A guide to an optical ground station site selection and evaluation using CV QKD protocol

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Background

Many countries around the world are working towards constructing quantum networks. To expand these networks to a global level and develop the 'quantum internet', the focus is on delivering quantum technology for satellite communications. One of the challenges is modelling the atmosphere in the path of signal (photon) propagation from earth to space. In our work, we analyze critical parameters that characterize atmospheric effects using the continuous variable quantum key distribution (CV QKD) protocol. These are geographic-dependent and vary with time, day, angle, distance and orientation of the link. This allows us to determine optimum locations on earth to establish ground stations.

Research Approach

Criteria for an optical ground station (OGS) site selection to set up CV QKD satellite link:

- ***Transmittance and Radiance -*** wavelength selection for free space optical link
- ***Diffraction & Atmospheric Extinction*** - beam broadening combined with turbulence induced short-term and long-term effects.
- ***Atmospheric turbulence*** - location dependent and change in refractive index
- ***Scintillation Index & Pointing error*** - function of receiver aperture, range and angle.
- ***Visibility and Cloud blockage -*** Probability of clear sky with suitable weather patterns
- ***Background Noise*** - solar irradiance based on wavelength and location.
- ***Downlink & Uplink Analysis*** - including transmittance using MODTRAN for Ireland

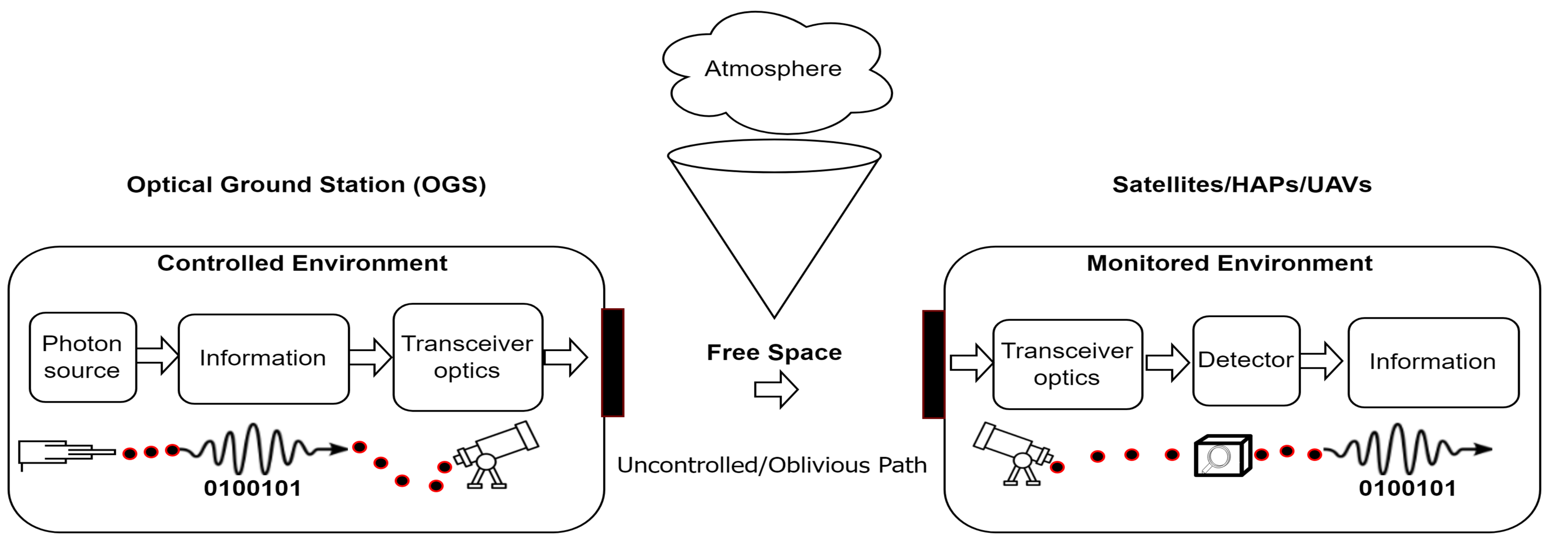
Scope & References

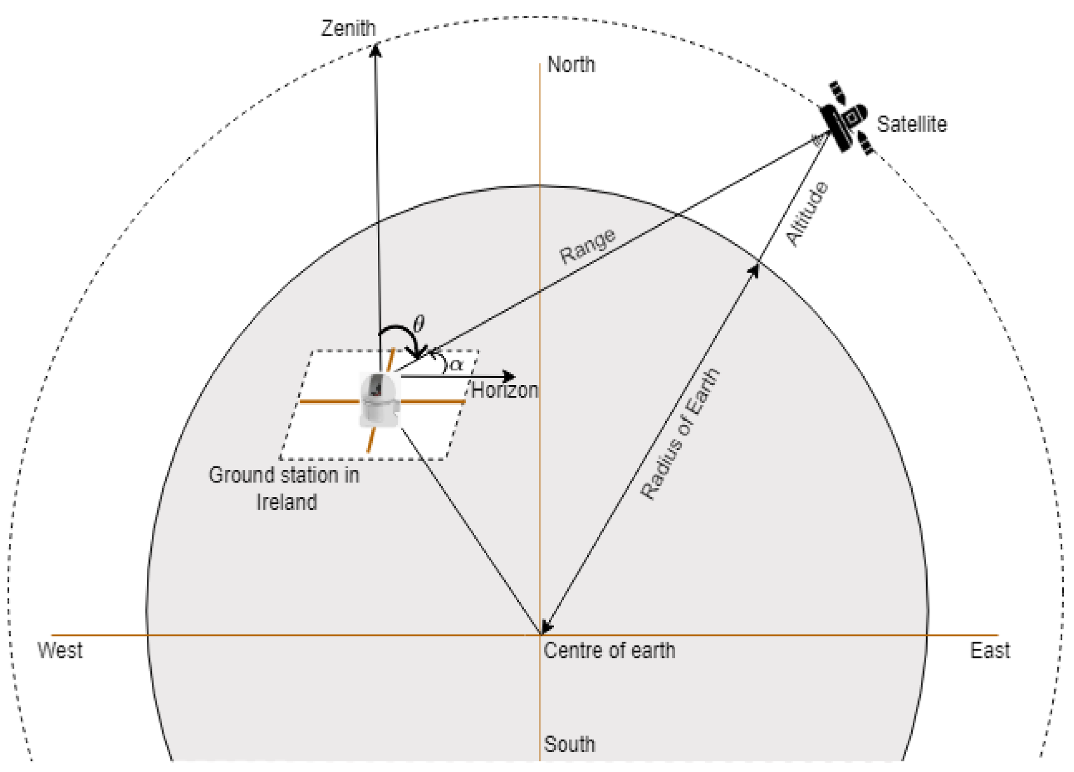
Developing simulation software to:

- Estimate achievable CV-QKD Secret Key Rate
- Determine optimum ground station location in Ireland.
- Extend analysis to multiple locations for geographical diversity.

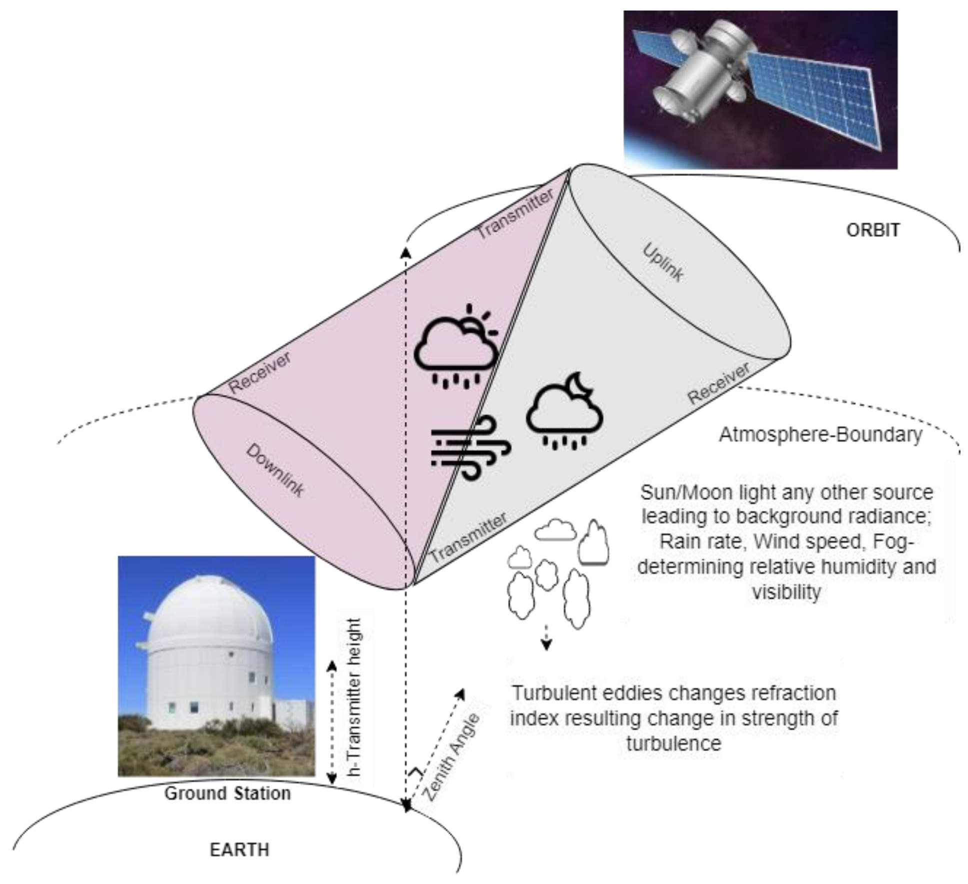
[1] J. S. Sidhu *et al.*, IET Quantum Communication, 2021
[2] S. Pirandola, Phys. Rev. Research, 2021
[3] D. Dequal *et al.*,npj Quantum Information, 2021

Research Problem Statement & Model Parameters





θ = Angle of zenith
α = Angle of elevation



Results

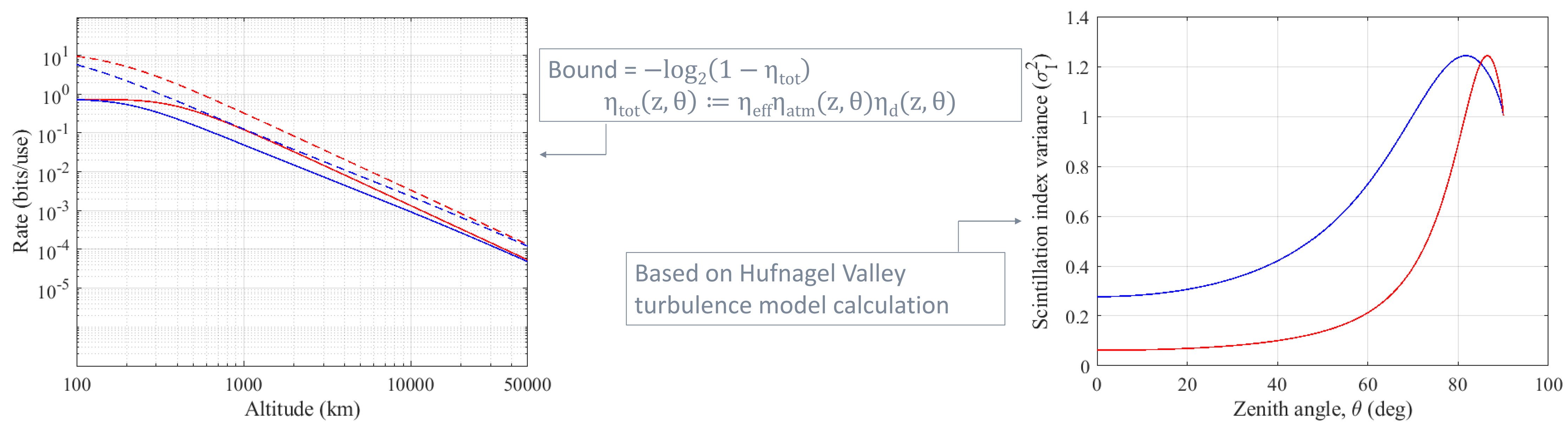


Fig.1 Upper bound of key rate in downlink with diffraction (dashed) and combined with effects (solid) of extinction, quantum efficiency at (θ= 0 (red) and 1 radiant (blue)).

Fig.2 Scintillation index variance versus zenith angle for typical ITUR night time (red) and day time (blue).

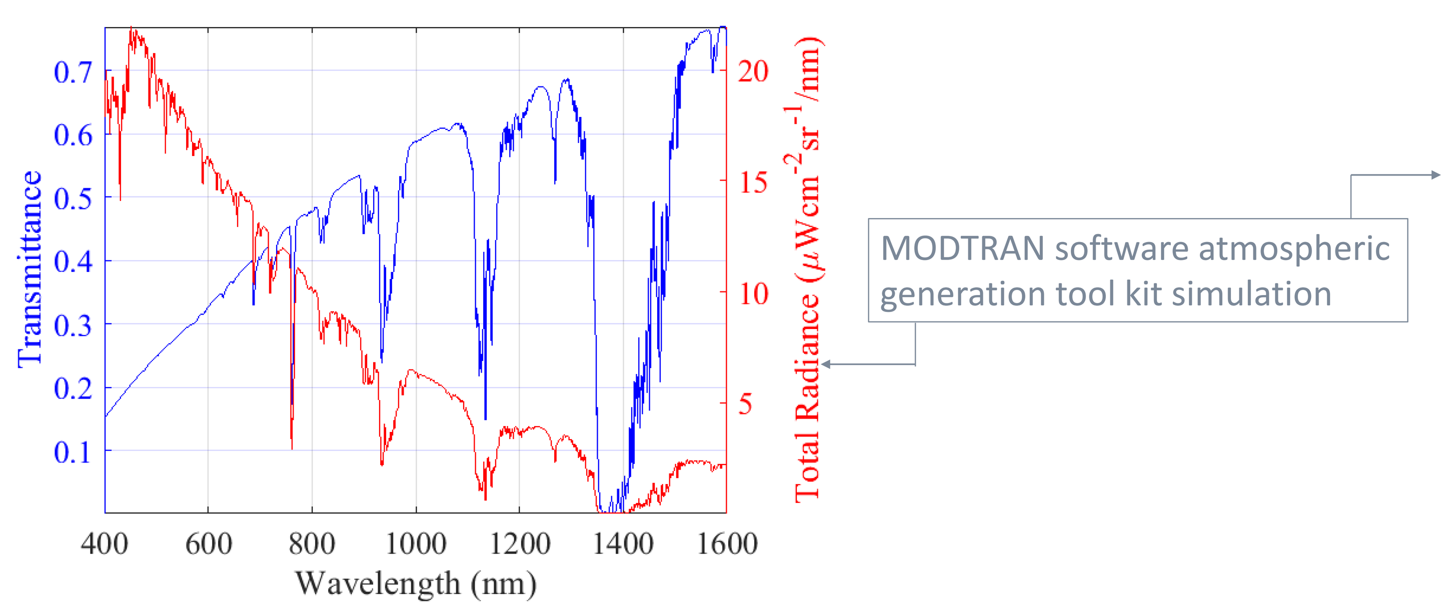


Fig.3 Transmittance and Total radiance for visibility 5 km.

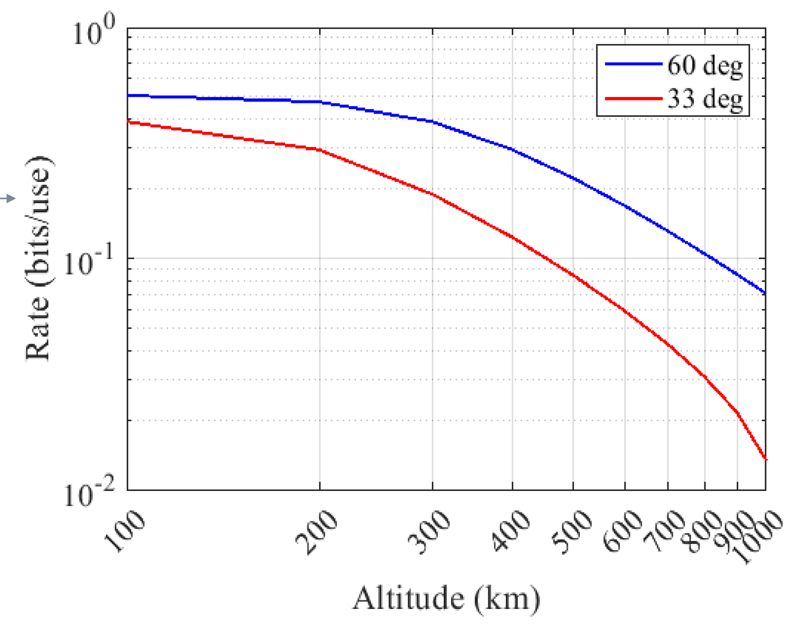


Fig.4 Theoretical upper bound of key rate for downlink configuration for CV- QKD at Waterford, Ireland. For α = 33 deg (red) and 60 deg (blue)

Parameter values used in current simulation

Receiver aperture radius = 60 cm, Wavelength = 1550 nm, Transmitter height = 30 m, beam waist = 28 cm
Nominal value of refractive index structure constant and wind speed
high wind day-time 2.75*10^(-14) m^(-2/3) and 57 m/s
low wind night-time 1.7*10^(-14) m^(-2/3) and 21 m/s
Satellite altitude = 400 km
MODTRAN Atmospheric Generation Tool kit for Waterford Coordinates 52.2538, -7.1888
Waterford Airport data sample, July 1st, 2022, Visibility = 19km

Observation: Optical visibility range of a location plays dominant role in resultant transmission

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