Deterministic radio propagation modeling and ray tracing

Using ray tracing (1/2)

- Ray tracing (RT) is not only a prediction tool, is a realistic multipath propagation model. Therefore using ray tracing doesn't only mean getting coverage or prediction results. As far as the model is realistic, it also allows ***simulation***, ***study***, ***analysis*** of the urban multipath propagation phenomenon.
- RT (or ray launching) is also the most accurate prediction model now available. In terms of radio coverage prediction, a mean error of a *fraction of dB* and a stdev of the error of ***5-7 dB*** are achievable in practice.
- Although RT isn't an empirical model, some *run parameters* must be set before running RT. The following is a list of typical parameter values for outdoor prediction in european cities

Control string: 3@***@2d1s

which means:

$N_{ev}=3$

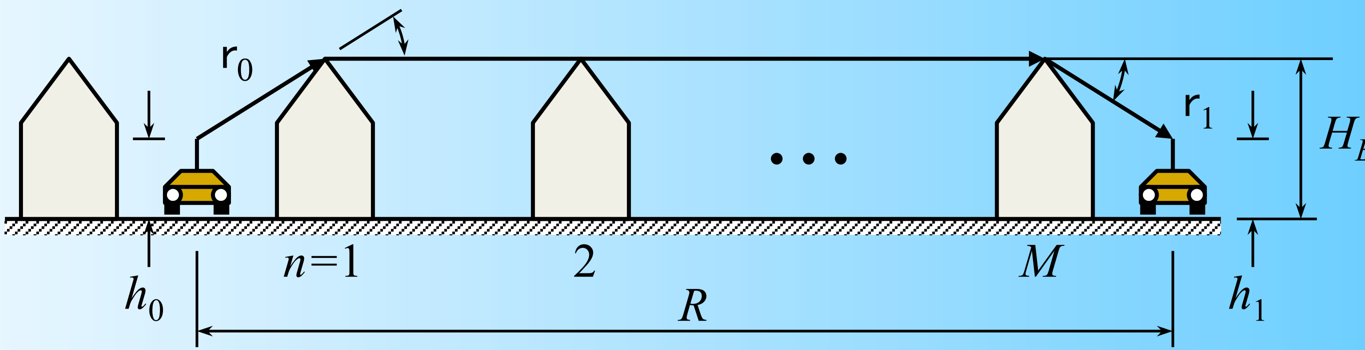
max. 2 diffractions

max. 1 scattering

Material parameters: $e_r=5$, s=0.01 [S/m] (for all building walls)

Coherent mode

Using ray tracing (2/2)

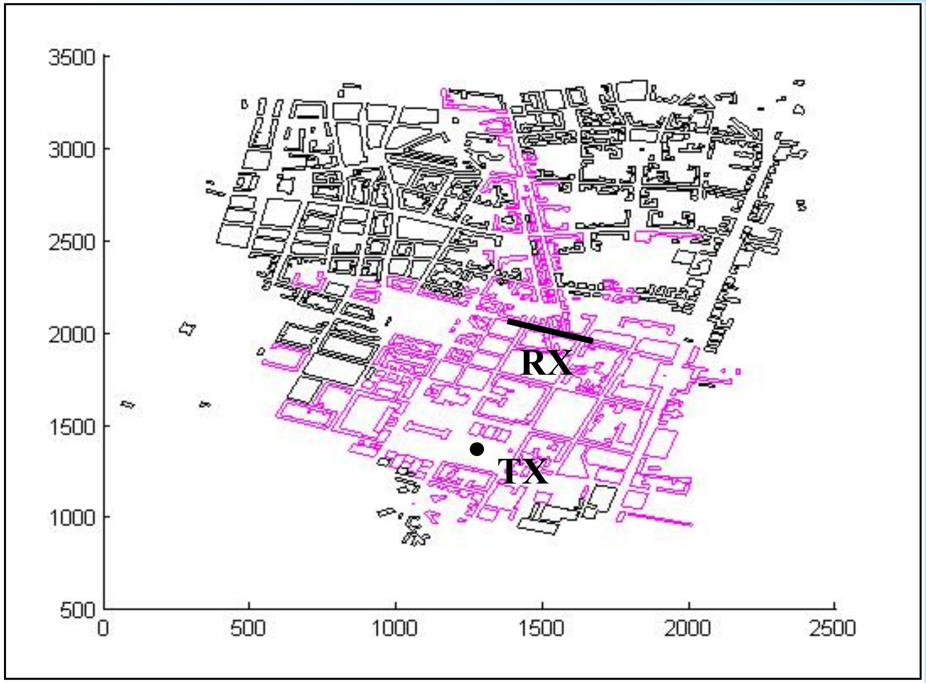


- Since diffraction is a very time-consuming interaction, and up to 10 or more diffractions are required for ORT paths, then often ORT propagation is treated off-line using a multi-diffraction ORT model even if the RT model is 3D
- Then multi-diffraction ORT is considered as one single interaction in the RT engine and in the view tree, so that it can be combined with other interactions even with N_{ev} is low
- Rays experiencing "ORT+scattering" or "ORT+reflected" are very important for time and angle dispersion

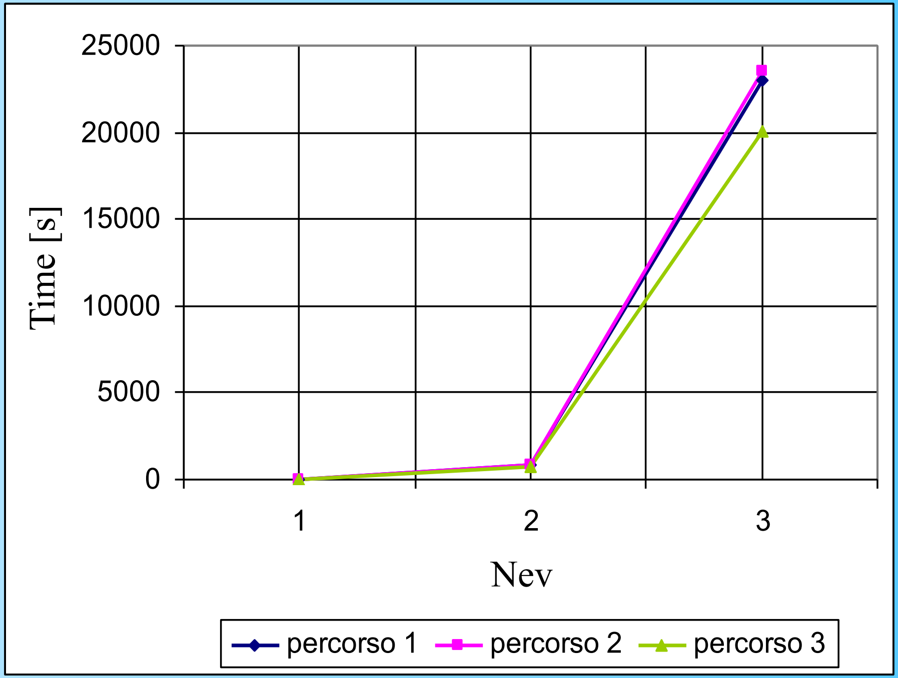
Using ray tracing (2/2)

- RT is also a useful didactic tool…

CPU time vs N_{ev}

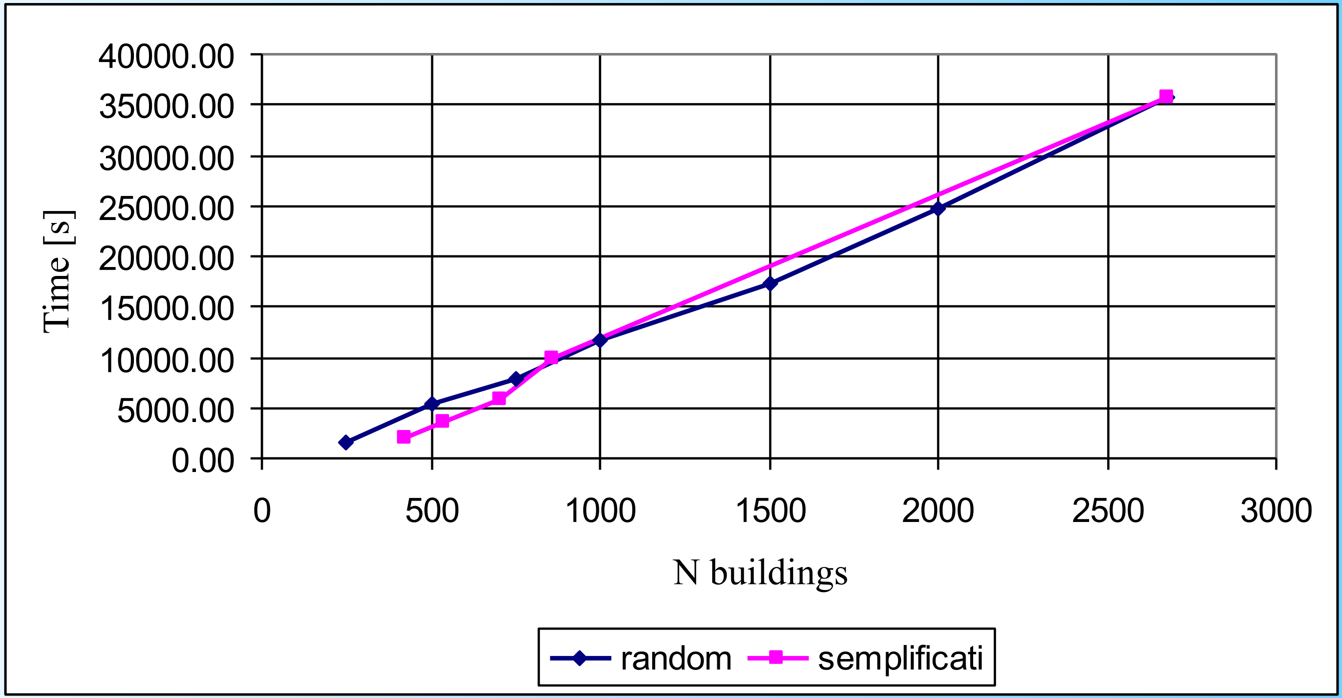


Munich scenario

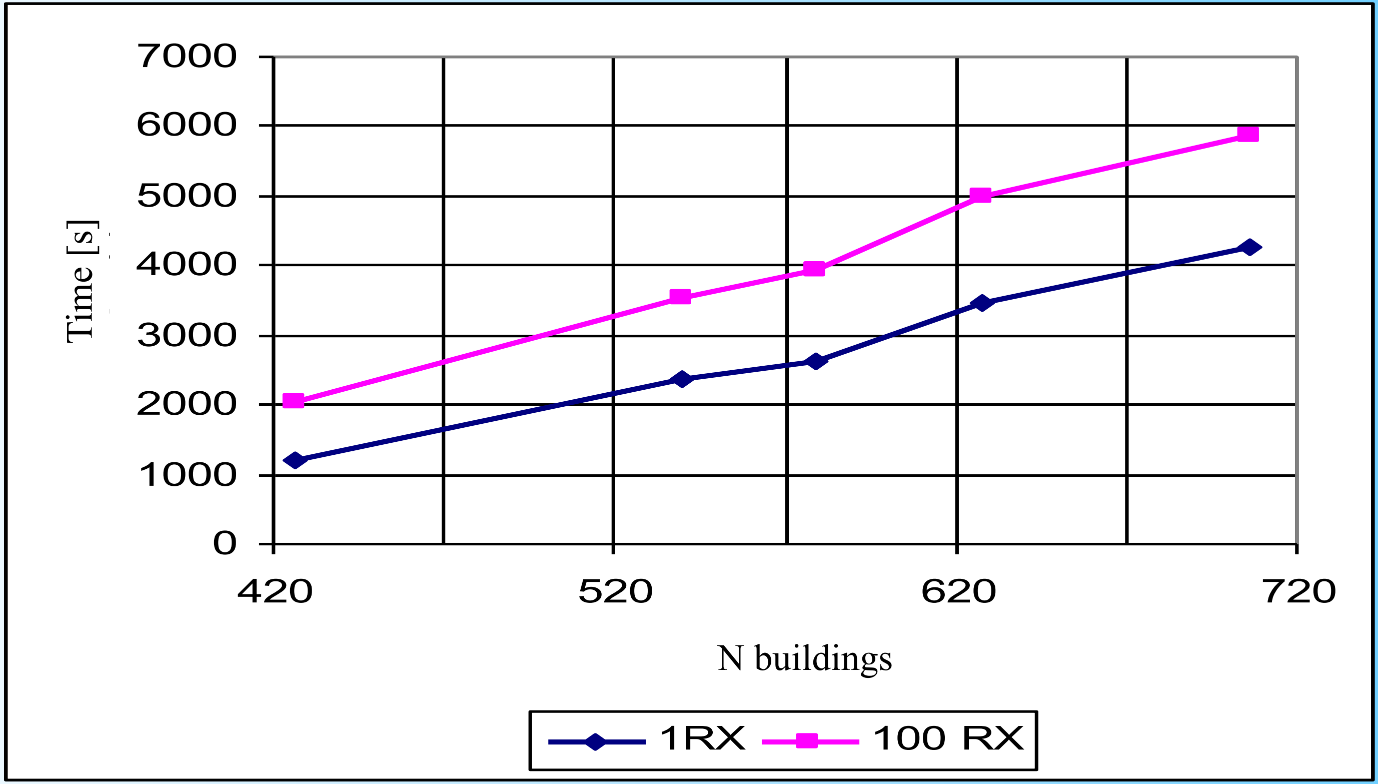


CPU time vs N_{ev}

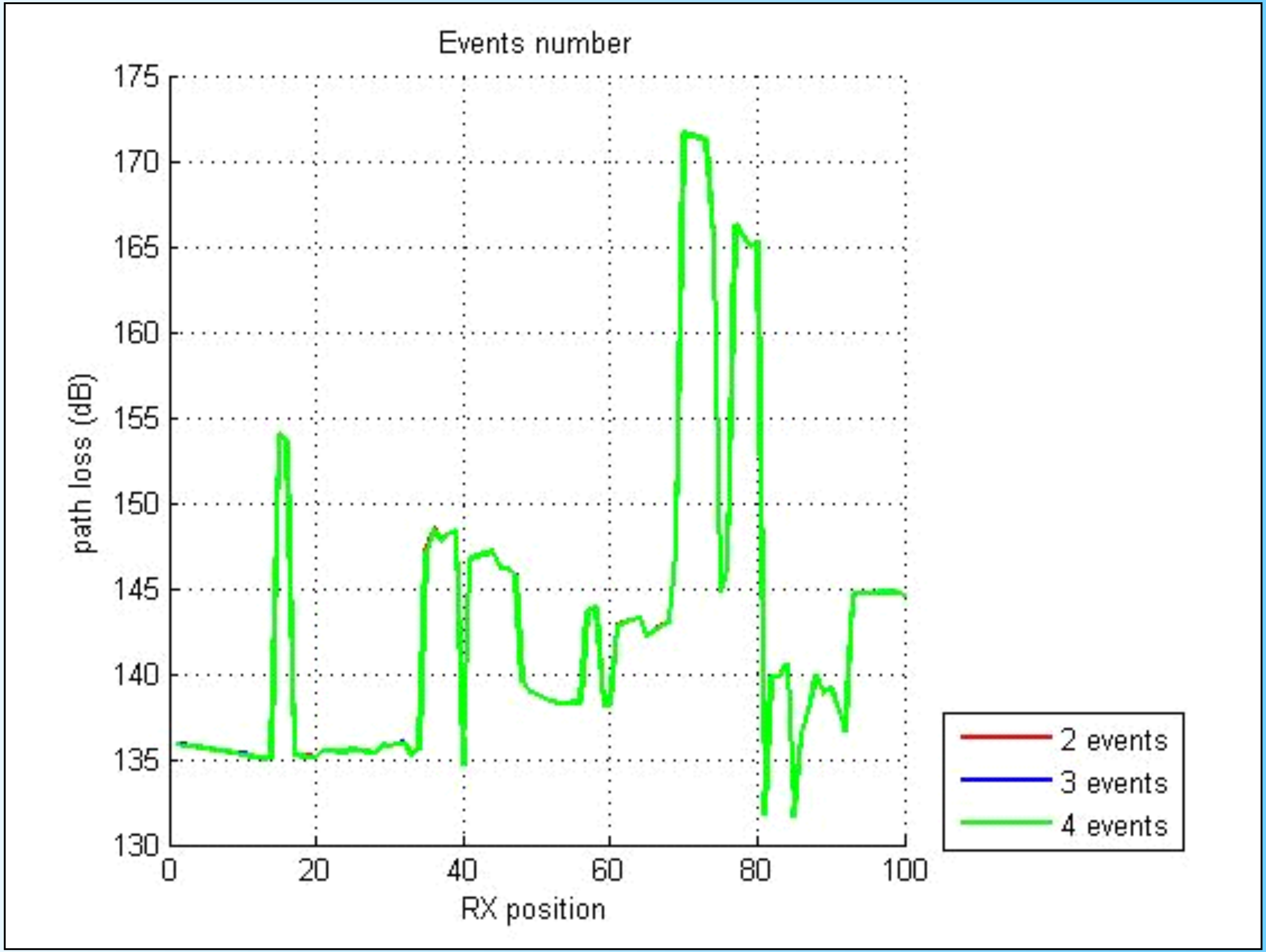
CPU time vs number of buildings



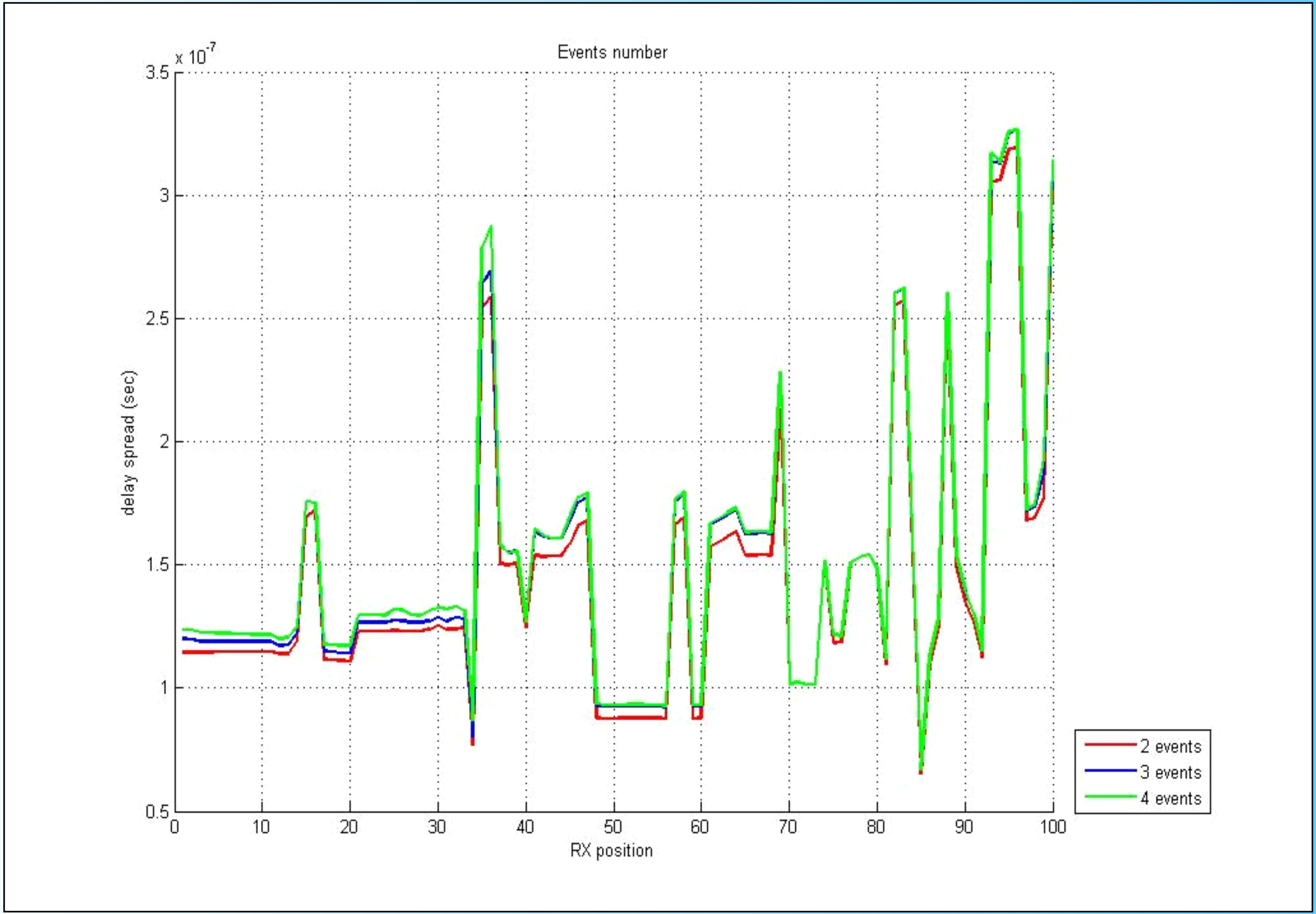
CPU time vs number of Rx points



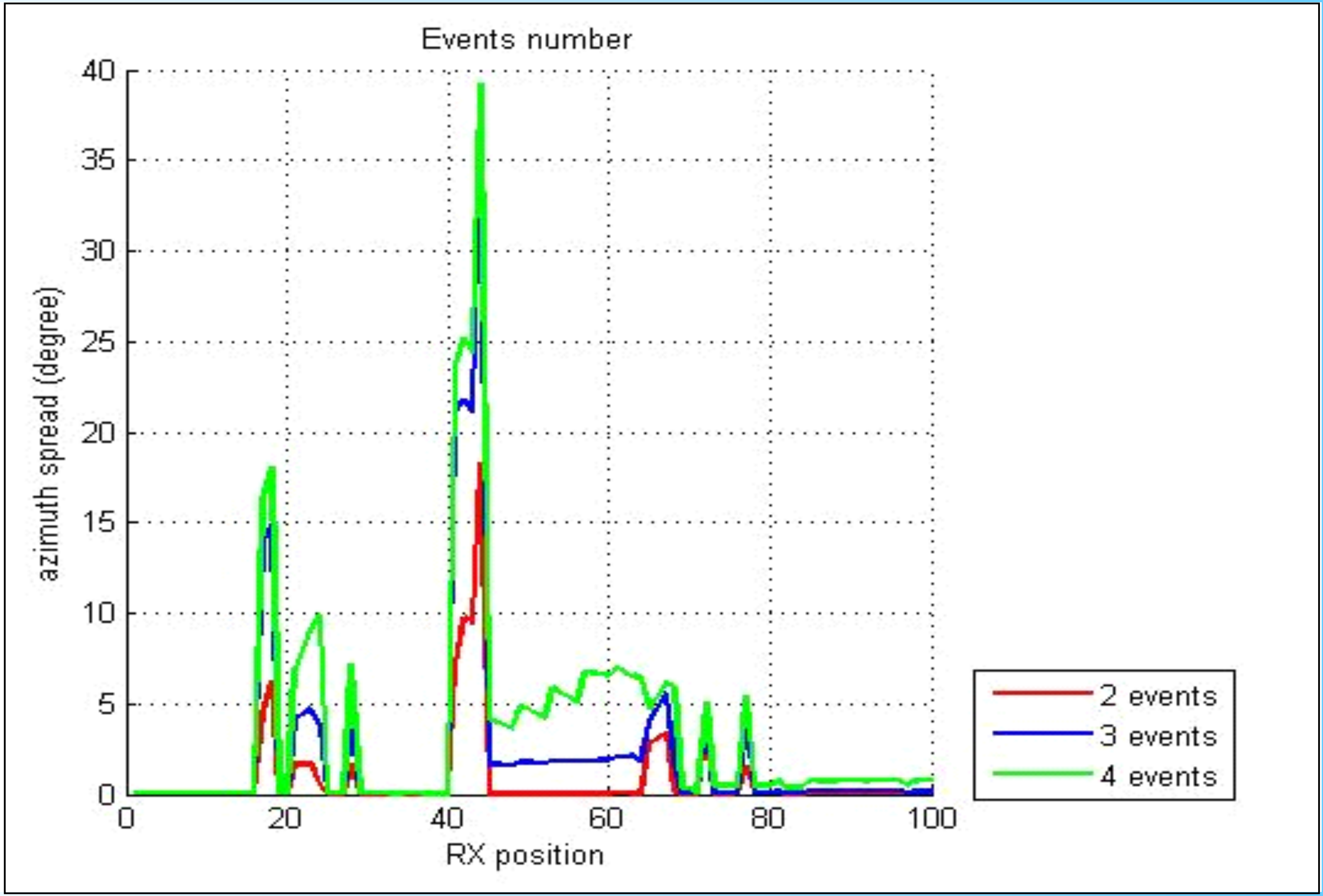
Path loss vs N_{ev}



Delay Spread vs N_{ev}



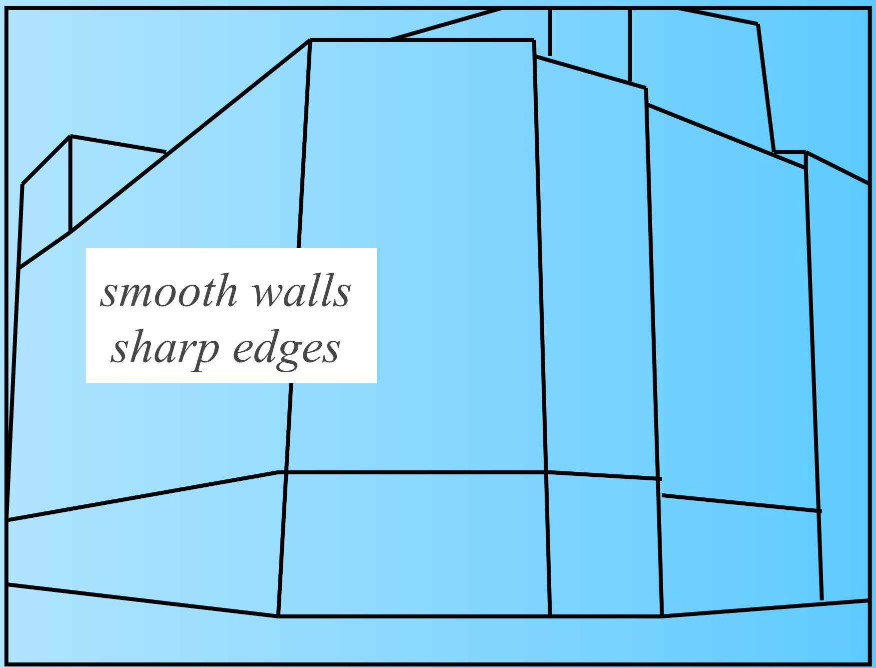
Azimuth Spread vs N_{ev}



Impact of different interactions

	Outdoor prediction		Indoor prediction	
Interaction	Relevance	CPU time	Relevance	CPU time
Reflection	High	Medium	Medium	Medium
Diffraction	High (μcells)	High	Low	High
ORT diffr.	High (macro-cells)	Medium	------------	------------
Scattering	High (multi-dim.)	High	Medium	High
Transmission	------------	------------	High (f<10GHz)	Low

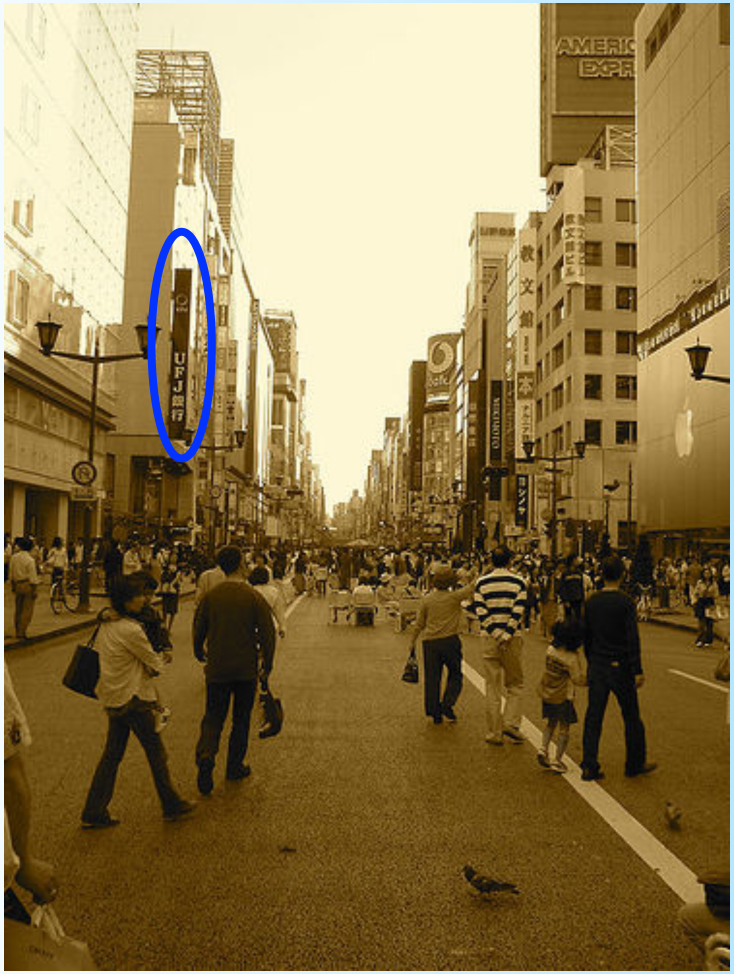
What is diffuse scattering?



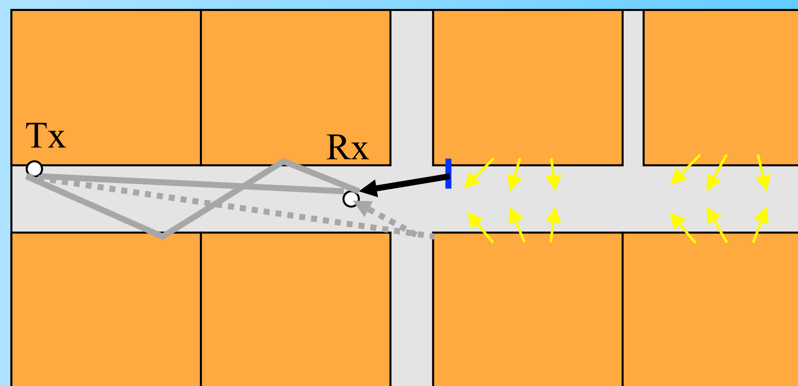
Real building

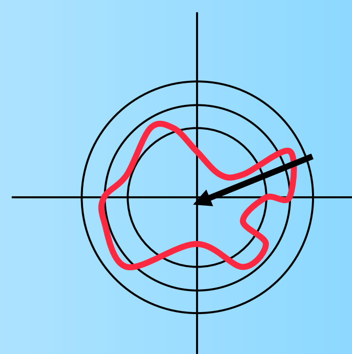
Representation (macro-structure only)

Real urban environment: diffuse scattering effect

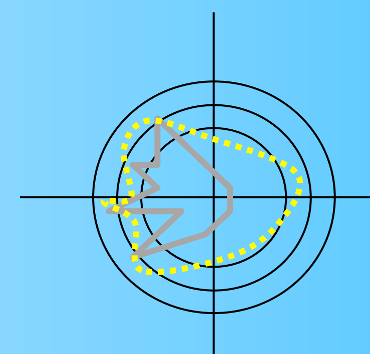


Top view



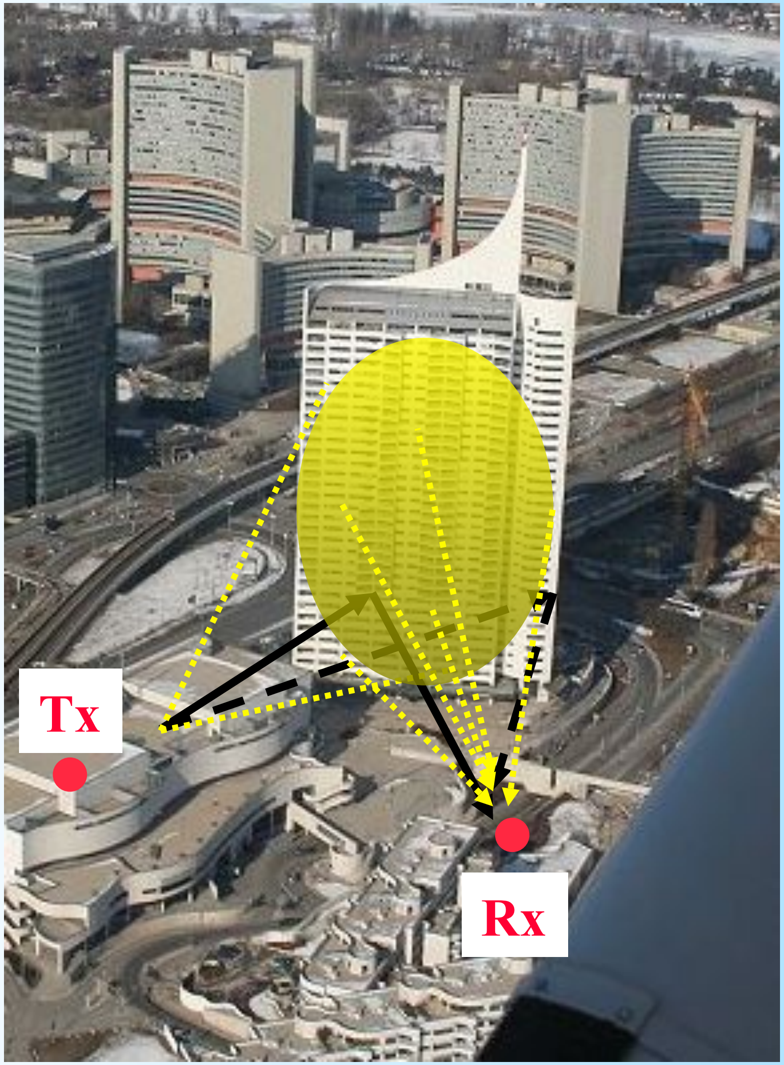


Measured power-angle profile at Rx

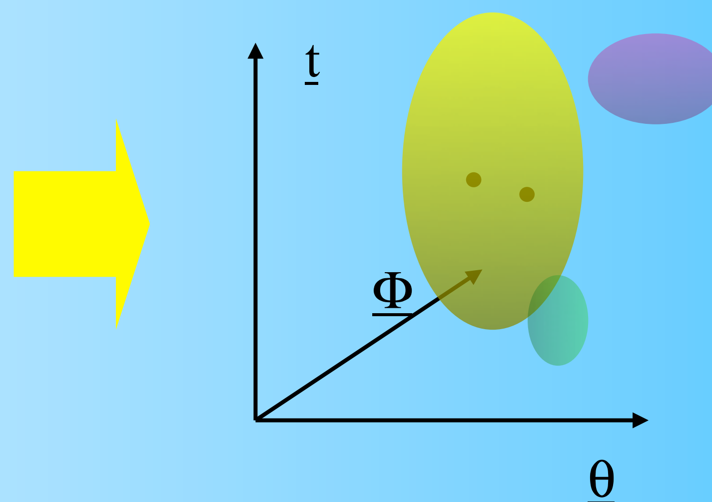


Simulated power-angle profile at Rx

Diffuse scattering effect (II)



Because of diffused/distributed scattering we get a dispersed **power-profile** or **cluster** of rays at the Rx



Computing all contributions in such a cluster would involve heavy computation

Diffuse scattering definition(s) (1/2)

The question:

What is the definition of diffuse/distributed scattering?

The possible answer(s):

- Any interaction with obstacles is scattering ➔ distributed obstacles yield distrubuted scattering

D.S.=EVERYTHING ?

- The macroscopic result of many interactions on “small” obstacles, most of which are actually reflections, transmissions, diffractions

D.S.=NOTHING ?

Empirical:

- All contributions which cannot be “resolved” by the measurement system

<u>Here</u>:

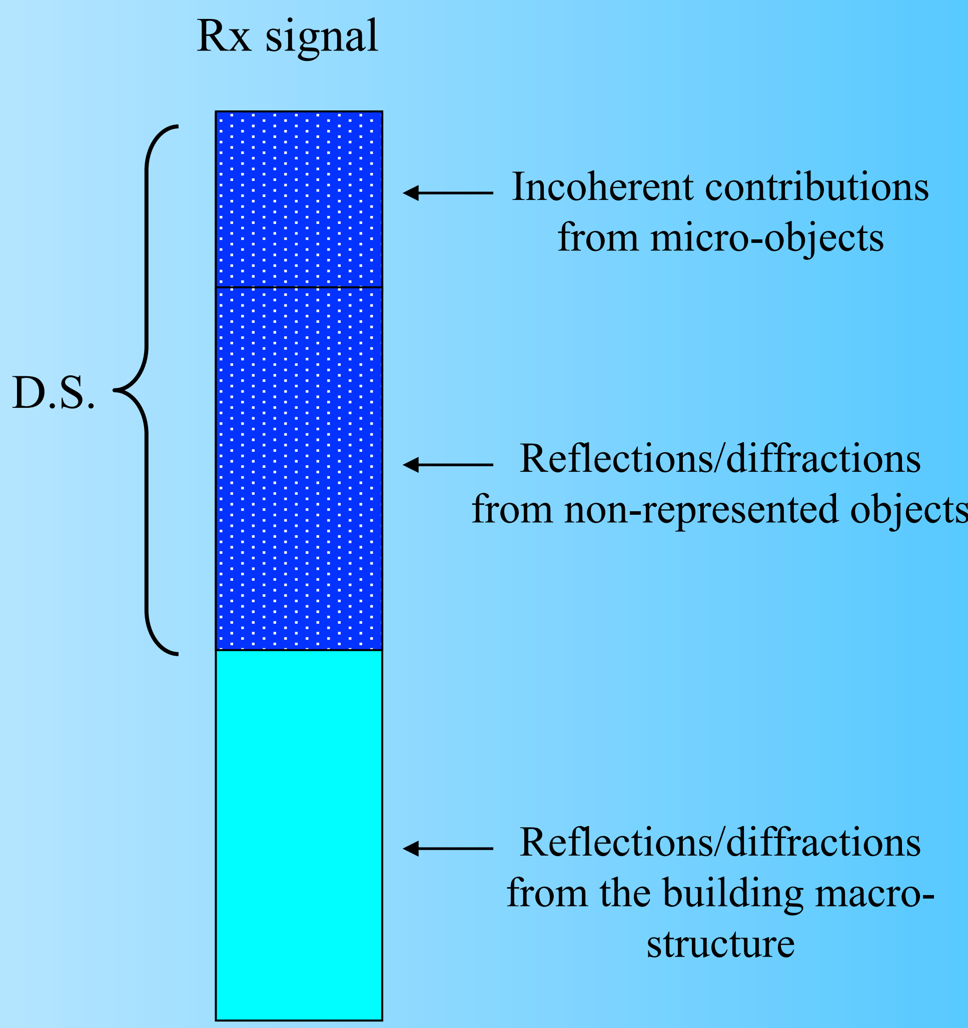
- All contributions except main reflections/diffractions on the building *macro-structure*

Diffuse scattering definition(s) (2/2)

Therefore :

Diffuse/distrubuted scattering includes everything that cannot be modelled with traditional ray models operating on building databases

<u>Ray models need to be extended somehow to diffuse scattering</u>

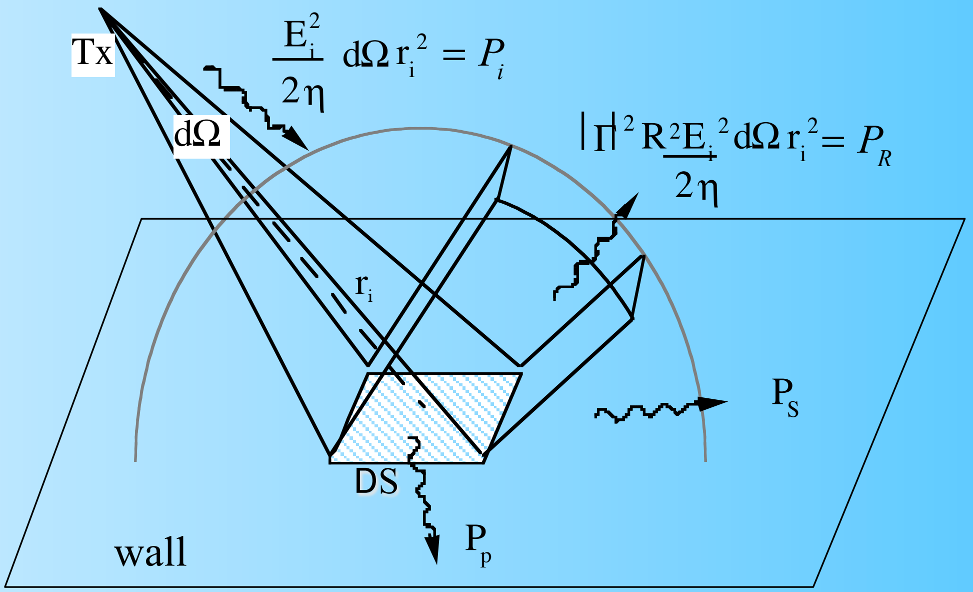


The Effective Roughness model (1/6)

- It is based on the assumption that if a given power amount impinges on the generic surface element, then a fraction of it is scattered with a given ***scattering pattern*** (reflection is thus attenuated accordinly)
- The scattering pattern must be intended in a ***statistical way*** ➔ ***p.d.f.***
- Similarly to the Fresnel's reflection coefficient a ***scattering coefficient S*** is defined so that S^2 is the fraction of scattered power

Reflection: $$\boxed{(\Gamma \cdot R)^2 = \frac{P_R}{P_i}}$$ $$0 \le R < 1$$

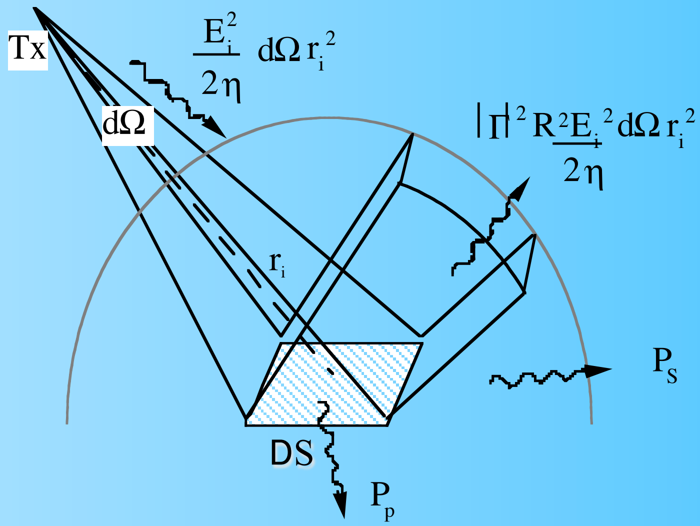
Scattering: $$\boxed{S^2 = \frac{P_S}{P_i}}$$



The Effective Roughness approach (2/6)

On Ds, the following power balance holds:

$$E_i^{\,2}\Delta\Omega r_i^{\,2} = |\Gamma|^2 R^2 E_i^{\,2}\Delta\Omega r_i^{\,2} + S^2 E_i^{\,2}\Delta\Omega r_i^{\,2} + 2\eta P_p$$



Thus:

$$1)\quad 1 = \Gamma^2 R^2 + S^2 + P_p / P_i$$

If now the surface 'becomes' smooth, assuming the penetrated power does not change (questionable…), we have (S=0, R=1):

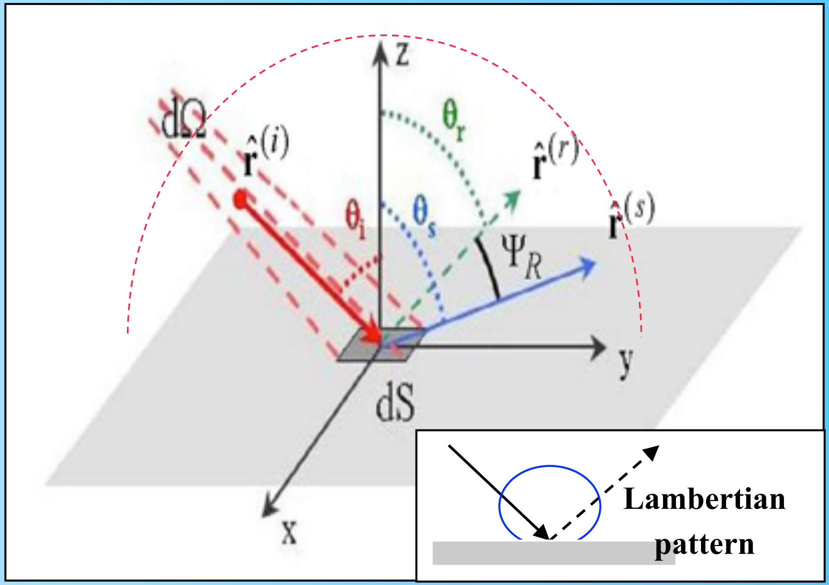
$$2)\quad 1 = \Gamma^2 + P_p / P_i$$

From 1) and 2) we therefore get:

$$R \cong \sqrt{1 - \frac{S^2}{\Gamma^2}} \quad (**)$$

The Effective Roughness approach (3/6)

If we now move away **in the far field** the following power balance for the diffused wave holds



3) $S^2 \cdot \left|\overline{E}_i\right|^2 \cdot d\Omega_i \cdot r_i^2 = \int\limits_{2\pi} \left|\overline{E}_s\right|^2 d\Omega_s \cdot r_s^{\,2}$

If the scattering pattern $|E_s|^2(\theta_s,\phi_s)$ is known, then 3) can be solved w.r.t. the scattered field. If the scattering pattern is *Lambertian* $\left(\left|\overline{E}_s\right|^2 = E_{S0}^{\;2} \cdot \cos\theta_s\right)$ we get:

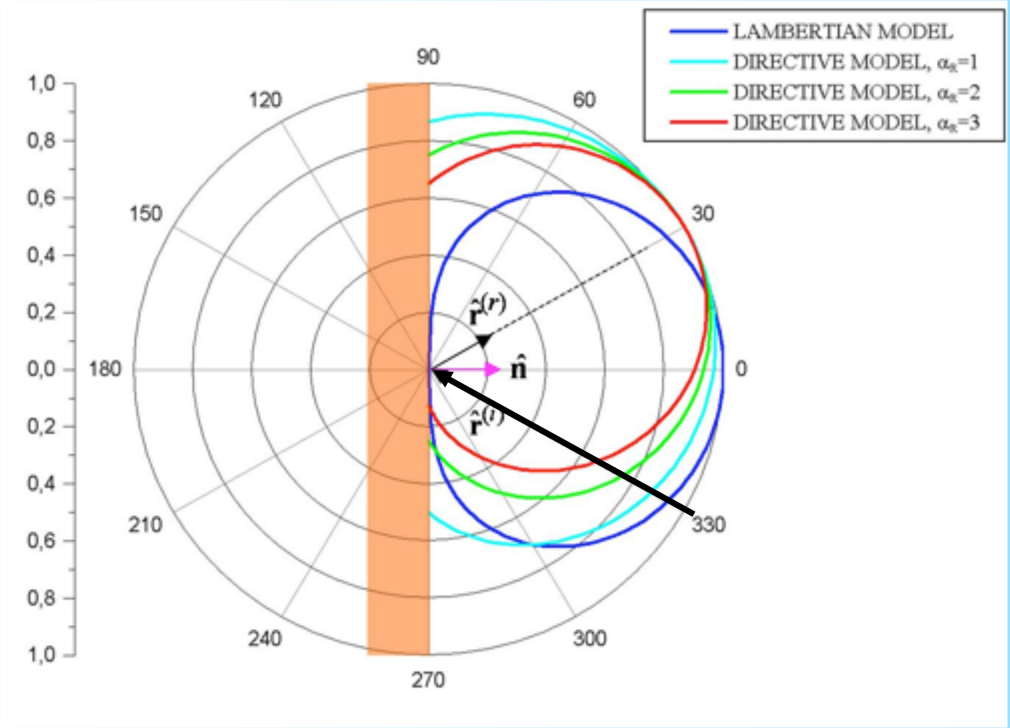
$$\left|\overline{E}_s\right|^2 = K_0^2 S^2 \frac{dS \cos\theta_i \cos\theta_S}{\pi} \frac{1}{r_i^2 r_S^2}; \quad K_0 = \sqrt{60 G_t P_t},$$

Notice that the scattered field has a different, stronger attenuation law vs. distance w.r.t. the reflected one:

$$A_s = \frac{1}{r_i\, r_S}; \quad (scattered\ \ field) \qquad A_r = \frac{1}{r_i + r_S} \quad (reflected\ \ field)$$

The Effective Roughness approach (4/6)

Several scattering pattern can be assumed. Of course power balance must always be satisfied. For each scattering pattern a different solution of eq. 3) can be found.



Most common scattering patterns:

Lambertian

$$\left|\overline{E}_s\right|^2 = E_{S0}^{\ 2} \cdot \cos\theta_s$$

Directive

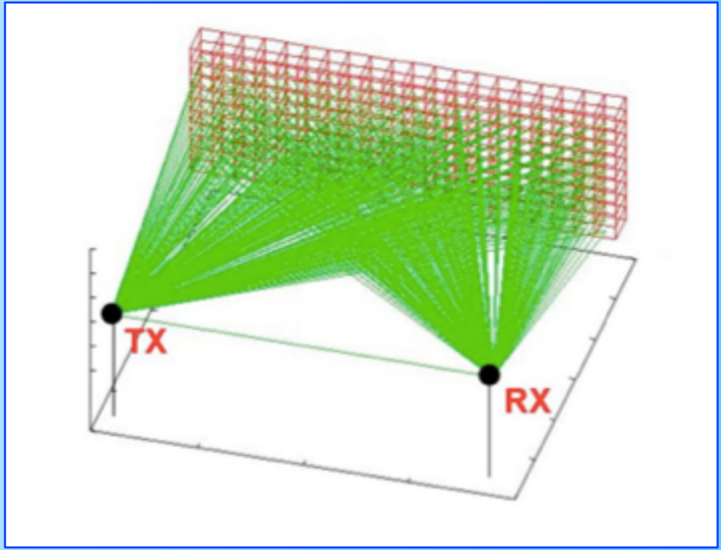
$$\left|\overline{E}_S\right|^2 = E_{S0}^{\ 2} \cdot \left(\frac{1+\cos\ \psi_R}{2}\right)^{\alpha_R} \quad \alpha_R = 1,2,\ldots,\mathrm{N}$$

The Effective Roughness approach (5/6)

● In the Lambertian case, for example, the total diffused power from a surface of area A can be therefore obtained through the following surface integral:

$$\left|\bar{E}_s\right|^2_{TOT} = \frac{K_0^2 S^2}{\pi} \iint_A \frac{\cos\theta_i \cos\theta_S}{r_i^2 r_S^2} \, dx \, dy$$

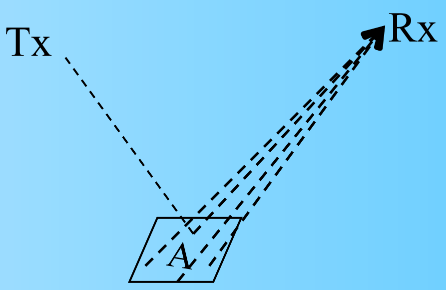
● If multidimensional prediction is needed, then each surface element contribution must be computed ➔ <u>very high computation time</u>



The Effective Roughness approach (6/6)

● If the surface is "far" from the terminals, thus distances do not change much over A, then we have a simpler expression:

$$\boxed{\left|\overline{E}_s\right|_{TOT}^2 = A\,K_0^2 S^2 \frac{\cos\theta_i \cos\theta_S}{\pi}\frac{1}{r_i^2 r_S^2}}$$



Yes, but how much?

Model parameters: conservative values

For example from [*] for a limestone slab, normal incidence, we have:

smooth surface

$|\Gamma| \sim 0.5$

rough surface ($s_h \sim 2.5$ cm)

(*) $|\Gamma'| = |0.5| R \sim 0.3$

But also the following must hold:

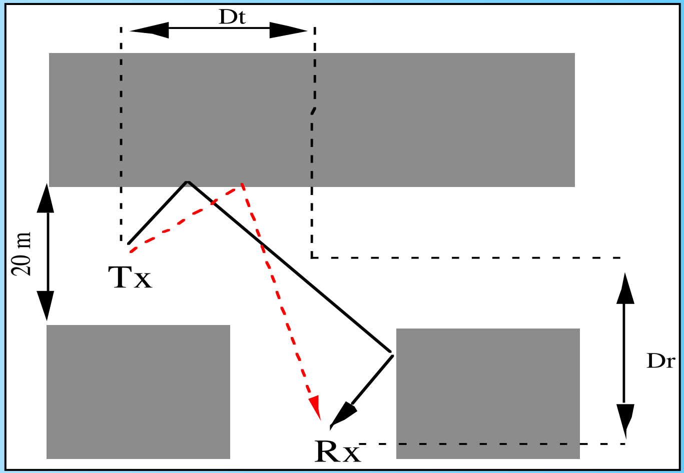
$$R \cong \sqrt{1 - \frac{S^2}{\Gamma^2}} \quad (**)$$

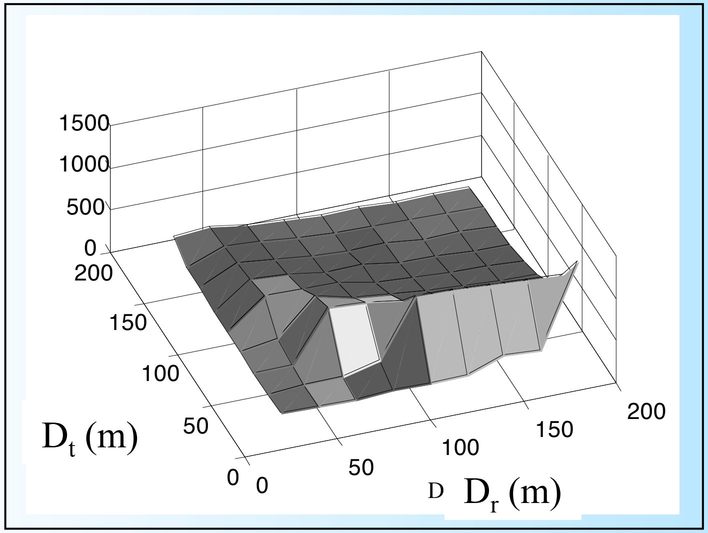
Therefore from (*) and (**) we get: **R=0.6, S=0.4**.
This means that in this simple case **16%** of the impinging power is scattered

[*] O. Landron, M. J. Feuerstein and T. S. Rappaport, "A comparison of theoretical and empirical reflection coefficients for typical exterior wall surfaces in a mobile radio environment," IEEE Trans. Ant. Propagat., vol. 44, no. 3, pp.341-351, March 1996.

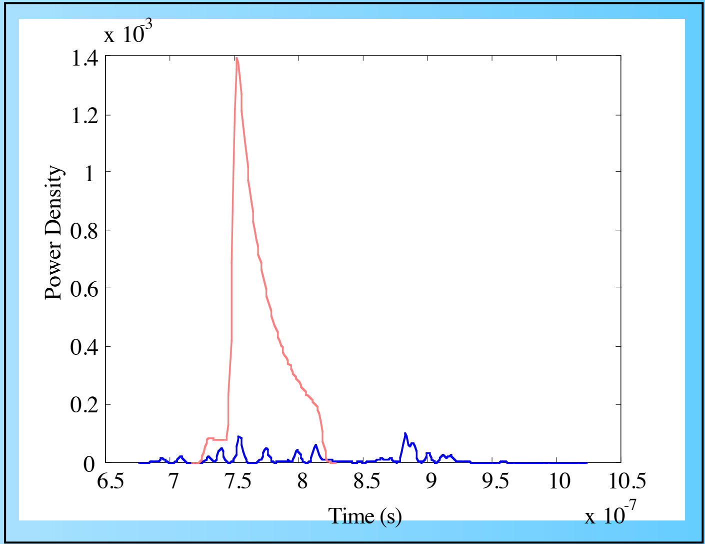
Application to a simple case

Ideal, T-shaped street intersection



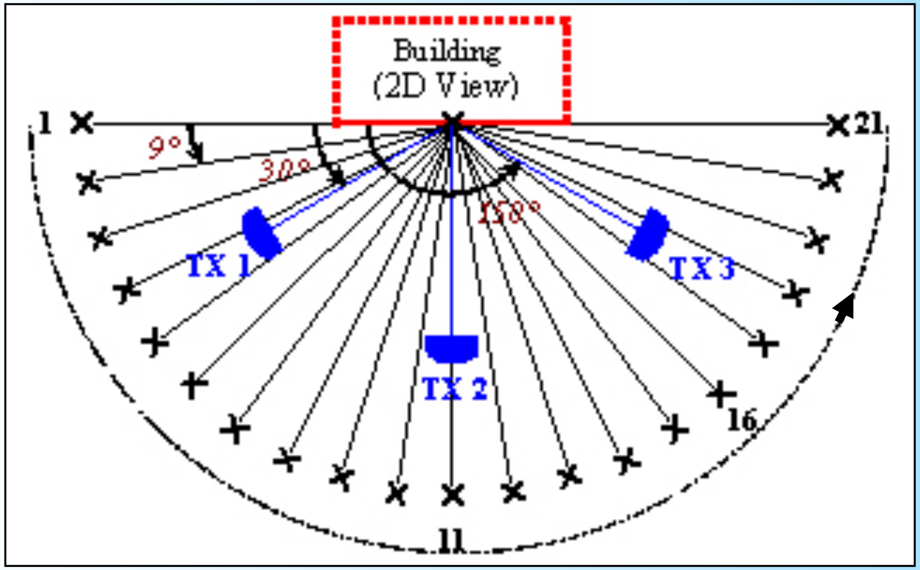


$Ps/P_{coherent}$*100 plotted vs D_t and D_r



Scattered (red) and coherent (blue) impulse response for D_t =30 m and D_r=190 m.

Measurements (1/3)



It is impossible, given the gear, to isolate diffuse scattering…

Comparison with ray tracing simulation including the ER model

Measurements (2/3)

Metal airport hangar

Brick wall

Abandoned Rural building

Three cases are considered, whose scattering contribution is presumably different (increasing)

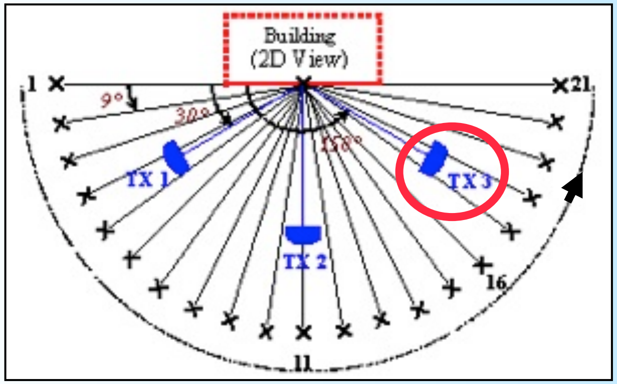
Frequency: 1296 Mhz

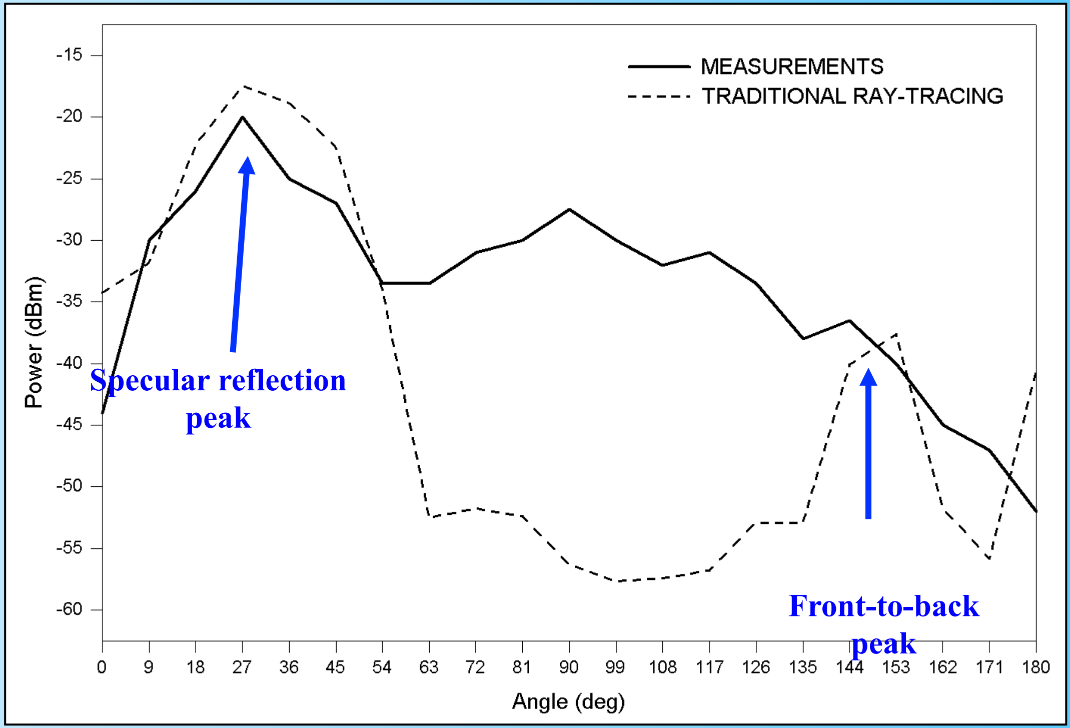
Co-polarized parabolic antennas

Measurements (3/3)

Ex: rural building

disabling the scattering contribution completely wrong ray tracing results are obtained

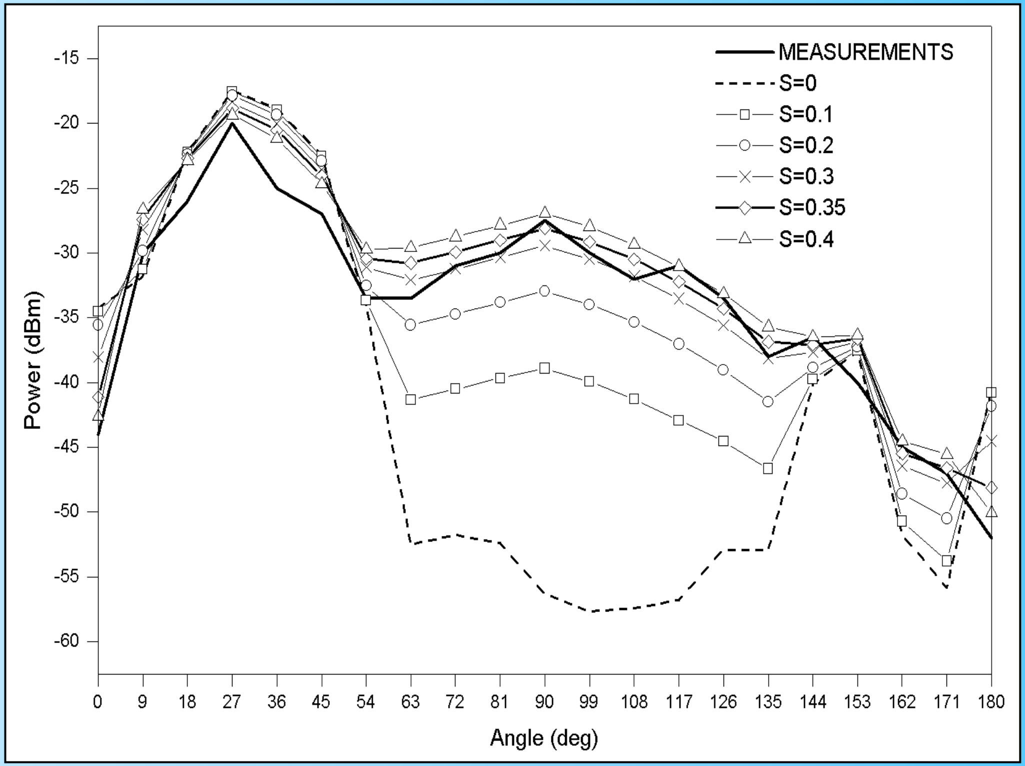




Best scattering parameter values

Directive scattering pattern – Rural building

The best value is therefore S=0.35



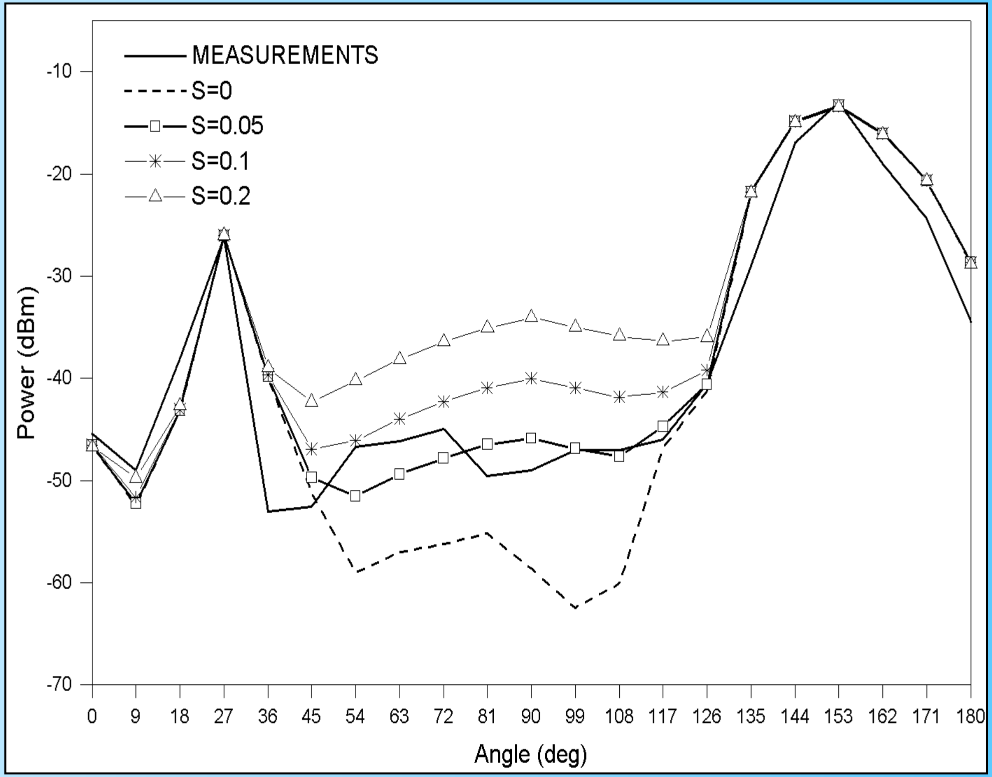
Best scattering parameter values

Directive scattering pattern – Hangar

The best value is therefore S=0.05

(very low scattered power)

Similar results are obtained with normal incidence



Notes

- In the considered cases the diffuse scattering phenomena are not negligible and must be accurately modeled to get good predictions.

- It has been shown that by adopting a single-lobe scattering pattern and appropriate values for the scattering parameter S a good agreement between RT simulations and measurements can be achieved

- The best scattering pattern is directive with α_R=3 and the best S values are 0.35, 0.2 and 0.05 for the rural, brick, and hangar buildings, respectively.

- In urban environment, due to cluttering, street signs, lampposts, etc. the actual diffuse scattering background is expected to be considerably greater than here. S=0.35 is therefore a lower-bound value.

- Further reading:

  V. Degli-Esposti, F. Fuschini, E. Vitucci, G. Falciasecca, "Modelling of scattering from buildings," IEEE Transactions on Antennas and Propagation, January 2007