Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: [Optical channel model based on Lambertian emitters and reflectors]
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Re: [Call for contributions for TG7 for channel modeling]

Abstract: [This contribution presents a model for wireless optical channels based on Lambertian emitters and reflectors]

Purpose: [This document is provided in response to the call for contributions for channel modeling in TG7]

Need for optical channel modeling

- Understanding the communication channel is the key to understanding and designing a communication system
- Optical channels are very different from RF communication channels
  - Traditional methods of RF modeling do not apply

Past relevant work

- There has been extensive work done for optical channel modeling for "infra-red" wireless communications.
  - Models developed are applicable to visible light communication

Classification

- Directivity
  - Directed links (aim to establish link)
  - Non-directed links (wide-angle TX/RX)
  - Hybrid
- Visibility
  - LOS (max power efficiency/low multipath distortion)
  - NLOS (robustness/ease to use/ease to design)

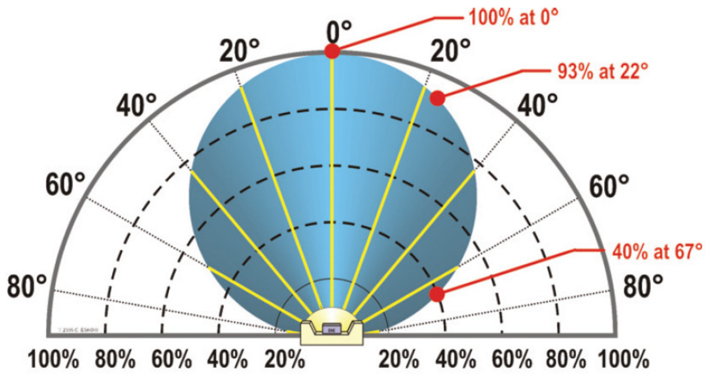
Channel model considerations

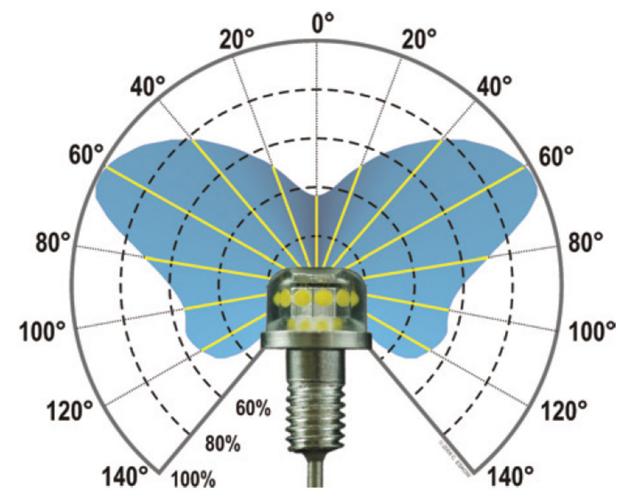
- Transmitter characteristics
- Receiver characteristics
- Reflections (channel)

Important TX characteristics for modeling the channel

- Radiation pattern (LED/Laser)
- Orientation
- Mode number of transmission
  - Directivity

Transmit patterns



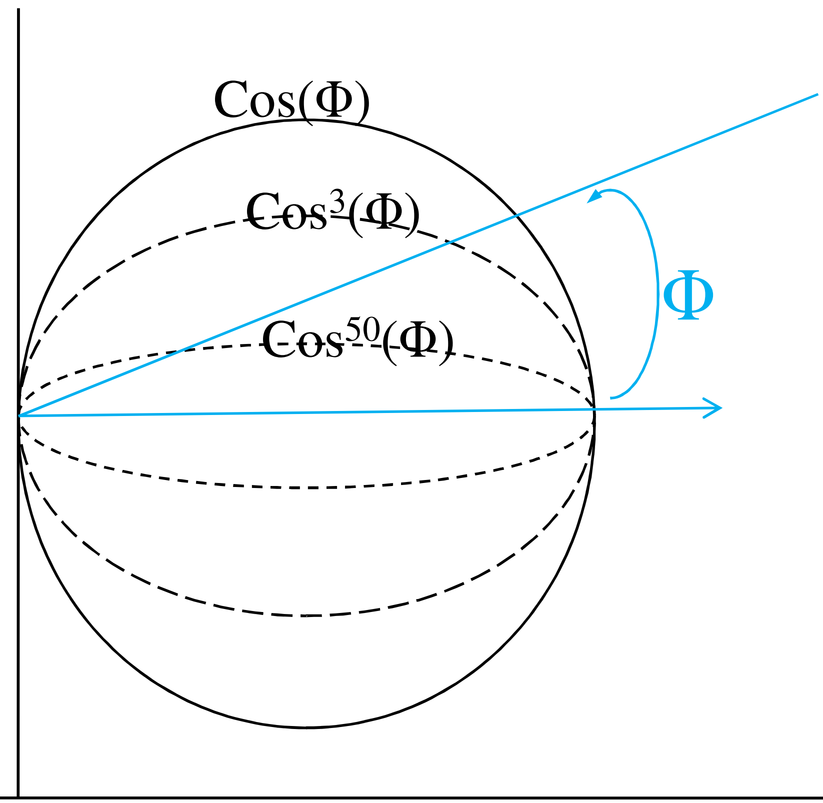


Lambertian, Bat-wing (Butterfly), Side-emitting

Figure borrowed from reference [3]

Mode number of transmission

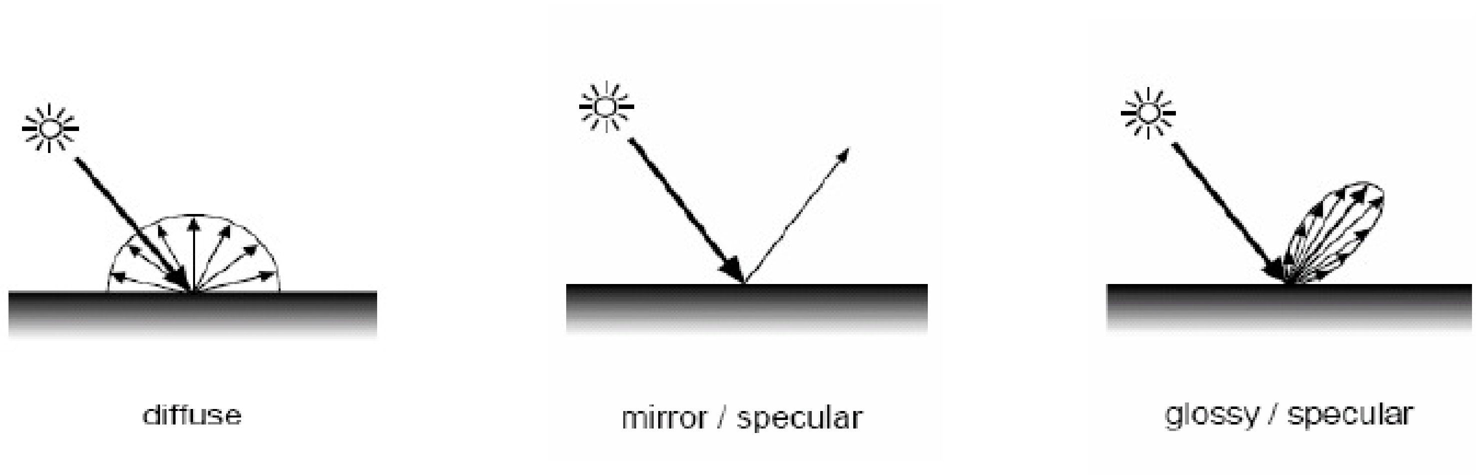
- Higher mode numbers imply more directivity.
- N = 1 – traditional lambertian



Important RX characteristics for modeling

- Receiver orientation
- Photo-diode surface area
- Field of vision

Channel surface reflection patterns



- Diffuse
  - Rough surface
    - Clothing, paper and asphalt road
  - Lambertian reflection
- Mirror/Specular
  - Smooth surface
    - Mirror or calm water
  - Reflection Index
- Glossy/Specular
  - Not diffuse,mirror
  - BRDF(Bidirectional Reflectance Distribution Function)

Figure borrowed from reference [2]

Popular optical channel models

- The effect of multipath fading in optical channel models can be neglected. Spectral nulls occur at frequencies where the reflections cause destructive interference. The "antenna" in a light detector has a radiation collection area of 1 cm^2. This antenna is large compared to the wavelength of light, on the order of $10^4\ \lambda$. The light detector is a square law device that integrates the square of the radiation impinging upon it. This large size of the detector compared to the wavelength provides a degree of inherent spatial diversity in the receiver that mitigates the impact of multipath fading.

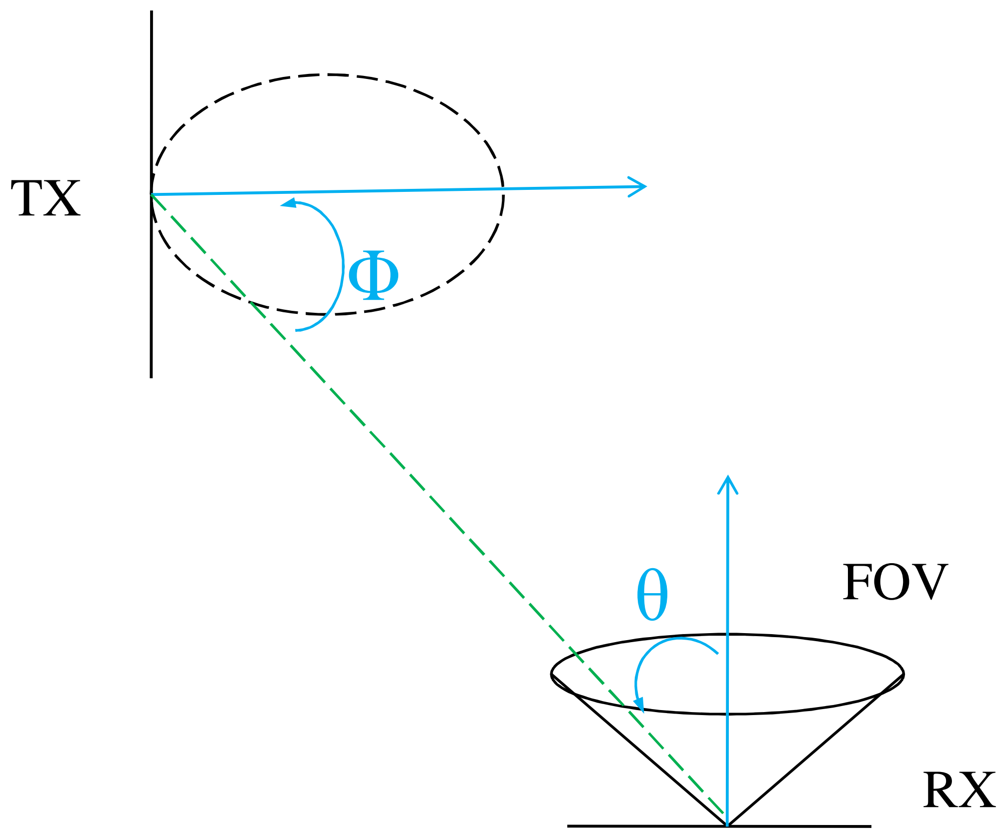
- Although fading is not an impediment, the temporal dispersion of the signal due to multipath propagation can cause ISI. This is a very important consideration for VLC design

- Popular methods for modeling:
  - Lambertian
  - Ray-tracing
  - Integrating sphere

Current model

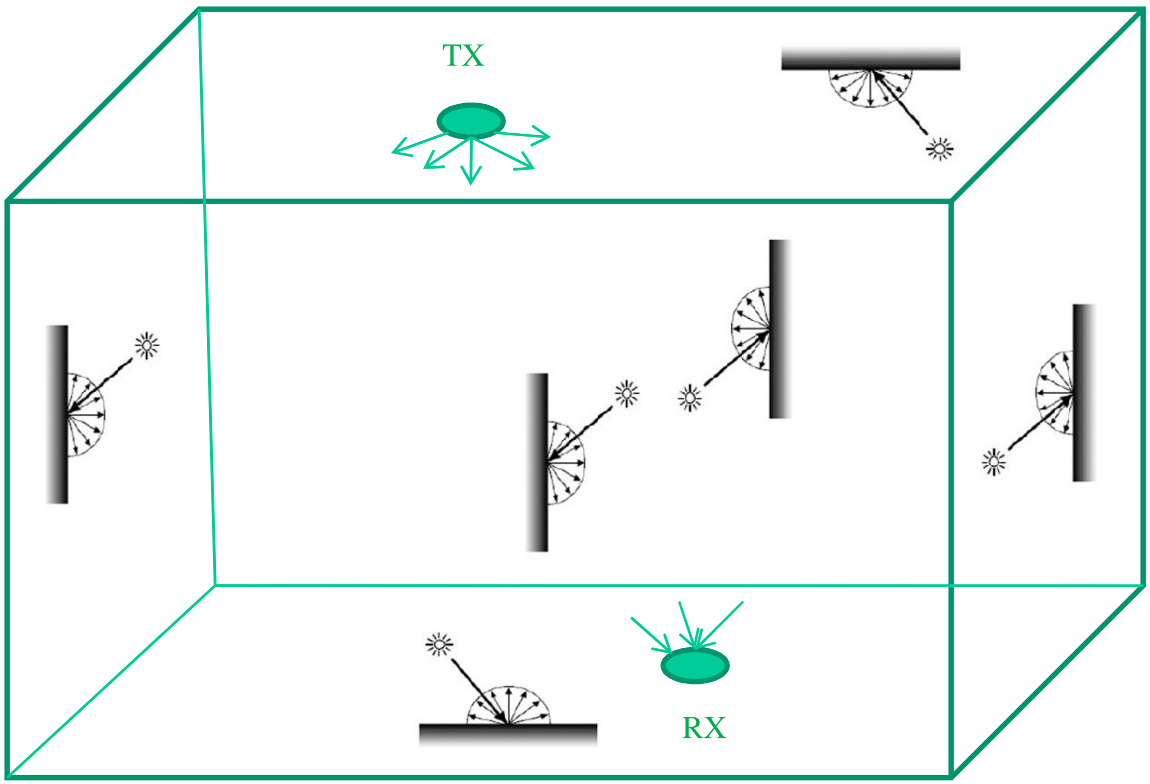
- General model
  - Any number of reflections
  - Any type of room and Tx/Rx placement
  - Source – generalized Lambertian pattern for emission
  - Reflectors – Lambertian reflectors

LOS component



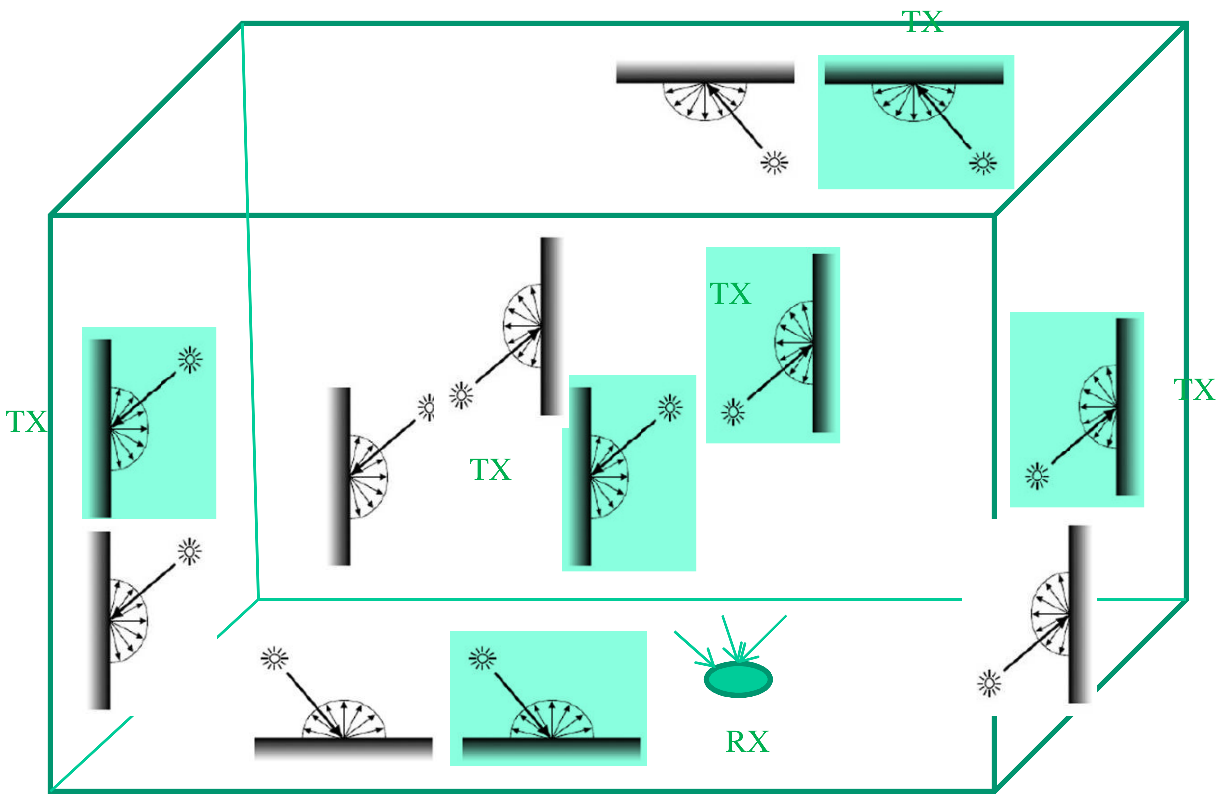
1st order reflection

Assume empty room. Light from the TX hits the wall, suffers a loss depending on the reflection coefficient and then hits the receiver.
To model this, all 6 sides of the wall are broken into tiny pieces of area and the net delay and path loss from all components are added at the receiver



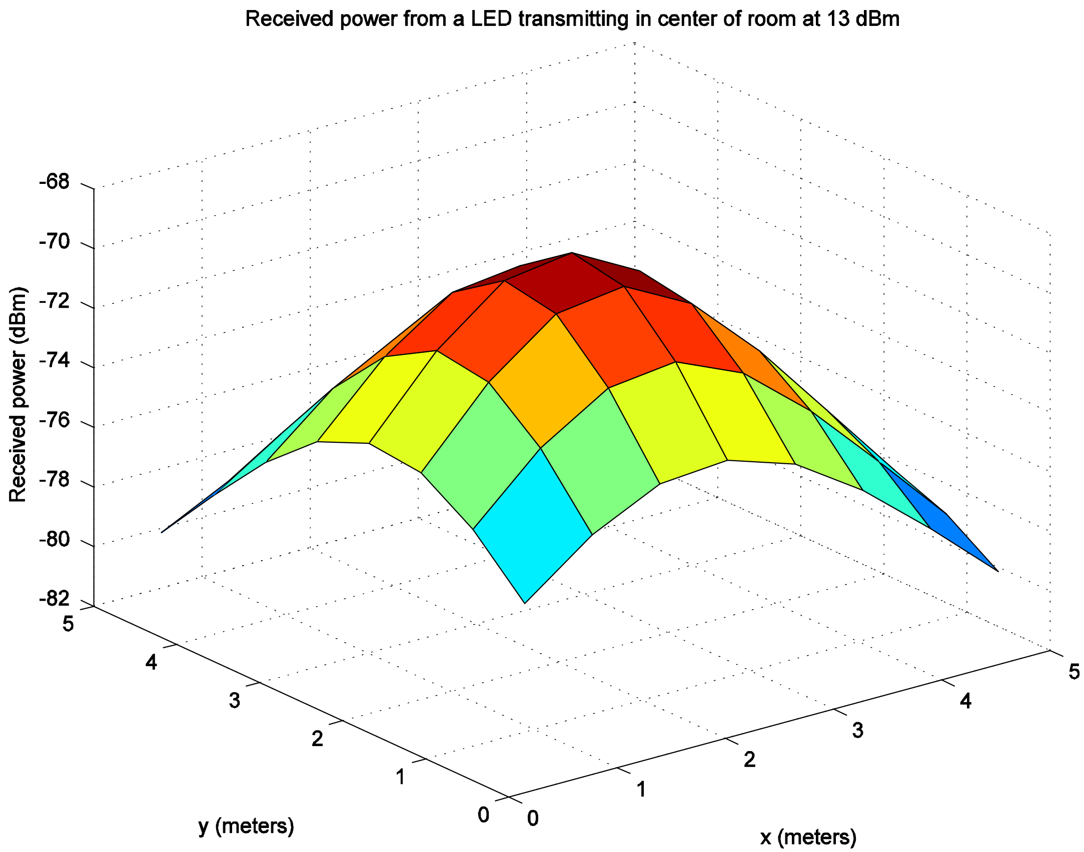
2nd order reflection

After hitting the wall once, each point is now considered as a transmitter and it now hits the walls again before it hits the receiver. The delay and path loss of all components are now computed again and added at the receiver

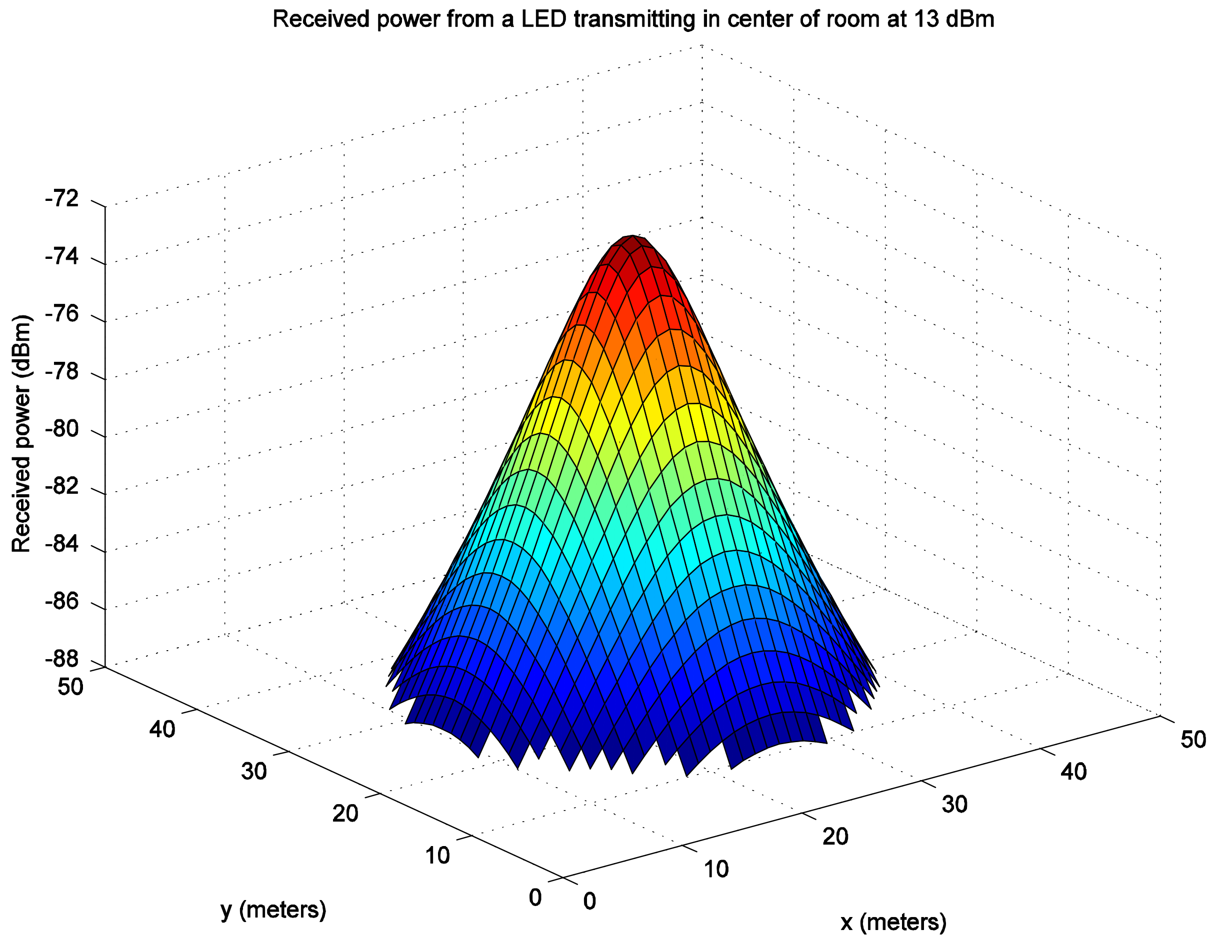


Initial simulation results

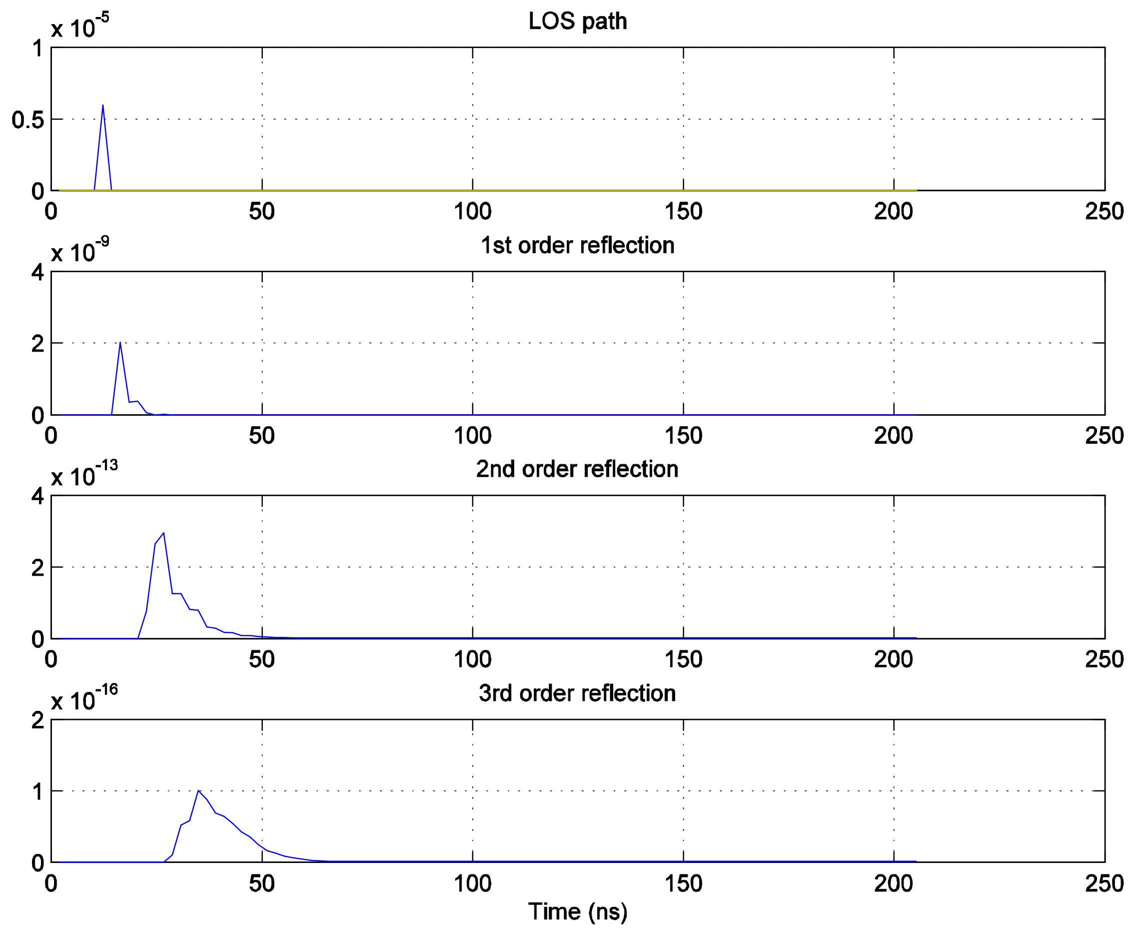
Simulation Results for (5x5x2.5m) room with LED at top center



Simulation Results for 50x50x3m room



Impulse response for 5x5x2.5m room



Issues not yet considered

- Multiple transmitters
  - (would need to integrate over all transmitters)
- Frequency dependent components
  - Variations in TX power spectrum etc.
- Outdoor environment will have refractive index changes due to atmosphere and temperature variations (scintillation effects)
  - Vehicular applications
- Ambient light and other natural interference must be added to the model

Summary

- An initial model for optical channels is presented based on Lambertian emitters and reflectors.
- This model is flexible and can support any configuration of Tx/Rx placement and any number of multipath reflections.
- Current simulations are very coarse (detailed simulation with different configurations could take multiple days – goal is to seek understanding and validity of model at this point)
- This model still has scope for refinement and improvement.

References

1. "Simulation of Multipath Impulse Response for Indoor Wireless Optical Channels", John R. Barry , Joseph M. Kahn, William J. Krause, Edward A. Lee,David G. Messerschmitt, IEEE Journal on Selected Areas in Communications, vol. 11, pages 367-379, 1993.
2. "VLC channel modeling with different reflection types", Jaeseung Son, Taehan Bae, Hyukchoon Kwon, Euntae Won, IEEE 802.15-08-0784-00-0vlc
3. "Designing illumination systems with high speed LEDs" – Cary Eskow, Avent Electronics
4. "Wireless Optical Communication Systems" ,Steve Hranilovic, Springer, 1st edition, 2004.
5. "VLC channel modeling in Home, Café", Jaeseung Son, Dongjae Shin, Taehan Bae, Hyukchoon Kwon, Euntae Won, Atsuya Yokoi, IEEE 802.15-08-0677-01-0vlc