A study on the optical power requirement of kilometer-range solar-blind NLOS communication links

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***Abstract*— Deep ultraviolet non-line-of-sight (NLOS) communication is favored due to its robustness and ability to traverse obstacles such as buildings. This paper shows simulations of the optical power requirement of kilometer-range NLOS links. A preliminary NLOS communication experiment has also been carried out in a laboratory.**

Keywords—non-line-of-sight, optical wireless communication, low-power detection, atmospheric scattering

I. Introduction

The demand for robust, high-speed, and secure wireless communications has drawn attention to deep-ultraviolet (DUV)-based non-line-of-sight (NLOS) optical wireless communication (OWC). Compared to conventional radio-frequency (RF) communication, OWC shows its strengths in high bandwidth and adaptation to various environments, e.g., free-space, atmospheric, and underwater [1]. Meanwhile, by taking advantage of its highly scattering property, UV-based NLOS communication links further extend the capability of OWC with the ability to communicate over a turbulent channel, overcome physical objects such as buildings that would otherwise block a LOS link [2]. A further benefit of operating at UV wavelength is that DUV radiation from the sun is mostly, or entirely, absorbed by ozone in the upper atmosphere, so solar background does not interfere with communications at these wavelengths at lower altitudes. This enables a link with a higher signal-to-noise ratio (SNR) compared to a visible/infrared link under the same conditions. Use cases include communication in military applications, disaster zones, aircraft landing assistance in foggy/dusty conditions, and inter-ship communication in turbid waters.

However, exposure to UV radiation presents hazards such as premature aging of the skin and eye problems. Therefore, for safety it is essential to control the transmitted power of a DUV NLOS communication system. Moreover, controlling the size, weight and power consumption (SWaP) of the DUV NLOS systems will be essential for most applications. Based on a 266-nm DUV laser as the transmitter and a multi-pixel photon counter (MPPC) as the receiver, this paper theoretically and experimentally characterizes the DUV scattering channel to gain an insight into the power requirements of such DUV NLOS links, and scope the future low-SWaP UV source designs.

II. Simulation & Experimental Study

Monte Carlo simulations were conducted using MATLAB® code based on a guide by Leathers *et al.* [3]. Assuming a 100-mW, 266-nm DUV continuous wave (CW) laser is used, the corresponding absorption and Mie/Rayleigh scattering coefficients in the air were assumed to be 0.802, 0.284/0.266 km^{-1} respectively, based on work by Ding *et al.* [4]. The laser emission was modelled as a "perfect" beam with zero divergence, and an emission area of 1×1 mm^2. It propagated along the z-axis, and is centred at x,y coordinates = (0,0). The modelled detector is a Hamamatsu S13371CQ-02 "Multi-pixel photon counter" (MPPC) of active area 6×6 mm^2, a photon detection efficiency of around 25%, a dark count rate of 4 MHz, and a bandwidth of 5 MHz. The simulated volume over which photons propagate was assumed to be homogenous, with no physical objects to block or reflect photons. Photons were permitted to travel a maximum distance of 5000 m and scatter a maximum number of 5 times before being "terminated".

Fig. 1(a) shows the received CW power density as viewed 10 m side-on to the path of the beam propagation. The estimated power density is in the range of 1×10^{-10} to 1×10^{-11} W/cm^2. Using the area of the MPPC, this corresponds to received optical power in the range of a few pW to a few tens of pW. This could be further increased up to hundreds of pW by using MMPC arrays. Fig. 1(b) shows the bit-error ratio (BER) versus received power for a given on-off keying (OOK) data rate. The red horizontal line indicates a BER of 3.8×10^{-3}, below which Forward Error Correction (FEC) with an overhead of 7% can be used to obtain "error free" transmission. It suggests that error-free NLOS data rates of several hundred kb/s to a few Mb/s should be achievable under these configurations.

The data presented in this abstract is available at https://doi.org/10.15129/6926c5f9-a32d-4fd3-a21e-343276ef0b2f

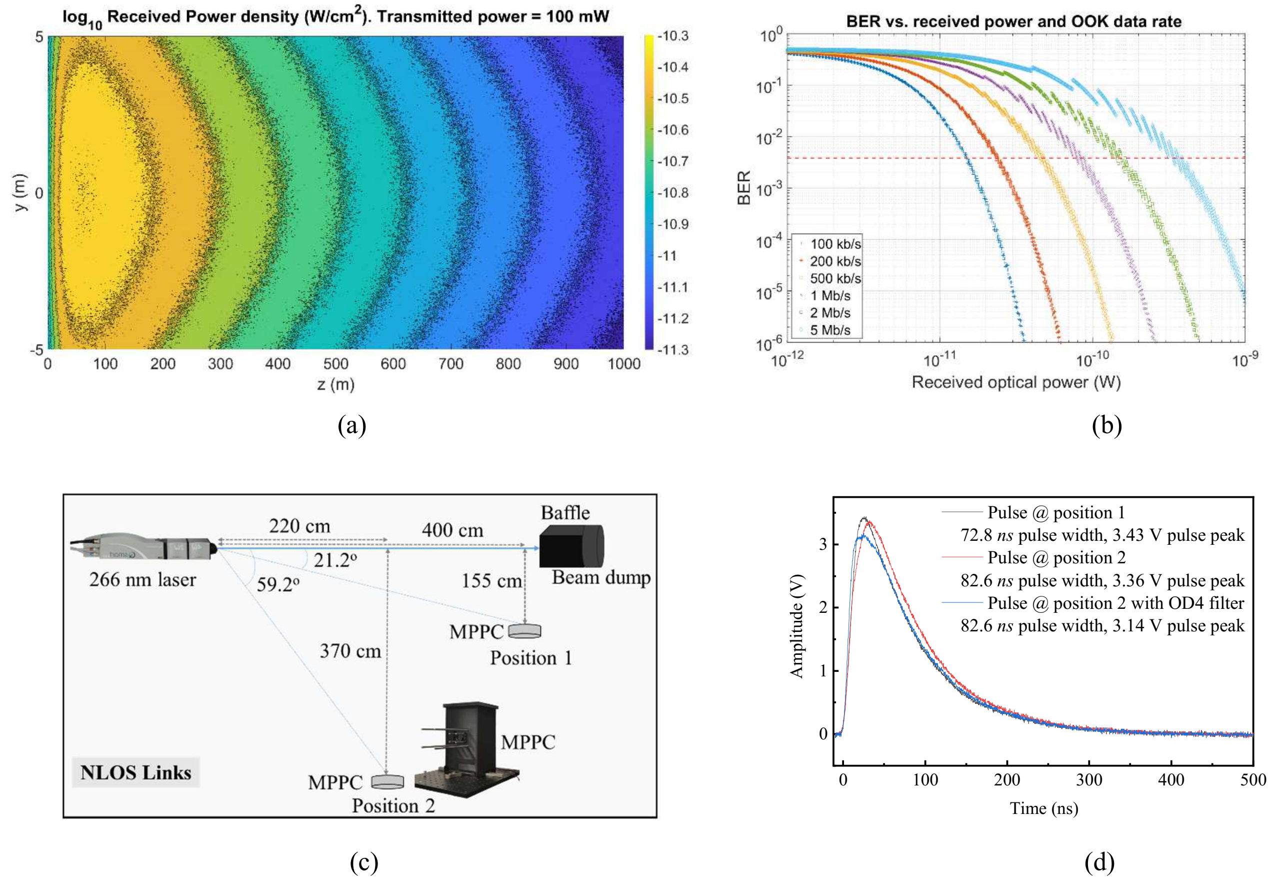

Fig. 1. (a) The received CW power density as viewed 10 m side-on to the path of the beam propagation. (b) The the relationship between bit-error ratio (BER) and received power for a given OOK data rate using a MPPC S13371CQ-02. (c) The experimental setup for detecting a 266-nm pulse with a NLOS configuration with different transceiver placements. (d) The detected pulses with with different transceiver placements.

Fig. 1(c) shows the experimental setup for detecting an optical pulse with a NLOS configuration with different transceiver placements. In this experiment, a Quantel Q-smart 450 compact pulsed Nd:YAG lasers is used as the 266 nm source. The pulse repetition rate is 20 Hz, with attenuated output energy of 30 μJ per 6 ns pulse. While different from the ~ 100 mW, high-repetition-rate sources desired in practice, this available source was used to perform preliminary experiments and lay the groundwork for development of more practical sources. At the end of the beam path, a beam dump is utilized to sink all the incoming photons after a baffle structure. The detector is installed in an enclosure box for rejecting background noise, as shown in Fig. 1(c). A UV bandpass filter FGUV5M (240 – 395 nm) is also installed in front of the detector for further reducing noise. The link performance is tested at two positions, as labelled in Fig. 1(c). At position 2, an OD4 filter is further installed. Fig. 1(d) suggests that all these three scenarios were more than sufficient to obtain a strong signal. The unchanged pulse width of 82.6 ns for the attenuated power of 3 nJ with OD4 filter at the same transceiver placement at position 2 demonstrates the feasibility of reducing the peak power to < 1 W for scoping future low-SWaP UV NLOS source designs. Further work is planned to test the communication performance at 10 – 100 mW.

III. Conclusions

We studied the power requirement of a 1000-m UV scattering link for building an effective NLOS communication link using Monte Carlo simulation. The results suggest that the received power is enough to support a few megabits per second data rate over 1000 m when a 100-mW CW 266-nm laser is used. The further experiment validates the feasibility to minimize the power requirement for scoping future low-SWaP UV NLOS source designs.

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