Deterministic radio propagation modeling and ray tracing

1) Introduction to deterministic propagation modelling
2) Geometrical Theory of Propagation I - The ray concept – Reflection and transmission
3) Geometrical Theory of Propagation II - Diffraction, multipath
4) Ray Tracing I
5) Ray Tracing II – Diffuse scattering modelling
6) Deterministic channel modelling I
7) Deterministic channel modelling II – Examples
8) Project - discussion

Envelope correlations (1/5)

It is useful to define <u>transfer function's envelope-correlations</u>. Considering the <u>module of the</u> <u>generic transfer function</u> |M(z)| <u>in a e-kind domain z</u>, the domain span Δz and the average value $\left|\bar{M}\right|_{\Delta z}$ over Δz we have:

<u>"z-wise" correlation</u> (envelope correlation)

$$R_z(\delta)=\frac{\int_{\Delta z}\left[\left|M(z)\right|-\left|\bar{M}\right|_{\Delta z}\right]\left[\left|M(z+\delta)\right|-\left|\bar{M}\right|_{\Delta z}\right]dz}{\int_{\Delta z}\left[\left|M(z)\right|-\left|\bar{M}\right|_{\Delta z}\right]^2 dz}; \quad R_z(0)=1,\ -1<R_z(\delta)\le 1$$

$$\lim_{\delta\to\infty}\left\{R_z(\delta)\right\}=0$$

Especially frequency and space correlations are useful. The last one is fundamental for diversity techniques and MIMO.

Envelope correlations (2/5)

<u>Ex: frequency correlation</u>

$$R_f(w) = \frac{\int_{\Delta f} \left[\left| H(f) \right| - \left| \bar{H} \right|_{\Delta f} \right] \left[\left| H(f+w) \right| - \left| \bar{H} \right|_{\Delta f} \right] df}{\int_{\Delta f} \left[\left| H(f) \right| - \left| \bar{H} \right|_{\Delta f} \right]^2 df}$$

<u>Space correlation</u> (along the x direction)

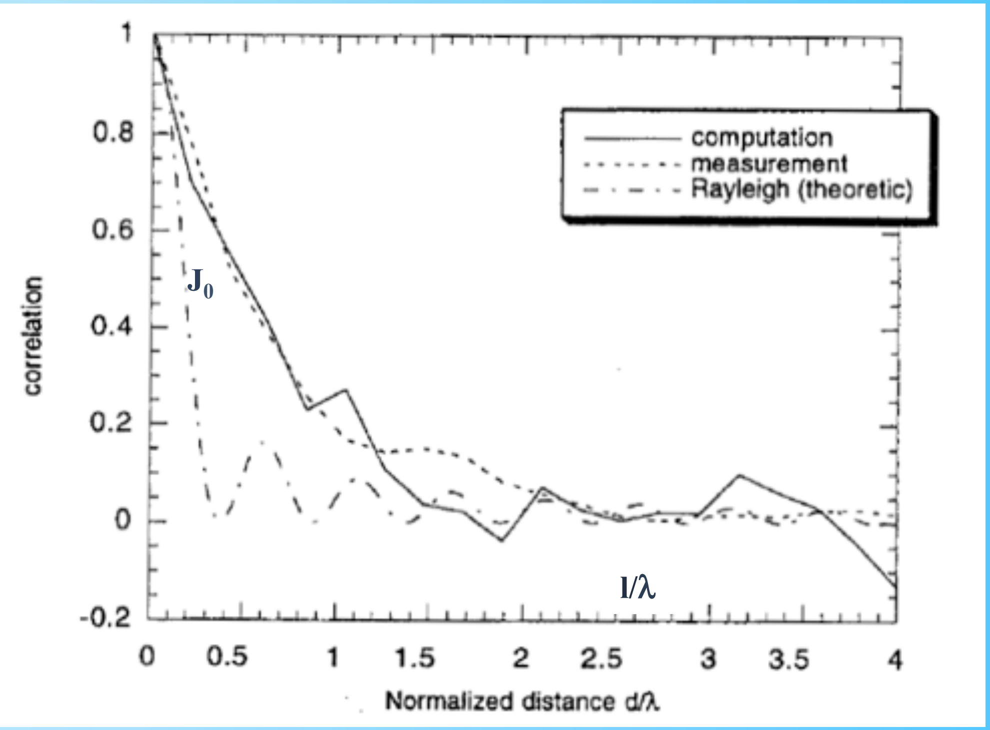
$$R_x(l) = \frac{\int_{\Delta x} \left[\left| H(x) \right| - \left| \bar{H} \right|_{\Delta x} \right] \left[\left| H(x+l) \right| - \left| \bar{H} \right|_{\Delta x} \right] dx}{\int_{\Delta x} \left[\left| H(x) \right| - \left| \bar{H} \right|_{\Delta x} \right]^2 dx}$$

Envelope correlations (3/5)

Ex. space correlation in a Rayleigh environment, i.e. with uniform 2D power-azimuth distribution with $p_\varphi(\varphi)=1/2\pi$ is:

$$R_x(l) = J_0\left(\frac{2\pi l}{\lambda}\right)$$

With J_0 the zero-order Bessel's function of the first kind. This means that the signal received from two Rx's $\lambda/2$ apart is nearly uncorrelated (see figure), and this can be useful to decrease fast fading effects



Envelope correlations (4/5)

Frequency correlation and time correlation allow a rigorous definition of coherence bandwidth and coherence time.

Given a reference, residual frequency correlation "a", then coherence bandwidth is:

$$B_C^{(a)} = \bar{w} \;\; with \;\; R_f\left(\bar{w}\right) \leq a \;\; \text{for} \;\; \mathrm{w} \geq \bar{w}$$

Similarly, given a reference, residual time correlation "a", then coherence time is :

$$T_C^{(a)} = \bar{t} \;\; with \;\; R_t\left(\bar{t}\right) \leq a \;\; \text{for t} \geq \bar{t}$$

Coherence distance L_c can also be defined in the following way:

$$L_C^{(a)} = l \;\; with \;\; R_x\left(l\right) \leq a \;\; \text{for x} \geq l$$

Envelope correlations (5/5)

The higher the coherence distance L_c the lower the angle spread.
All considered we have:

$$B_c^{0.1} \simeq \frac{1}{DS} \qquad L_c^{0.1} \approx \frac{\lambda}{4}\frac{1}{\sigma_{\vec{\Omega}}}$$

Multidimensional parameters and MIMO (1/2)

For optimum antenna/space diversity performance the received signal at the different antennas should be **incorrelated**, i.e. the signal envelope should have fast changes with space (along s).
Therefore the power-angle profile should be very spread → there must be a large **angle spread**.

To achieve good spatial multiplexing there must be a large number of strong paths well spaced (independent) in the angle domain in order for the MIMO matrix to have high rank → there must be a large **angle spread**.

In other words there must be a high **multipath richness**

Also absolute-time and Doppler domains (not considered here) are very important for **space-time coding**, i.e. **transmit diversity** and other MIMO coding techniques

Multidimensional parameters and MIMO (2/2)

Angle spread and **delay spread** are two possibile measures of **multipath richness**.

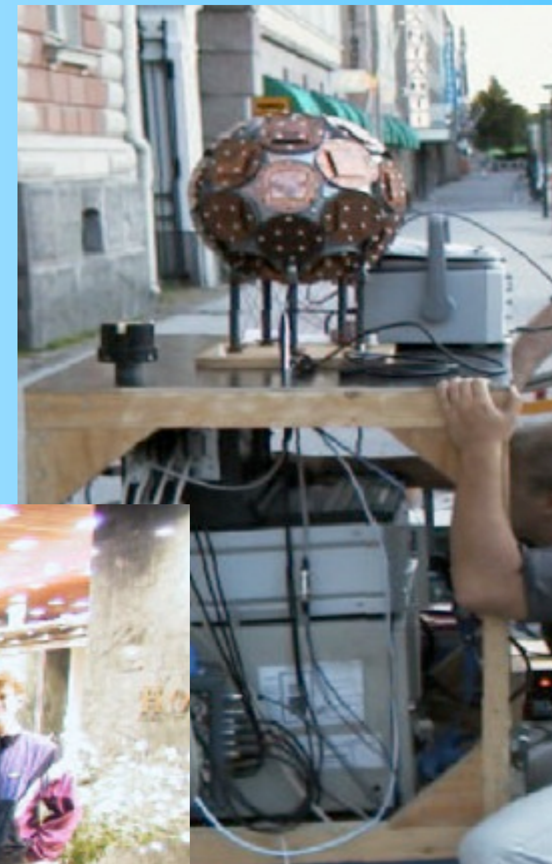
SNR remains however the most important parameter for the performance pf small-size MIMO schemes (i.e. 2x2 or 4x4 etc)

Recent studies have shown that for unnormalized channel, the channel capacity usually rises when moving from NLOS into LOS since the loss in multipath richness is more than compensated for by an increase in SNR.

Dual-polarized MIMO schemes are very attractive as a doubling in the MIMO order is achieved with a less-than-proportional increase in the antenna size.

In Dual polarized MIMO schemes the **XPD** (Cross-Polarization Discrimination) is very important. If the XPD is high (low correlation btw polarization states) then multiplexing is possible, otherwise polarization diversity is preferable.

Multidimensional measurements[*] (1/2)

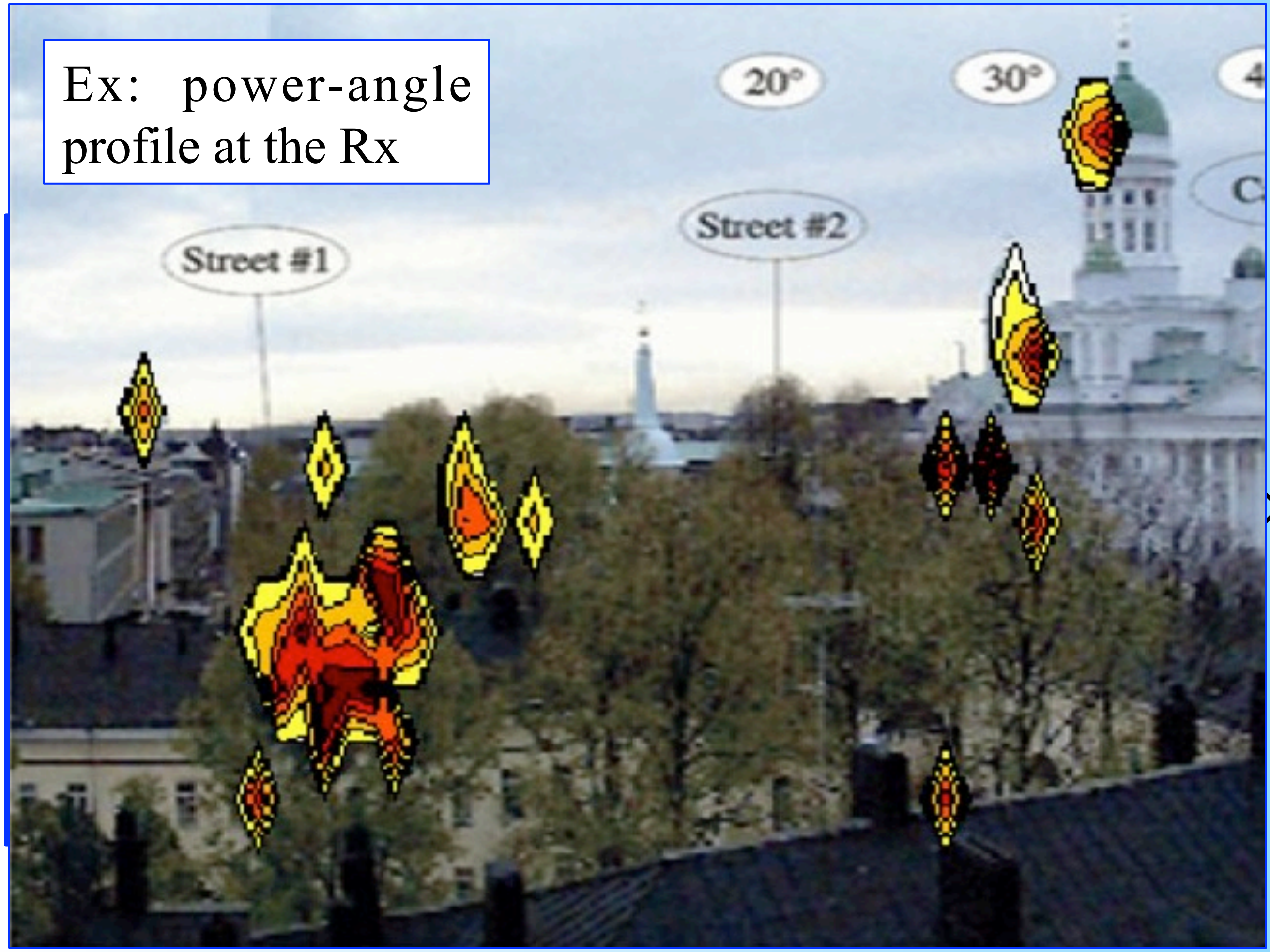


Transmitter

Receiver

[*] V.-M. Kolmonen, J. Kivinen, L. Vuokko, P. Vainikainen, "5.3 GHz MIMO radio channel sounder," IEEE Trans. Instrum. Meas., Vol. 55, No. 4, pp. 1263-1269, Aug. 2006

Multidimensional measurements (2/2)



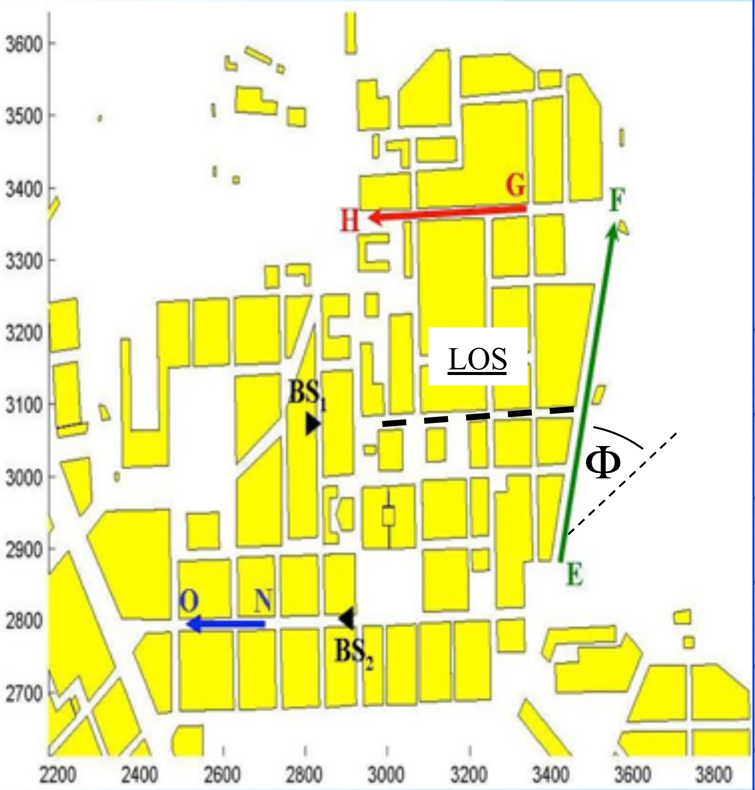
Dominant path structure

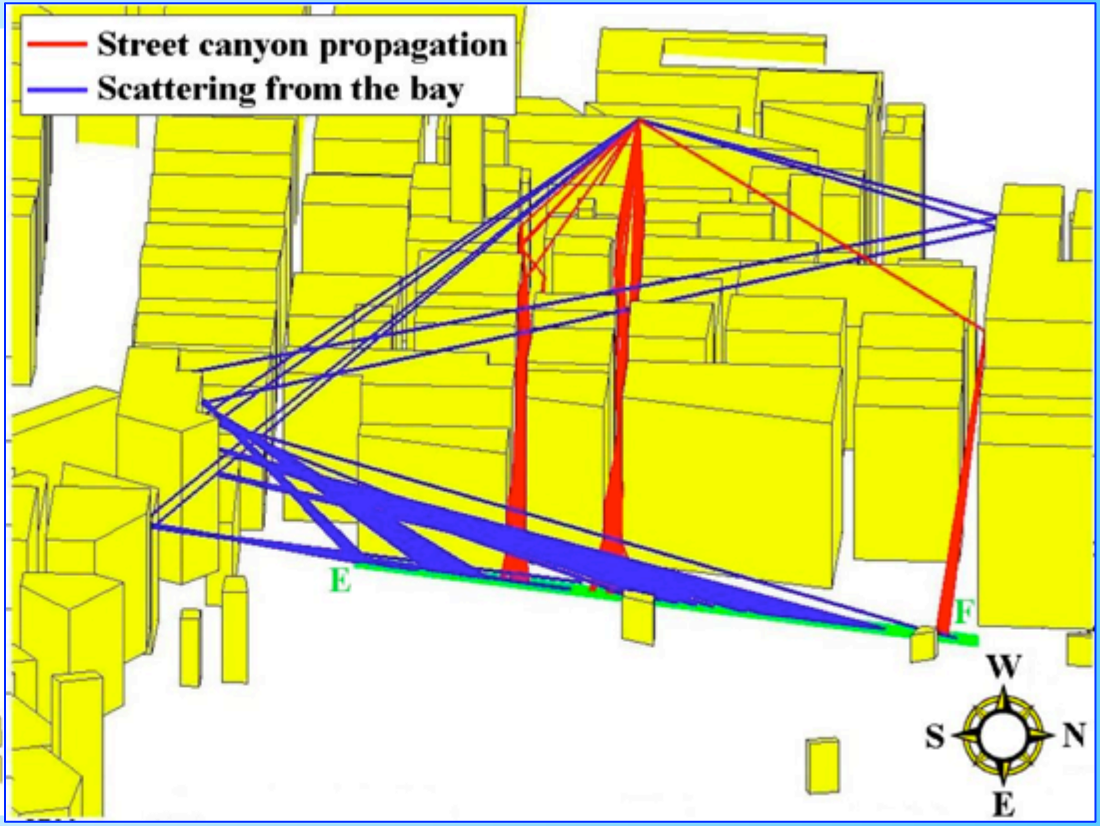
$\rho_i, t_i, \theta_i, \chi_i, \psi_i$

Power profiles, etc.

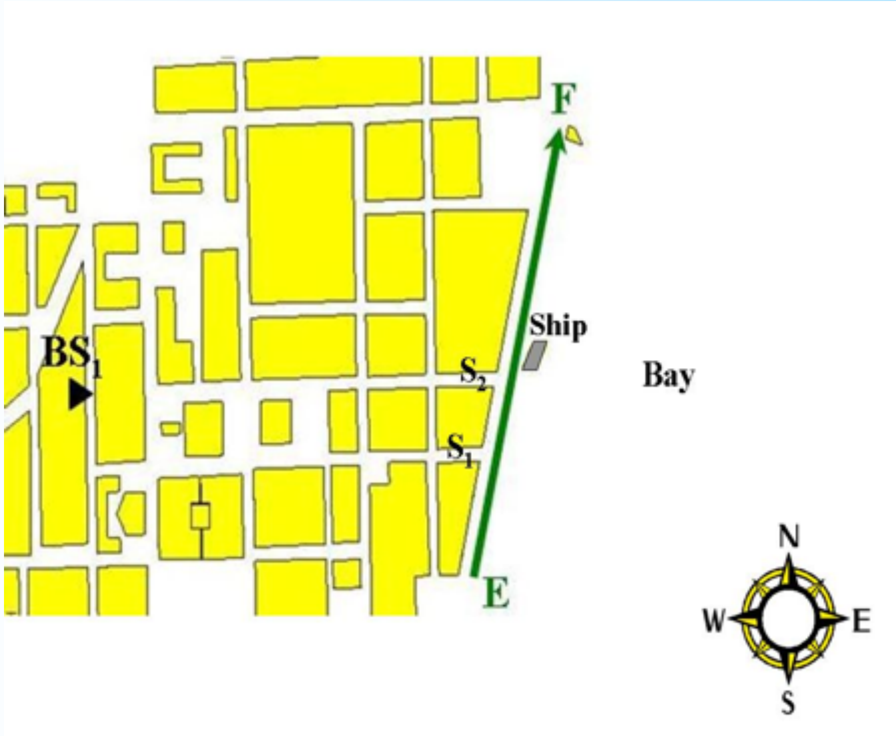
Multidimensional prediction using ray tracing Examples (I)

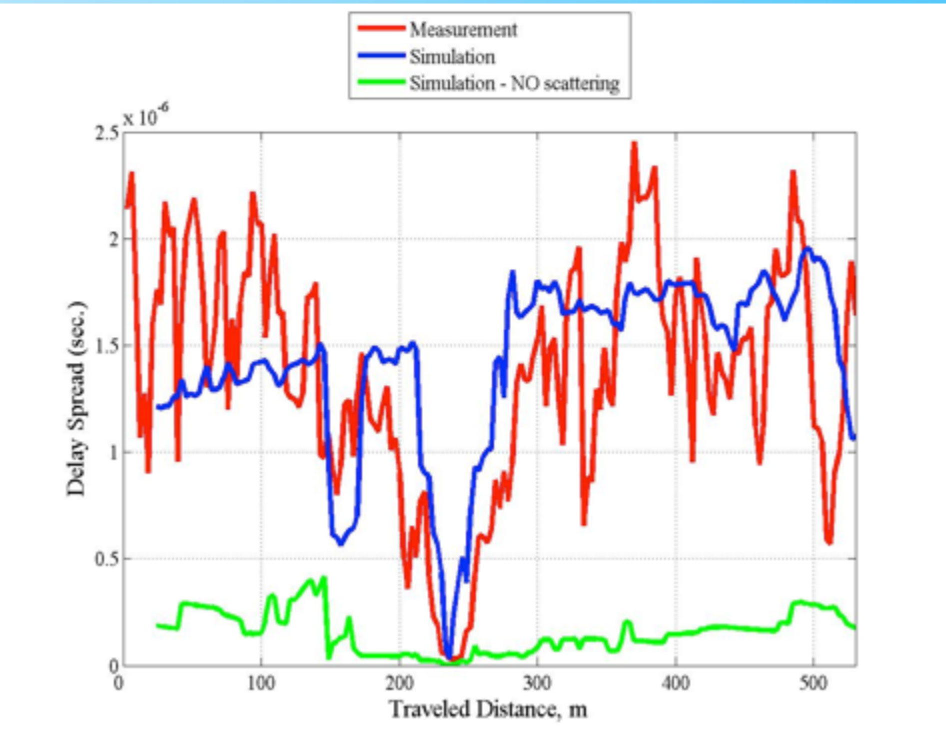
Helsinki route EF: Azimuth Spread comparison (AS)





Helsinki route EF: Delay Spread comparison (DS)

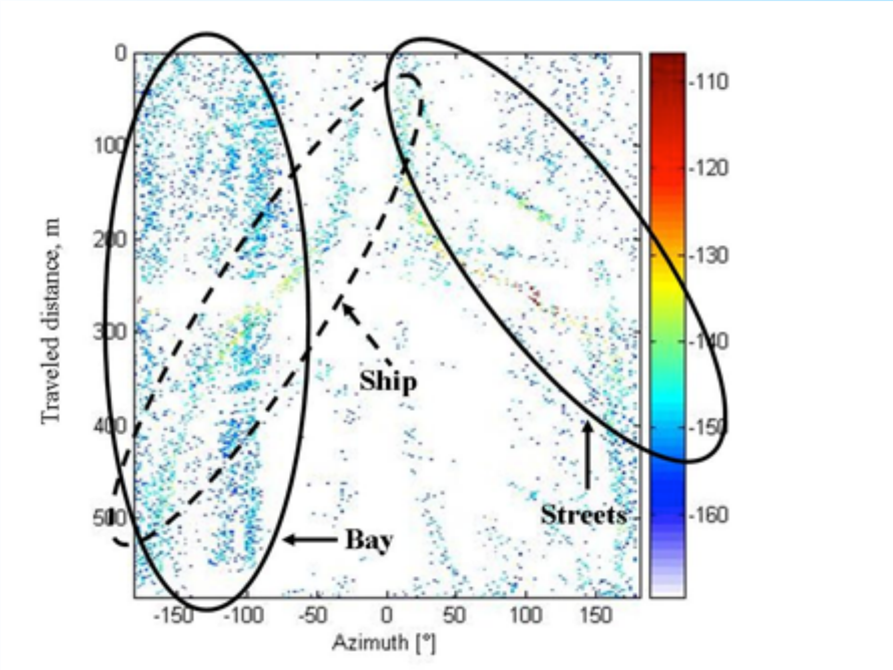




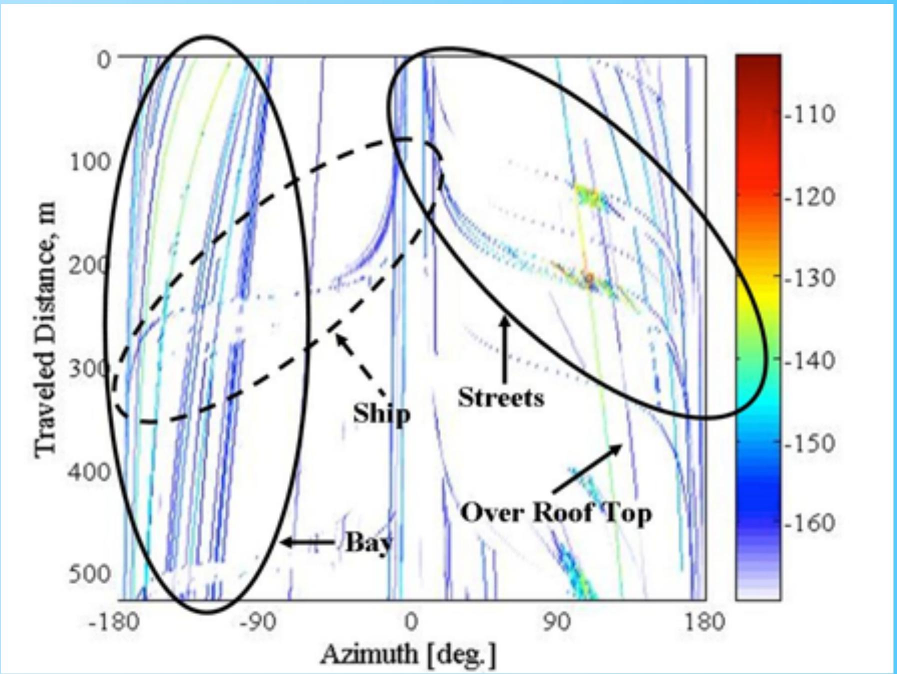
Multidimensional prediction by ray tracing Examples (II)

Helsinki route EF: azimuth-distance plot

measured



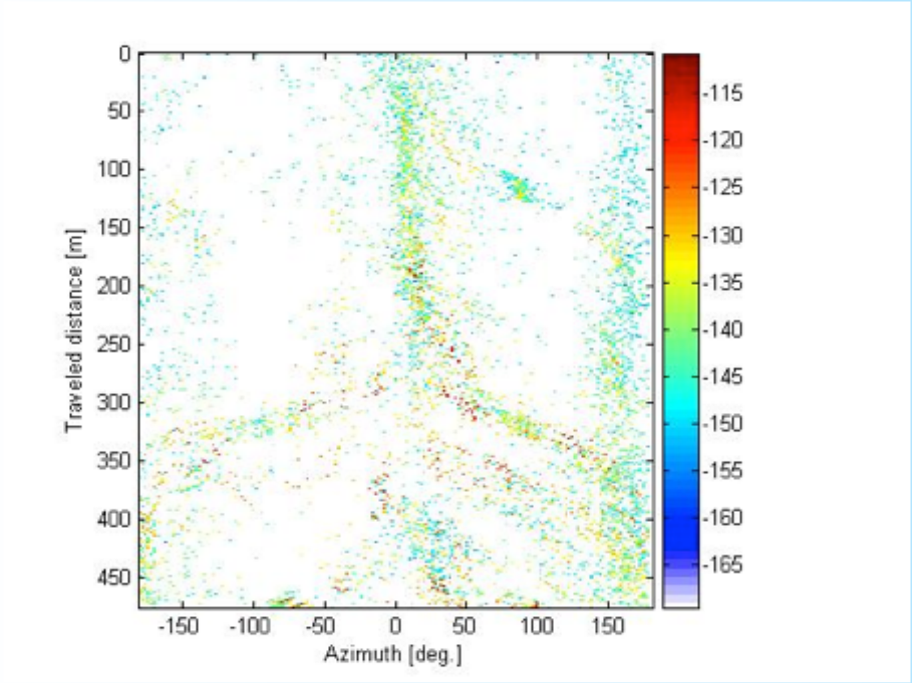
RT simulated



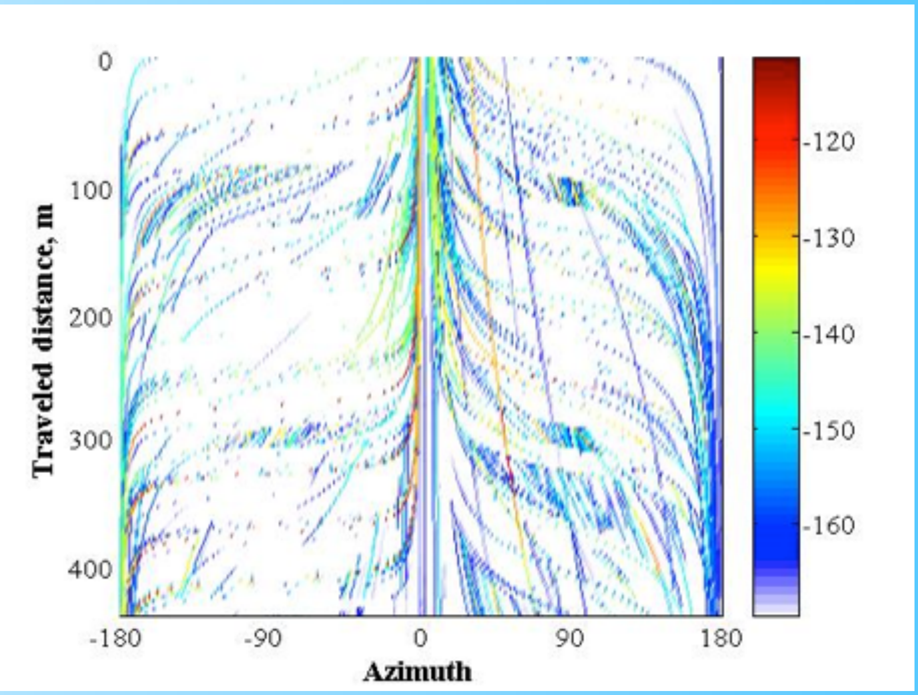
Multidimensional prediction by ray tracing Examples (III)

Helsinki route GH: azimuth-distance plot

measured



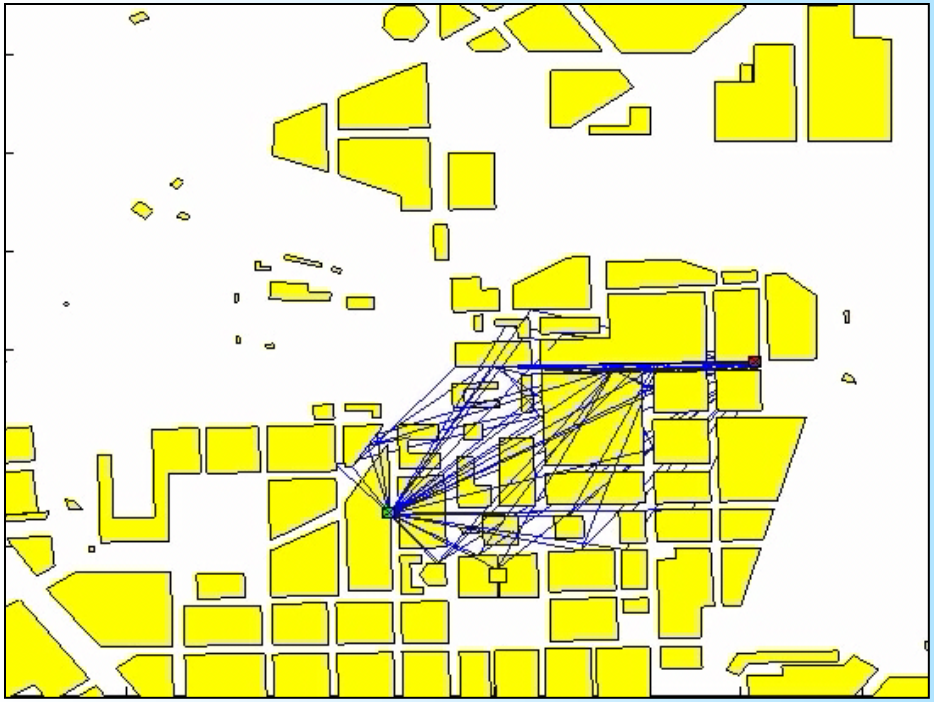
RT simulated

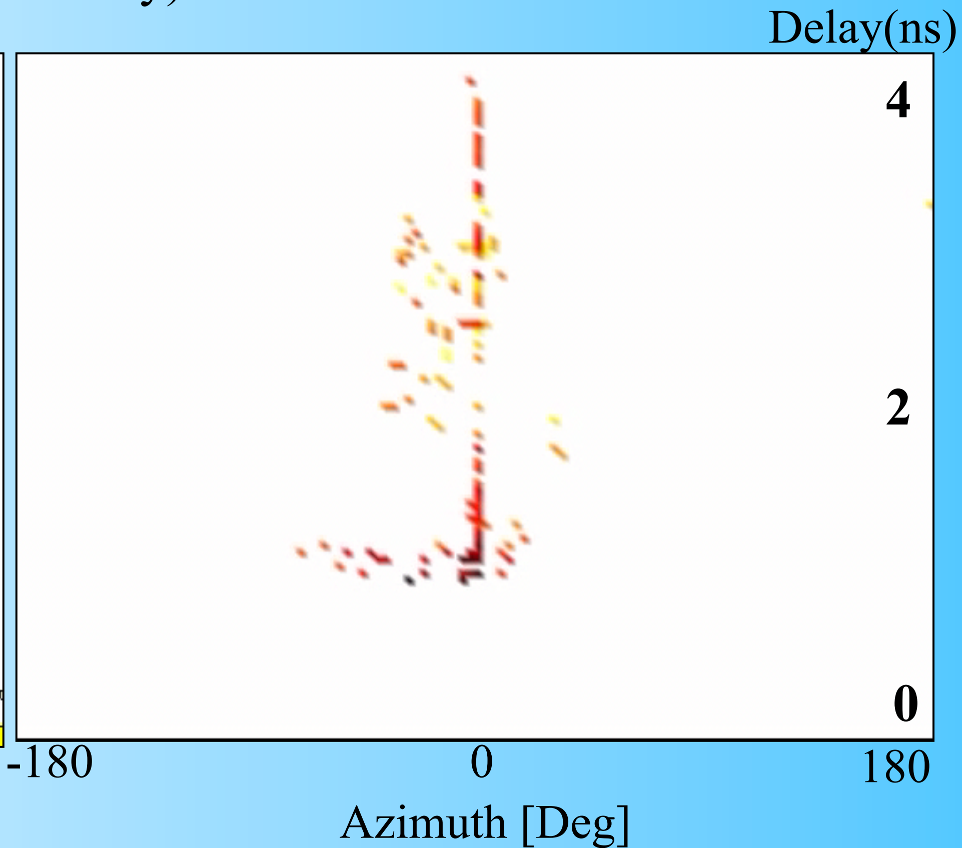


Multidimensional prediction by ray tracing Examples (IV)

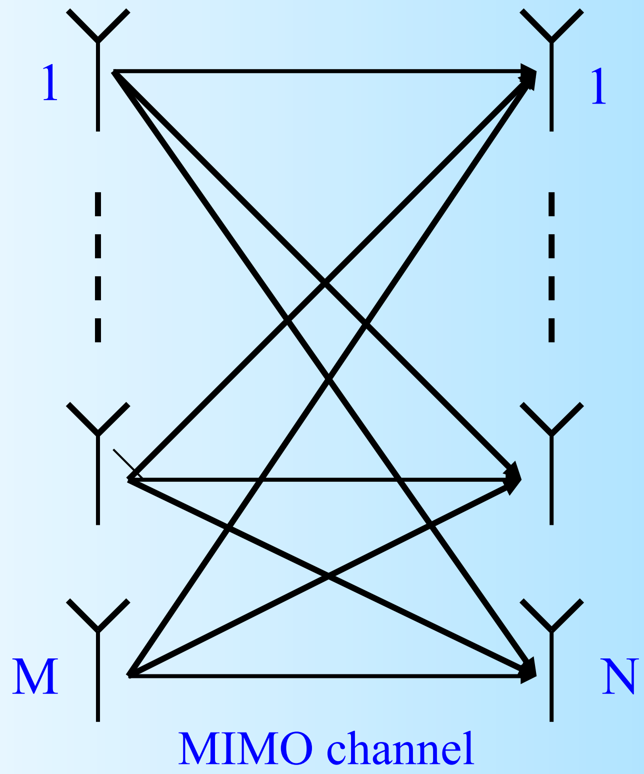
Helsinki route GH: azimuth-delay animation

(RT simulation only)





MIMO capacity estimates through ray tracing simulation



$$\mathbf{v}(t) \cong \mathbf{H}(t) \cdot \mathbf{u}(t) + \mathbf{n}(t)$$

MIMO channel matrix

$$\mathbf{H}(t) = \begin{bmatrix} h_{11}(t) & . & . & h_{1M}(t) \\ . & . & . & . \\ . & . & . & . \\ h_{N1}(t) & . & . & h_{NM}(t) \end{bmatrix}$$

$h_{ij}(t)$ impulse responses

Basic MIMO formulation

- ***Hp: narrow band channel***

$\Downarrow$

- h_{ij} complex coefficients: transfer function between the i-th Rx antenna and the j-the Tx antenna

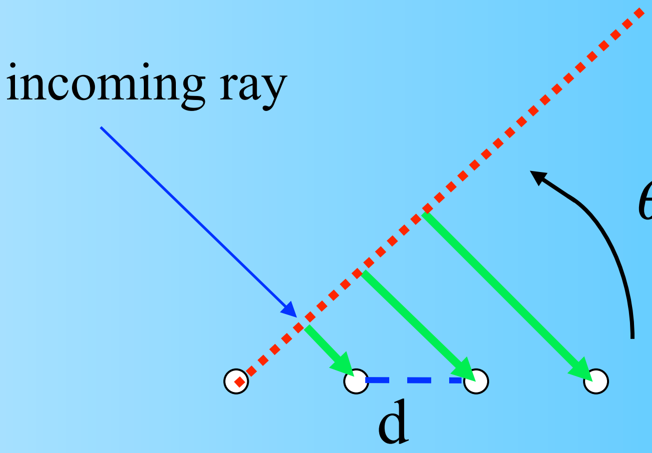
- **Mean capacity** estimate of the MIMO channel:
  (*Foschini-Telatar Formula*)
  (ρ : mean SNR at the Rx)

$$\overline{C} = E_{\mathrm{H}}\left\{\log_2\left[\det\left(\mathbf{I}_{\mathrm{N}} + \frac{\rho}{M}\mathbf{H}\mathbf{H}^{\mathrm{H}}\right)\right]\right\}$$

Ray tracing application to MIMO

- The H matrix can be easily computed through ray tracing
- By adopting a ***Montecarlo Method*** a large set of channel capacity estimates in a reference scenario is derived using Foschini's formula
- To decrease the computational burden the ***narrowband array assumption*** is made

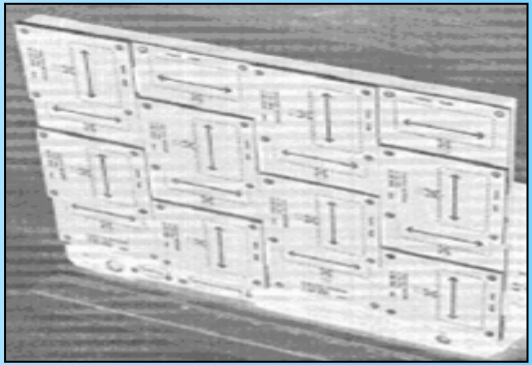
"The multipath pattern is the same for all array elements, only the phase of each ray is different"



$$\Delta\phi = \mathrm{d}\cos\theta$$

Comparison with measurements

- Reference scenario: manhattan-like
- Capacity measurement performed by Valenzuela et alii. in Manhattan [*]

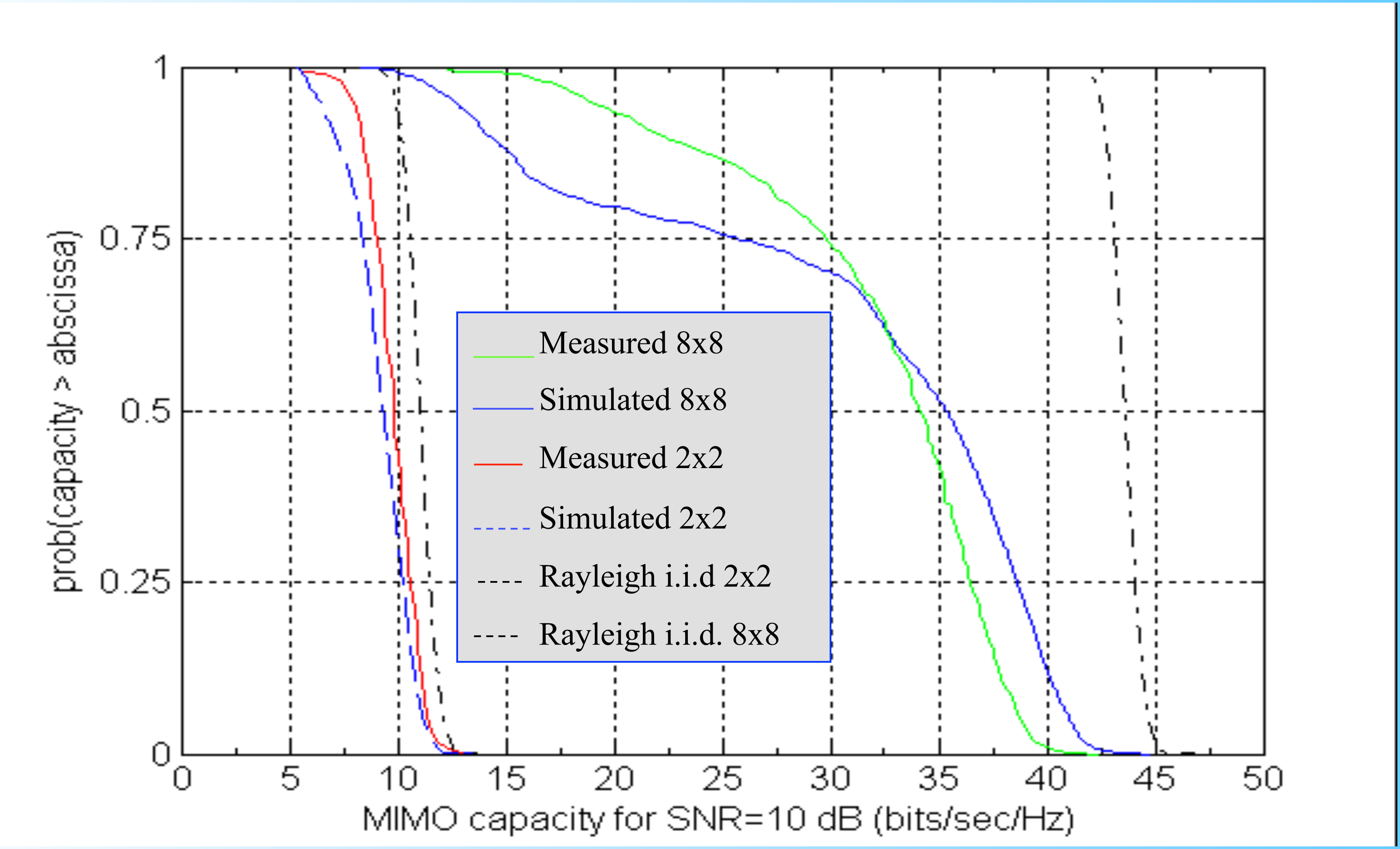


- MIMO 8×8 element system
- *dual-polarized* antennas
- Linear Tx array
- Planar (vertical plane) Rx array

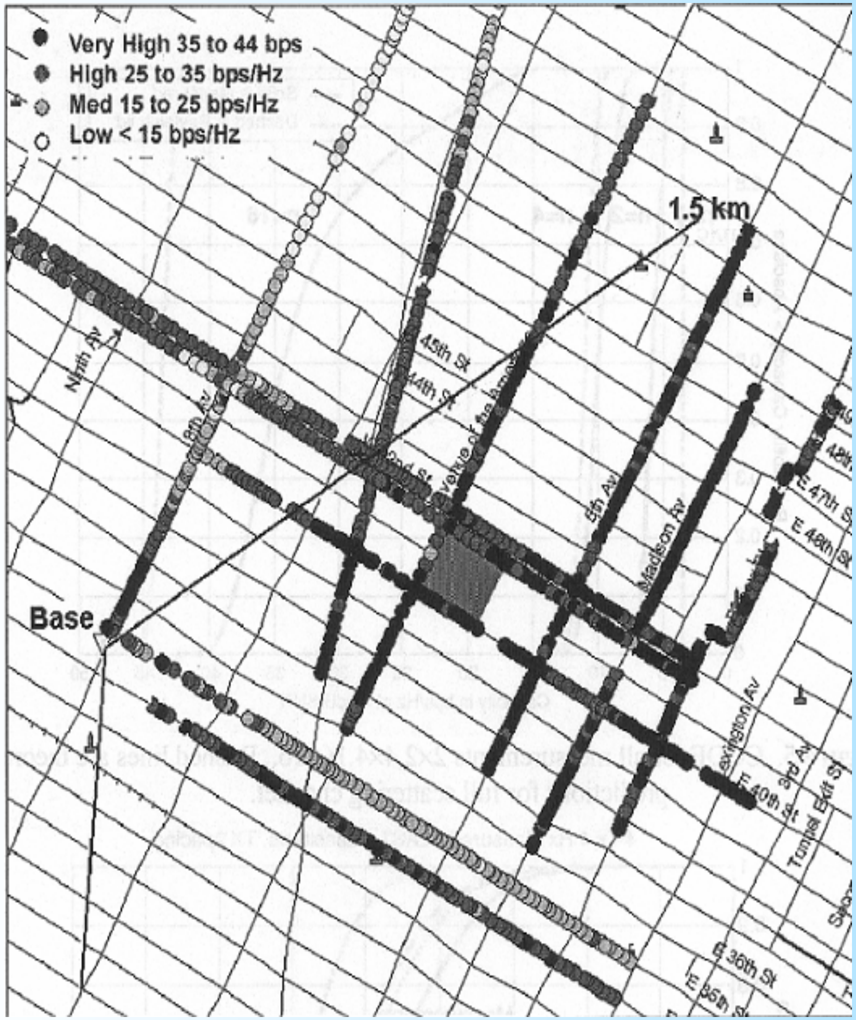
- Ray tracing simulations with N_{ev}=3, 1 diffraction and 1 diffuse scattering using the Effective Roughness model

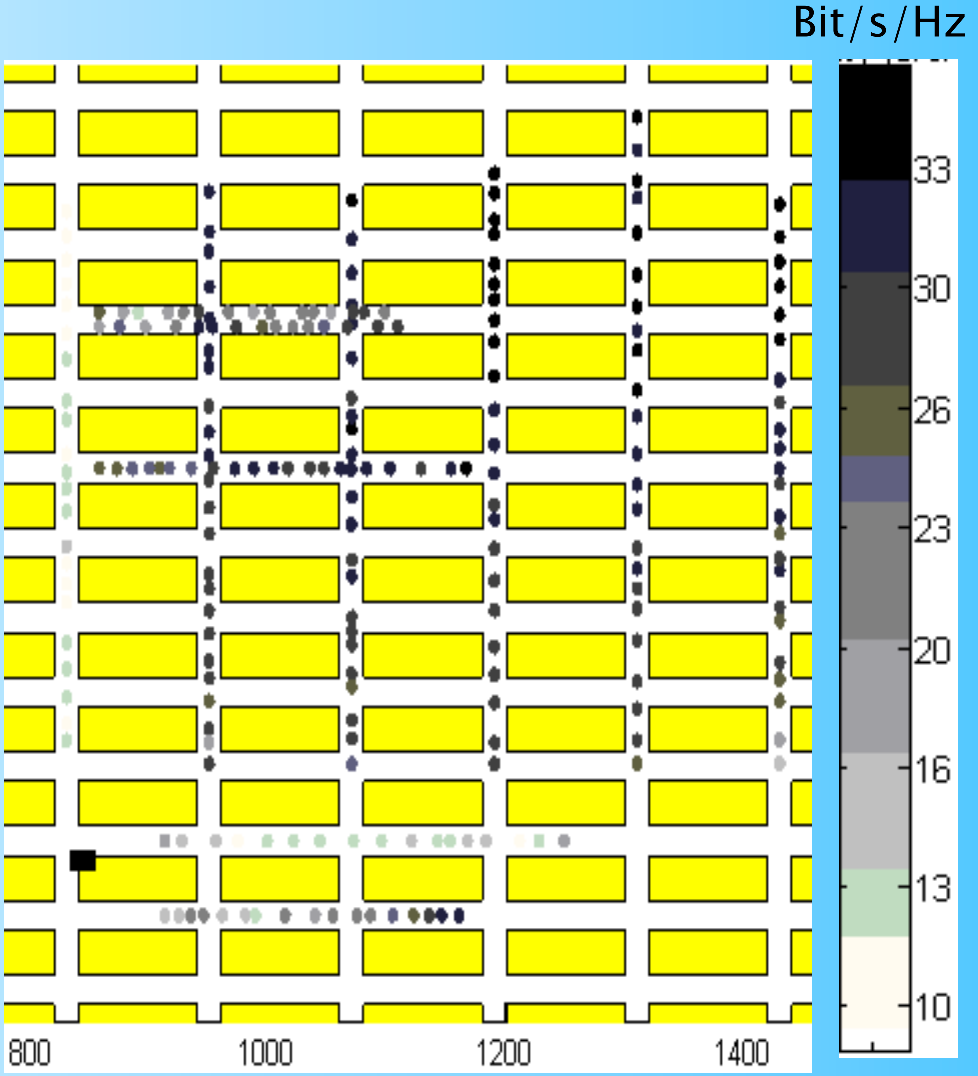
[*] D. Chizhik, J. Ling, P. W. Wolniansky, R. A. Valenzuela, "Multiple-Input-Multiple-Output Measurements and Modeling in Manhattan", IEEE Journal on selected areas in communications, April 2003

Comparison with measurements (II)



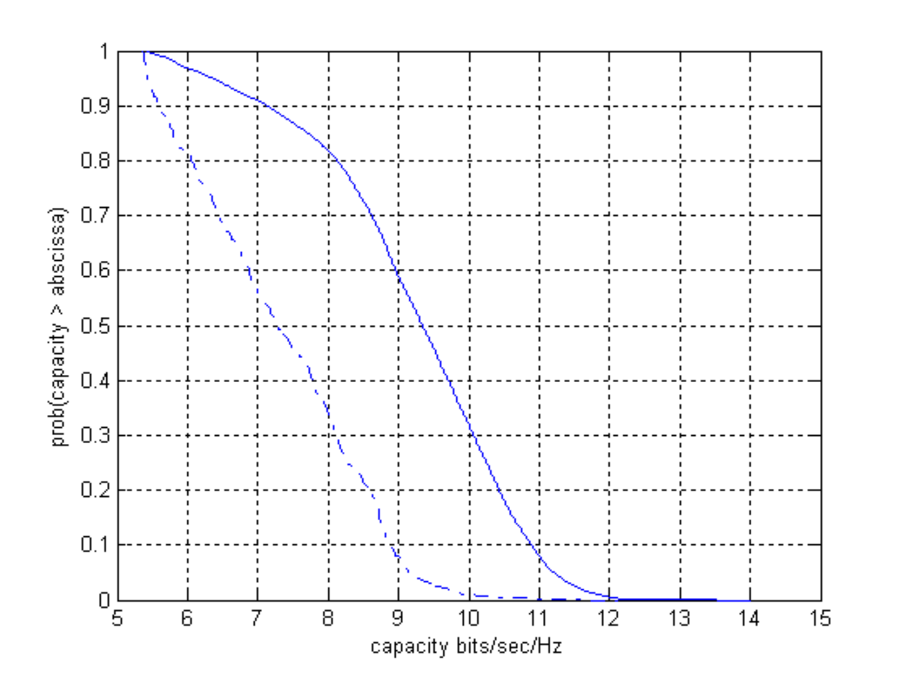
Comparison with measurements (III)



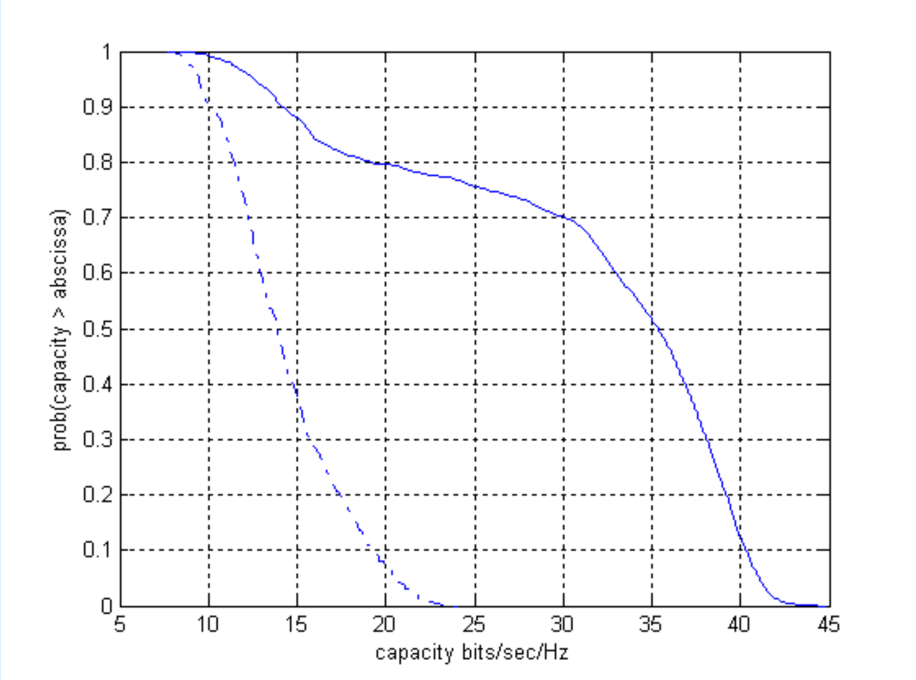


Comparison with measurements (IV)

Estimated capacity with and without diffuse scattering
(with random phase assumption for diffuse scattering)



2×2 element



8×8 element

The End

For questions or reference:

v.degliesposti@unibo.it

http://www.elettra2000.it/vdegliesposti/