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Invited Paper

Determining the feasibility of Free Space Optical Communication in Namibia

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ABSTRACT

Namibia has a great potential for Free Space Optical Communication (FSOC) because of its clear skies. This paper determines the feasibility of FSOC in Namibia by using theoretical models. Visibility, wind speed, and altitude data for several locations are used to compute atmospheric losses under average and worst case atmospheric conditions. Optimal FSOC link distances for all the locations are determined under both conditions by evaluating each location's atmospheric loss against the power link margin. Results show that under average conditions, an FSOC optimal link distance of up to 7500 m can be achieved for inland locations. On the other hand, Grootfontein and Katima Mulilo, at 6900 m, have the longest distance under worst case atmospheric conditions. Walvis Bay has the shortest FSOC link distances of 3224 m and 2500 m under average and worst case conditions respectively. This study shows that FSOC in Namibia is feasible for last mile broadband access networks, where link distances are generally less than 10 km. These results are based on theoretical models, which have taken into account reasonable realistic assumptions. Practical field tests using FSOC equipment will be conducted as part of future work. Comparisons will be made with theoretical results obtained in this study.

1. Introduction

Free Space Optical Communication (FSOC) is a line-of-sight (LOS) technology that transmits a modulated beam of visible or infrared light (IR) through the atmosphere to provide high bandwidth optical connections [1,2]. This is in contrast to the widely deployed Optical Fiber Cable (OFC) network, which uses OFC cores as a communication medium [3]. FSOC is a relevant technology for last mile access networks. Although FSOC offers lower bandwidth than OFC networks, it is characterized by low installation costs. Unlike radio frequency (RF) communication, FSOC offers higher bandwidth, license-free operation, and low initial capital expenditure (CAPEX). FSOC systems are difficult to intercept, hence secure [4]. FSOC is insensitive to electromagnetic interferences because it makes use of the laser diode and hence it is robust [5]. FSOC is being considered as an economically viable alternative to RF communication [1,2].

Nevertheless, FSOC faces a number of challenges. It is sensitive to weather conditions, which can result in loss of optical signal power [5]. Heavy rain, fog, dust, snow or strong wind may completely make the FSOC services unavailable [6]. These atmospheric obscurants turn the propagation environment into a multiple scattering medium thereby creating scattering losses [1,3]. FSOC requires the transmitter and the receiver to be properly aligned because it requires a direct LOS path between a sender and receiver [6,7]. FSOC signals may also suffer from absorption as they encounter gaseous elements in the atmosphere [8]. FSOC also suffers from atmospheric turbulence, which causes fluctuations in both the intensity and the phase of the received light signal, thereby impairing link performance [2].

Namibia is generally an arid country [9,10] with clear skies and low annual rainfall. These conditions present a great potential for FSOC. To the best of our knowledge, a study on the feasibility of FSOC in Namibia has, however, not been carried out. This study is, therefore, aimed at determining the feasibility of FSOC in Namibia. Six locations are chosen across the country [11], namely Windhoek, Ondangwa, Keetmanshoop, Walvis Bay, Grootfontein, and Katima Mulilo. Visibility and wind speed data are collected from Namibia Meteorological Service for all the locations for 5-year periods. Visibility profiles for the locations are determined and classified by using statistical techniques. Average scattering and turbulence losses, which are major contributors to atmospheric loss in FSOC [4], are computed for each location. The optical link margins and the optimal link distances are determined for all the

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locations under average and worst case atmospheric conditions. An analytical discussion of results is carried out in order to determine the feasibility of FSOC in Namibia.

The rest of the paper is organized as follows. Atmospheric losses and optimal link margin considerations are presented in Section 2. The atmospheric losses are calculated and discussed in Section 3. The worst case performance is presented in Section 4. The paper is concluded in Section 5.

2. Atmospheric losses and optical link margin considerations

In this work, atmospheric losses are composed of scattering and turbulence losses only. This is because scattering and turbulence are major contributors to atmospheric loss in FSOC operations [4].

2.1. Scattering losses

This is an occurrence in which the direction, frequency, or polarization of the wave is changed when the wave encounters discontinuities in the medium, or interacts with the material at the atomic or molecular level [6]. The atmospheric attenuation due to scattering [4] can be calculated using

$$A_{atm} = \alpha_{10}(V) \times L \quad [\mathrm{dB}], \tag{1}$$

where $\alpha_{10}(V)$ is an atmospheric attenuation or total extinction coefficient and L is the distance between a transmitter and a receiver in kilometers. The total extinction coefficient is further given by

$$\alpha_{10}(V) = \sigma_m + \sigma_a + \beta_m + \beta_a \quad [\mathrm{dB/km}], \tag{2}$$

where σ_m is the molecular absorption coefficient, σ_a is the aerosol absorption coefficient, β_m is the molecular or Rayleigh coefficient and β_a is the aerosol or the Mie scattering coefficient. From [2,7], the FSOC wavelengths of interest make the gas absorption, aerosol absorption and molecular scattering negligible. Thus the attenuation due to Mie scattering is related to wavelength and visibility as described in [4,5,7,12] and given by

$$\alpha_{10}(V) = \beta_a = \frac{3.91}{V} \times \left(\frac{\lambda}{550\ \mathrm{nm}}\right)^{-q} \quad [\mathrm{dB/km}], \tag{3}$$

where V is visibility in kilometers, λ is the wavelength in nanometers, and q is the particle size distribution of the scattering particles [13], which can be determined using

$$q = \begin{cases} 0.585 \times V^{1/3} & \text{if } V < 6\ \mathrm{km}, \\ 1.3 & \text{if } 6\ \mathrm{km} \le V \le 50\ \mathrm{km}, \\ 1.6 & \text{if } V > 50\ \mathrm{km}. \end{cases} \tag{4}$$

2.2. Turbulence losses

Turbulence is an atmospheric phenomenon which affects the laser beam by causing phase front distortion, beam broadening, beam ramble and redistribution of intensity within the beam which is known as scintillation. In the case of strongly divergent beam, scintillation is the most significant source of turbulence [4]. Turbulence is a problem even over relatively short propagation paths [2]. Turbulence loss [14,15] is determined by using

$$\rho(L) = 2 \times \sqrt{23.17 \times k^{7/6} \times C_n^2 \times L^{11/6}} \quad [\mathrm{dB}], \tag{5}$$

where $k = 2\pi/\lambda$ and C_n^2 is refractive index structure parameter in $\mathrm{m}^{-2/3}$, which can be determined by using the widely used Hufnagel–Valley model [2,16,17] as follows:

$$C_n^2(a) = 0.00594\left(\frac{ws}{27}\right)^2 (10^{-5}a)^{10} \exp\left(\frac{-a}{1000}\right) + (2.7 \times 10^{-16}) \exp\left(\frac{-a}{1500}\right) + T_s \exp\left(\frac{-a}{100}\right), \tag{6}$$

where ws is the wind speed in m/s, a is the altitude in meters, constant T_s is the turbulence strength at the ground level, typically set to 1.7×10^{-14}.

2.3. Optical link margin and link availability

The laser power, beam divergence, receiver sensitivity, coupling losses, and receiver lens area define how the FSO is able to mitigate atmospheric effects. These parameters are used to determine the optical link margin $M(L)$ in dB [4], which is given by

$$M(L) = P_0 - A_{TX} - 20 \log \frac{\sqrt{2}L\theta}{D} - A_{RX} - P_{RX_{min}}, \tag{7}$$

where P_0 is the mean optical power of a laser diode; A_{TX} includes the coupling loss between the laser and the transmitter lens and the attenuation loss in the lens; A_{RX} denotes the coupling loss between the receiver lens and photodiode and the attenuation and reflection at the lens; $P_{RX_{min}}$ is the receiver's sensitivity; θ is the divergence halfangle, which defines the spreading of the beam when propagating toward infinity; and D is lens aperture diameter. In (7), L is expressed in meters.

The optical link power margin shows the degree by which a system can compensate for both scattering and turbulence losses at a given range [18]. An FSOC link of length L will function correctly if $M(L) \ge A_{atm}(L)$, where $A_{atm}(L)$ denotes atmospheric losses at L. If L is in kilometers, the minimum required visibility V_{min} for correct operation of FSOC is defined [4] by

$$V_{min} = \frac{13L}{M(L)}\left(\frac{\lambda \times 10^9}{550}\right)^{(-q(V))} \quad [\mathrm{km}]. \tag{8}$$

3. Atmospheric loss calculations for Namibia

Atmospheric losses were determined by adding scattering and turbulence losses. In Section 2, it has been shown that scattering loss depends on visibility while turbulence loss depends on altitude and wind speed. The six locations used in this study (Windhoek, Ondangwa, Katima Mulilo, Grootfontein, Walvis Bay, and Keetmanshoop [11]) are spread out across the country. They may eventually serve as major commercial centers to drive FSOC deployment in the country. To determine scattering and turbulence losses, altitude data and five year (2009–2013) visibility and wind speed data for the six locations were obtained from the Namibia Meteorological Service.

3.1. Average attenuation coefficients due to scattering

Average visibility was computed for the locations in order to calculate average scattering losses for the locations. A visibility statistical comparison was carried out amongst the six locations using the paired sample *T*-Test in software program for social scientists (SPSS). It was found that there was a statistically significant difference among all locations, except for Grootfontein and Katima Mulilo, which are classified in the same group, as shown in Table 1. These two locations are far more inland and they have more or less the same climatic conditions. The same locations (Katima Mulilo and Grootfontein) exhibit the highest visibilities at 74.98 km and 74.95 km respectively. Ondangwa and Keetmanshoop, at 74.44 km