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Path Loss Models for Air-to-Ground Radio Channels in Urban Environments

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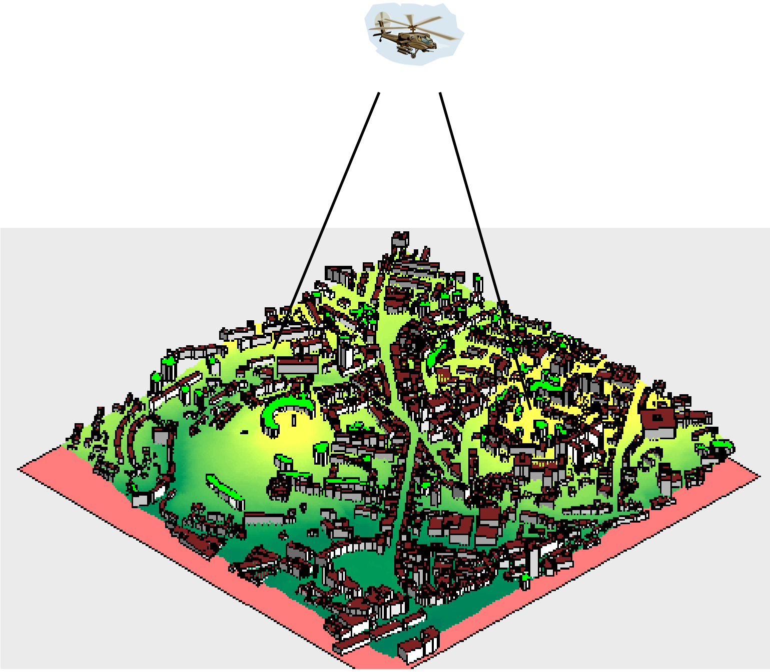
Outline

- Introduction
- Modelling methods
- Models
- Conclusions and future work

Scenario



Bristol city centre

- Enhanced ground to ground connectivity via airborne relays.
- No existing model is capable of modelling this scenario (high antenna height and randomly distributed mobile nodes).
- New model
  - LoS probability,
  - mean path loss (MPL),
  - shadowing.

Conventional path loss models

- Log-distance path loss model:

$$L_b(d)[\mathrm{dB}] = L(d_0) + 10n\log(d/d_0) \quad \text{for } d \ge d_0 \qquad (1)$$

where n is the path loss exponent, d is the Tx-Rx distance, and d_0 is commonly expressed as the free space reference distance.

- Log-Normal shadowing model:

$$L_s[\mathrm{dB}] = N(0, \sigma_s)$$

- Limitations:
  - Incapable of modelling path loss for the continuously varying airborne height.
  - Models as a function of elevation angle is more convenient.

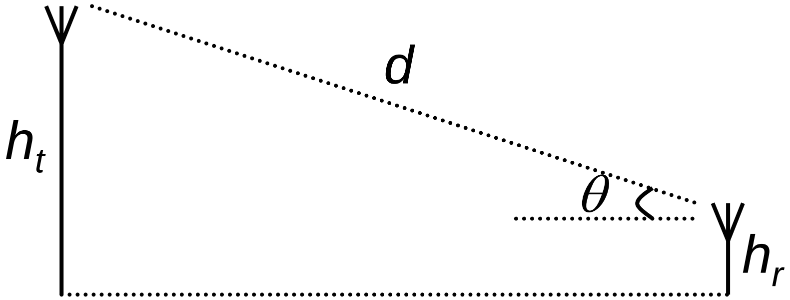
Proposed method (1/2)

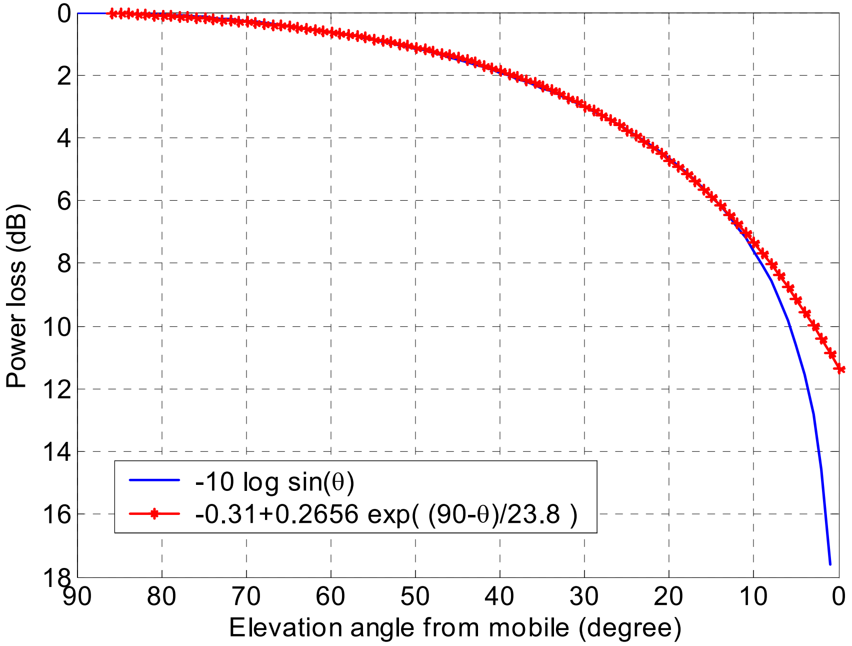
Let $d_0 = h_t - h_r$, then equation (1) becomes:

$$\boldsymbol{L_b}(\theta)[\text{dB}] = \boldsymbol{L_f}(\boldsymbol{d}_0) - 10\boldsymbol{n}\log\sin\theta \quad \text{for } \boldsymbol{d} \ge \boldsymbol{d}_0$$

when $\theta > 10°$,

$$-10\log\sin\theta \approx -0.3115 + 0.2656e^{(90-\theta)/23.8}$$





The path loss can be modelled as a function of the elevation angle.

Proposed method (2/2)

Proposed mean path loss model:

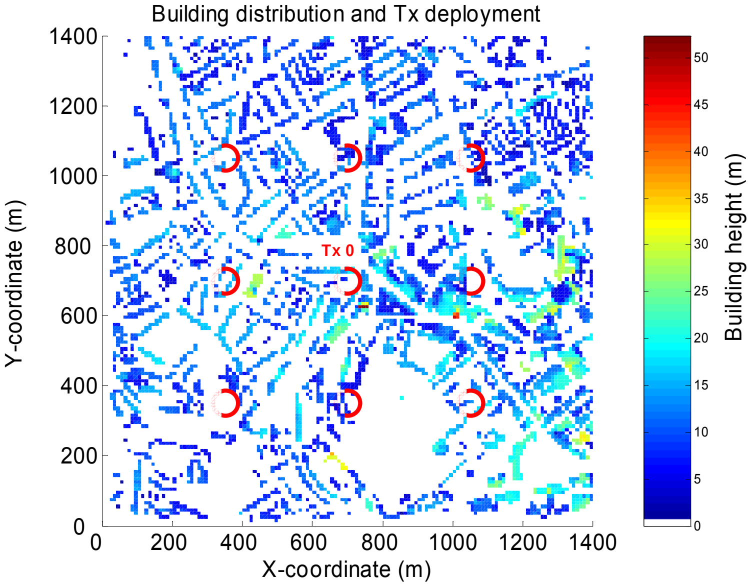
$$L(\theta)[\mathrm{dB}] = \underbrace{L_f(d_0)}_{\text{A function of } h_t} + \underbrace{L_2(\theta)}_{\text{A function of } \theta} \quad \text{for } \theta > 10° \qquad (2)$$

where

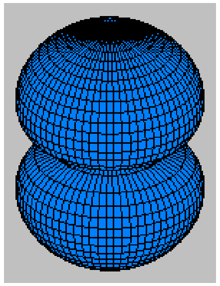
$$L_2(\theta)[\mathrm{dB}] = \alpha_0 + \alpha_1 e^{(90-\theta)/\beta}$$

- Modelling path loss as a function of the elevation angle to the airborne platform, rather than the more usual separation distance used for terrestrial mobile communications.

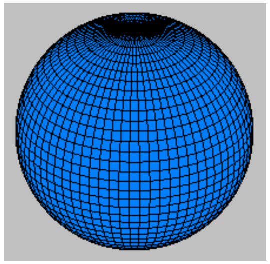
Ray tracing set-up



E_θ



E_φ



- Operating environment:

  1.4km × 1.4km, central Bristol.

  building coverage 28%,

  mean building height 11.7m,

  terrain height STD 17.5m.

- Mobile nodes:

  1.5m above ground level (AGL),

  20,000 uniformly distributed outdoor locations,

  receiver sensitivity -120dBm,

  crossed dipole antenna.

- Airborne nodes:

  100 / 200 / 500 / 1000 / 2000m AGL,

  9 locations,

  transmit power 30dBm,

  crossed dipole antenna.

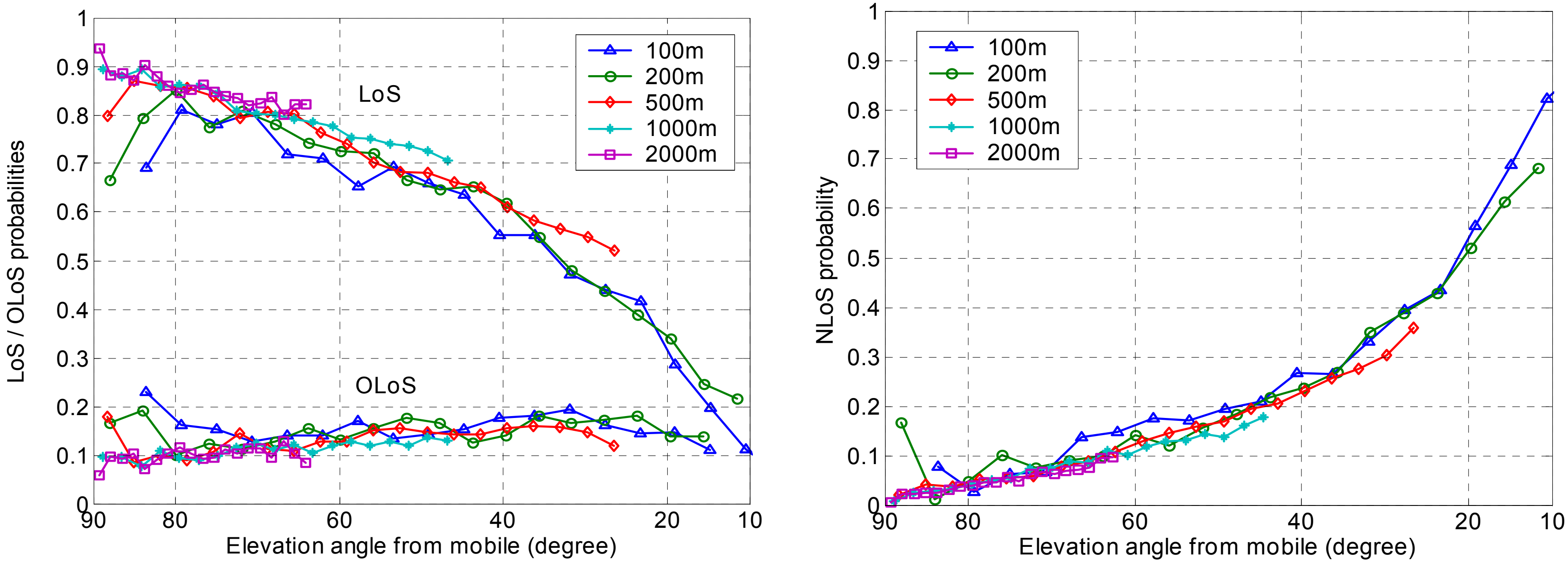
- Frequencies:

  200M / 1G / 2G / 2.5G / 5GHz

Radio channel category

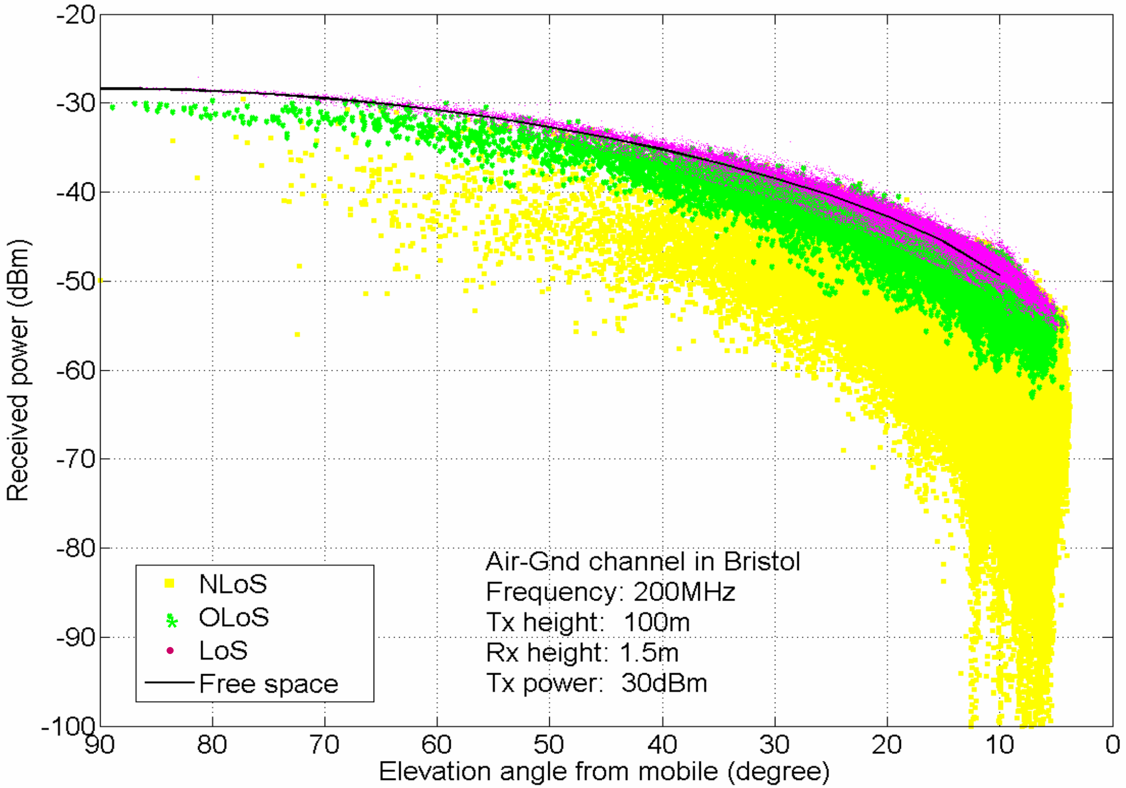
- LoS requires a direct path with sufficient clearance of the first Fresnel zone.
- If the direct path is partially attenuated by foliage only, the channel is defined as Obstructed LoS (OLoS).
- If the direct path is blocked by one or more buildings, the channel is regarded as Non-LoS (NLoS).

LoS/OLoS/NLoS probabilities



- The probabilities are independent of the airborne height.

Mean path loss (1/2)



- ☐ The received power is seen to decrease exponentially with decreasing elevation angle. This supports our method of modelling path loss with elevation angle.

Mean path loss (2/2)

LoS/ OLoS

$$L(\theta)[\text{dB}] = L_f(d_0) + L_2(\theta) \quad \text{for } \theta > 10°$$

$$L_2(\theta)[\text{dB}] = \alpha_0 + \alpha_1 e^{(90-\theta)/\beta}$$

NLoS

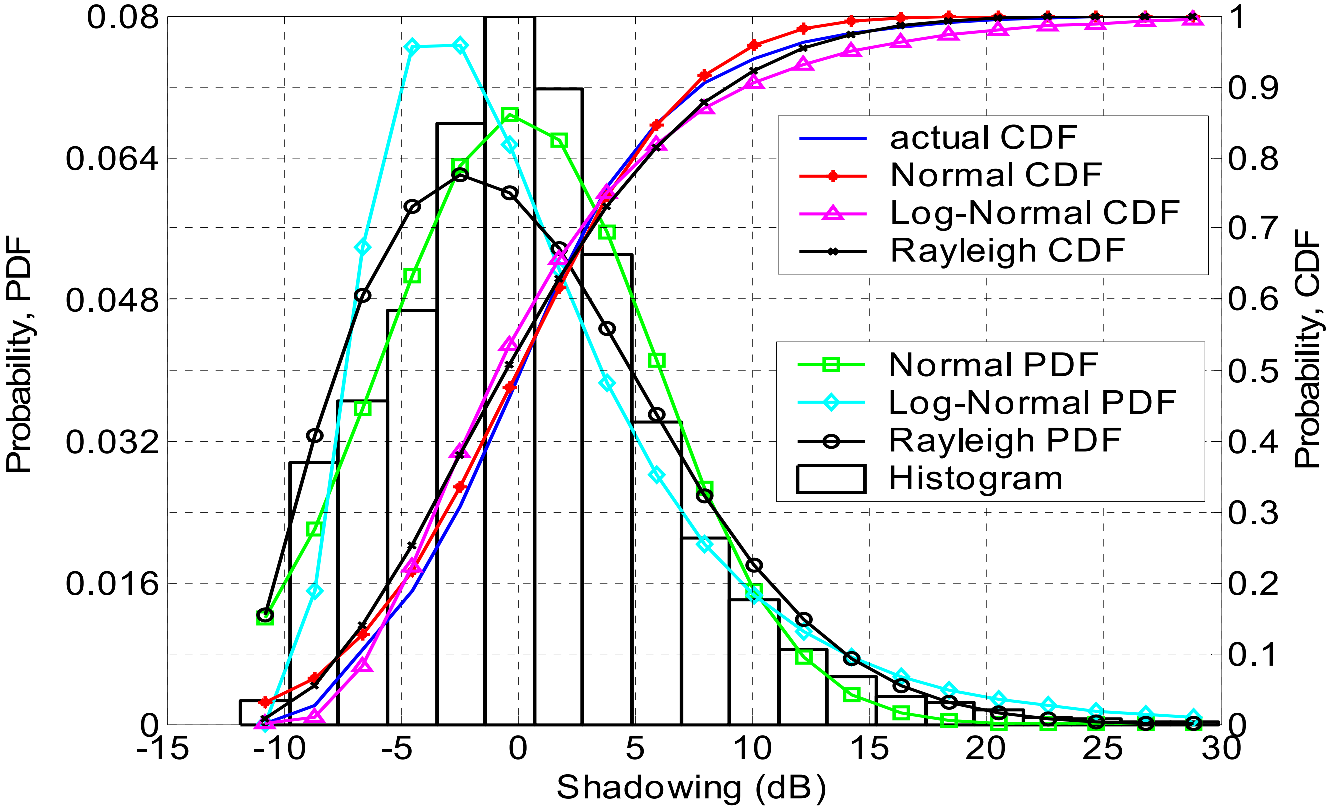
$$L(d,\theta)[\text{dB}] = L_f(d) + L_3(\theta) \quad \text{for } \theta > 10°$$

$$L_3(\theta)[\text{dB}] = \eta_0 - \eta_1 e^{-(90-\theta)/\nu}$$

☐ L_2 for OLoS and L_3 for NLoS is basically independent of the airborne antenna height.

Shadowing (1/2)

NLoS:



- The Normal distribution is considered to be a reasonable and simple assumption for shadowing loss.

Shadowing (2/2)

Standard deviation (STD) of shadowing:

$$\sigma_s[\mathrm{dB}] = \rho(90 - \theta)^{\gamma}$$

☐ STD of shadowing for OLoS and NLoS channels are independent of airborne height.

☐ Shadowing (in dB) follows a zero-mean Normal distribution about the MPL (in dB), with an elevation-angle-dependent STD (in dB).

Conclusion and future work

- Novel air-to-ground channel model
  - Based on elevation angle instead of separation distance.
  - Coefficients are independent of the airborne height:
    - LoS/OLoS/NLoS probabilities,
    - the second part (L_2, L_3) of MPL,
    - STD of shadowing for OLoS/NLoS channels.
  - our models are capable of modelling the scenario of continuously varying airborne height.
- The models are based on a hilly terrain in a typical European city. Further direction will work on flat terrain and other geographical cities.