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Wireless Communications Channels Lecture 2: Propagation Mechanisms

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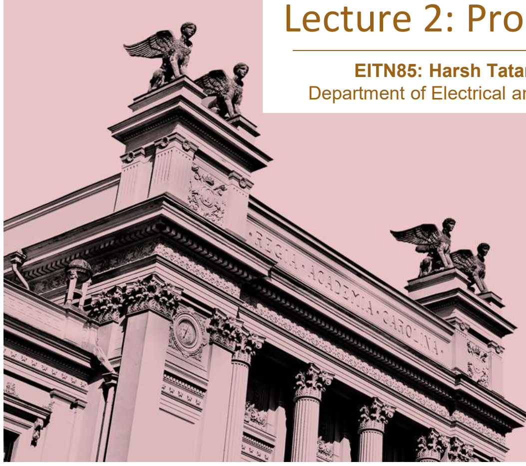

Contents

Propagation mechanisms:

- ❑ Free space attenuation
- ❑ Reflection and transmission
- ❑ Diffraction
- ❑ Diffuse scattering
- ❑ Waveguiding

Examples from real world propagation scenarios

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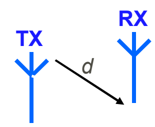
Free space attenuation

- Assume TX and RX antennas in **free space** and would like to derive the received power as a function of link distance



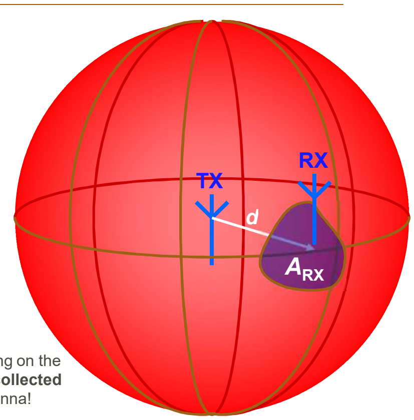
Free space attenuation

- Assume TX and RX antennas in **free space** and would like to derive the received power as a function of link distance
- Energy conservation: integral of power density over any **closed surface** = transmit power
- If TX antenna radiates isotropically, then power density on surface is $P_{\mathrm{TX}}/(4\pi d^2)$. Then,

$$P_{\mathrm{RX}}(d) = P_{\mathrm{TX}} \frac{1}{4\pi d^2} A_{\mathrm{RX}}$$

Question!

Power impinging on the area which is **collected** by the RX antenna!



Shpere of radius *d*

Free space attenuation

- Assume TX and RX antennas in **free space** and would like to derive the received power as a function of link distance
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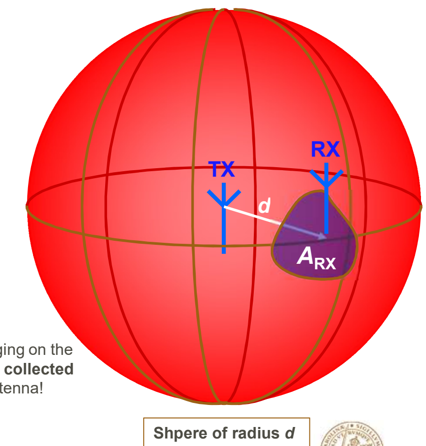
Question!

Power impinging on the area which is **collected** by the RX antenna!

- Relationship between effective area and antenna gain: $G_{\mathrm{RX}} = \left(\frac{4\pi}{\lambda^2}\right) A_{\mathrm{RX}}$
- Product of TX power and gain is known as: effective isotropic radiated power (EIRP)



Free space loss: Friis' law

Received power, with antenna gains G_{TX} and G_{RX}:

$$P_{RX}(d) = \frac{G_{RX} G_{TX}}{L_{free}(d)} P_{TX} = P_{TX} \left(\frac{\lambda}{4\pi d}\right)^2 G_{RX} G_{TX} \quad *$$

Free space loss factor

RX power goes down as a function of frequency, for a fixed distance.

$$P_{RX|dB}(d) = P_{TX|dB} + G_{TX|dB} - L_{free|dB}(d) + G_{RX|dB}$$

$$= P_{TX|dB} + G_{TX|dB} - 10\log_{10}\left(\frac{4\pi d}{\lambda}\right)^2 + G_{RX|dB}$$

Question: What happens if *d* is 0 in * ?

Free space loss: What and where is the far field?

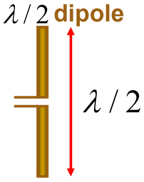
The free space loss calculations are only valid in the ”far field” of the antennas.

Far-field conditions are assumed far beyond the ”Rayleigh” distance:

$$d_R = \frac{2L_a^{\ 2}}{\lambda}$$

where L_a is the largest dimension of the antenna.

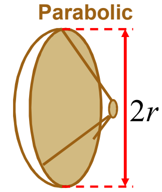
$\lambda/2$ **dipole**



$L_a = \lambda/2$

$d_R = \lambda/2$

Parabolic



$L_a = 2r$

$d_R = \frac{8r^2}{\lambda}$

Another rule of thumb is: ”*At least* 10 wavelengths”

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Quiz

Compute the Rayleigh distance of a square patch antenna receiving a signal with a gain of 10 dB.

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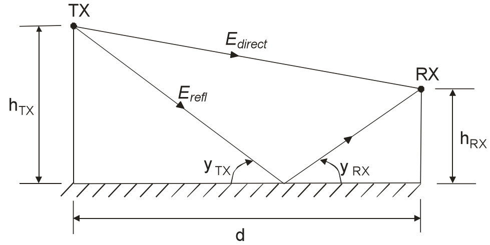
The d^{-4} law – I

Instead of just considering a direct path, let's look at the following scenario



the power behaves as

$$P_{RX}(d) \approx P_{TX}G_{TX}G_{RX}\left(\frac{h_{TX}h_{RX}}{d^2}\right)^2$$

for distances greater than

$$d_{break} \gtrsim 4h_{TX}h_{RX}/\lambda$$

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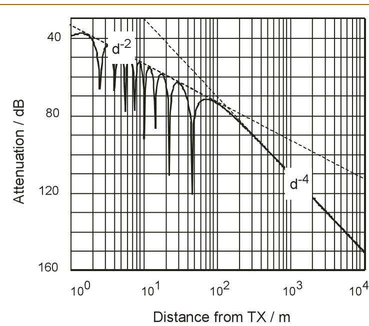
The d^{-4} law – II



- However …..
  - n=4 is not a universal decay exponent
  - Theoretical model is not fulfilled in practice
  - Breakpoint is rarely where theoretically predicted
  - Second breakpoint at the radio horizon

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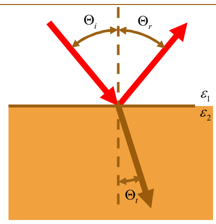
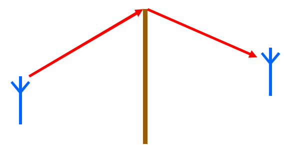
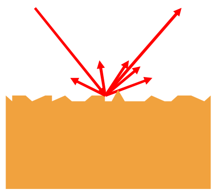
Fundamental propagation mechanisms



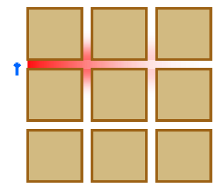
Reflection and transmission



Diffraction



Scattering



Waveguiding

Complex dielectric constant

Lets take a homogeneous planewave incident onto a dielectric half-space

$$\delta_i = \varepsilon_i - j\frac{\sigma_{e,i}}{2\pi f_c}$$

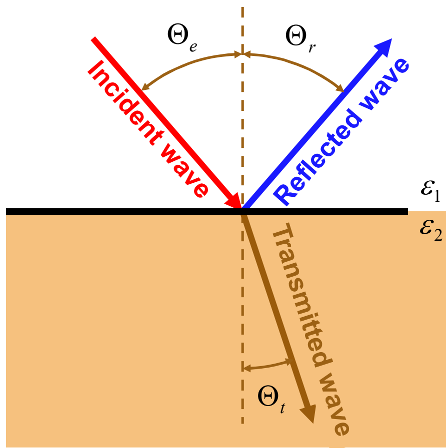
conductivity

dielectric constant, permittivity

Describes the dielectric material in one single parameter

Examples	Permittivity	conductivity
Concrete	6	10^{-2}
Gypsum	6.5	10^{-2}
Wood	23	10^{-11}
Glass	5	10^{-12}
Air	1	

Reflection and transmission



Reflected angle:

$$\Theta_e = \Theta_r.$$

Transmitted angle:

$$\frac{\sin\Theta_t}{\sin\Theta_e} = \frac{\sqrt{\varepsilon_1}}{\sqrt{\varepsilon_2}}$$

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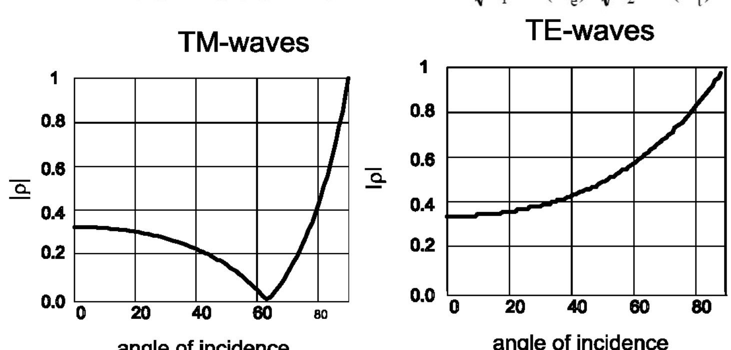
TM and TE Component Behaviors

Reflection coefficient

$$\rho_{TM} = -\frac{\sqrt{\delta_2}\cos\Theta_e - \sqrt{\delta_1}\cos(\Theta_t)}{\sqrt{\delta_2}\cos\Theta_e + \sqrt{\delta_1}\cos(\Theta_t)} \qquad \rho_{TE} = \frac{\sqrt{\delta_1}\cos(\Theta_e) - \sqrt{\delta_2}\cos(\Theta_t)}{\sqrt{\delta_1}\cos(\Theta_e) + \sqrt{\delta_2}\cos(\Theta_t)}$$

Transmission coefficient

$$T = \sqrt{1-\rho^2}$$



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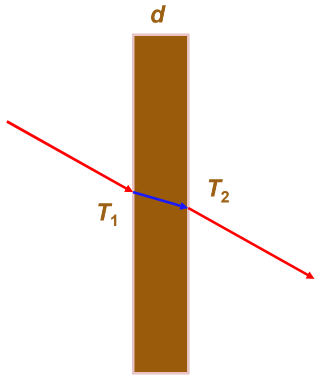
Transmission through layered structures



Total transmission coefficient

$$T = \frac{T_1 T_2 e^{-j\alpha}}{1+R_1 R_2 e^{-2j\alpha}}$$

total reflection coefficient

$$\rho = \frac{\rho_1+\rho_2 e^{-j2\alpha}}{1+\rho_1 \rho_2 e^{-2j\alpha}}$$

with the electrical length in the wall

$$\alpha = \frac{2\pi}{\lambda}\sqrt{\varepsilon_1}\, d_{\text{layer}} \cos(\Theta_t)$$

Wall with thickness *d* and two dielectrics

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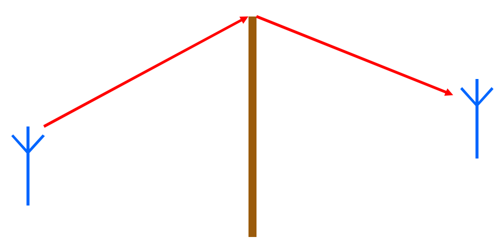
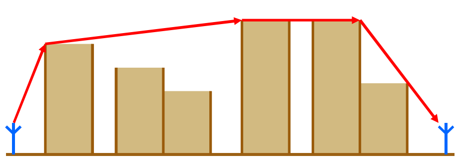
Diffraction: The principle





- Single or multiple edges
- makes it possible to go behind corners
- less pronounced when the wavelength is small compared to objects

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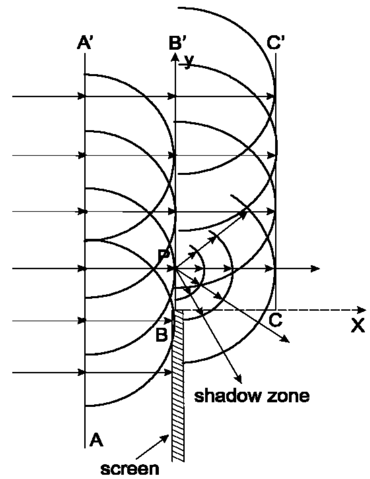
Diffraction: Huygen's principle



Each point of a wavefront can be considered as a source of a spherical wave

➡ **Bending around corners and edges**

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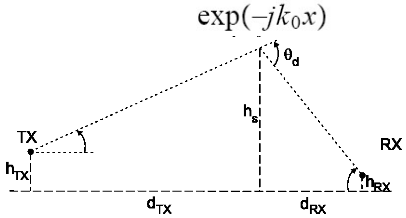
Diffraction coefficient



Total field

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

Fresnel integral

The Fresnel integral is defined

$$F\left(\nu_F\right) = \int_0^{\nu_F} \exp\left(-j\pi \frac{t^2}{2}\right) dt.$$

with the Fresnel parameter

$$\nu_F = \alpha_k \sqrt{\frac{2 d_1 d_2}{\lambda (d_1 + d_2)}}$$

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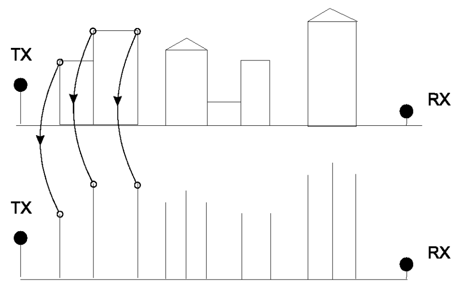
Diffraction in real environments



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

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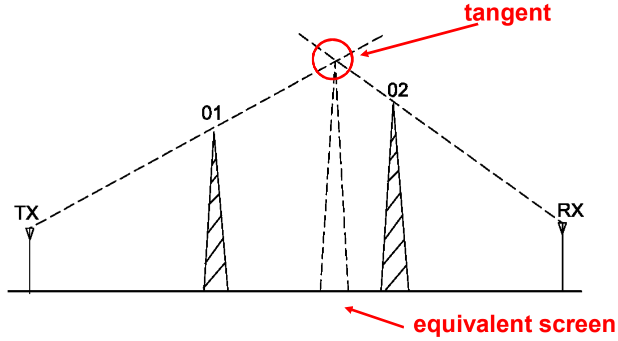
Diffraction: Bullington's method



Replace all screens with one equivalent screen

Height determined by the steepest angle

Simple but a bit optimistic

$$E_{\text{total}} = \exp(-jk_0x)\left(\frac{1}{2} - \frac{\exp(-j\pi/4)}{\sqrt{2}}F\left(\nu_F\right)\right) \qquad \nu_F = \alpha_k\sqrt{\frac{2d_1d_2}{\lambda(d_1+d_2)}}$$

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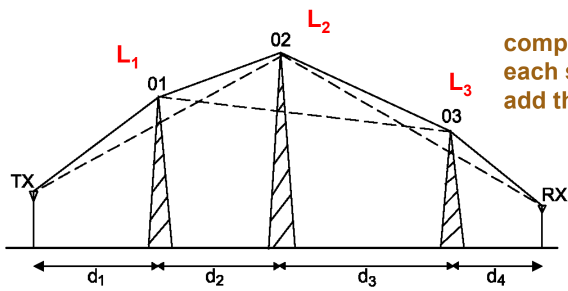
Diffraction – Epstein-Petersen Method

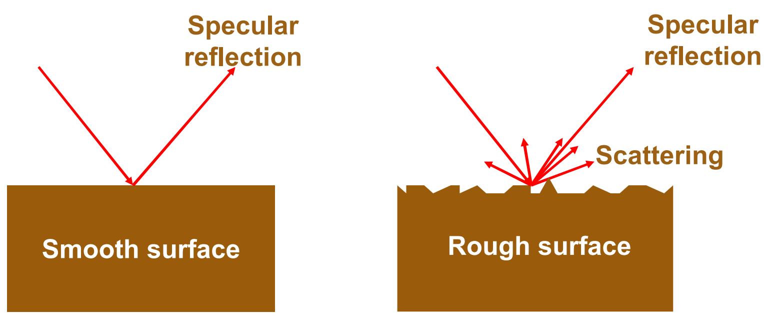


compute diffraction loss for each screen separately and add the losses

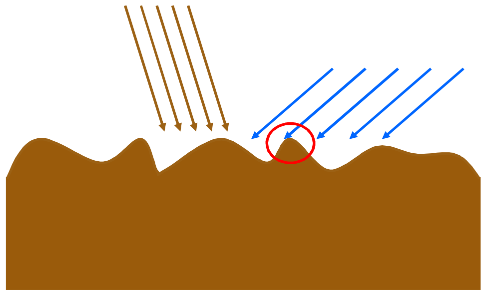
$L_{tot}=L_1+L_2+L_3$

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

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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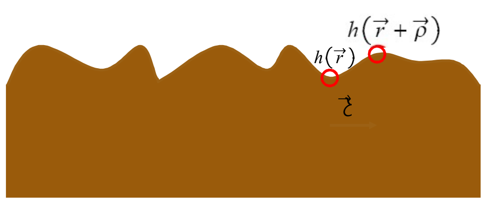
Pertubation theory – scattering by rough surfaces

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



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

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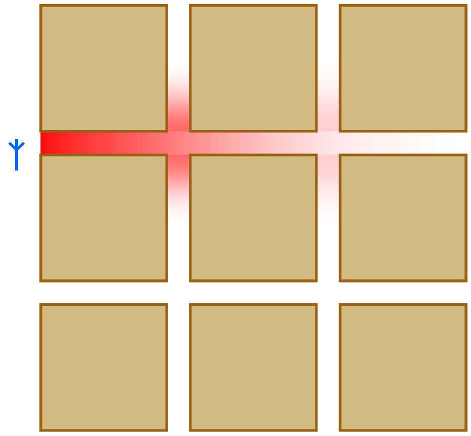
Waveguiding



Waveguiding effects often result in lower propagation exponents

***n* =1.5-5**

This means lower path loss along certain street corridors

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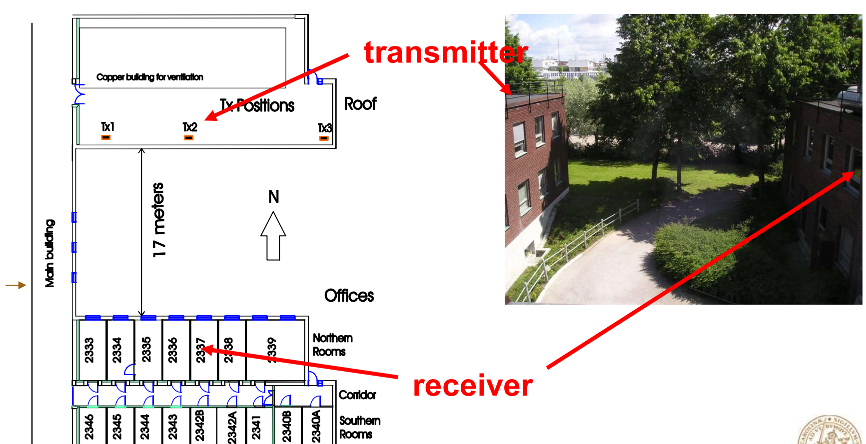
How does the signal reach the receiver Outdoor-to-indoor



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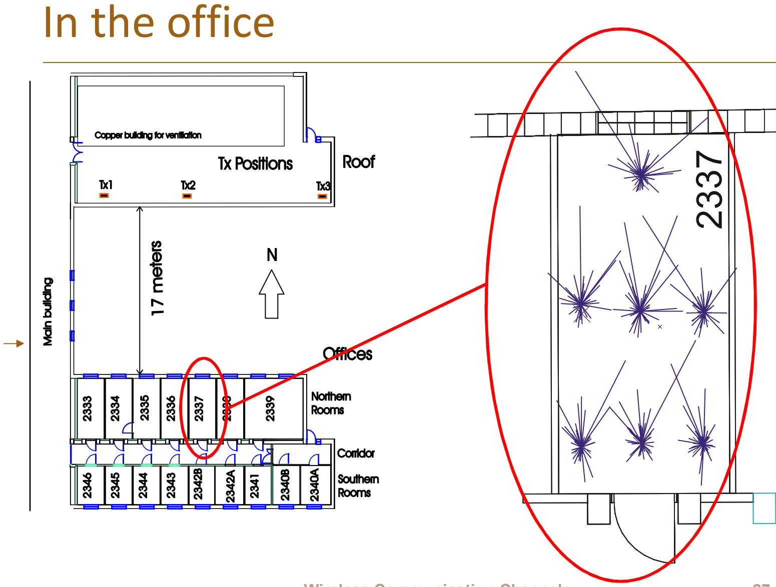
How does the signal reach the receiver In the office



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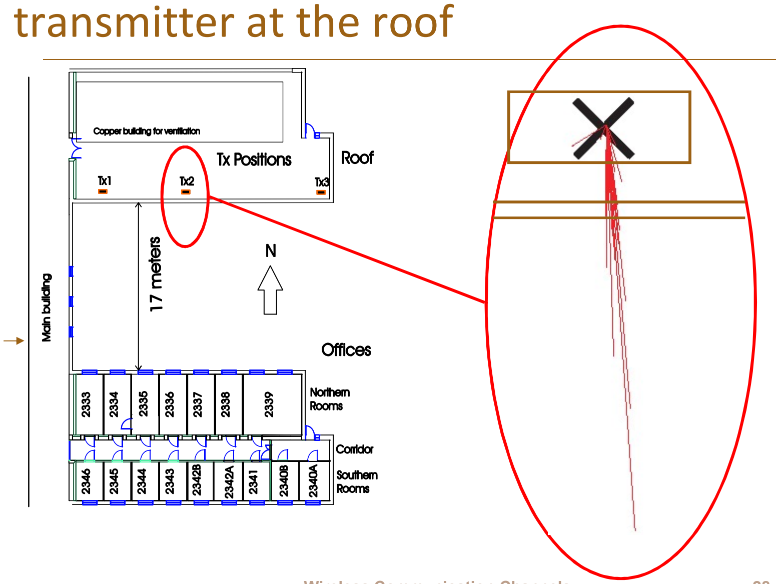
How does the signal leave the transmitter at the roof



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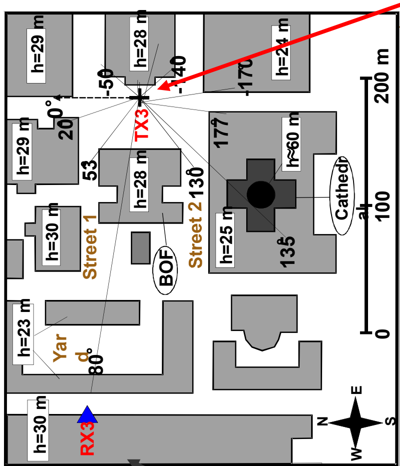
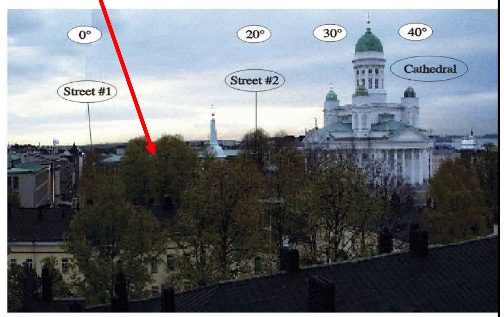
How does the signal reach the receiver outdoor urban





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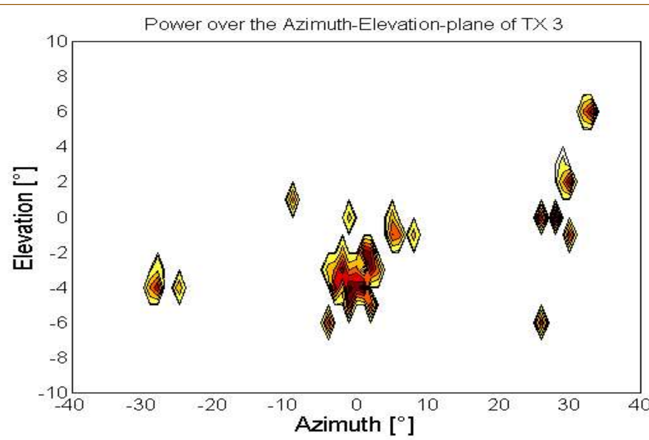
Signal arrives from some specific areas



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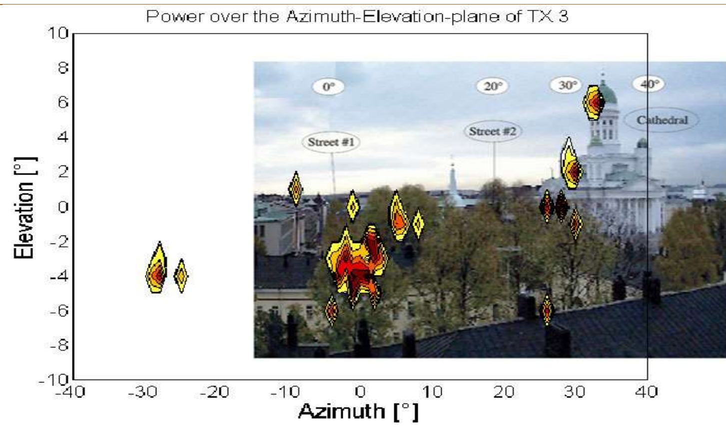
Diffraction, reflection, scattering, transmission



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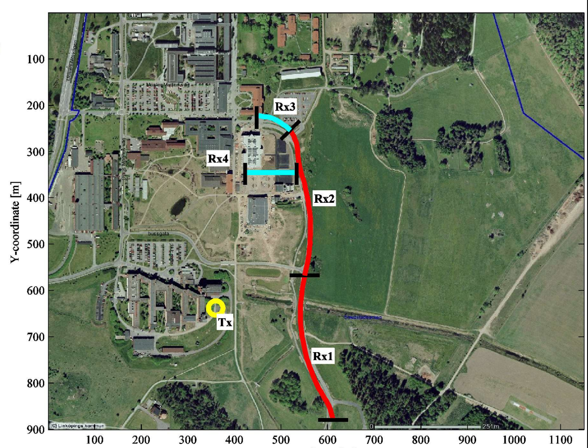
Outdoor 300 MHz peer-to-peer scenario

- Center frequency:
  - 285 MHz, 20MHz bandwidth
- Peer-to-peer measurement:
  - TX, 1.8m (BS)
  - RX, 2.1m (MS)
- Four routes:
  - 322, 320, 80, 110 m
  - semi-rural scenario
  - sub-urban scenario



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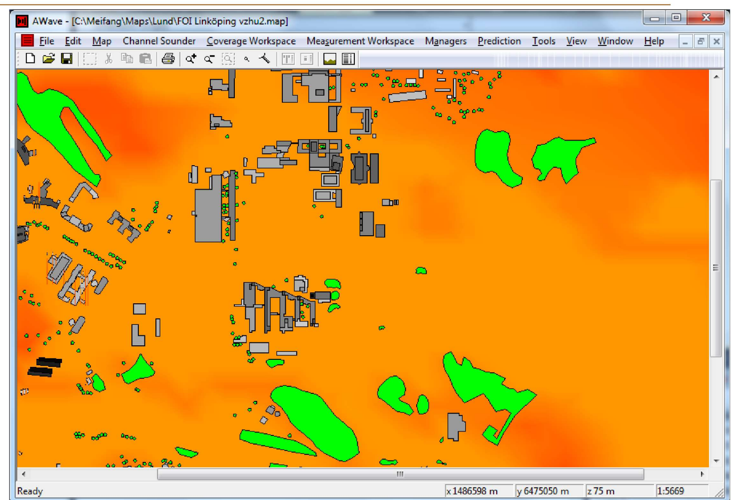
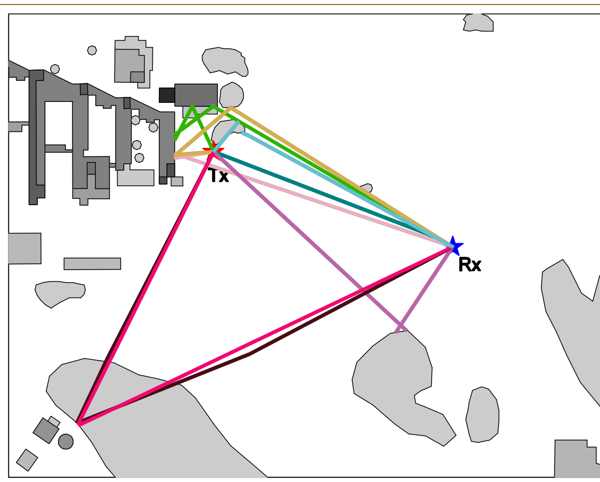
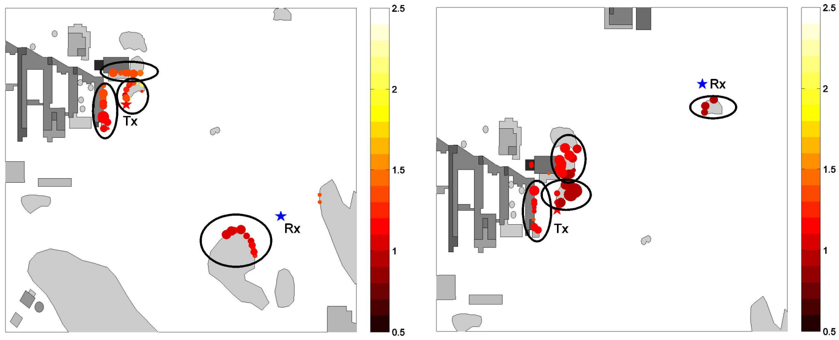
Digital 3D map of the environment



Visualized paths for a particular Tx/Rx position



Interaction points, 20 strongest MPCs

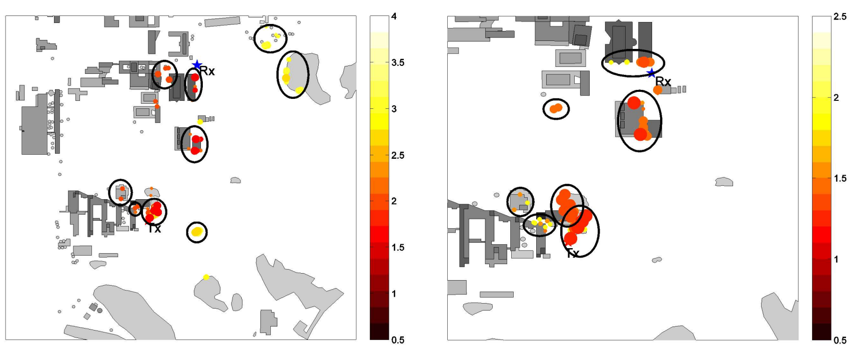


LOS

NLOS

Radius of circles reflects power, color reflects delay

Interaction points, 20 strongest MPCs

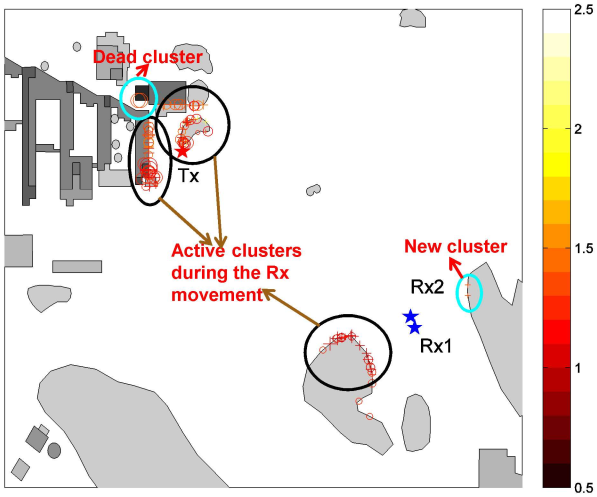


NLOS

NLOS

Radius of circles reflects power, color reflects delay

Multipath components tend to appear in clusters, moving Rx



As Rx is moving (10 wavelengths, approximately 10 meters), clusters disappear and new clusters appear.

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