Channel estimation, MMSE-LE equalization, and multi-level amplitude modulation for the dual-wavelength free space optical communications system using modified vector radiative transfer theory

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Fog is a highly dispersive medium at optical wavelengths and the received pulse waveform may have suffered significant distortion. Therefore it is desirable to have the impulse response of the propagation channel to recover data transmitted through fog. A method based on the use of a dual-wavelength system is presented for estimating the average particle diameter D_{avg} and the particle number density ρ parameters for the atmospheric channel comprised of fog with optical depths in the range of $1 \le \tau \le 15$, and approximating the particle size distribution function $n(D)$. The method is based on forming the ratio of measured received intensities at the two operating frequencies, which can be related to the ratio of optical depths. An inversion technique is then used to infer candidate values for D_{avg}. Approximations such as Gaussian and log-normal are evaluated for the particle size distribution functions. The estimated particle number density ρ can then be calculated. The estimated parameters serve as inputs to compute an estimate of the atmospheric channel impulse response $\hat{h}(t)$ using the modified vector radiative transfer theory.

The estimated channel response is used to design a minimum-mean-square-error linear equalization filter (MMSE-LE) to correct the distortion in the received signal waveform due to intersymbol-interference and additive white Gaussian noise. Using numerical simulations, the bit-error-rate performance versus E_b/N_0 of the estimated equalizer is examined as a function of the estimation error and compared against the performance of the ideal equalizer designed using the true channel response function, which is unknown in practice but provides optimal equalizer performance in theory.

We found that the MMSE-LE filter equalization works well for OOK modulation and is fairly tolerant of small parameter estimation errors, while the BER performance decreases rapidly with additional levels of amplitude modulation due to increasing sensitivity to estimation error. In the case of 8-level modulation, the MMSE-LE filter works well with the true channel response, but performance is unacceptable using our best channel impulse response estimate.