ABSORBING AEROSOLS: BOON OR BANE IN FREE-SPACE OPTICAL COMMUNICATION SYSTEMS?

The impact of enhanced local heating due to absorption of solar radiation by high-altitude aerosol Black Carbon (BC) layers in the performance of Free-Space Optical (FSO) communication links is investigated. It is seen that a strong elevated BC layer at an altitude around 4.5 km enhances the local atmospheric stability and leads to large reduction in the atmospheric refractive index structure parameter (C_n^2, a parameter denoting the fluctuations in the refractive index), leading to improved performance of the FSO communication links. For layers in the tropical atmosphere with sufficiently high BC concentration, the signal attenuation due to BC absorption is alleviated by the large reduction in C_n^2 due to BC-induced warming and brings down the probability of the communication link being down. Synergy between reduction in C_n^2 and long wavelength transmission improves the link budget significantly by reducing the beam wander and number of adaptive optics units required. Our results highlight the possible role of BC, which is generally looked upon as a bane in FSO communication systems, as a boon in aerial FSO communication systems.

The main inferences are the following:

1. Aerial nodes can be used as sub-ad-hoc networks between ground stations after estimating the least-Cn^2 altitude using BC profiling, and by utilizing multiple-hopping. The up-time and link length will be higher if BC layers span more horizontally.

2. During daytime, EBC layers can be used as a proxy to estimate altitudes to implement aerial FSO communication systems. A mere real-time vertical profiling of BC using a lidar will increase the performance and reduce the cost of implementation.

3. Usage of 1.55 μm transmitting wavelength will reduce BC absorption, Rayleigh scattering losses and the probability of solar radiation to act as background noise. Moreover, absorption by BC layers is easily mitigated by the large reduction in C_n^2 by BC warming.

4. Coupling of numerical weather prediction models with observational data will enable us in estimating a global map of possible least-C_n^2 altitudes for aerial FSO communication links.

5. Presence of multiple BC layers may open the path for improved spatial-multiplexing in FSO communication systems and the reduced atmospheric turbulence observed at EBC layers can be exploited as the comfortable flying altitudes for aircrafts.

This study indicates the necessity for investigations spanning different seasons and geographic locations to understand the combined effects of BC-induced transient attenuation changes and suppression of convection by BC warming, on the performance of aerial FSO communication systems.

Reference: N. Anand, K. Sunilkumar, S. K. Satheesh, and K. K. Moorthy, "Distinctive roles of elevated absorbing aerosol layers on free-space optical communication systems," Applied Optics, 57, 7152-7158 (2018).

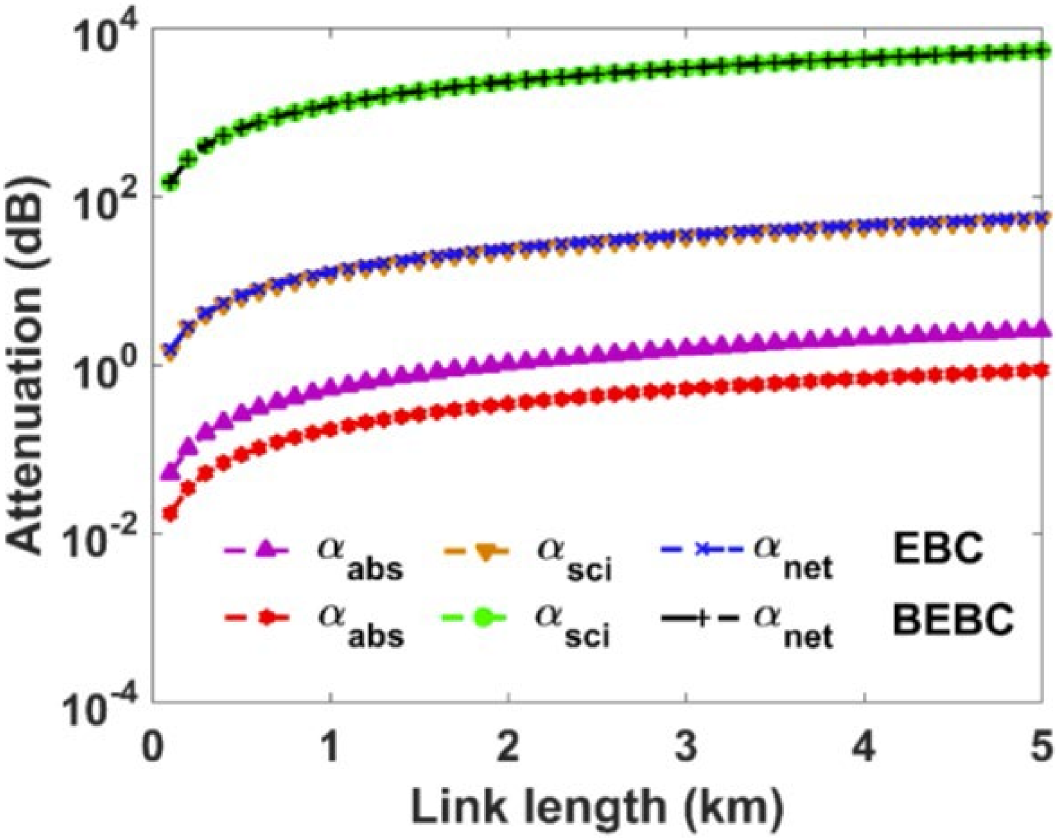

Figure 1: Signal attenuation at elevated black carbon (EBC) and below elevated black carbon (BEBC) layers. α_{abs} and α_{sci} represent the attenuation due to BC absorption and refractive index fluctuations, and α_{net} is the total attenuation.

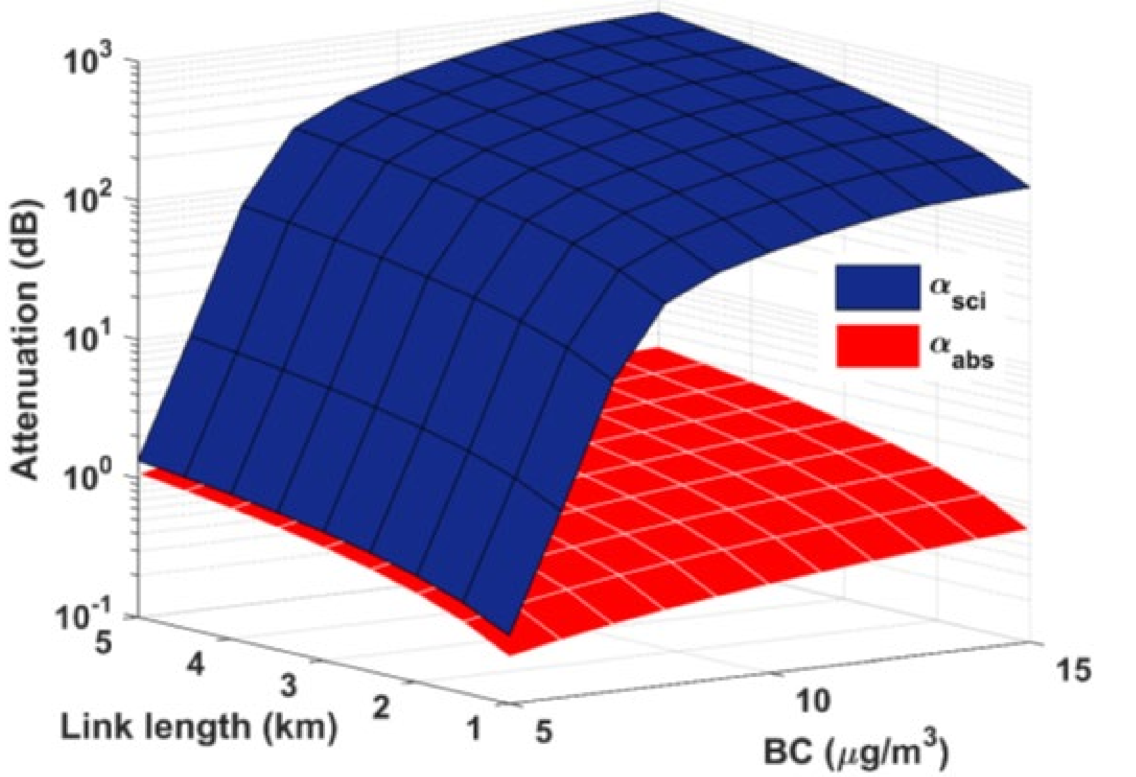

Figure 2: Signal attenuation for varying BC concentrations and link lengths at EBC layer, done as part of a sensitivity study.