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Wireless Communications Channels
Lecture 2: Propagation Mechanisms

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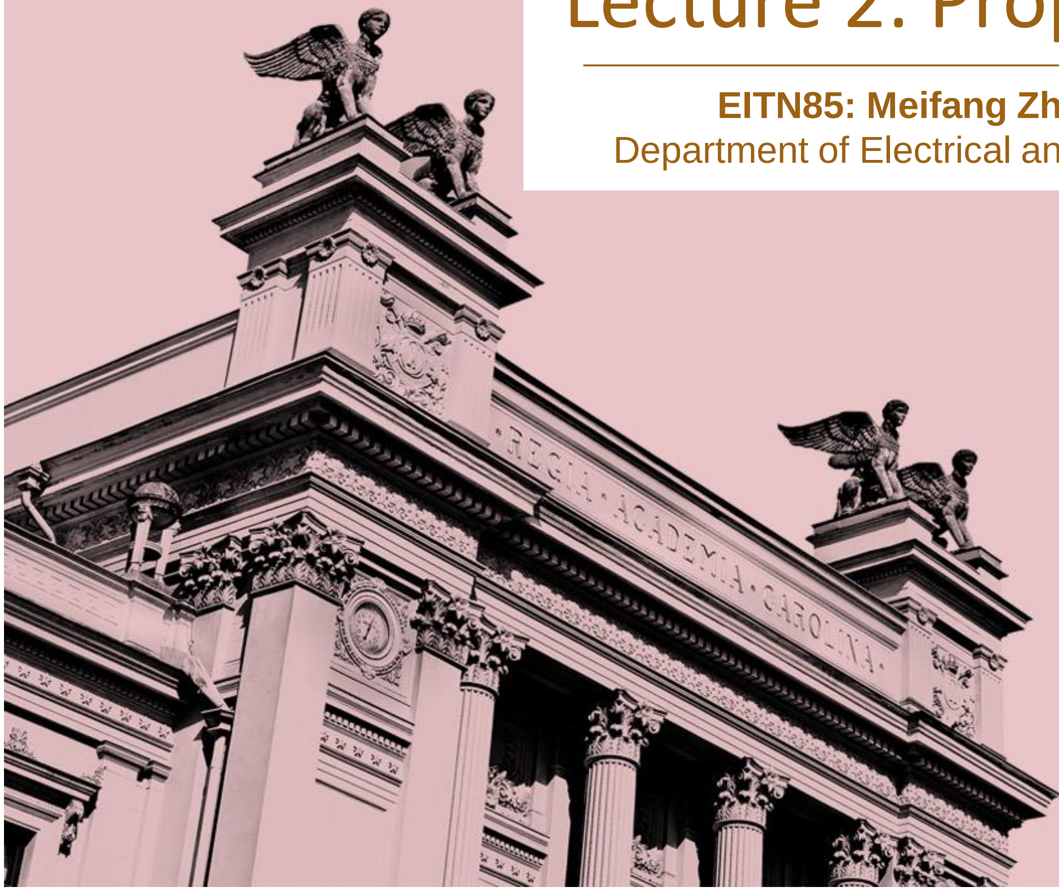

Recap:Last lecture

- Free space path loss
  - Friis's law
  - The d^{-4} law

- Reflection and transmission

- Diffraction
  - Fresnel integral

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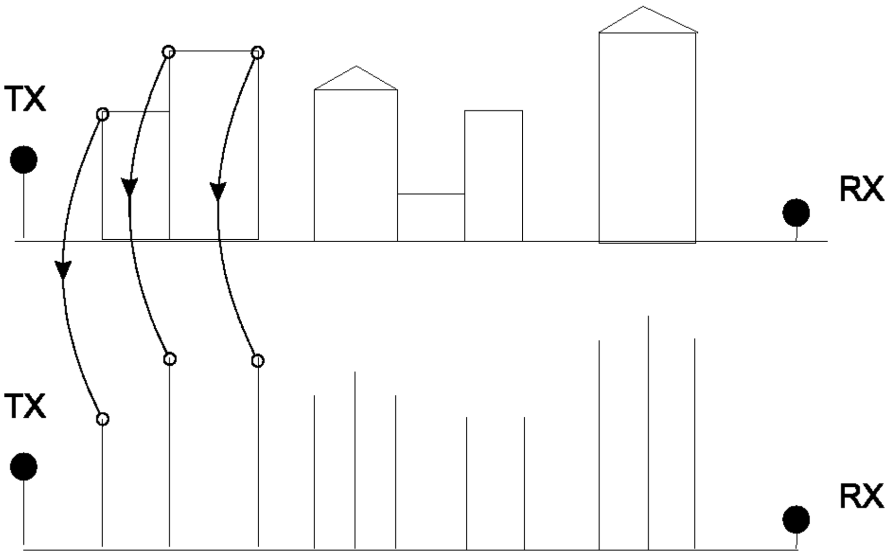
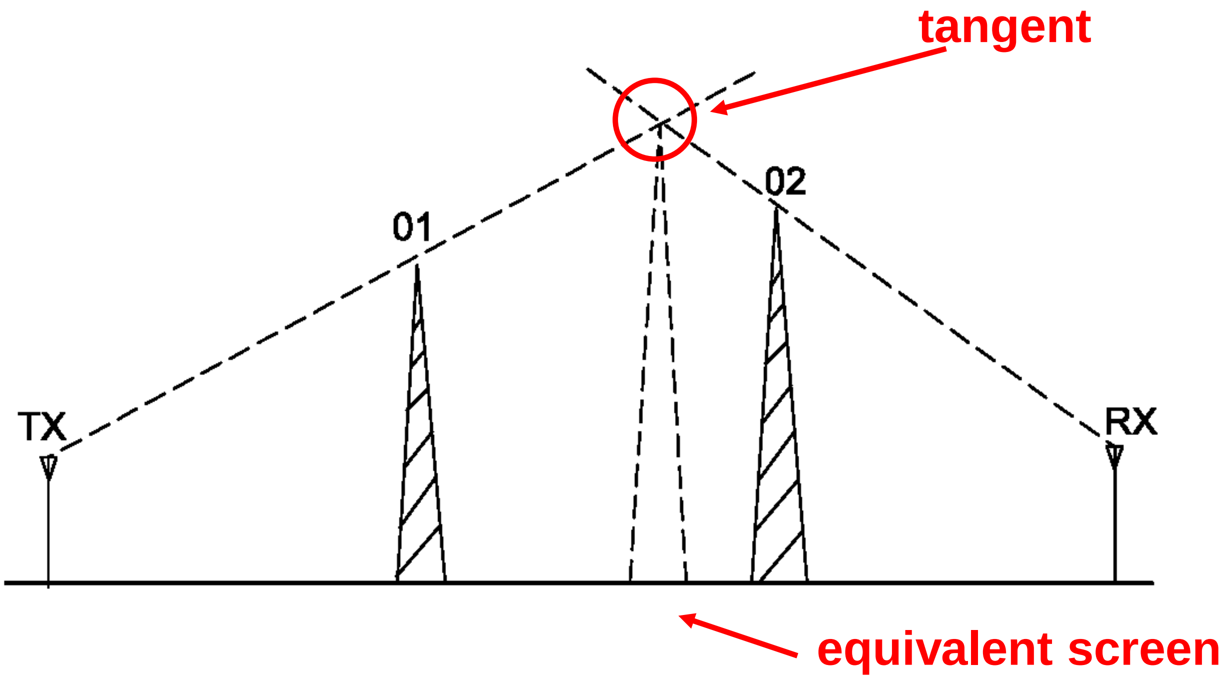
Diffraction in real environments



For real environments we can represent buildings and objects as multiple screens

Diffraction: Bullington's method



Replace all screens with one equivalent screen

Height determined by the steepest angle

Simple but a bit optimistic

$$E_{\text{total}} = \exp(-jk_0 x)\left(\frac{1}{2} - \frac{\exp(-j\pi/4)}{\sqrt{2}} F\left(\nu_{\text{F}}\right)\right)$$

$$\nu_{\text{F}} = \alpha_k \sqrt{\frac{2d_1 d_2}{\lambda(d_1+d_2)}}$$

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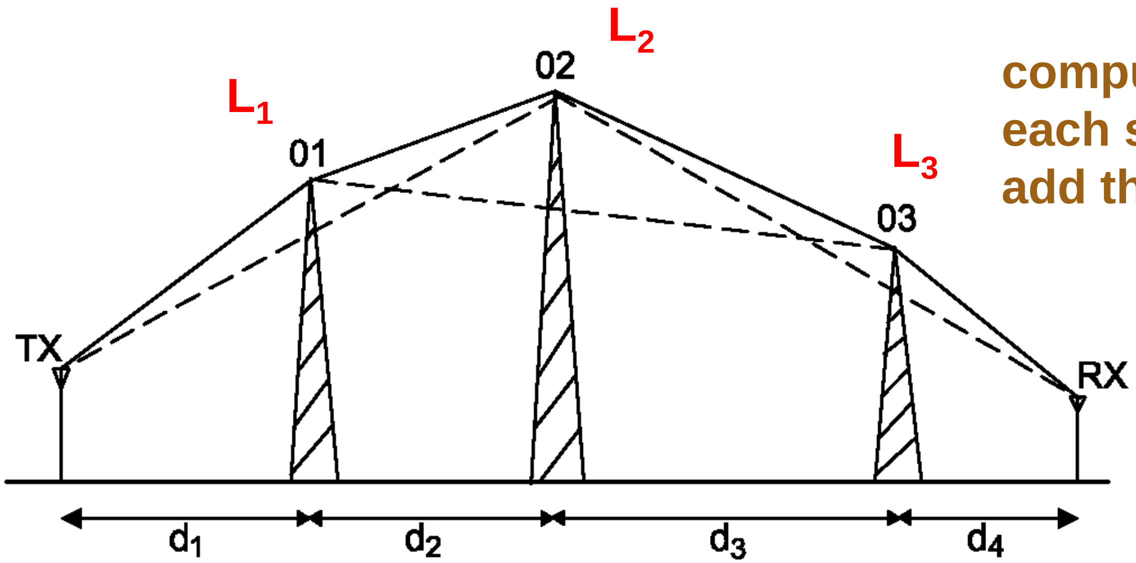
Diffraction – Epstein-Petersen Method



compute diffraction loss for each screen separately and add the losses

$$L_{tot}=L_1+L_2+L_3$$

The same approach is used also for the ITU model, but with an empirical correction factor

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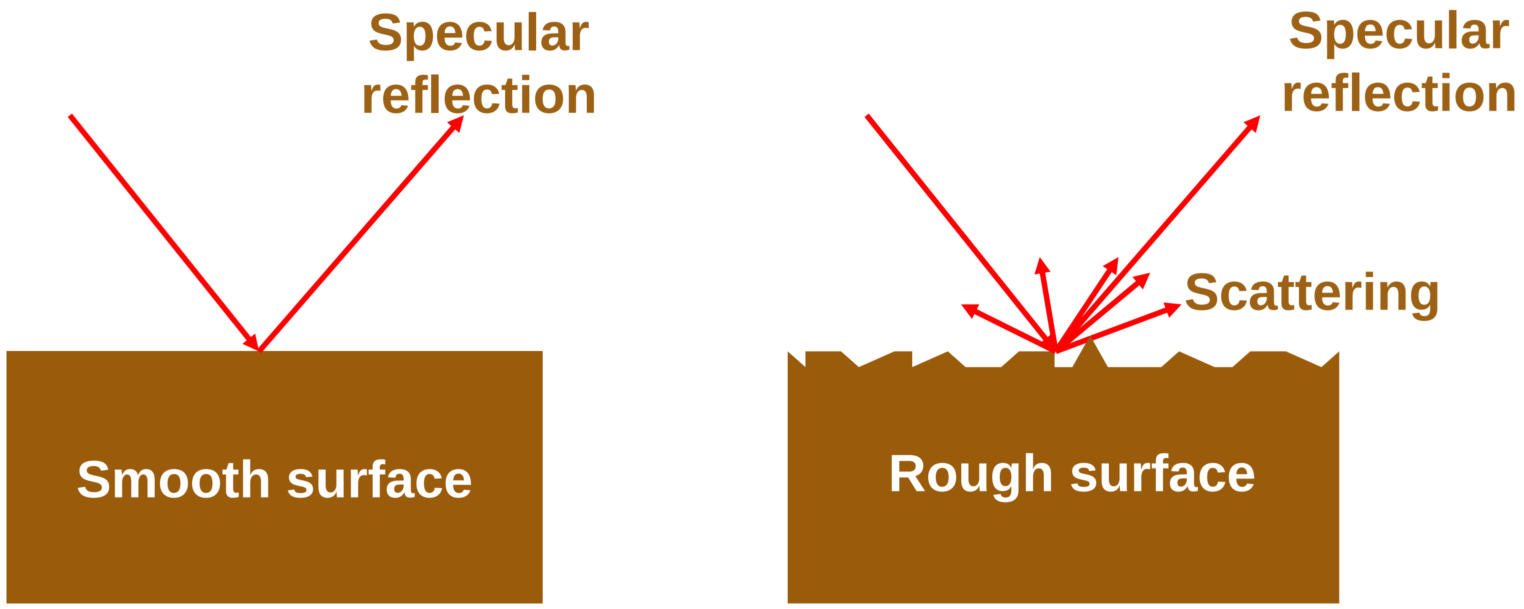
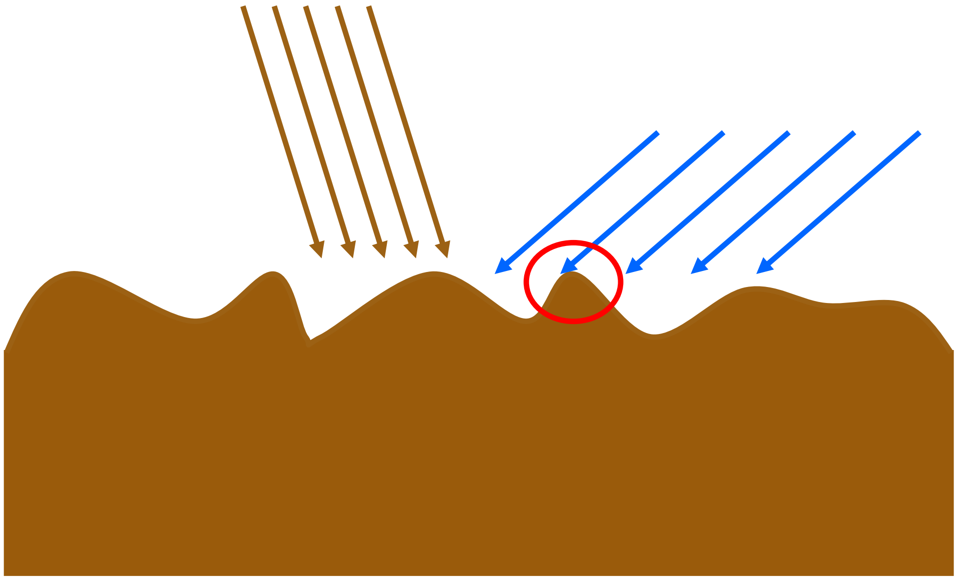
Diffuse Scattering



Kirchhoff theory – scattering by rough surfaces



calculate distribution of the surface amplitude

assume no "shadowing" from surface

calculate a new reflection coefficient

for Gaussian surface distribution

$$\rho_{\text{rough}} = \rho_{\text{smooth}} \exp\left[-2\left(k_0 \sigma_{\text{h}} \sin\psi\right)^2\right]$$

angle of incidence

standard deviation of height

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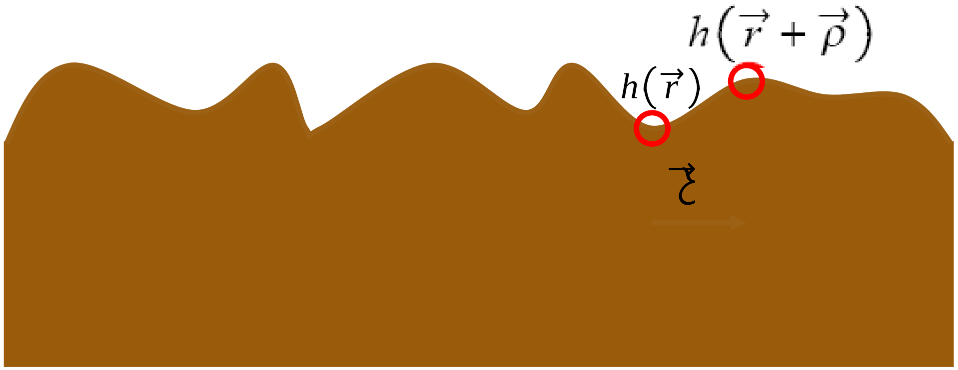
Pertubation theory – scattering by rough surfaces

$$\sigma_{\mathrm{h}}^2 W(\vec{\rho}) = E_{\vec{r}}\{h(\vec{r})h(\vec{r}+\vec{\rho})\}$$



Include shadowing effects by the surface

includes spatial correlation of surface – how fast are the changes in height

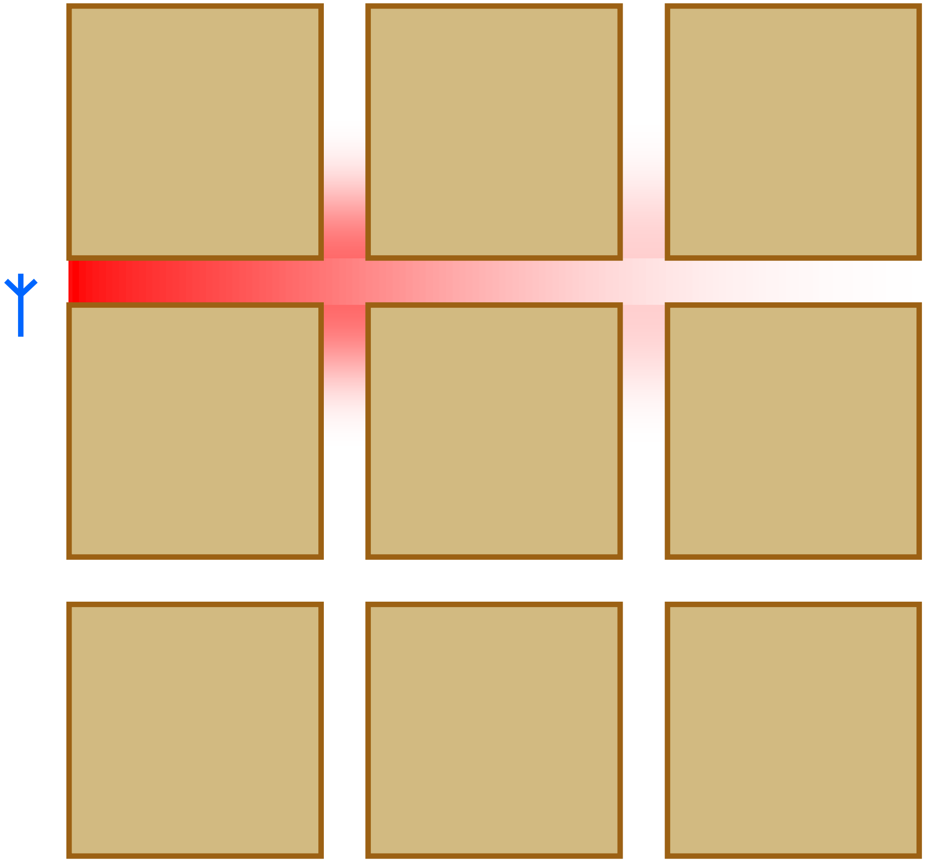
based on calculation of an “effective” dielectric constant

More accurate than Krichhoff theory, especially for large angles of incidence and “rougher” surfaces

Quiz/Discussion

Increase carrier frequency from 1GHz to 100GHz, will you see more scattering or less at an rough surface? Why?

Waveguiding

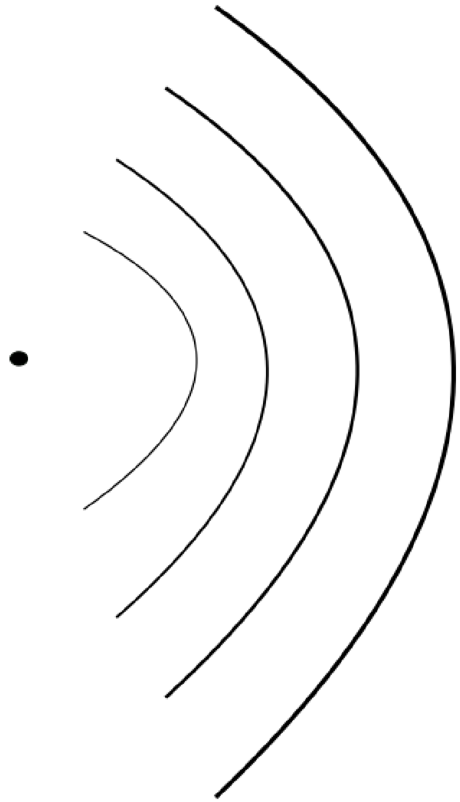


Waveguiding effects often result in lower propagation exponents

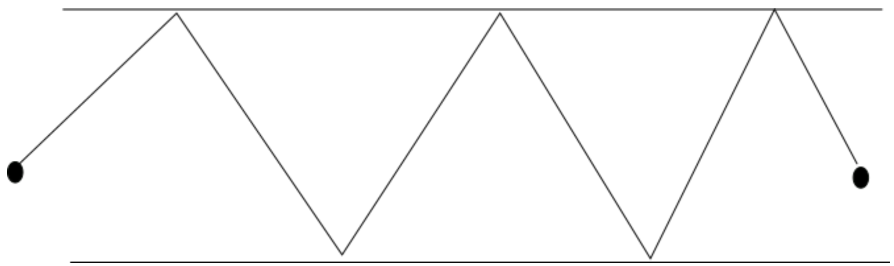
n **=1.5-5**

This means lower path loss along certain street corridors

Does friis law breaks?

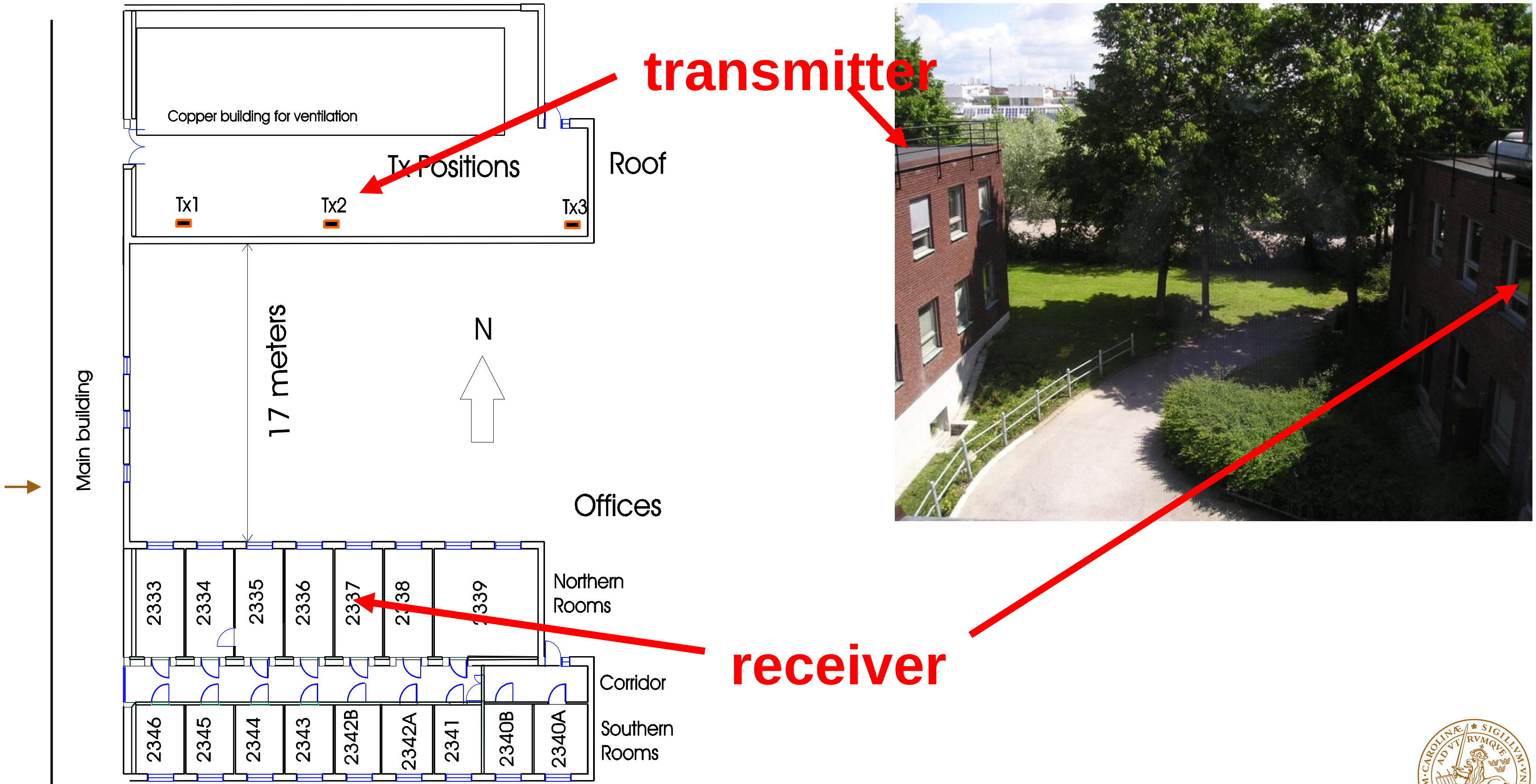


3D direction

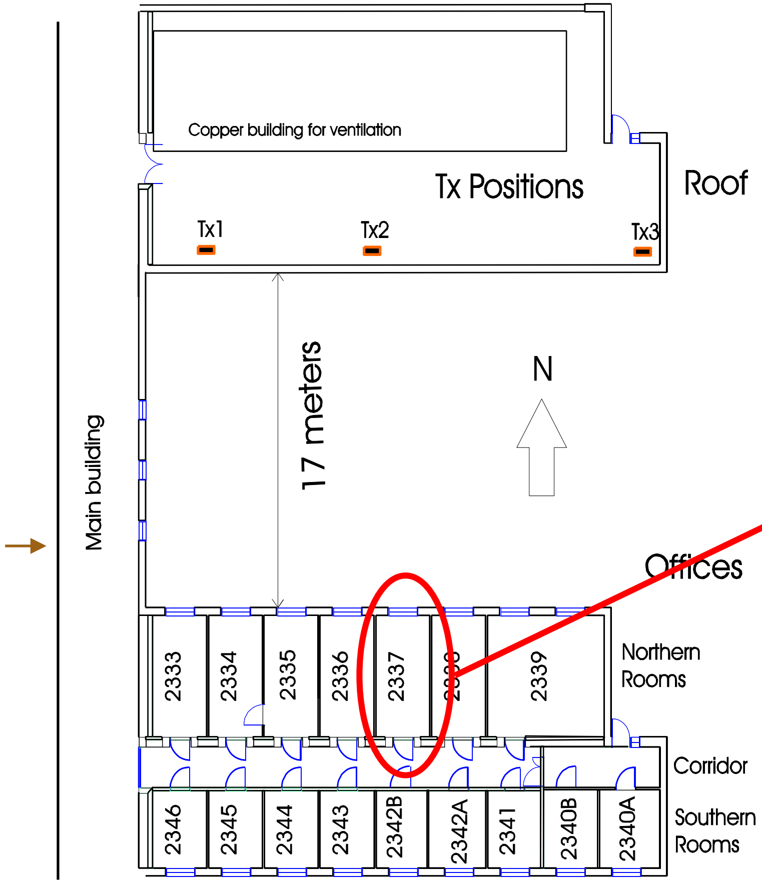


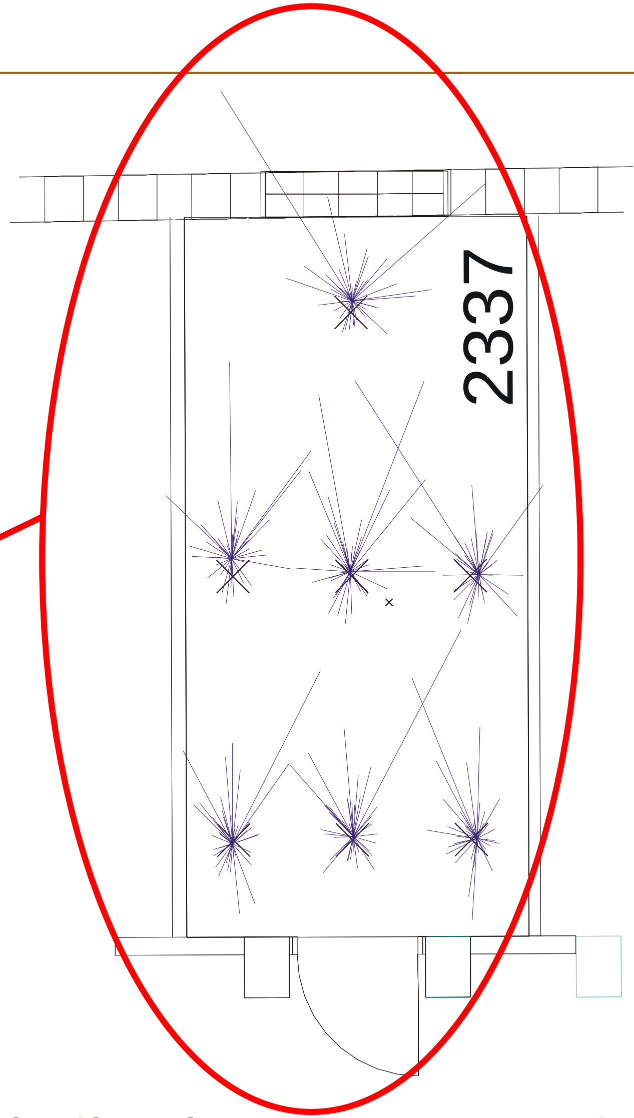
Limited range

How does the signal reach the receiver
Outdoor-to-indoor

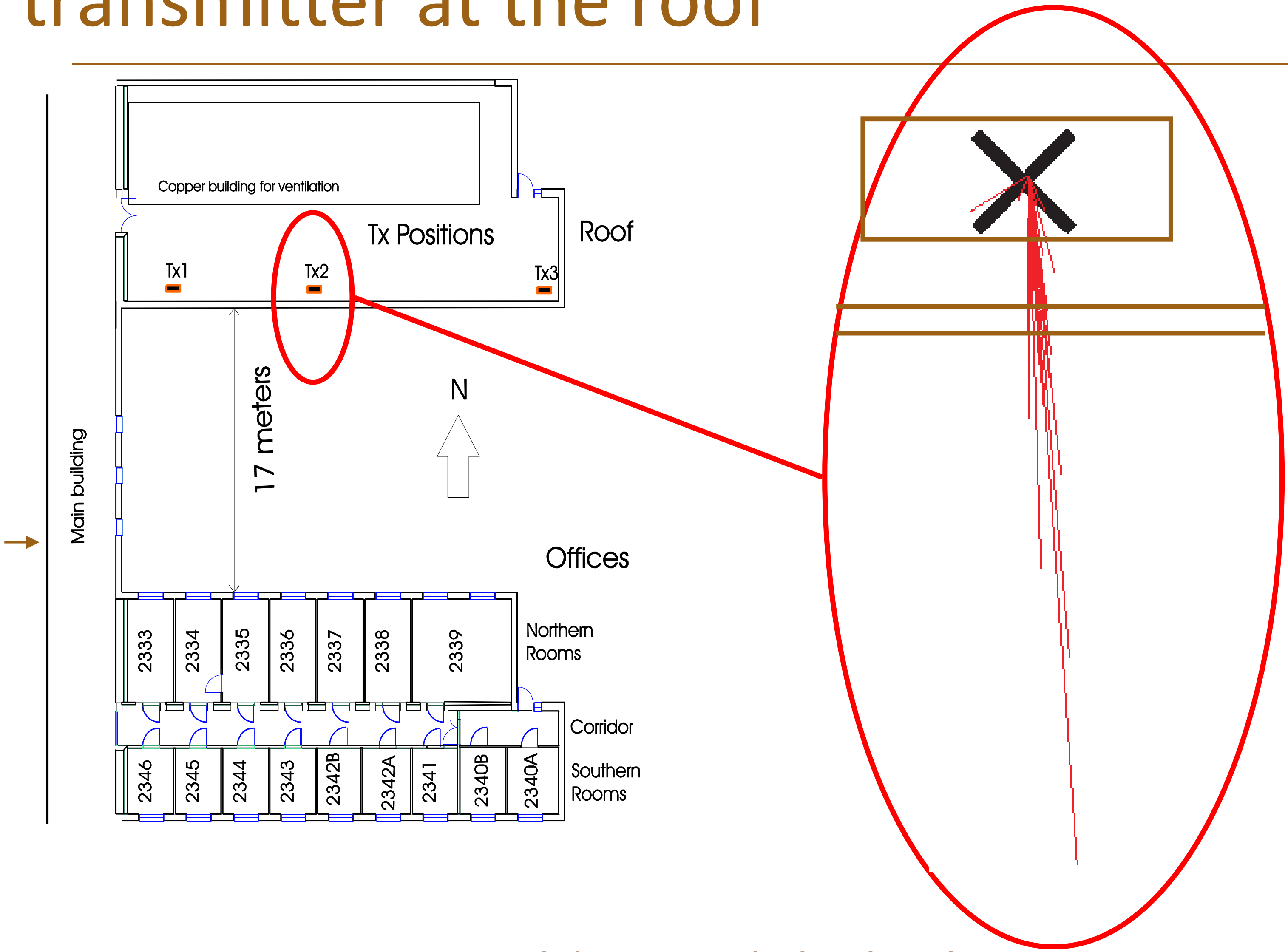


How does the signal reach the receiver In the office





How does the signal leave the transmitter at the roof



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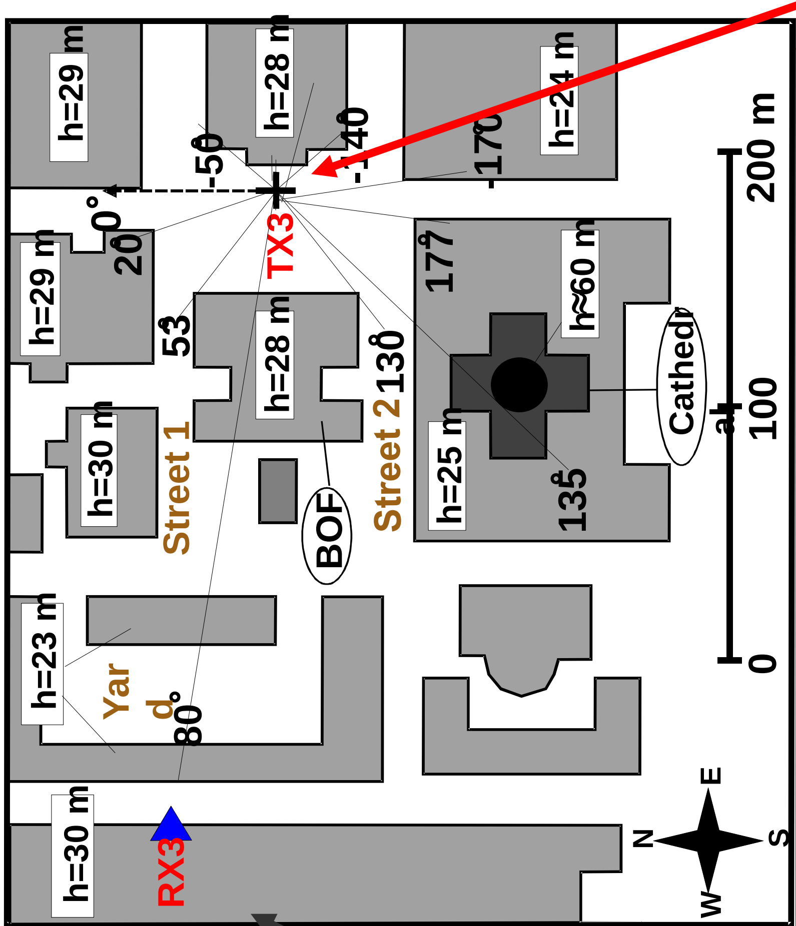
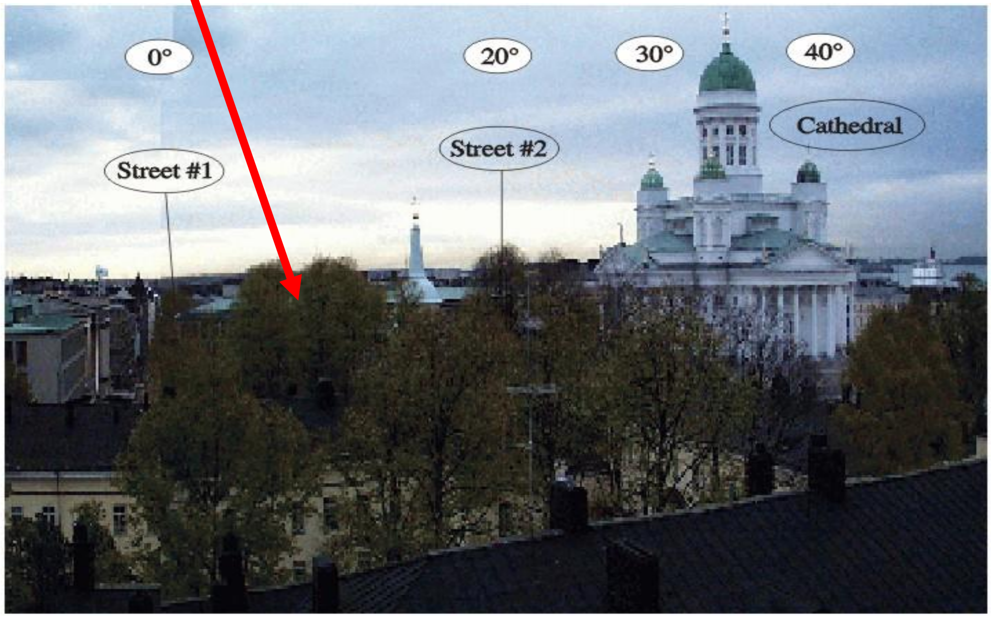
How does the signal reach the receiver outdoor urban

Transmitter





Receiver

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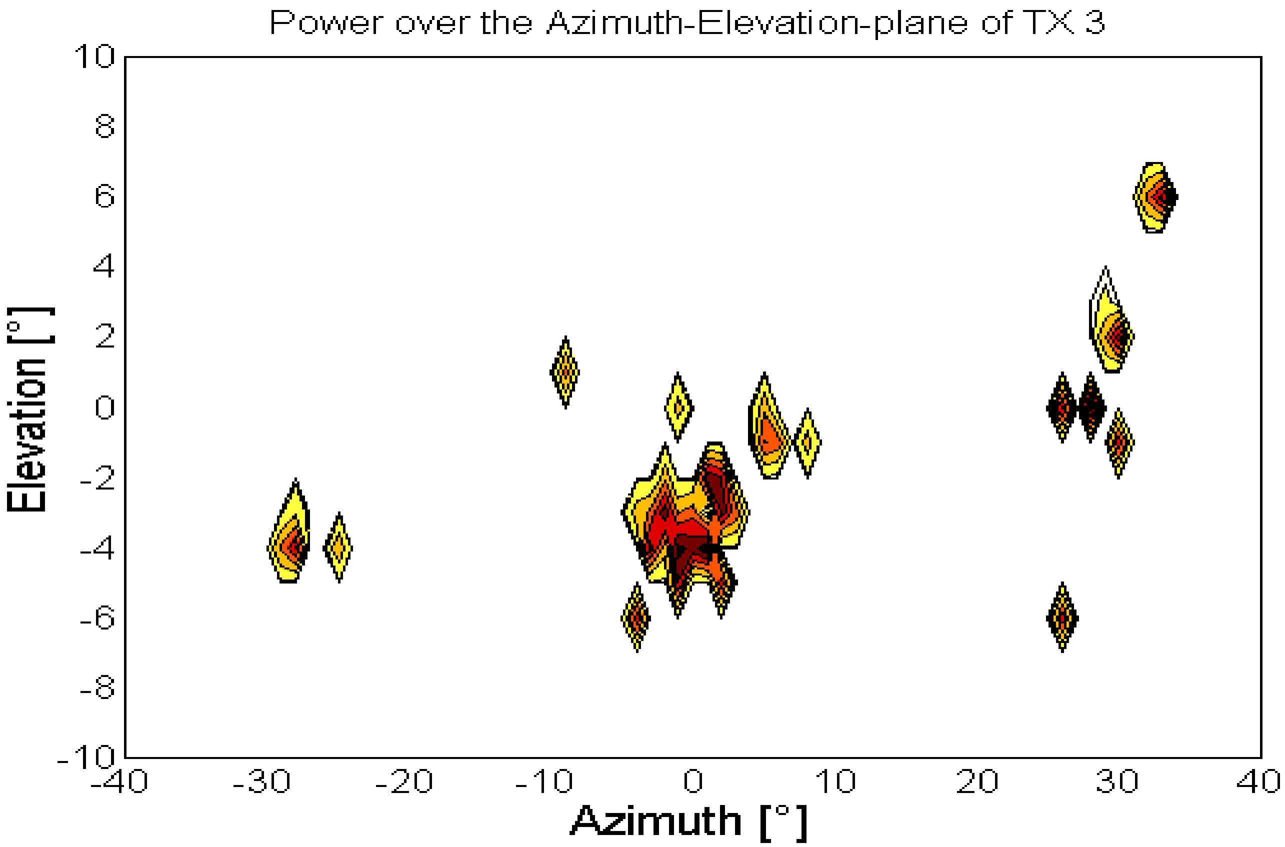
Signal arrives from some specific areas



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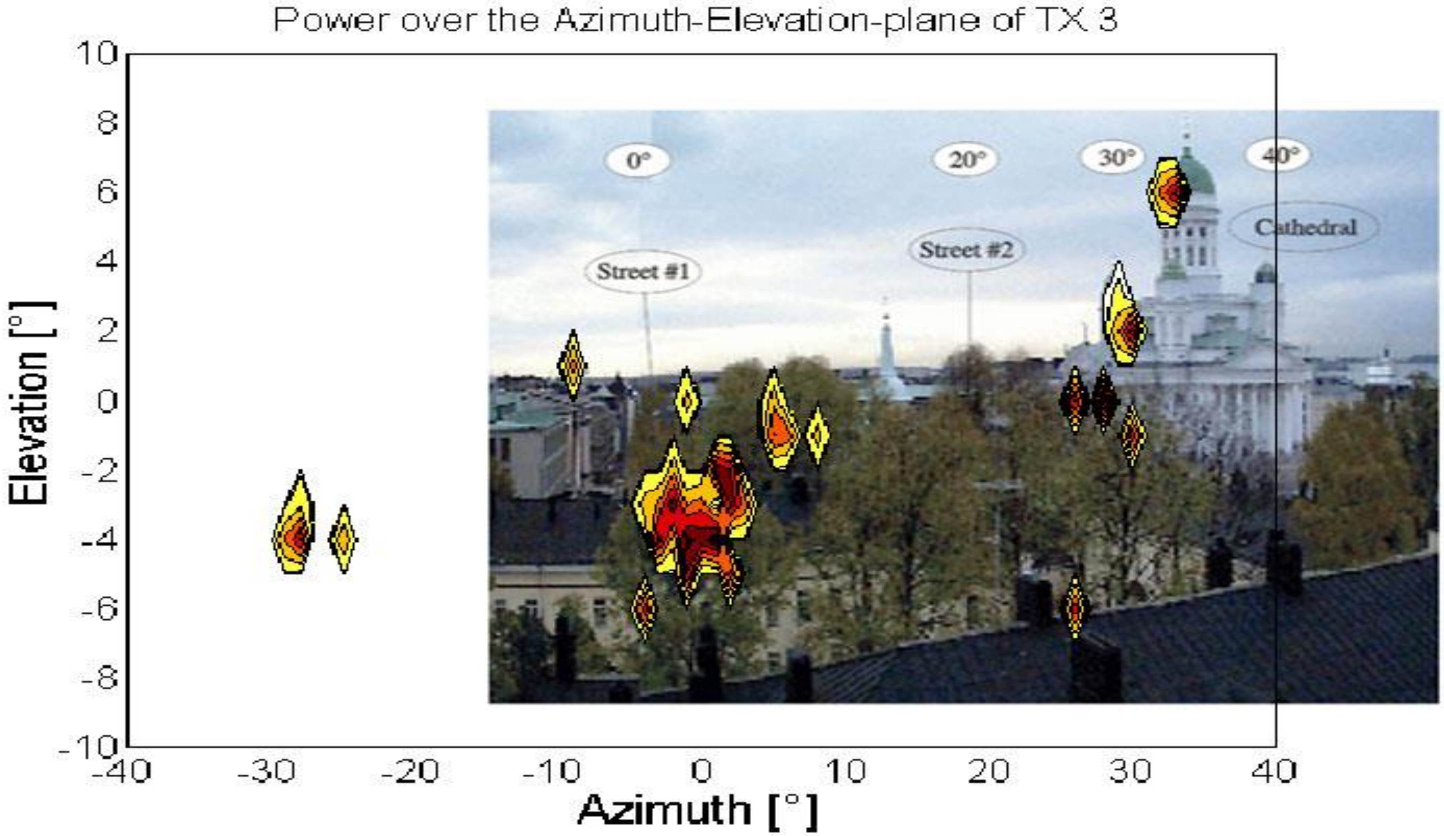
Diffraction, reflection, scattering, transmission



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Wireless Communications Channels
Lecture 3: Fading

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Fading – Statistical description of the wireless channel

- **Why statistical description**
- **Large scale fading**
- **Small scale fading:**
  - without dominant component
  - with dominant component
- **Statistical models**
- Measurement example

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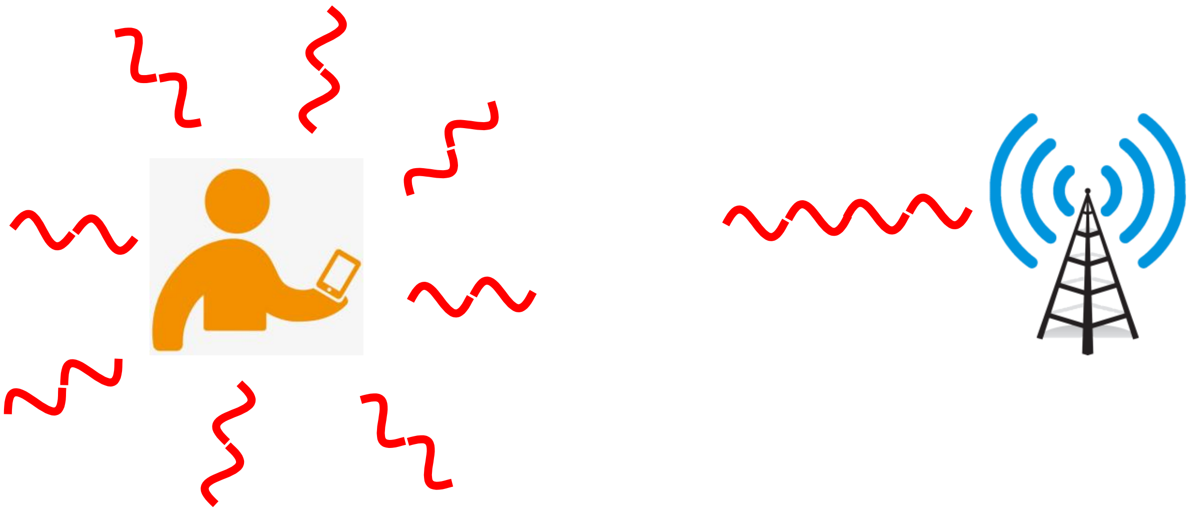
Why “statistical” description?

- Complex, unknown environment
- Can not describe everything in detail
  - Maxwell’s equations far too complex in real scenarios
- Large variations depending on the TX, RX and interacting object locations
- **Need a statistical measure since we can not describe every point everywhere**

“There is a x% probability that the amplitude/power will be above the level y”

The WSSUS model: Assumptions

Recall: the channel is composed of a number of different contributions (incoming waves), the following is assumed:



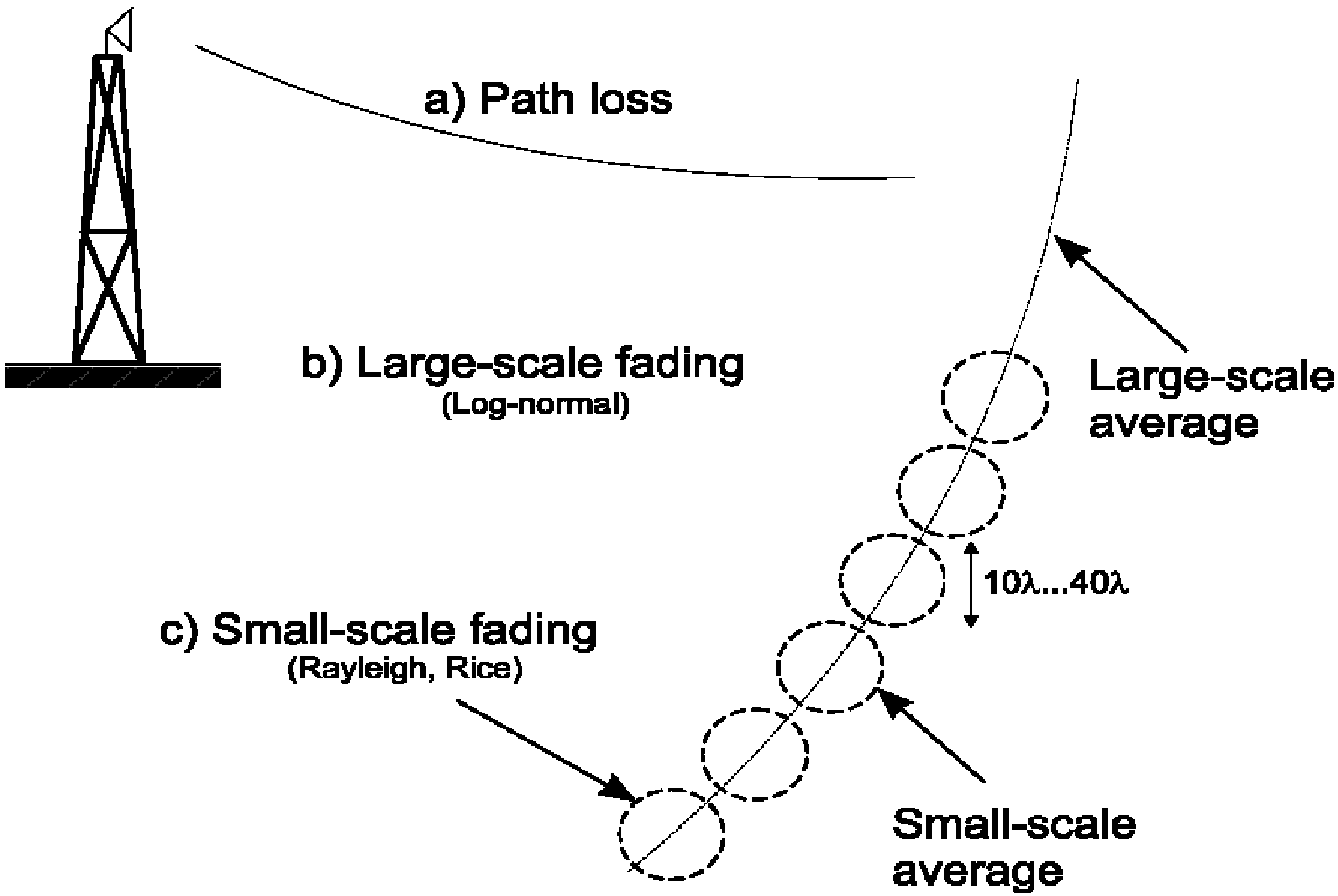
A very common channel model is the WSSUS-model: Statistical properties remain the same over the considered time (or area)

WSSUS model

- The channel is **Wide-Sense Stationary (WSS),** meaning
  a. $\mathrm{E}(\mathrm{h}(\mathrm{t})) =$ constant, for all t, the expectation of the channel is constant over time
  b. $R_h(t_1, t_2) = R_h(t_1 - t_2)$, the **correlation** of the channel is **invariant** over time.

- The channel is built up by **Uncorrelated Scatterers (US), meaning** that the **frequency** correlation of the channels is **invariant** over frequency. (Contributions with different delays are uncorrelated.)
  a. $R_h(t_1, t_2; \tau_1, \tau_2) = R_h(t_1 - t_2; \tau_1)\delta(\tau_1 - \tau_2)$

What is large scale and small scale?



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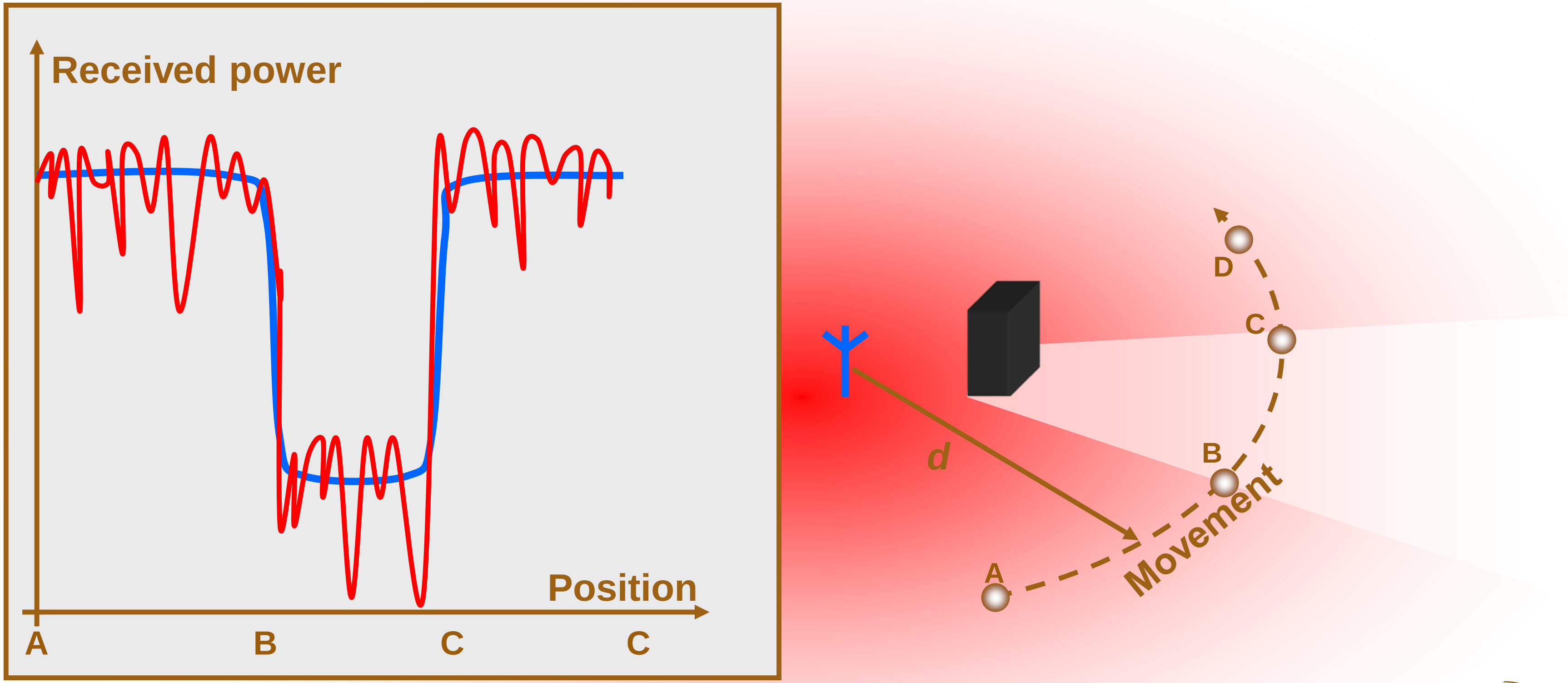
Large-scale fading: Basic principle



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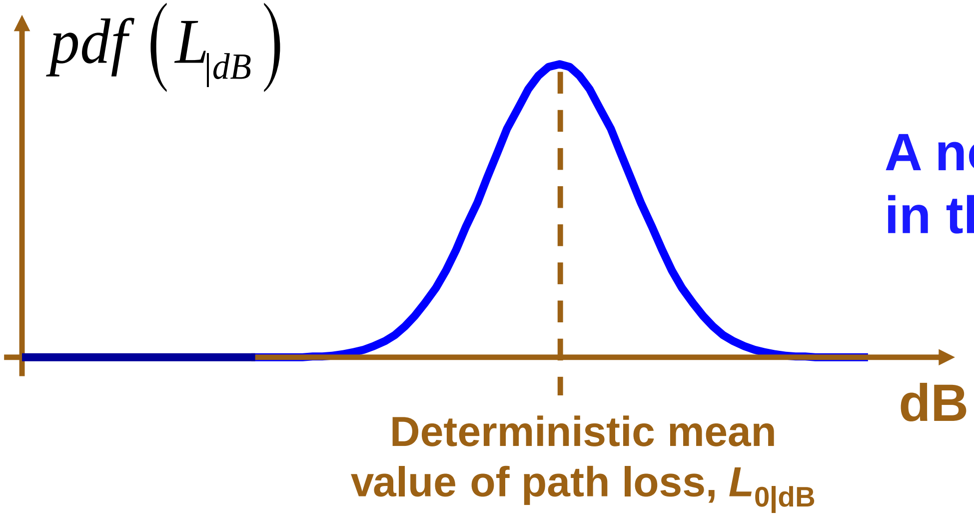
Large-scale fading: Log normal distribution

Confirmed by propagation channel measurements over the past 50 years.

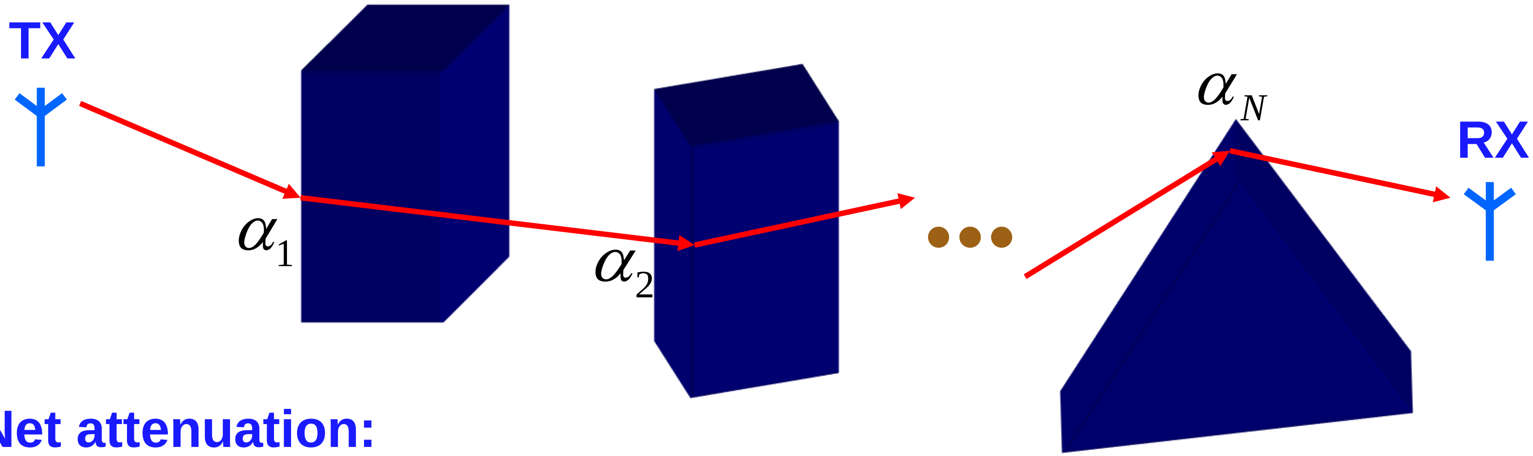


A normal distribution in the dB domain.

$$pdf\left(L_{|dB}\right)=\frac{1}{\sqrt{2\pi}\sigma_{F|dB}}\exp\left(-\frac{\left(L_{|dB}-L_{0|dB}\right)^2}{2\sigma_{F|dB}{}^2}\right)$$

Large-scale fading: Why log-normal?

Many diffraction points adding extra attenuation to the pathloss.
This is, however, only one of several possible explanations.



Net attenuation:

$$L_{tot} = L(d) \times \alpha_1 \times \alpha_2 \times \ldots \times$$
$$L_{tot|dB} = L(d)_{|dB} + \alpha_{1|dB} + \alpha_{2|dB} + \ldots + \alpha_{N|dB}$$

If these are considered random and independent, we should get a normal distribution in the dB domain.

Example: Shadowing from people

Two persons communicating with each other using cell phones, signal sometimes blocked by randomly moving humans

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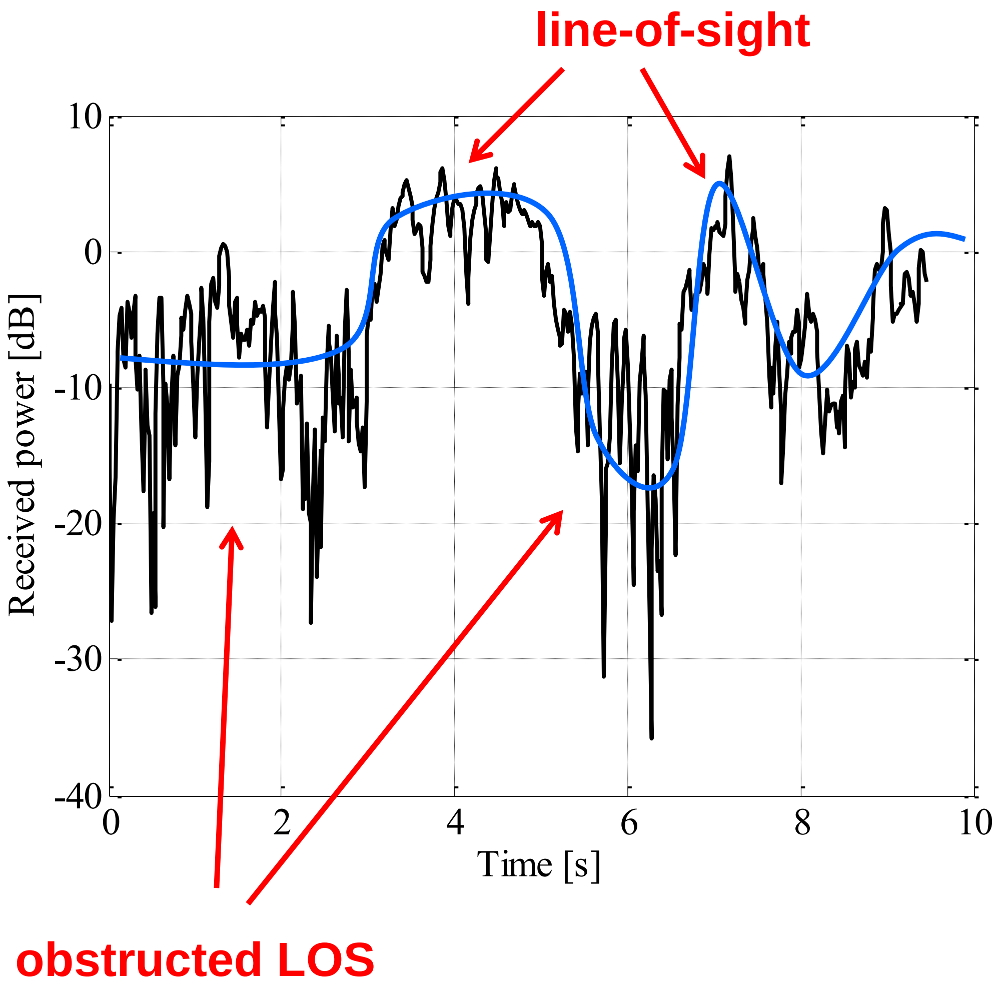
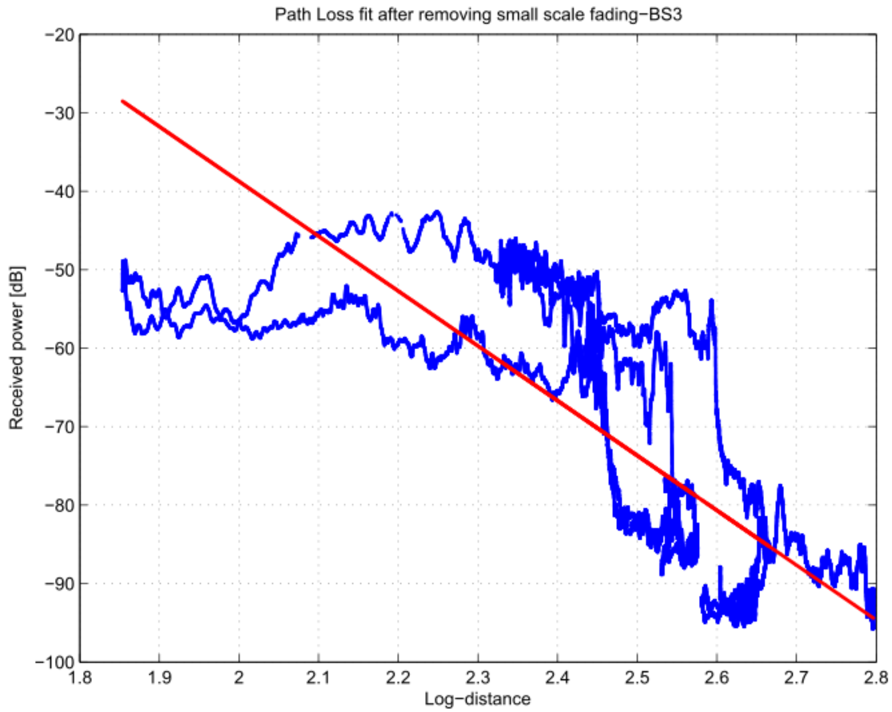
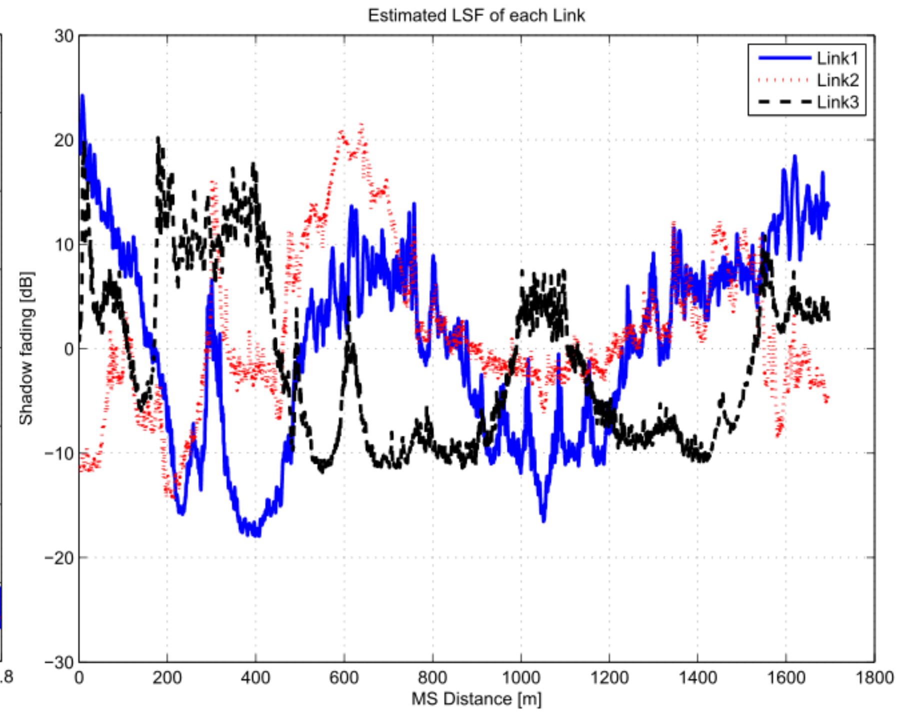
Example: Shadowing from humans



Example: Extracting LSF from measurements





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Quiz/Discussion

- Is shadowing depedent on the system bandwidth?