Indoor Optical Wireless Communications using Quantum Key Distribution at 1370 nm

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***Abstract*—Quantum Key Distribution (QKD) can be used to secure indoor optical wireless links. In this paper, we consider an indoor QKD link operating at a wavelength between 1360 – 1370 nm and show that it is robust to the effects of sunlight.**

Keywords— ambient light, indoor optical wireless, QKD, simulation

I. Introduction

Privacy is a major concern in the digital information era. Quantum Key Distribution (QKD) allows the secure distribution of encryption keys and offers enhanced physical layer security with eavesdropper detection to guarantee security. QKD has been demonstrated for long distance optical communications, both fibre [1] and free-space [2]. A key challenge in implementing an indoor free-space QKD link are mitigating the effects of artificial lighting and ambient light at the receiver. Artificial lighting [3] can impair the performance of wireless QKD in indoor environments and impairments due to LED lighting have been investigated [4]. However, in indoor environments there can be both LED lighting and sunlight. Illumination from the sun can be much stronger than any artificial illumination and is potentially the main cause of impairment of the QKD link. The spectral irradiance of sunlight at sea level (air mass 1.5) with cloudless atmospheric conditions [5] is shown in Figure 1, for a detector with 2π steradian field of view. Data from the solar spectrum shows there is significantly lower irradiance in the band between 1360 – 1370 nm. In this paper, we investigate the operation of a QKD link in this range of wavelengths, where LED lighting does not contribute noise. The effect of sunlight is modelled at a typical indoor level of 1000 lux (corresponding to that of bright workspace lighting).

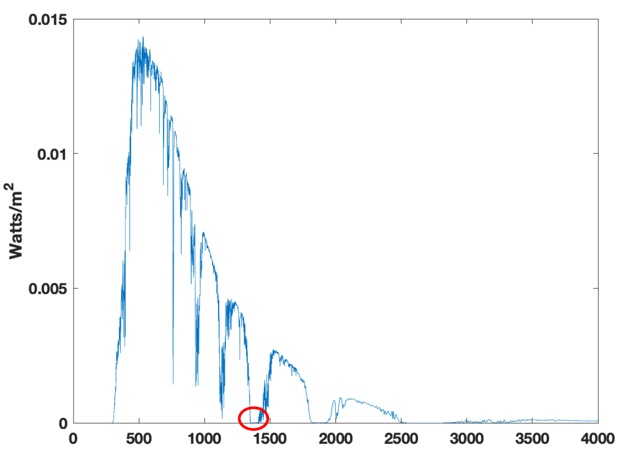

Fig. 1. ASTM measured spectral irradiance vs wavelength [5]

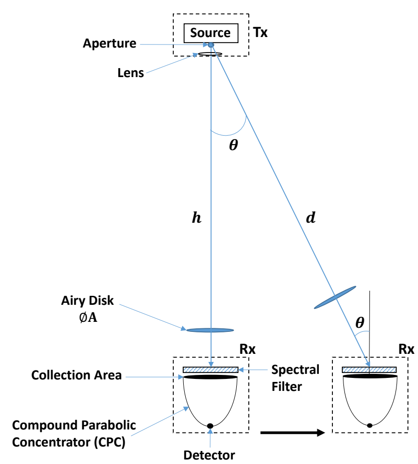

Fig. 2. Free-space link diagram

The QKD link is modelled as shown in Figure 2. The transmitter (Tx) is a 1370 nm source that can output the minimum required power necessary for single photon transmission to the receiver. The transmitter is above the receiver at *h*=3 meters. The Airy disk diameter (ØA) is the beam diameter of the Airy disk at the receiver plane. The receiver (Rx) has the ability to detect single photons at 1370 nm. It uses a narrowband filter to reject ambient light and a compound parabolic concentrator (CPC) gain with n=1.5 to increase the collection area. A Single Photon Avalanche Diode (SPAD) detector with 25 μm diameter is modelled. It is assumed the transmitter and receiver can track each other when the receiver is outside the transmitter field of view (see [6] for possible implementations). The receiver is placed at a distance *d* at every half angle field of view (FOV) θ with respect to the normal of the Rx.

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II. Results

A common Quantum Bit Error Rate (QBER) threshold for the BB84 protocol is 11% [7] [8] and a realistic threshold to satisfy is 4% especially for a mean photon number = 0.1 [9]. In order to determine whether such a link is feasible a simulation is undertaken, focusing on the variation in Signal to Noise Ratio (SNR) with link field of view. This takes into account polarization misalignment (which contributes 1% to the BER)[9] and the effect of sunlight. QKD links will be narrow field of view, in order to minimize both loss, and the amount of ambient light noise picked up, but maximizing the field of view in order to relax tracking requirements is desirable. For each half angle FOV θ, a new spectral filter bandwidth must be designed to ensure the QKD signal remains within the passband of the filter for a range of angles from 0 to θ, leading to an increase in the optical bandwidth of the system as the FOV of the link is increased. Figure 3 shows the results of the simulation using different Airy disk diameters for SNR across half angle FOV θ. Polarization misalignment dominates the noise term in SNR up to θ = 4 degrees. As θ increases beyond 4 degrees, the filtered ambient light dominates the noise term [10]. Measurements of the irradiance from sunlight were made indoors, and used in the simulation model, and the results are shown in Figure 4. The measured results indicate higher levels of impairment due to ambient light than simulated (reasons for this are under investigation), but show that a link with a field of view of 4 degrees can be operated using a 0.8 nm optical filter, maintaining the required FOV.

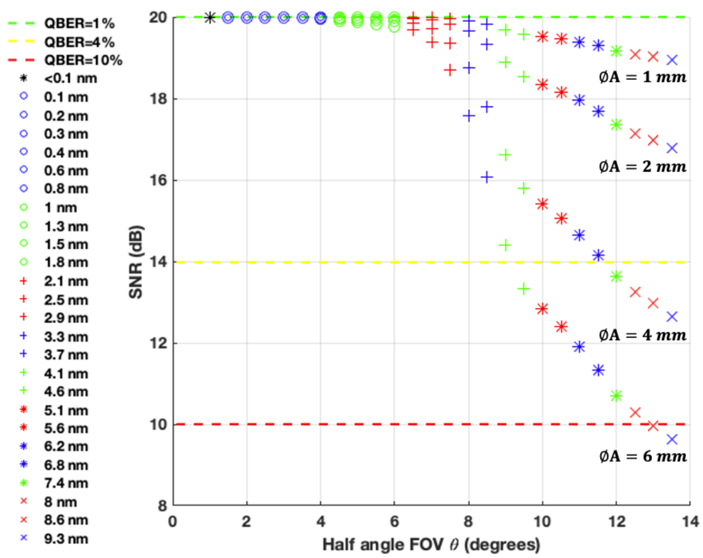

Fig. 3. SNR vs FOV. QBER is calculated as the ratio of noise photons to sifted photons [9].

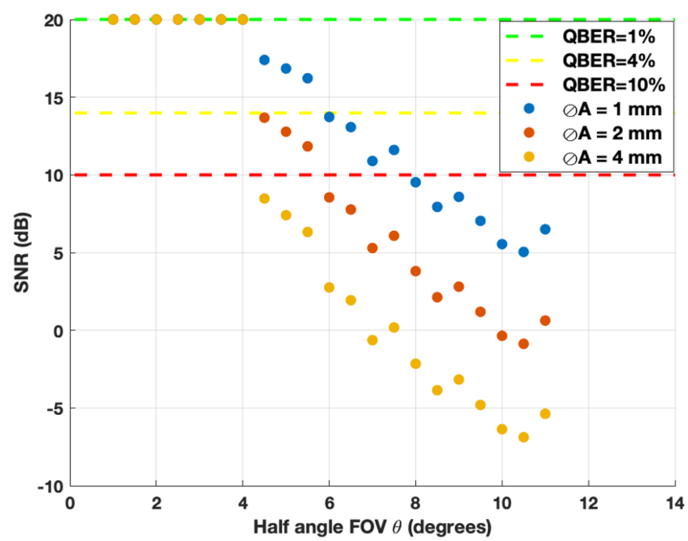

Fig. 4. SNR vs FOV with indoor solar irradiance measurements

III. Discussion and Conclusions

The simulation results indicate that a QKD link operating at 1370 nm is feasible at a QBER = 4% up to 9 degrees half angle FOV θ in the presence of sunlight. For this a 4.1 nm spectral filter bandwidth is used, with a 6 mm diameter beam (Airy disc diameter) at the receiver. Measured irradiance results reduce the available field of view to ~4 degrees with a 1 mm diameter beam, using a 0.8 nm filter. Typically, such links require very narrow filter bandwidths and narrow FOV to reduce the ambient light impairments, but the reduced level of ambient light offers promise of more practical QKD links. Work to implement such a design is underway.

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