhibit frequent outages introduced by scintillation and beam wandering effects, severely affecting system reliability particularly in the presence of wind and rain. To enable reliable communication in strong turbulence regime, in recent papers we advocated the use of entanglement assisted communication concepts. Unfortunately, the data rates for quantum communications are typically very low. In our previous demonstration, we have shown that by performing the optical phase-conjugation, which is required in EA communication before homodyne detection takes place, on idler photons instead of signal photons we can simplify the receiver design and operate the system based on BPSK at 125 Mb/s in strong turbulence regime [4]. In this paper, we have made several improvements to system design and implementation so that we can significantly improve the data rate up to 10 Gb/s, which represents a record data rate for quantum communications. One of the key changes is related to the selection of the pump laser wavelength so that both signal and idler are in C-band thus improving the nonlinear conversion efficiency significantly. We have also made improvements in both expanding and compressing telescope's designs. To improve the bit-error rate (BER) system performance further, we use the adaptive optics subsystem.

The block diagram in Figure 1, represents the overall scheme of our experimental testbed. The entanglement assisted (EA) communication part of the experiment is comprised of the following stages: 1) generating entangled photons, 2) separating signal and idler photons by compact coarse WDM demultiplexer, 3) modulating signal photons, transmitting them over the FSO link, and collecting them back by the compressing telescope, 4) delaying the idler photons, and 5) finally performing balanced detection and computing BER to measure the performance of the scheme. We compare the EA results with corresponding classical results obtained by performing the same experiment but this time modulating a classical laser at 1550nm and performing balanced detection with a local laser. The experiment is located in ECE room 549 (5th floor) of the ECE building at University of Arizona. The entanglement photon pair are generated using a tunable laser set to 1545.9 nm, which we split in two parts using a 50:50 beam splitter and amplified using two separate EDFAs as shown in Fig 1. The output of 1st EDFA is given to a type-0 periodically poled lithium niobate (PPLN) waveguide. In this PPLN waveguide the entangled photon pairs are generated by processes of secondary harmonic generation (SHG), followed by the spontaneous parametric down-conversion (SPDC). The entanglement pair we chose are 1550 nm as signal photons and 1541.8 nm as idler photons. The signal photons are modulated using a phase modulator, which is modulated by the RF signal from an arbitrary waveform

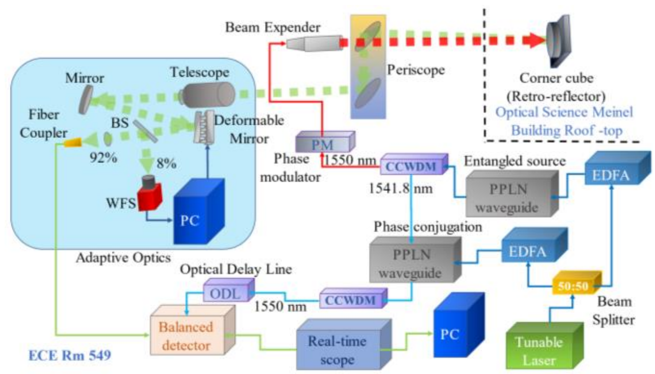

Fig. 1. The 10 Gb/s entanglement assisted FSO communication testbed.

generator (AWG), set to 10 Gb/s, in which the (3992, 2497) LDPC encoded BPSK information sequence is recorded. We then transmit these phase modulated signal photons out of the Lab towards a retro reflector placed around 750 meters away on the roof top of Optical Sciences Meinel building. The reflected beam at ECE 549 lab window, after a round trip of ~1.5 km, is collected by the periscope and compressing telescope. On the other hand, we perform the optical phase-conjugation on idler photons by mixing them with 1545.9 nm amplified pump signal and passing them through the bottom PPLN waveguide, thus performing the difference frequency generation. The output of the bottom (phase-conjugation) PPLN waveguide is passed through CCWDM, we select 1550nm output, and the phase-conjugated photons are propagated over 1 km of SMF, which serves as the optical delay line. After collecting the signal photons by a compressing telescope, we pass them over the optical bench with an adaptive optics setup and finally couple it in an optical fiber. The signal photons and phase-conjugated idler photons are fed to a balanced homodyne detector and the RF output of the balanced detector is recorded by a real-time oscilloscope running at sampling rate of 100 GSa/s. The recorded waveforms are then transferred to the PC to perform uncoded BER calculation, LDPC decoding, and post-FEC BER calculation. Further, we made improvements in BER by applying adaptive optics where the beam after the compressing telescope goes through AO setup, which is composed of a deformable mirror (DM) and a wavefront sensor (WFS) operated in a servo loop.

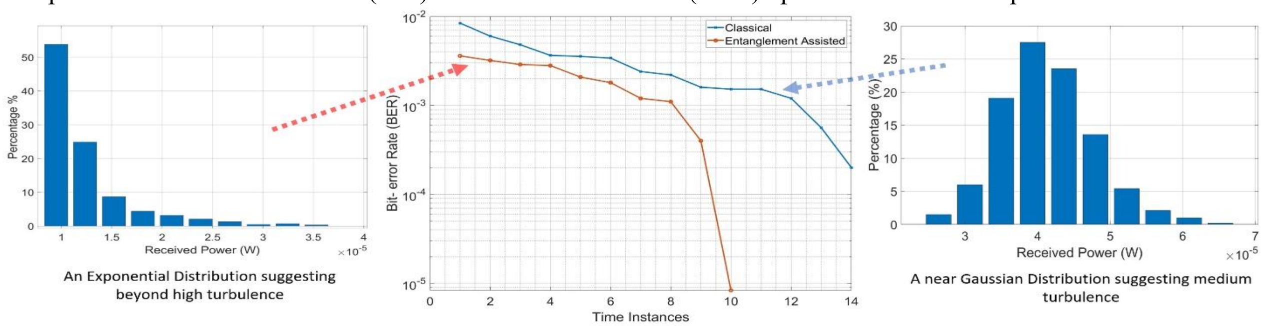

Fig. 2. Uncoded BERs of entanglement assisted communication operating in beyond strong turbulence regime vs classical communication in medium turbulence regime for different channel transmissions.

In Fig. 2 we show the comparison of entanglement assisted communication system operating in saturation turbulence against the classical laser communication in medium turbulence regime, for different channel transmissions. The laser communication was not operational at all in saturation regime. Evidently, the EA communication in saturation regime outperforms the classical communication in medium turbulence regime thus representing a clear quantum advantage. For certain channel realizations (see instance 10 to 14), the EA communication demonstrates significantly better tolerance to turbulence effects. For both curves we measured the averaged received power histograms. The exponential distribution for the EA case indicates the saturation regime, while log-normal to Gaussian-like distribution for classical communications, indicates the medium turbulence. To improve further the system BER performance for the EA communication case we used the adaptive optics (AO) subsystem (described in Fig. 1), and in Fig. 3 we compare the BER results when the AO is used against the EA case when AO is not used. Clearly, even though the AO is designed for astronomic systems operated in weak turbulence, it provides relevant BER performance improvement medium-to-strong turbulence regime. The LDPC decoder corrected any remaining errors.

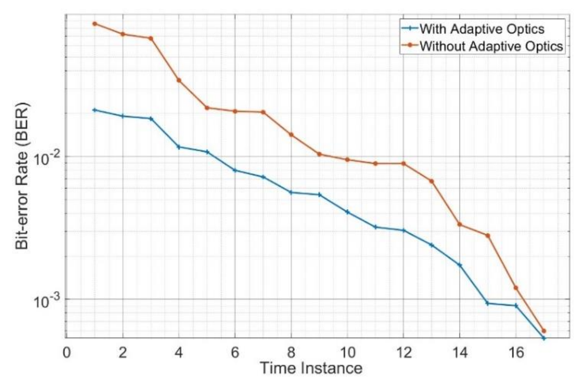

Fig. 3. Improvement in uncoded BER by applying adaptive optics to entanglement assisted communication in medium-to-strong turbulence.

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