Topic 12

12. Non-line-of-sight Communications

12.1 Introduction

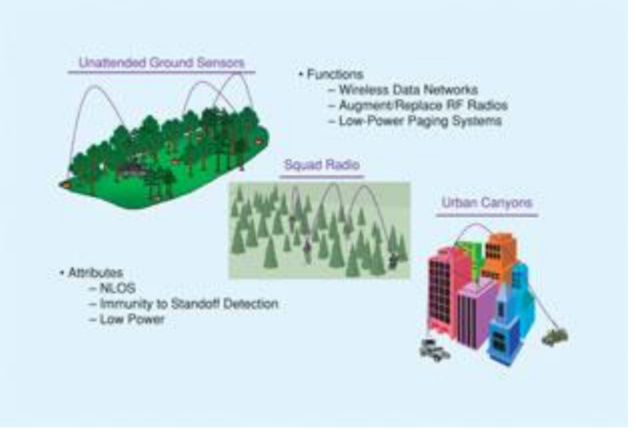
12.2 Applications

12.3 Advantages of NLOS

12.4 System and design

12.5 Major component: UV LEDs

12.6 Current challenges



Introduction

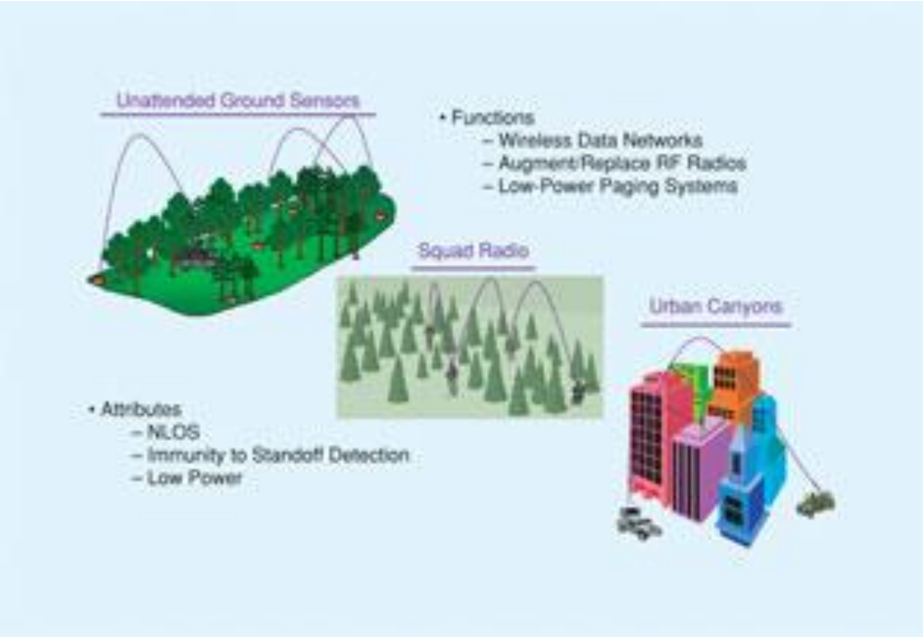
- **Line-of-sight (LOS) communication**: direct links, such as Infrared (IR) technology; and VLC system; Outdoor solar background; indoor florescence; IR performance receiver limited by dark noise

- **Some scenarios**: direct path may not be available; LOS optical communication is not possible

- **Non-Line-of-sight (NLOS)** communications is the option that would be interesting for these cases. It is a short range communication system, depending on a number of factors
  - It requires a large number of scattering centres for signal photons, which can generate **Non-Line-of-sight** paths for signals.
  - Less sensitivity to solar and other background interference, leading to less impact on the signal to noise ratio of a detector.
  - Short-range communications: strong absorption of signal beyond a certain range for security purpose.

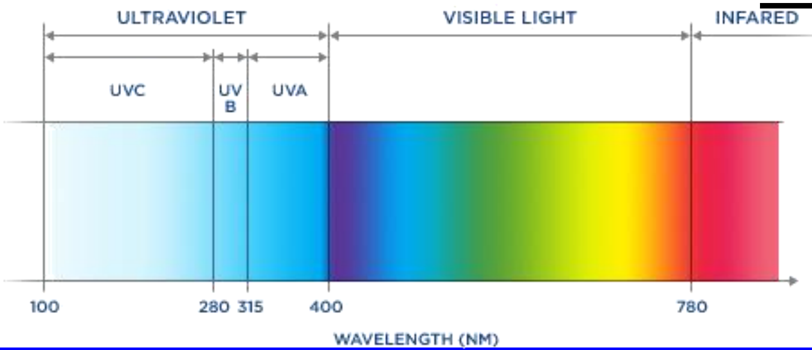
- **NLOS** is an ultraviolet (UV) based communication system

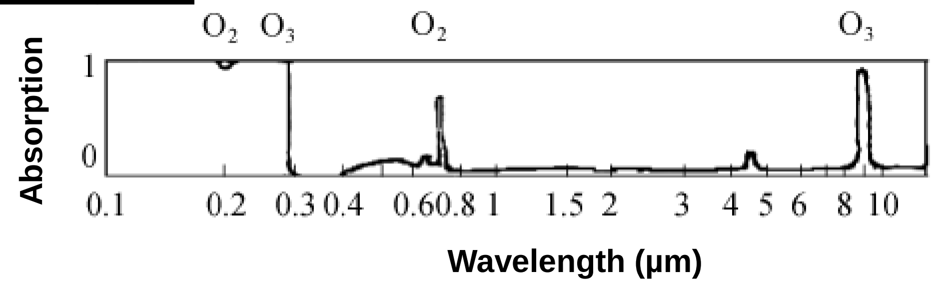
Applications



- Used when line-of-sight communication is not possible
- For a short range (<4km) and low-rate (<5Mb/s) communications
- For example:
  - In urban area as a backup network
  - For military applications in the battlefield

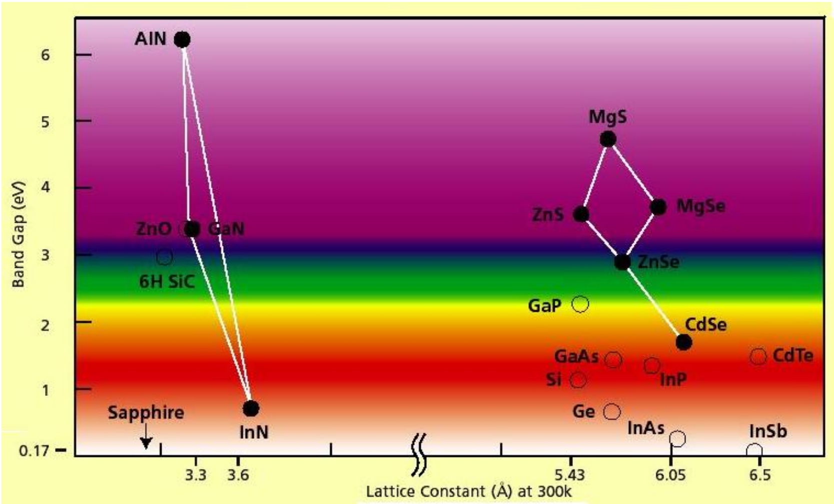
UV Light

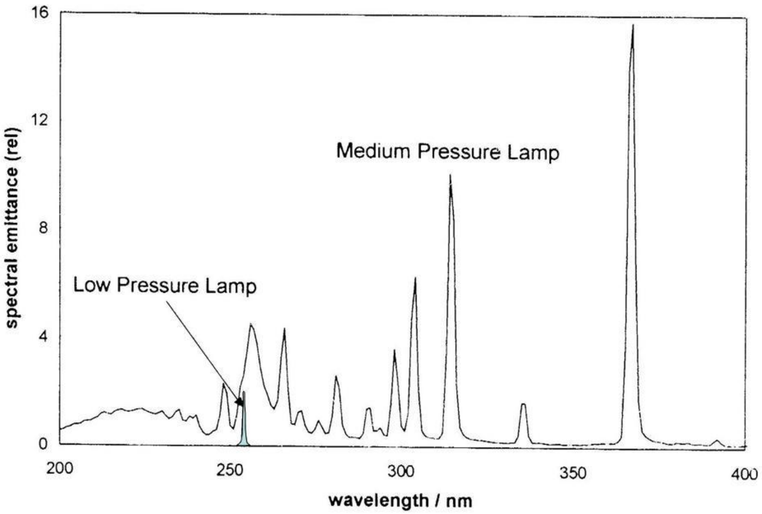




- **UV region** is divided into three parts
  UVA (315 - 400 nm); UVB (280 - 315 nm); UVC (100 - 280 nm)
- Photons in UV region have higher energies, and large numbers of them are harmful for human health
- **UV-C band (200-280 nm)**: solar bind at the ground level, meaning the solar radiation in this band from the Sun is filtered by the ozone layer in upper atmosphere
- **Rayleigh Scattering:** light scattering by particles of size << wavelength of light, inversely proportional to fourth power of wavelength (UV can be heavily scattered) $\boxed{I_s = K \cdot \lambda^{-4} \cdot sin^2 \cdot (\pi / 2 - \theta)}$
- **Mie scattering:** Water droplets, aerosols and dust particles are much larger than the wavelengths of UV; Such scattering does not depends on wavelength like small mirrors. The grey-white clouds is due to it.

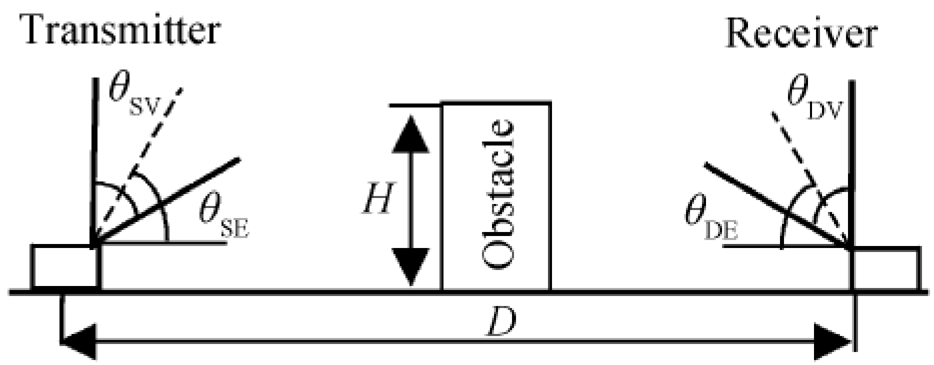
UV Lighting Sources

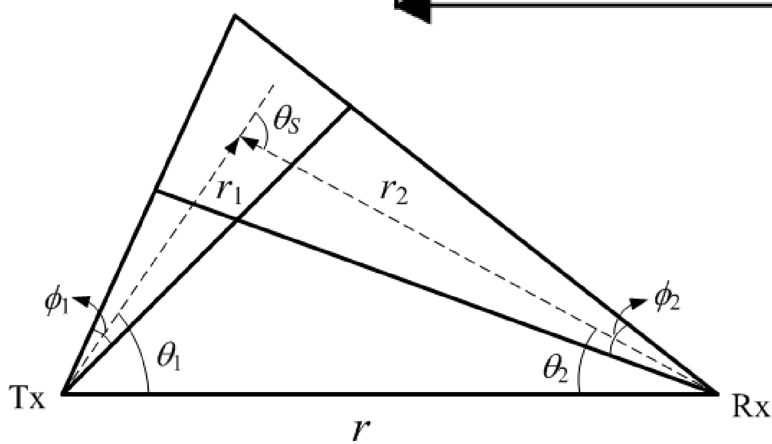


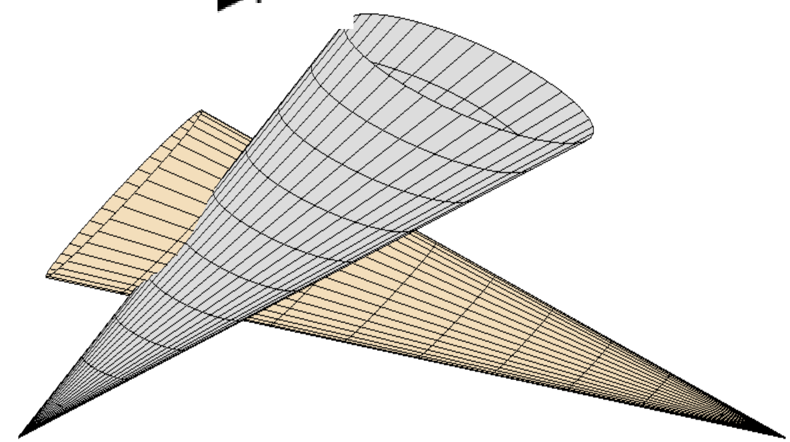


- **LED (AlGaN-based)**
  - ✓ Ideal; Current of UV-LEDs are still under development, in particular, LEDs in UV-C band due to a number of growth/device fabrication challenges (discussed later in part II)
- **Mercury Lamps**
  - ✓ Cheap; not environmentally friendly; but generate high power
  - ✓ Not portable and fragile
  - ✓ Two peaks at 253.7 nm and 185 nm due to the peak emission of the mercury: 85%-90% of the produced UV is at 253.7 nm
  - ✓ Slow modulation

Schematic of NLOS UV Systems







The NLOS UV channel involves a variety of phenomena: including molecular scattering and absorption, aerosol scattering and absorption, and atmospheric turbulence as a result of scattering of light due to the presence of the suspended particles in the atmosphere.

Channel Modeling-I

•The study of NLOS is still in an infant stage, although an understanding of the potential for UV systems began with how UV interacts with the atmosphere in 1965

• Study of NLOS is still based on simulation in order to calculate the impulse-response and link loss. Two method are widely used

✓**Monte-Carlo** (impulse-response and link loss):

• Employ a photon tracing and Mote Carolo technique to simulate the behaviour wave propagation and scattering in a homogenous medium.

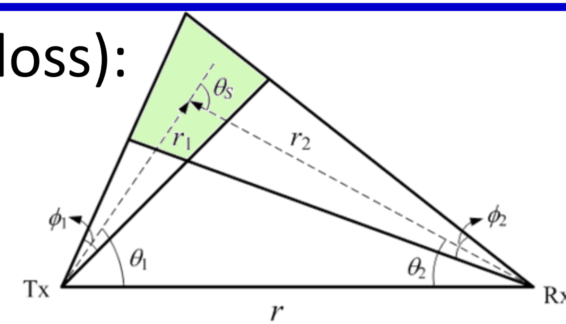
• Light consists of a large number of photons and an individual photon migration process is modelled by the physical law that governs this photon's position migration. Based on a large number of simulated photons, statistical results can be obtained for light propagation.

• A photon moves length Δ*s, and then suffer being either* ***scattered or absorbed****. Each photon survived that will be* renewed after each migration. The photon is repeatedly migrated until it either reaches the receiver or its disappearance (considered as lost). The procedure is repeated for many photons independently

✓ **Numerical integration (will not discuss)**

Channel Modeling-II

✓**Monte-Carlo** (impulse-response and link loss):



•Each photon's initial direction is confined within the full beam angle ϕ_1 with solid angle $2\pi(1-\cos(\varphi_1/2))$.

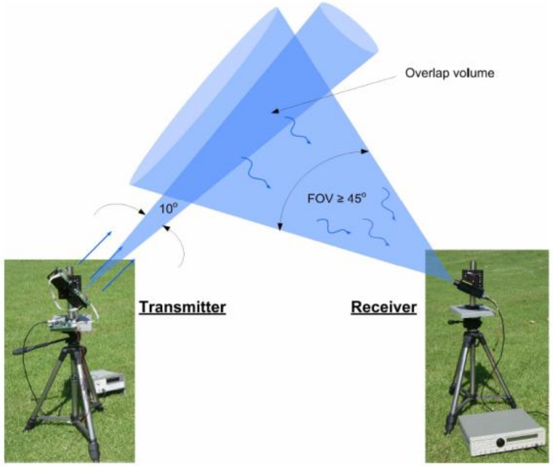
•The photon trajectory is then simulated by successive migration paths among different scattering centers in the channel.

• After each interaction between a photon and a scattering center, the photon's propagation follow the law of single scattering until it reaches the next scattering center, or arrives at the receiver, or is considered lost.

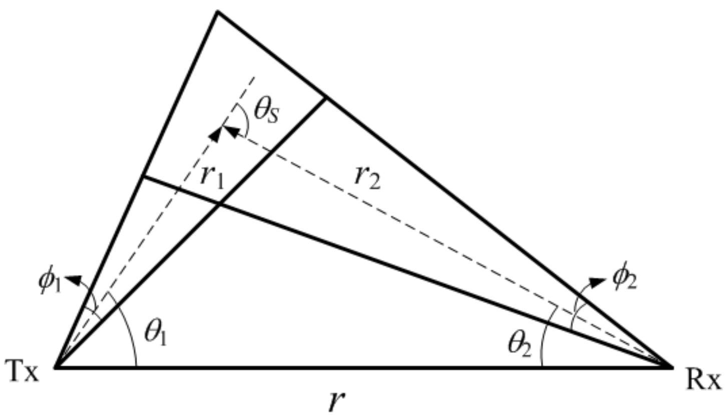
• You need to calculate a survival probability that the photon arrives at the receiver after n scattering steps

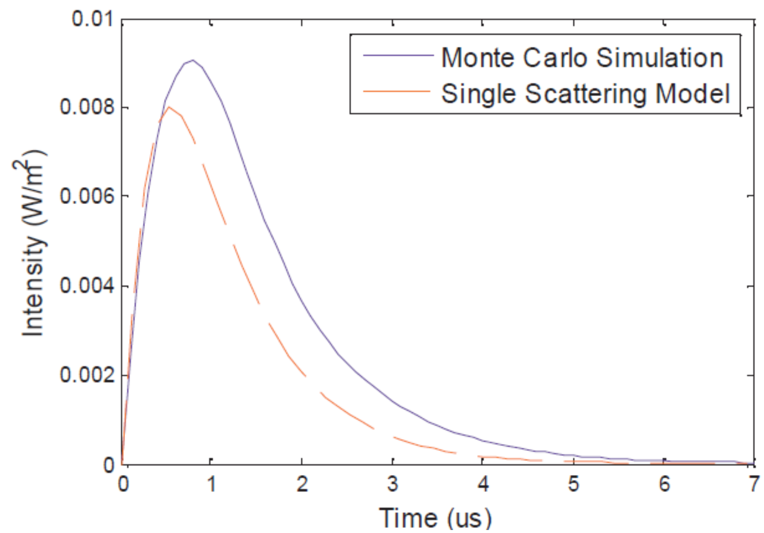
•The total arrival probability of one photon represents the percentage of photon energy that can be detected by the receiver

Channel Modeling-II



- **Transmitter**: an array of 7 ball-lens UV LEDs. Each LED yielding an average power of 0.3 mW
- **Atmospheric coefficients** at 260 nm given by $k_{Ray}=0.266\text{m}^{-1}$, $k_{Mie}=0.284\text{m}^{-1}$, and absorption coefficient $k_a=0.802\text{m}^{-1}$.
- **Geometric and model simulation parameters** $(\phi1, \phi2, \theta1, \theta2)=(17°, 30°, 90°, 90°)$, r=100m, and
- **Receiver area**: 1.77cm^2.

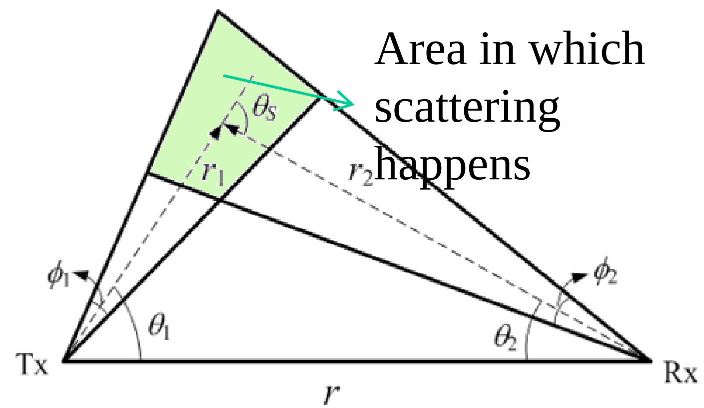




- Simulated impulse response under single and multiple scattering assumptions.

Challenges of NLOS-I

- Previously, we have learnt that one of the major mechanisms for bit error generation: **Inter-symbol interference (ISI)**, namely, some of the energy belongs to one particular bit period actually in one of the adjacent bit periods



- **Mechanisms for ISI**
  - Scattered energies from particles travels different paths to get to receiver
  - The energy transmitted at a certain time is received in different times
  - Transmitted pulses are subjected to a high temporal dispersion
  - Increasing the range, transmitted beam angle, or receiver field of view, become larger, leading to severe ISI issue

Challenges of NLOS-II

Received power

- UV pulse propagation depends on scattering, leading to absorption and being lost: the channel suffer a great loss
- The detector receives very weak powers
- Increasing the range, leading significant reduction in received power

NLOS UV communication is suitable for short-range links, but it is very good in terms for information security

T12 Summary and Tutorial Questions

- Mechanism and application of NLOS system
- Major advantages of NLOS compared with LOS and IR
- Key components of VLC: white LEDs
- Challenges of current NLOS
- Methods and simulations employed to study NLOS
- Principles for the simulations for channel modelling