Chapter 7

Channel modeling

Models are needed for wireless system design and operational deployment of such systems.
Chapter 7 deals with simulation models derived the mathematics discussed to this point.
The problem - what accuracy is required for a wireless channel model?

Modeling methods

- Stored channel impulse responses
  - realistic
  - reproducible
  - hard to cover all scenarios

Use Channel Sounder techniques described in Chapter 8. Impulse responses used in network planning & system management (detail level of design)

- Deterministic channel models
  - based on Maxwell's equations
  - site specific
  - computationally demanding

to determine the impulse response

geographical databases

- Stochastic channel models
  - describes the distribution of the field strength, etc.
  - mainly used for design and system comparisons

models the pdf of the channel impulse response - predicts pdf over a large area - not site specific

Used more in the conceptual level of a system design

Narrowband models
Review of properties

Narrowband models contain ”only one” attenuation, which is modeled as a propagation loss, plus large- and small-scale fading.

The Impulse Response h(t, tau) is a function of time and delay for narrowband or wideband quasi-static channels. Equation 7.1 a function of attentuation and fading

Path loss: Often proportional to $1/d^n$, where n is the propagation exponent. (n may be different at different distances)

Large-scale fading: Log-normal distribution (normal distr. in dB scale)

Small-scale fading: Rayleigh, Rice, Nakagami distributions .. (**not** in dB-scale)

See Chapter 5 Slide 102

Okumura's measurements

`Details in Appendix 7.A`

applicable more to large cells

Extensive measurement campaign in Japan in the 1960's.

Parameters varied during measurements:

Frequency	100 – 3000 MHz
Distance	1 – 100 km
Mobile station height	1 – 10 m
Base station height	20 – 1000 m High antenna!!
Environment	medium-size city, large city, etc.

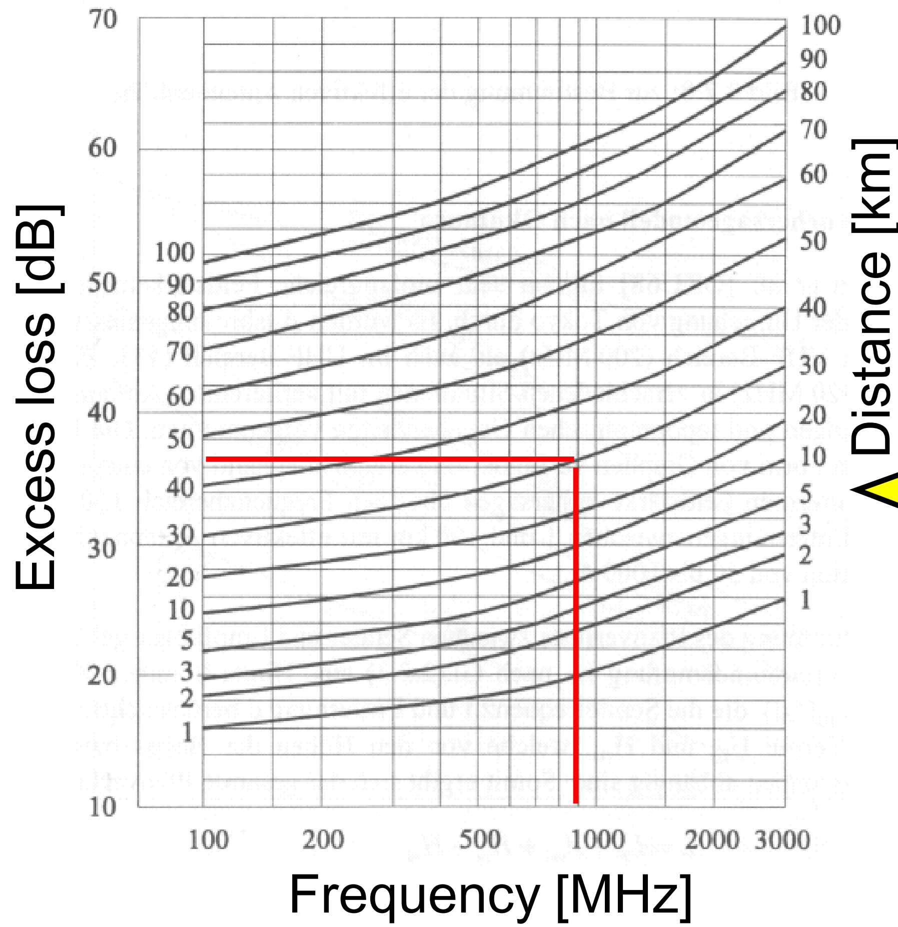
Propagation loss is given as **median** values (50% of the time and 50% of the area).

Okumura's measurements excess loss

Example

from Appendix 7.A

FIGURE 7.12



These curves are only for h_b=200 m and h_m=3 m

900 MHz and
30 km distance

From [Okumura et al.]

The Okumura-Hata model
How to calculate prop. loss

$$L_{O-H} = A + B\log\left(d_{|km}\right) + C$$

h_b and h_m in meter

$$A = 69.55 + 26.16\log\left(f_{0|MHz}\right) - 13.82\log\left(h_b\right) - a\left(h_m\right)$$

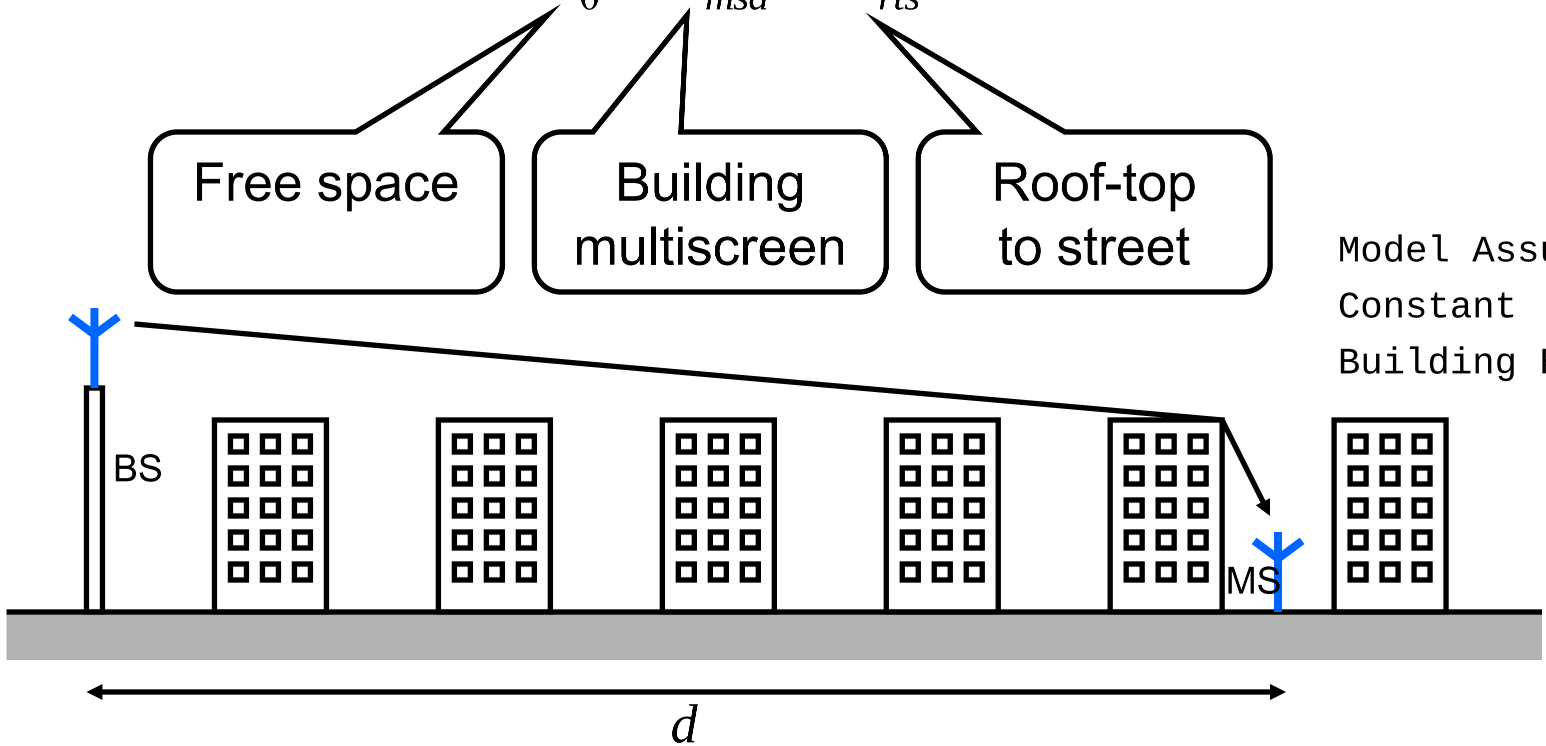
$$B = 44.9 - 6.55\log\left(h_b\right)$$

	$a\left(h_m\right) =$	$C =$
Metropolitan areas	$8.29\left(\log\left(1.54h_m\right)\right)^2 - 1.1$ for $f_0 \le 200$ MHz $3.2\left(\log\left(11.75h_m\right)\right)^2 - 4.97$ for $f_0 \ge 400$ MHz	0
Small/medium-size cities	$\left(1.1\log\left(f_{0\|MHz}\right) - 0.7\right)h_m - \left(1.56\log\left(f_{0\|MHz}\right) - 0.8\right)$	0
Suburban environments	$\left(1.1\log\left(f_{0\|MHz}\right) - 0.7\right)h_m - \left(1.56\log\left(f_{0\|MHz}\right) - 0.8\right)$	$-2\left[\log\left(f_{0\|MHz}/28\right)\right]^2 - 5.4$
Rural areas	$\left(1.1\log\left(f_{0\|MHz}\right) - 0.7\right)h_m - \left(1.56\log\left(f_{0\|MHz}\right) - 0.8\right)$	$-4.78\left[\log\left(f_{0\|MHz}\right)\right]^2 + 18.33\log\left(f_{0\|MHz}\right) - 40.94$

The COST 231-Walfish-Ikegami model
How to calculate prop. loss

Model is good for small cells

$$L = L_0 + L_{msd} + L_{rts}$$ (Doesn't consider wave guiding)



Model Assumes Constant Building Height

Details about calculations can be found in Appendix 7.B

Motley-Keenan indoor model

For indoor environments, the attenuation is heavily affected by the building structure, walls and floors play an important rule

$$PL = PL_0 + 10n\log(d/d_0) + F_{\mathrm{wall}} + F_{\mathrm{floor}}$$

distance dependent path loss

sum of attenuations from walls, 1-20 dB/wall

sum of attenuation from the floors (often larger than wall attenuation)

site specific, since it is valid for a particular case

Not very accurate because of attenuation complexity produced by Interfering Objects IOs

Wideband models

- Tapped delay line model often used

The taps represent the multi-path components of the originating signal

$$h(t,\tau)=\sum_{i=1}^{N}\alpha_i(t)\exp\left(j\theta_i(t)\right)\delta\left(\tau-\tau_i\right)$$

The similar Equation 7.3 on Page 128 has the LOS component

- Often Rayleigh-distributed taps, but might include LOS and different distributions of the tap values

N tap Rayleigh fading model

- Mean tap power determined by the power delay profile

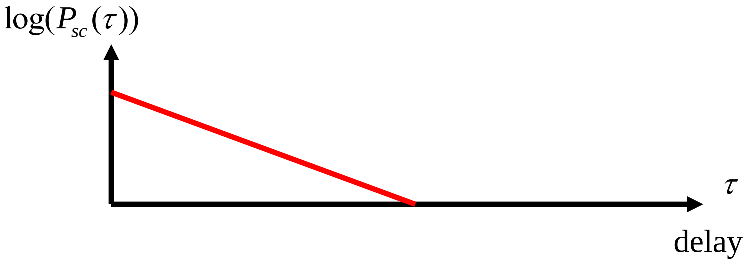
Numerical values of delay spread for different environments are given on page 129

Power delay profile

- Often described by a single exponential decay

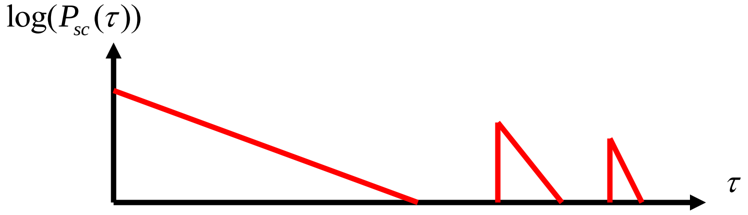
$$P_{sc}(\tau) = \begin{cases} exp(-\tau / S_\tau) & \tau \geq 0 \\ 0 & otherwise \end{cases}$$

delay spread



- though often there is more than one "cluster" (of interacting objects)

$$P(\tau) = \begin{cases} \sum_k \frac{P_k^c}{S_{\tau,k}^c} P_{sc}(\tau - \tau_{0,k}^c) & \tau \geq 0 \\ 0 & otherwise \end{cases}$$



Function of power delay & delay spread

arrival time

- If the bandwidth is high, the time resolution is large so we might resolve the different multipath components
- Need to model arrival time pg 130
- The Saleh-Valenzuela model:

MPCs arriving within clusters where both the clusters and the rays (MPCs) within the clusters are Poisson Distributed

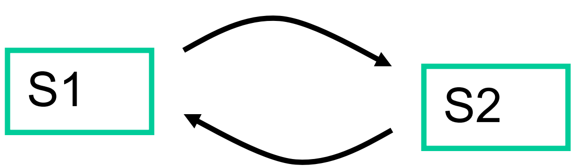
Model presumes multipath components (MPC) exist

ray arrival time (Poisson)

$$h(\tau) = \sum_{l=0}^{L} \sum_{k=0}^{K} \alpha_{k,l}(\tau)\delta(\tau - T_l - \tau_{k,l})$$

cluster arrival time (Poisson)

- The Δ-K-model:



MPC arrives --> transition to S2. If no further MPCs arrive in the interval, a transition back to S1 at the end of the interval

arrival rate: $\lambda_0(t)$ $K\lambda_0(t)$

Wideband models
COST 207 model for GSM

A special case of a tapped delay line model

The COST 207 model specifies:

FOUR power-delay profiles for different environments. four types derived from a large number of measurements

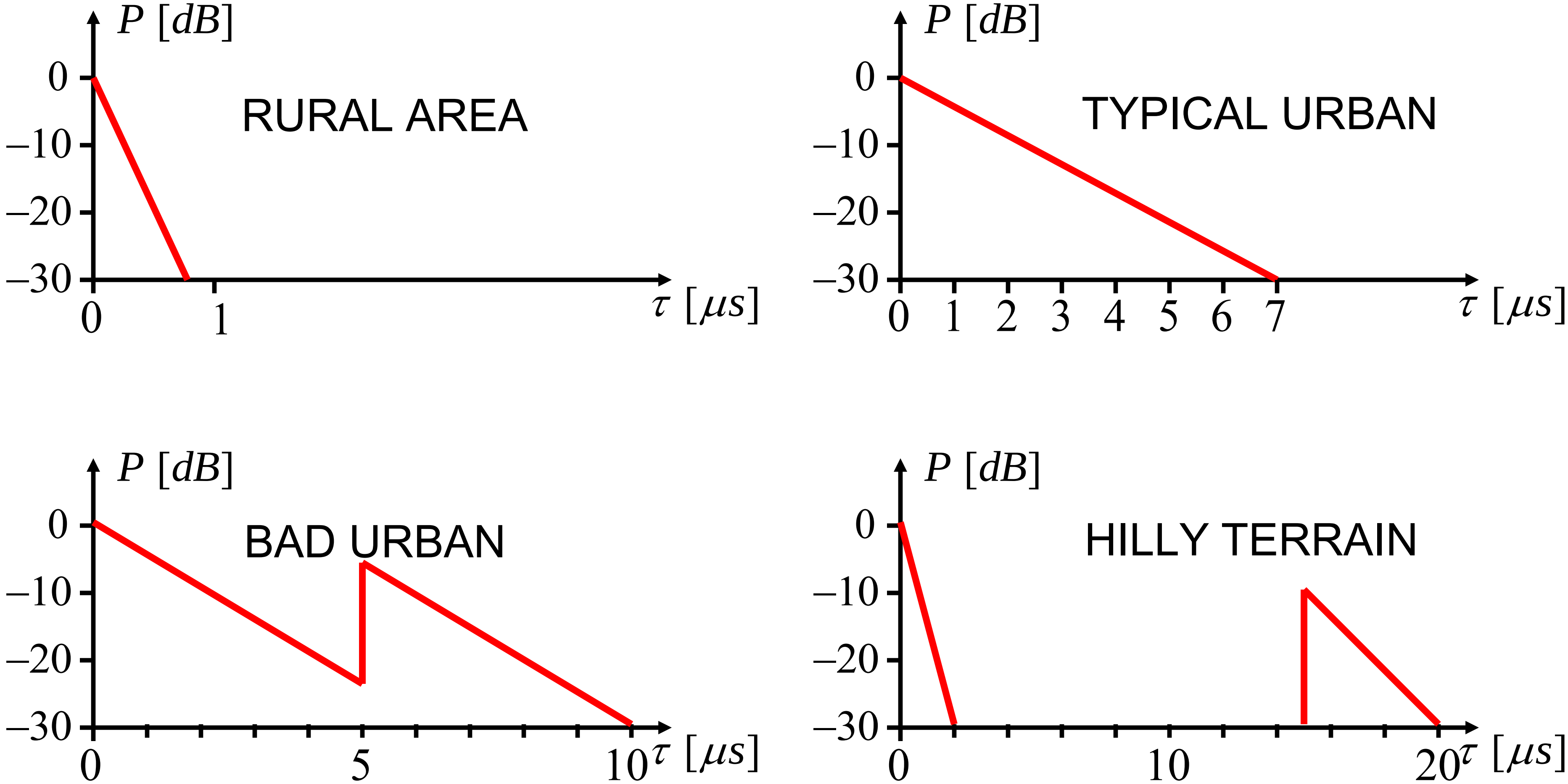
FOUR Doppler spectra used for different delays.

IT **DOES NOT** SPECIFY PROAGATION LOSSES FOR THE DIFFERENT ENVIRONMENTS!

Developed in Europe for low-bandwidth systems (200 kHz or less). Details in Appendix 7.C
For 3G and later (bandwidth > 5 MHz), ITU (International Telecommunications Union) developed another set of models, detailed in Appendix 7.D

Wideband models
COST 207 model for GSM

Four specified power-delay profiles



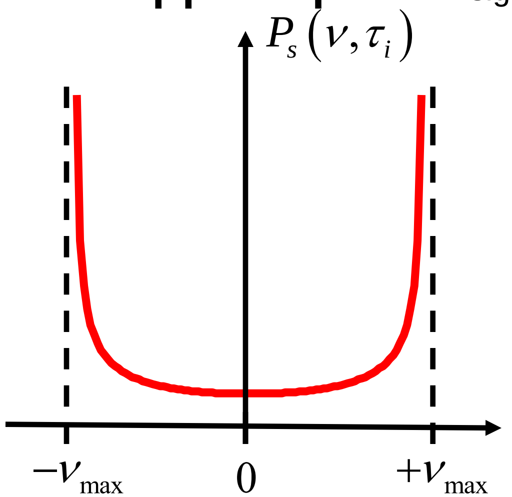
Four specified Doppler spectra

for different cases of frequency dispersion - the Doppler effect with signal components arriving at different Doppler shifts

CLASS

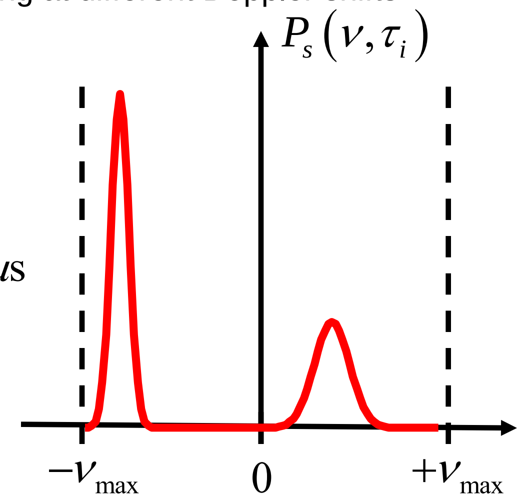
$\tau_i \leq 0.5\ \mu s$

classical Jakes Doppler spectrum with delays not in excess of 500 nS



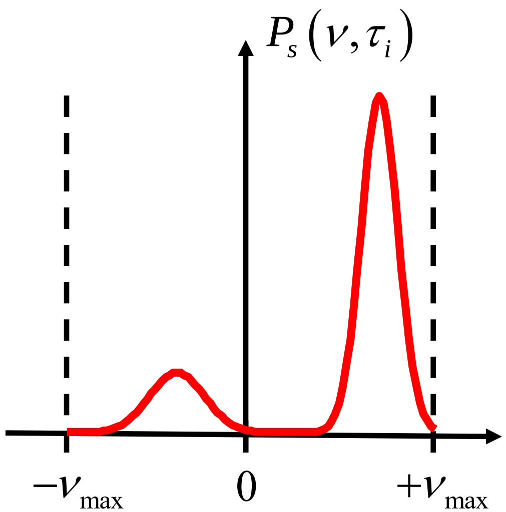
GAUS1

$0.5\ \mu s < \tau_i \leq 2\ \mu s$



GAUS2

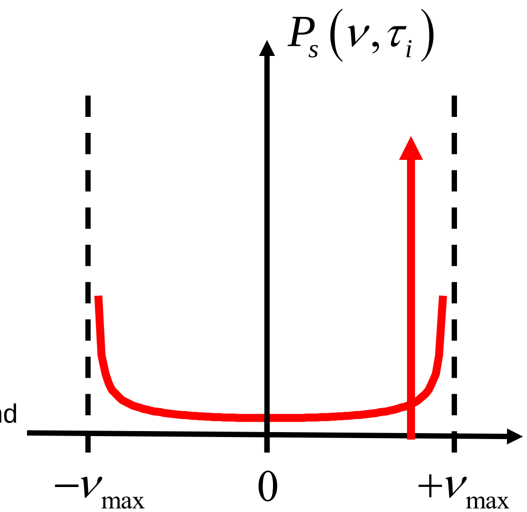
$\tau_i > 2\ \mu s$



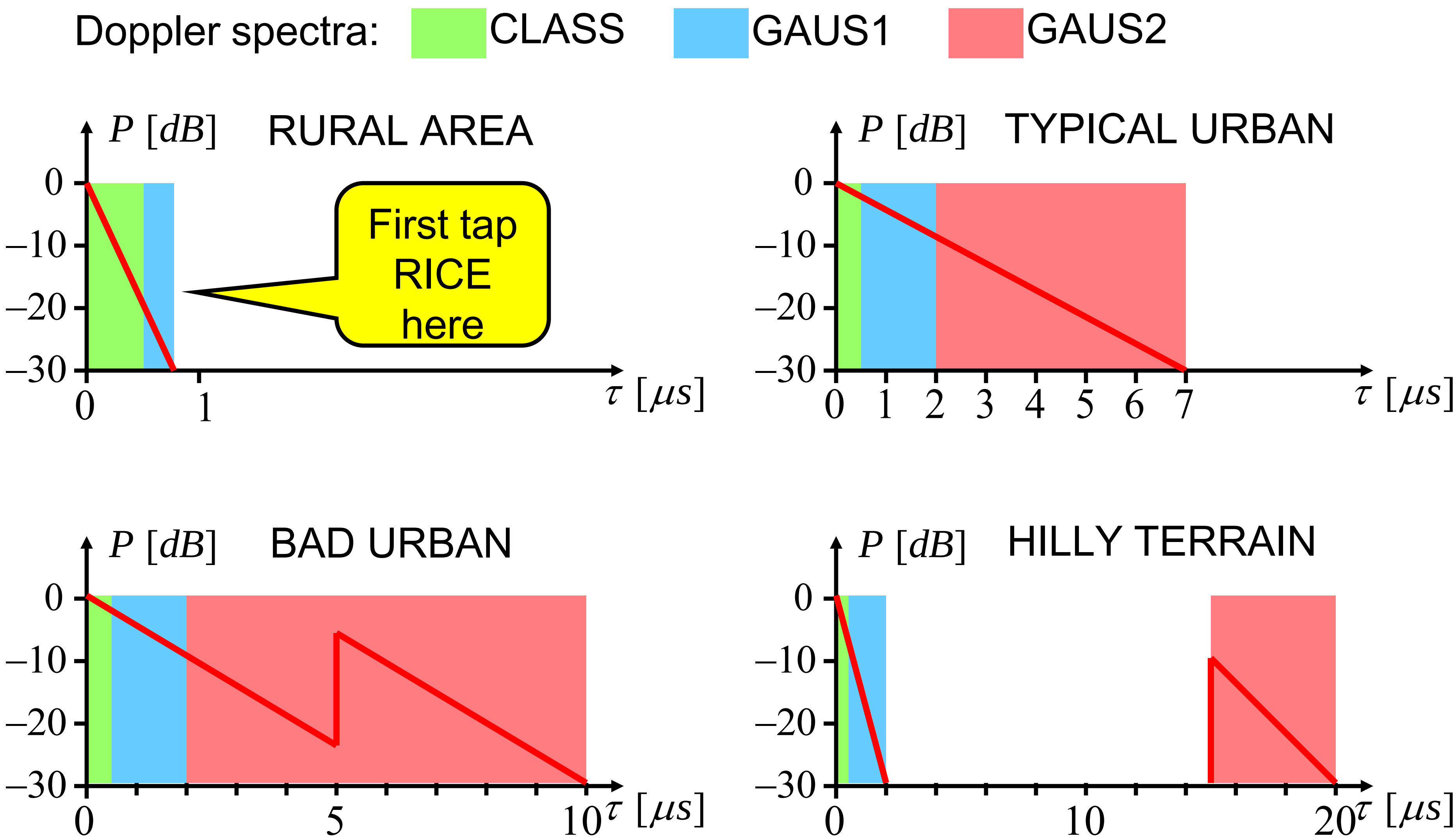
RICE

Shortest path in rural areas

Jakes spectrum and one direct path



Wideband models
COST 207 model for GSM



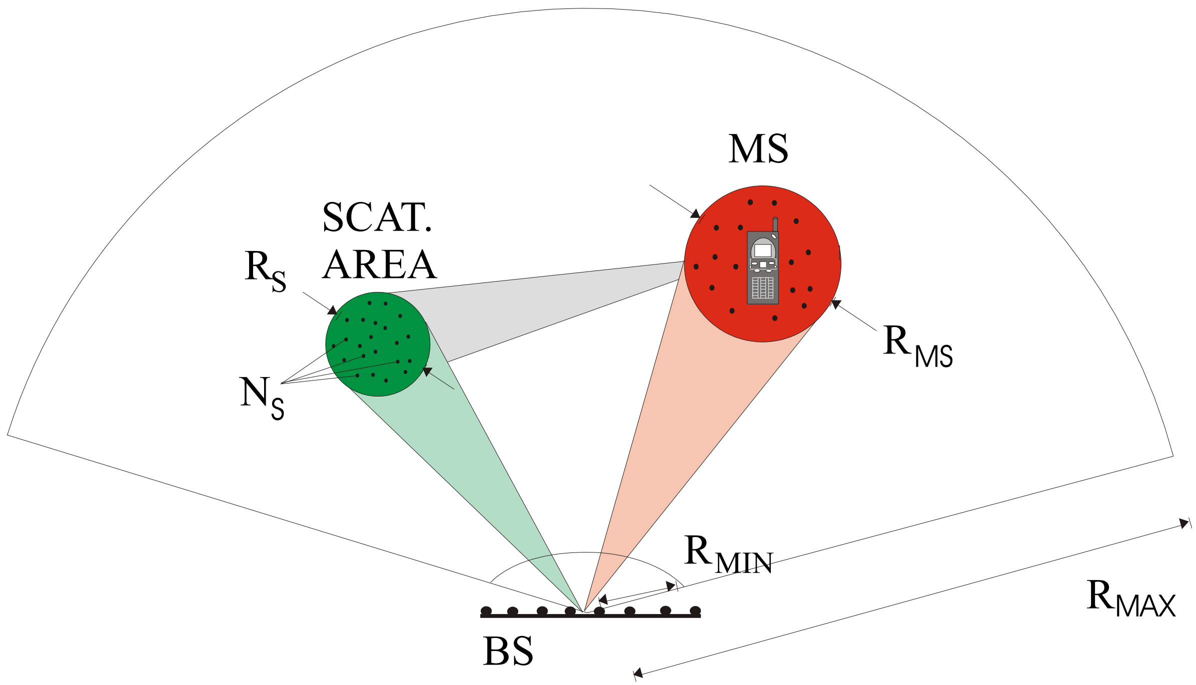
Wideband models
ITU-R model for 3G

Parameters for three additional models based on a tapped delay-line implementation

Tap No.	delay/ns	power/dB	delay/ns	power/dB
INDOOR	**CHANNEL A** (50%)		**CHANNEL B** (45%)	
1	0	0	0	0
2	50	-3	100	-3.6
3	110	-10	200	-7.2
4	170	-18	300	-10.8
5	290	-26	500	-18.0
6	310	-32	700	-25.2
PEDESTRIAN	**CHANNEL A** (40%)		**CHANNEL B** (55%)	
1	0	0	0	0
2	110	-9.7	200	-0.9
3	190	-19.2	800	-4.9
4	410	-22.8	1200	-8.0
5			2300	-7.8
6			3700	-23.9
VEHICULAR	**CHANNEL A** (40%)		**CHANNEL B** (55%)	
1	0	0	0	-2.5
2	310	-1	300	0
3	710	-9	8900	-12.8
4	1090	-10	12900	-10.0
5	1730	-15	17100	-25.2
6	2510	-20	20000	-16.0

Geometry-based stochastic channel model (GSCM) for a Directional Channel Model (DCM)

Model the location of the interfering objects (IOs) and the strength of the interactions to obtain the directionally resolved impulse response

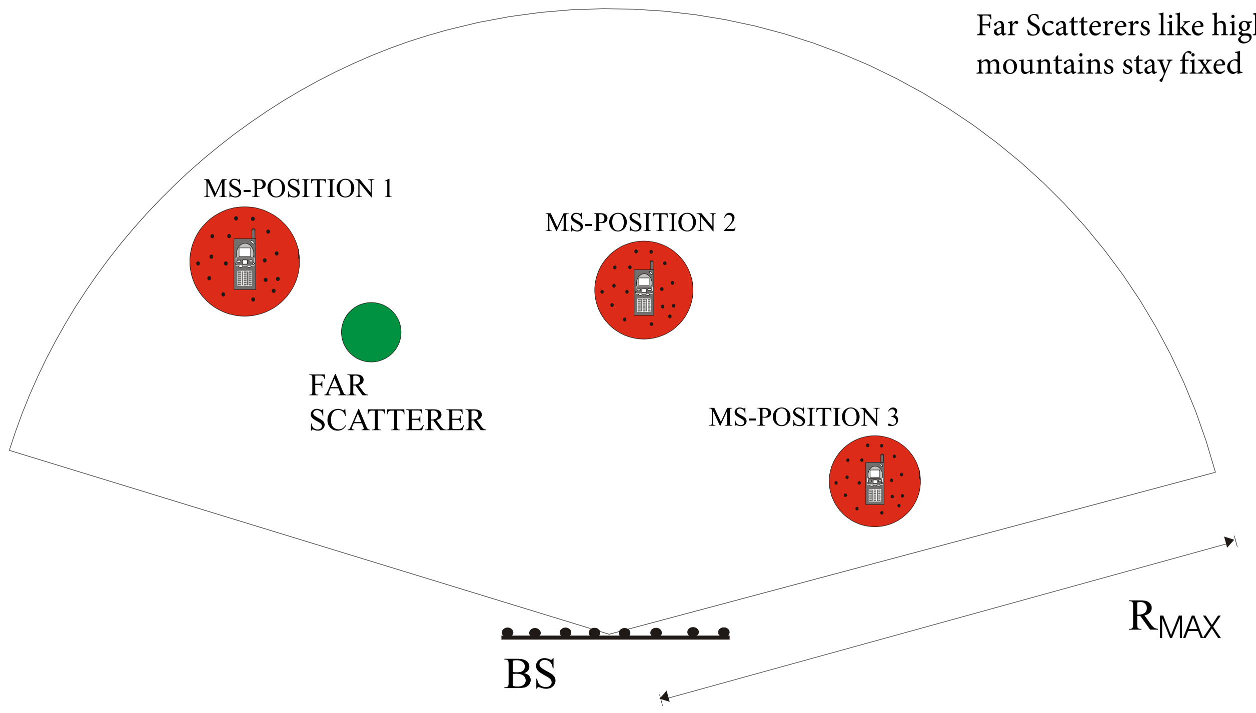


Temporal evolution - GSCM

- Temporal evolution of channel easily implemented

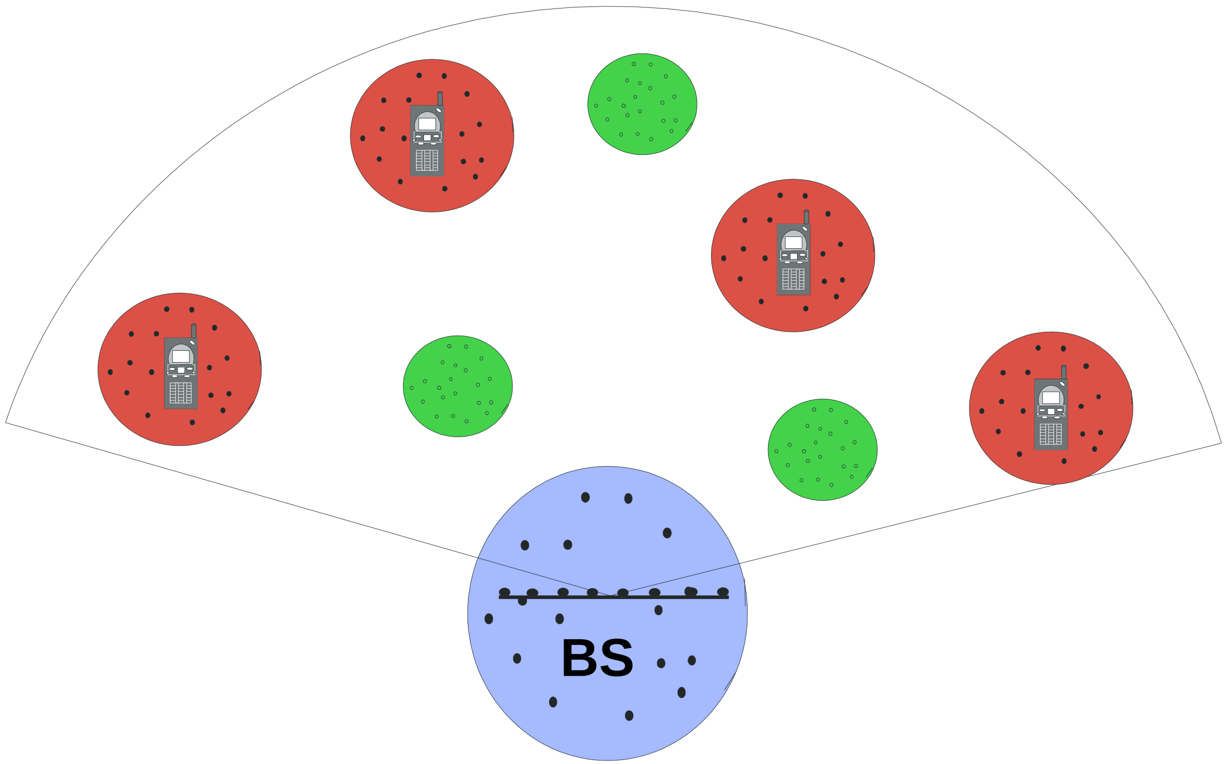
Diagram shows movement of MS

Far Scatterers like high rise buildings and mountains stay fixed



Modeling interference with GSCM

- Spatial correlation between interfering mobiles



MIMO channel

- channel matrix

Impulse response matrix for a MIMO channel showing amplitude stats of each matrix entry but also the correlation between the states

$$\boldsymbol{H}(\tau)=\begin{bmatrix} h_{11}(\tau) & h_{12}(\tau) & \cdots & h_{1M_{\mathrm{Tx}}}(\tau) \\ h_{21}(\tau) & h_{22}(\tau) & \cdots & h_{2M_{\mathrm{Tx}}}(\tau) \\ \vdots & \vdots & \ddots & \vdots \\ h_{M_{\mathrm{Rx}}1}(\tau) & h_{M_{\mathrm{Rx}}2}(\tau) & \cdots & h_{M_{\mathrm{Rx}}M_{\mathrm{Tx}}}(\tau) \end{bmatrix}$$

- signal model

$$\boldsymbol{y}(t)=\sum_{\tau=0}^{D-1}\boldsymbol{H}(\tau)\cdot\boldsymbol{x}(t-\tau)$$

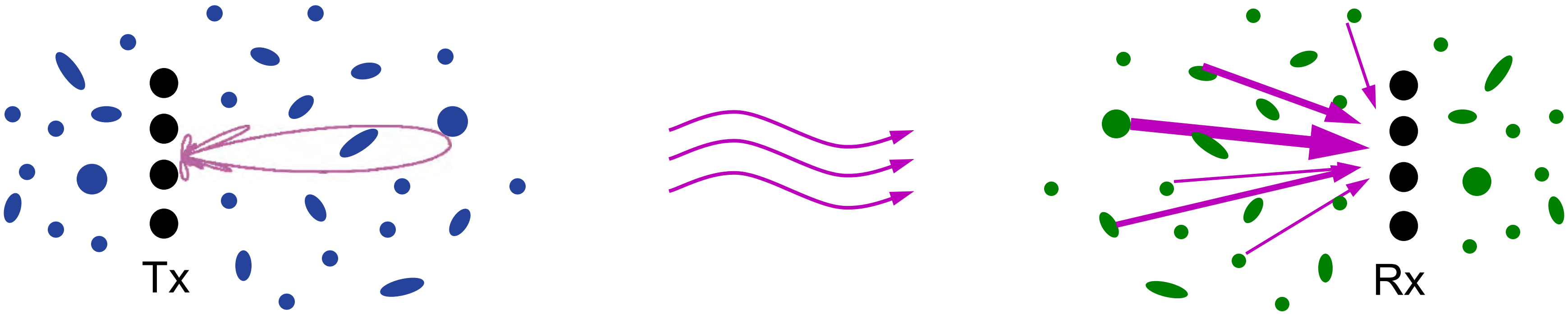
- mean channel

$$\overline{\boldsymbol{H}}(\tau)=\mathrm{E}\{\boldsymbol{H}(\tau)\}$$

- correlation *tensor* of order four

$$R_{mp}^{nq}(\tau)=\mathrm{E}\{h_n^m(\tau)\cdot h_p^{q^*}(\tau)\}$$

Kronecker model



- The spatial structure of the MIMO channel is neglected.
- The MIMO channel is described by separated link ends:

$$\boldsymbol{R}_{\boldsymbol{H}} = c \cdot \boldsymbol{R}_{\mathrm{Tx}} \otimes \boldsymbol{R}_{\mathrm{Rx}} \qquad \boldsymbol{H} = \boldsymbol{R}_{\mathrm{Rx}}^{1/2} \boldsymbol{G} \boldsymbol{R}_{\mathrm{Tx}}^{\mathrm{T}/2}$$

Any **transmit signal results in one and the same receive correlation!**

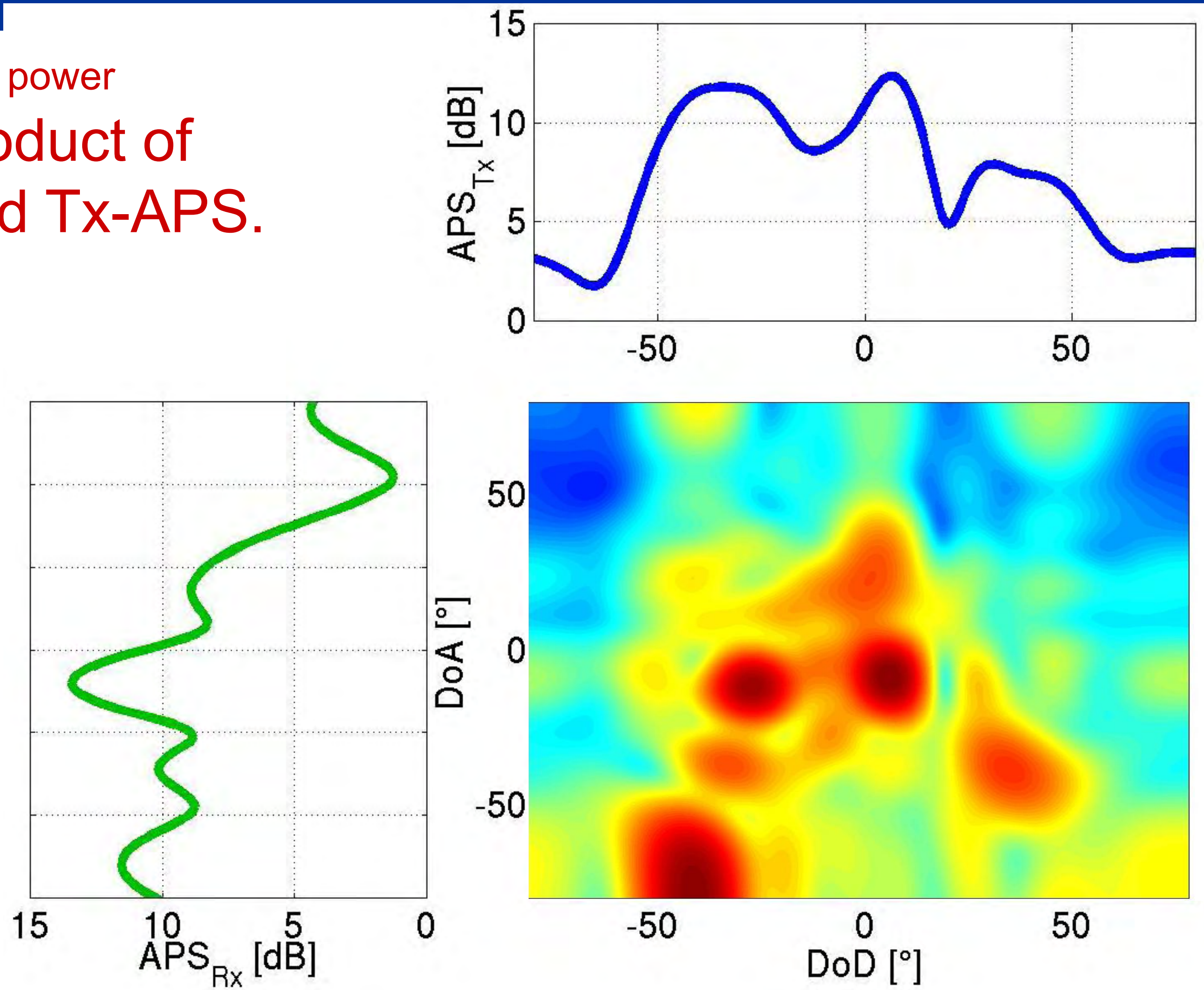
thus independent of the direction of transmission

Kronecker model (cont.)

Joint APS (angular power spectrum) is the product of marginal Rx- and Tx-APS.

DoD/DoA = angle of Departure /Arrival

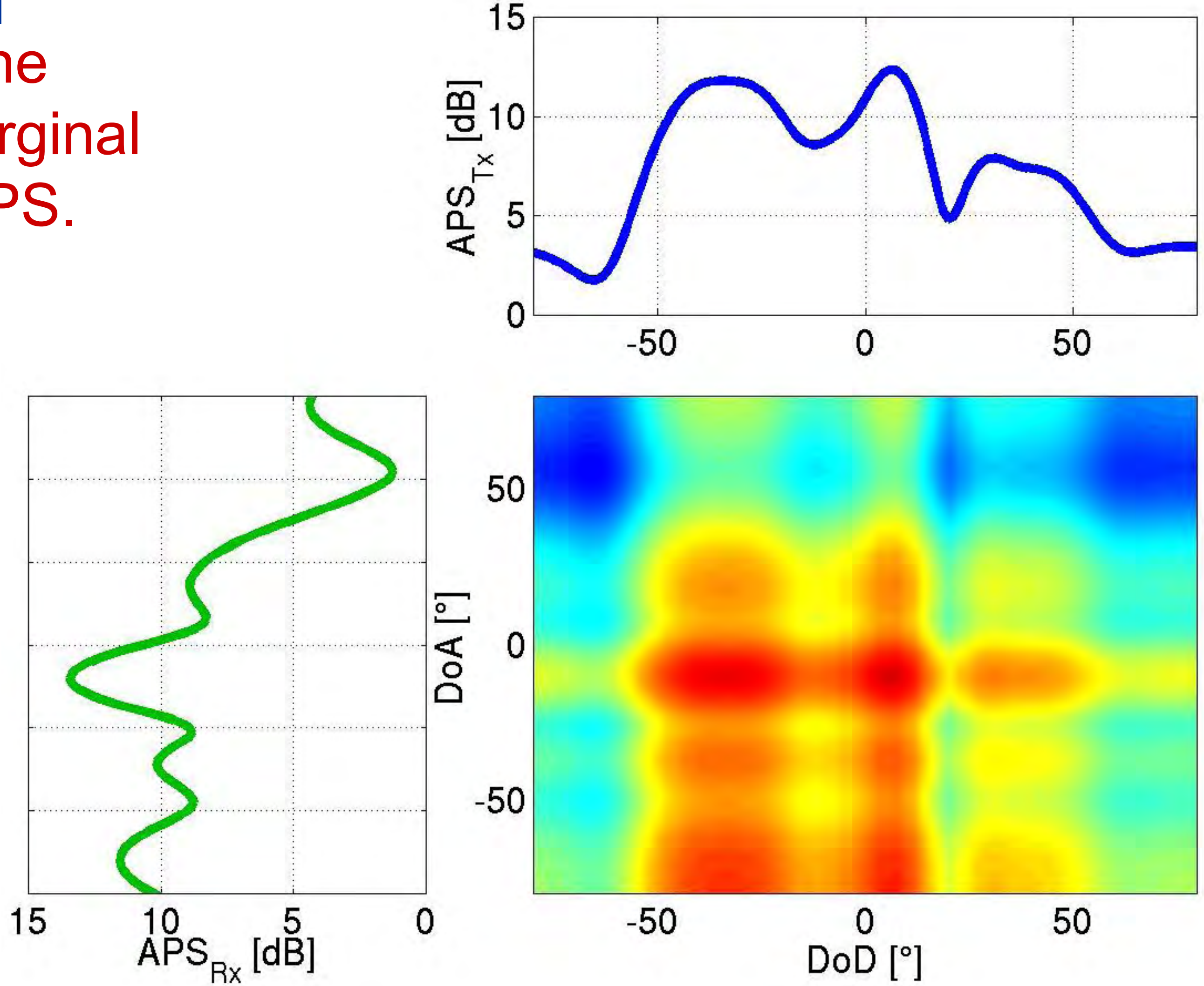
measurement



Kronecker model (cont.)

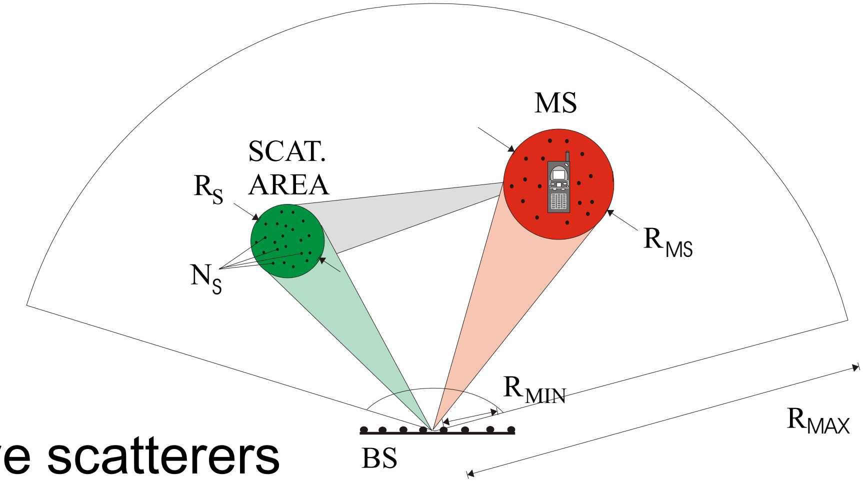
Joint APS is the product of marginal Rx- and Tx-APS.

Kronecker approximation



GSCM for MIMO

- GSCM – original version:
  - Locate scatterers according to certain pdf
  - only single scattering



- MIMO version:
  - model **all** effects that involve scatterers
  - Relative strength of propagation processes by weighting
  - Single scattering is not sufficient for MIMO!
  - MIMO capacity strongly depends on the angular spread.
  - Double- (multi-) Scattering increases angular spread.

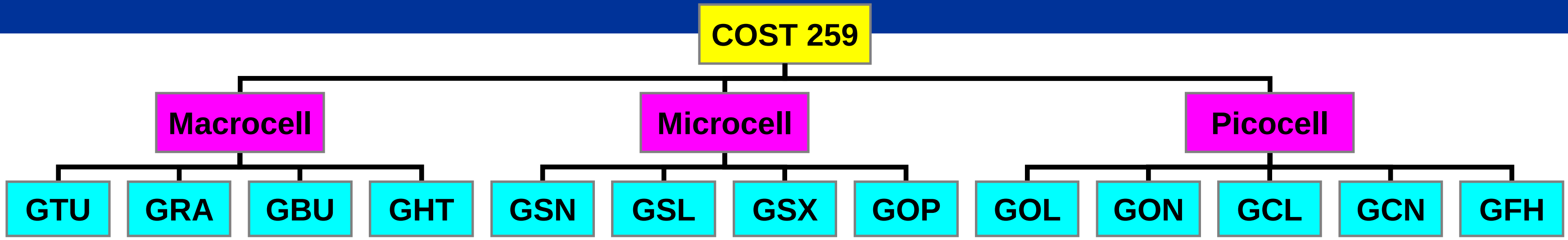
The COST 259 DCM

- COST 259 “Flexible Personalized Wireless Communication” Subgroup 2.1 Directional Channel Model
- European research initiative (Model is rather involved)
- Includes operators, manufacturers, universities
- Close cooperation with other European programs
- Model widely used for smart antenna simulations
- Now also used for MIMO

COST 259 DCM - Philosophy

- Parametric approach, WSSUS not required
- No statement about implementation method (stochastic or GSCM)
- Based on clustering approach
- Multi-layer approach:
  - Radio environments (13 different cases)
  - Large-scale effects e.g., Delay & Angular Spread, shadowing
  - Small-scale effects e.g., Double Directional Impulse Responses created by small scale fading

Radio environments



GTU	Generalized Typical Urban
GRA	Generalized Rural Area
GBU	Generalized Bad Urban
GHT	Generalized Hilly Terrain

GSN	Generalized Street NLOS
GSL	Generalized Street Canyon LOS
GSX	Generalized Street Crossing
GOP	Generalized Open Place

GOL	Generalized Office LOS
GON	Generalized Office NLOS
GCL	Generalized Corridor LOS
GCN	Generalized Corridor NLOS
GFH	Generalized Factory Hall

COST 259 DCM - Simulation procedure

Simulation steps:

1) select scenario

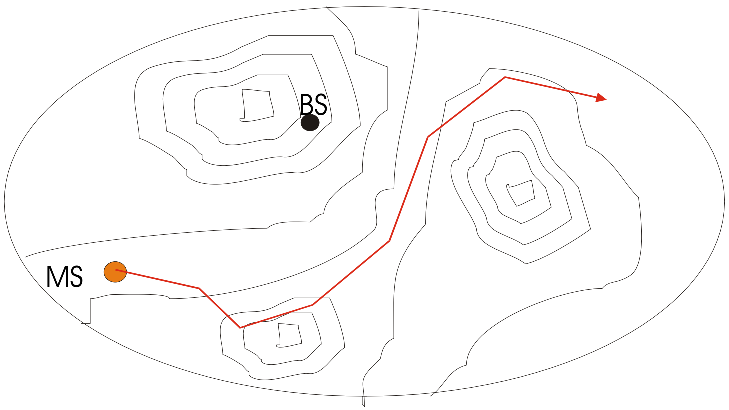
2) select global parameters (number of clusters, mean Rice factor,....)

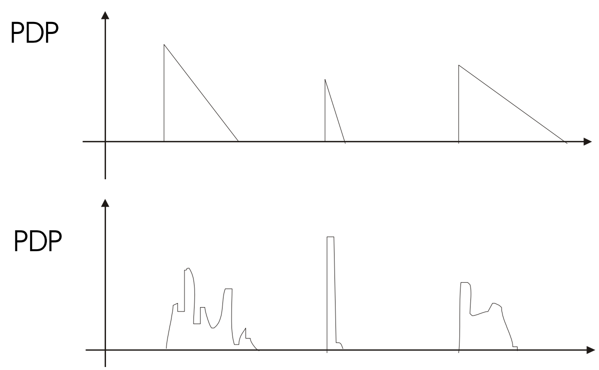
3) REPEAT

compute one realization of global parameters. This realization prescribes small-scale averaged power profiles (ADPS)

create many instantaneous complex impulse responses from this average ADPS

Generalized Hilly Terrain (GHT)





realization of
global parameters:
3 clusters, Rice factor of first: 3.2,
Rice factor of later clusters: 0
delay spread of clusters: 1,0.3,2s µ

COST 259 DCM - Important features

- Very realistic !
- Distinguishes 13 different radio environments over 3 broad catagories
- Treats large-scale and small-scale variations
- Far scatterer clusters included, with birth/death process signal becomes weak & dies
- Delay spread and angular spread treated as (correlated) random variables
- Angular spectra are functions of delay
- Azimuth and elevation

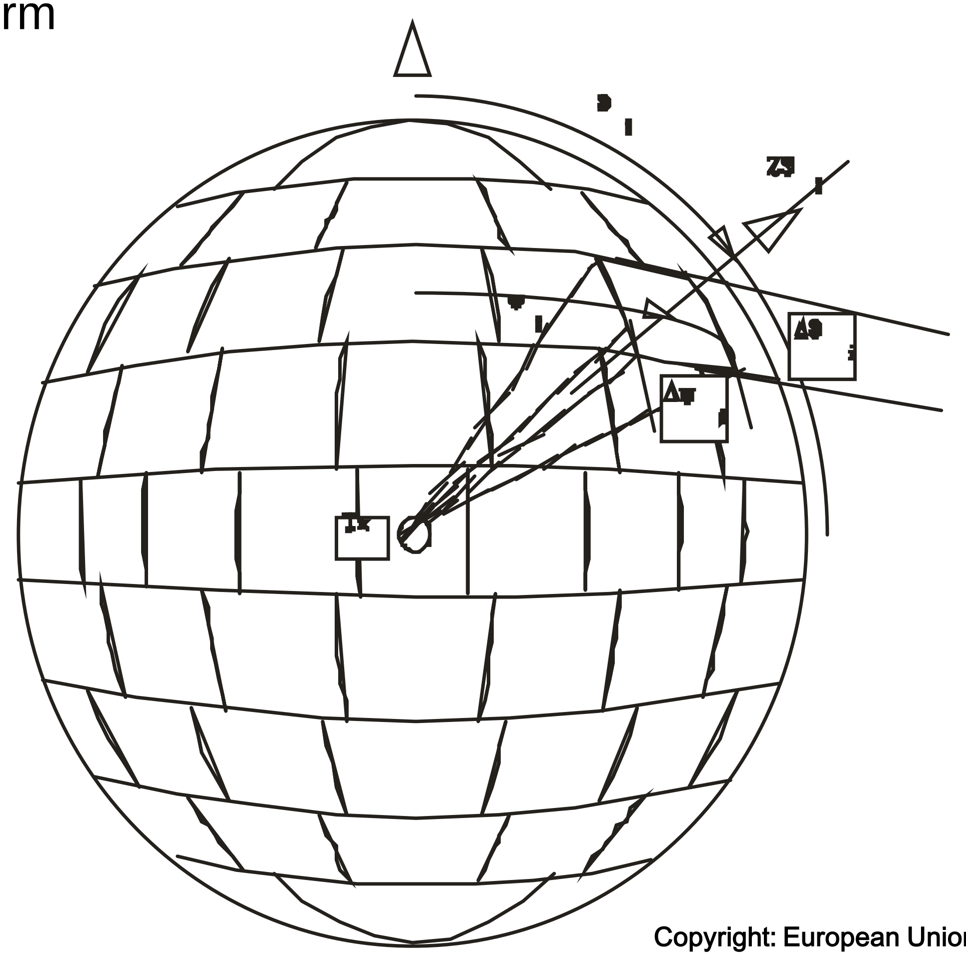
Deterministic modeling methods

- Solve Maxwell's equations with boundary conditions (location, shape & dielectric/conductive properties of all objects in the environment)
- Problems:
  - Data base for environment (Shuttle terrain data for entire world, Google Earth??)
  - Computation time especially exact solutions
- "Exact" solutions
  - Method of moments
  - Finite element method
  - Finite-difference time domain (FDTD)
- High frequency approximation
  - All waves modeled as rays that behave as in geometrical optics
  - Refinements include approximation to diffraction, diffuse scattering, etc.
  - -- Most widespread approximation is to model electromagnetic waves as rays

Ray launching

another deterministic channel modeling method. Textbook Section 7.5.1 pg 139

Transmit antenna 'launches' rays into different directions normally divided into N uniform sections over entire spatial angle.

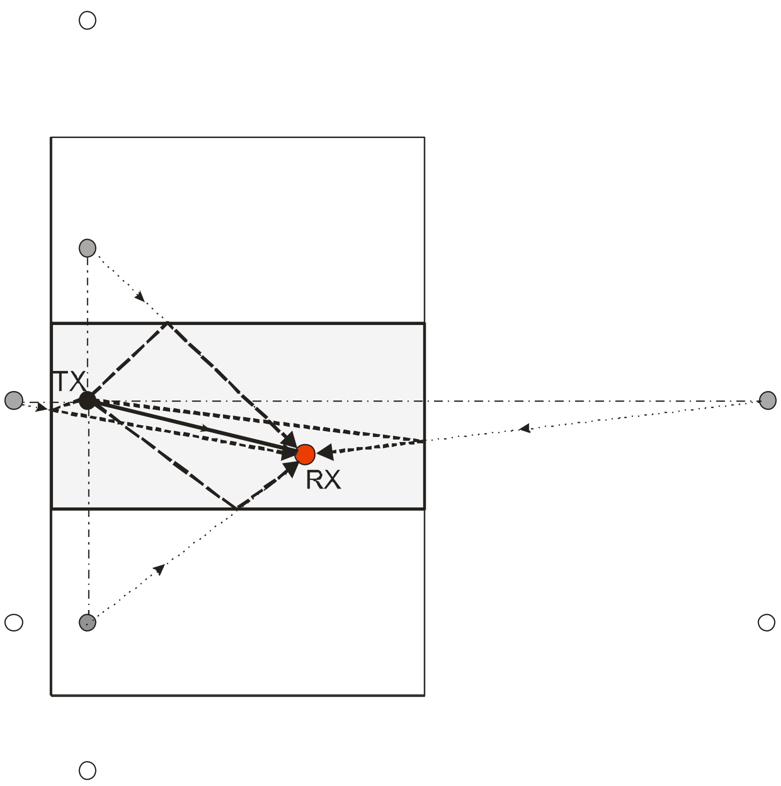


Ray tracing

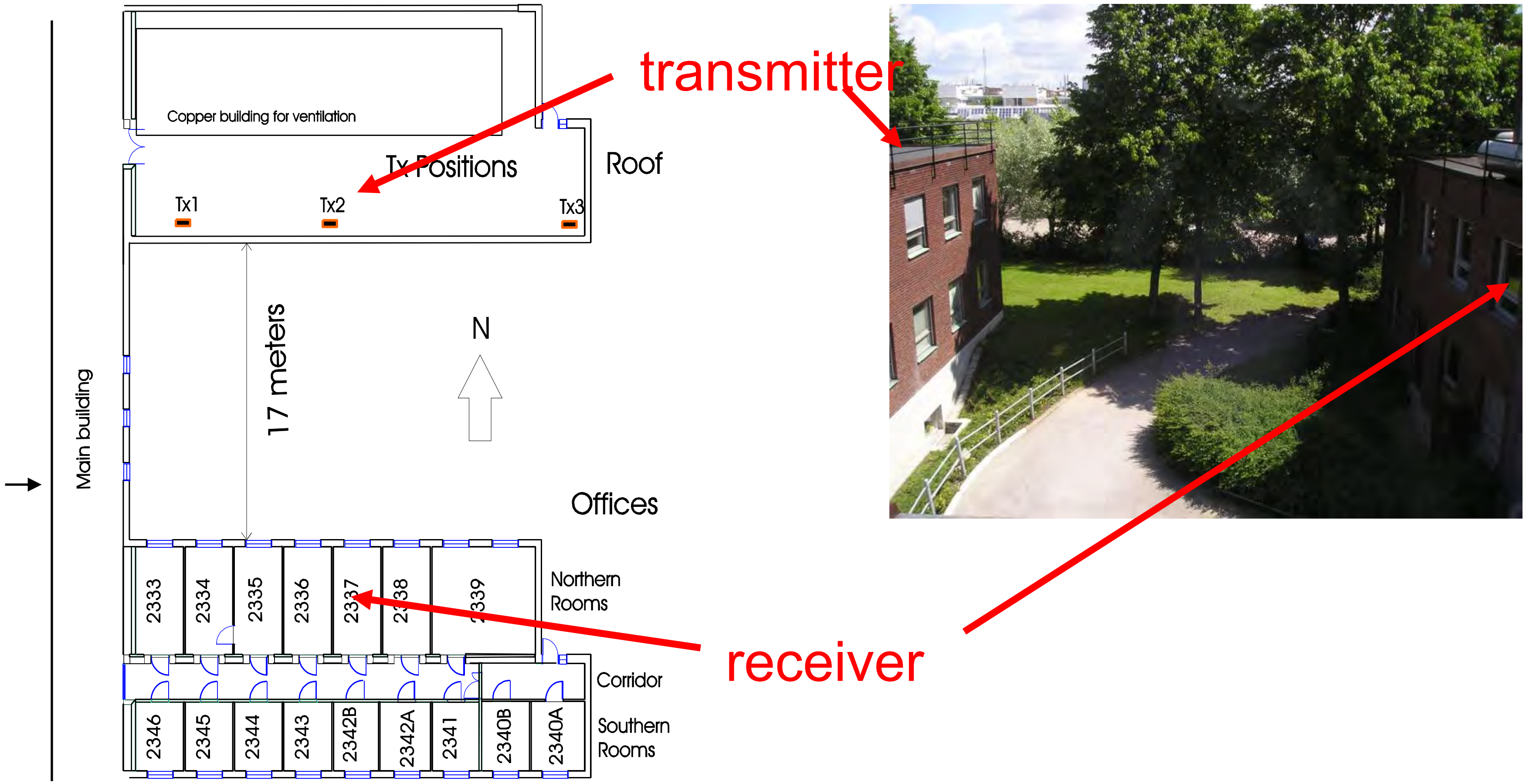
- Determines rays that can go from one TX position to one RX position
  - Uses imagining principle
  - Similar to techniques known from computer science

- Then determine attenuation of all those possible paths

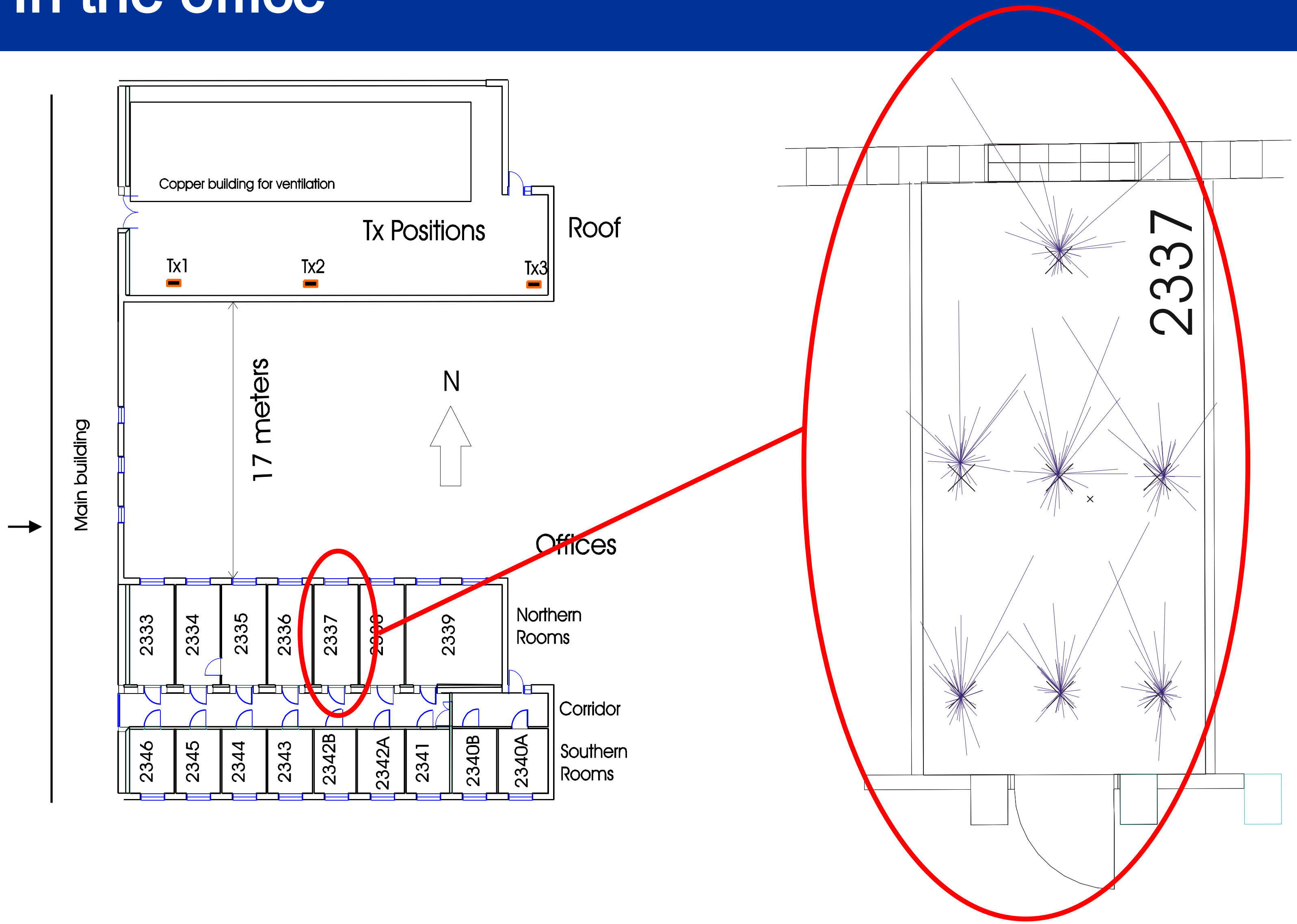
Effects taken into account: free space attenuation, reflections which cause additional attenuation and diffraction/diffuse scattering where a ray on an IO gives rise to several new rays



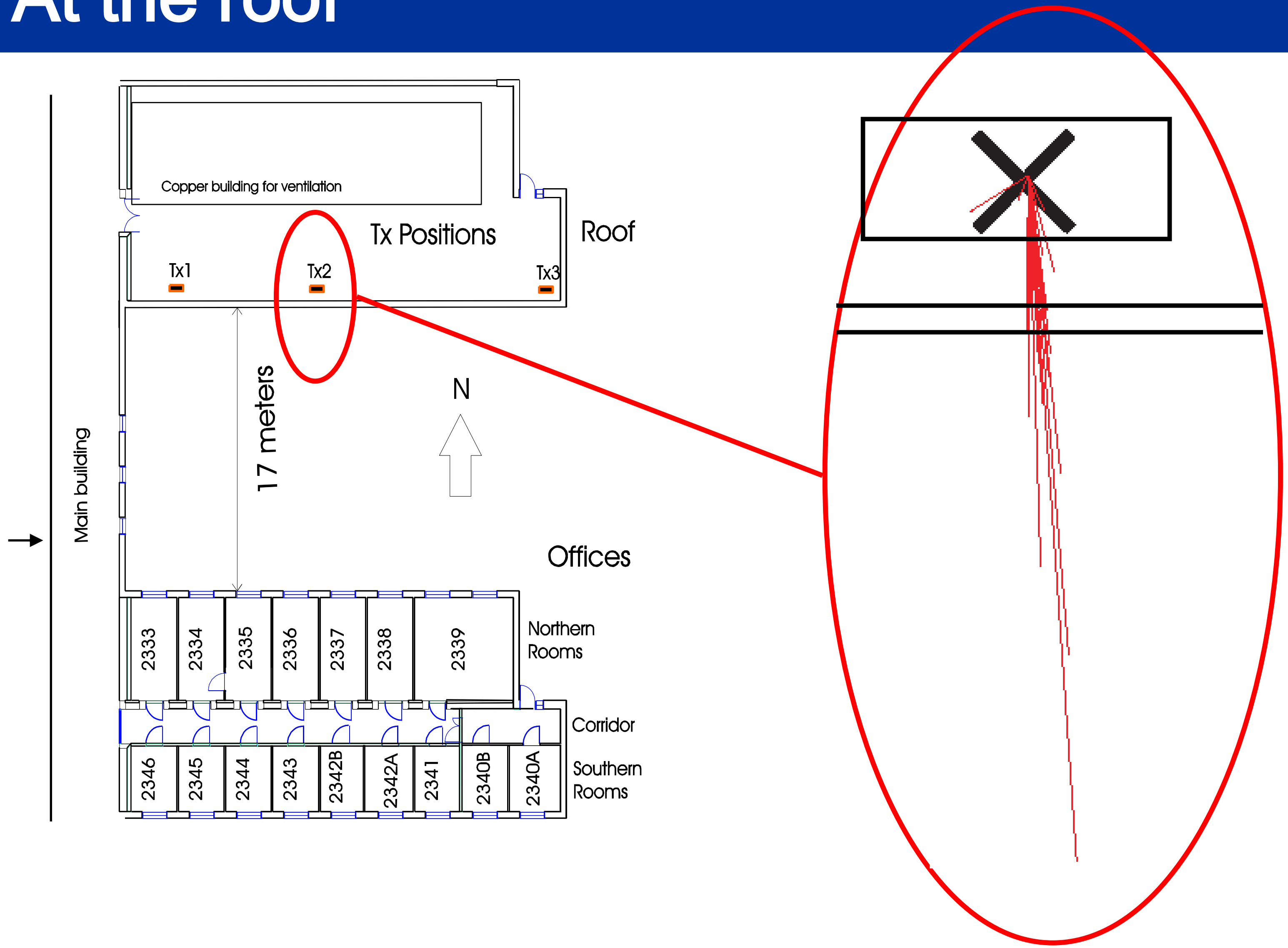
How does the signal reach the receiver Outdoor-to-indoor



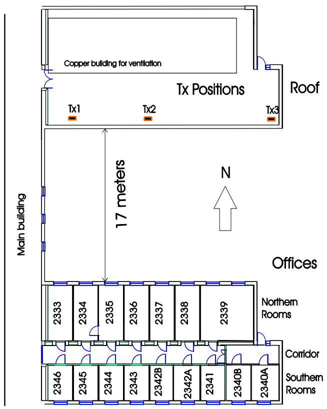
How does the signal reach the receiver
In the office

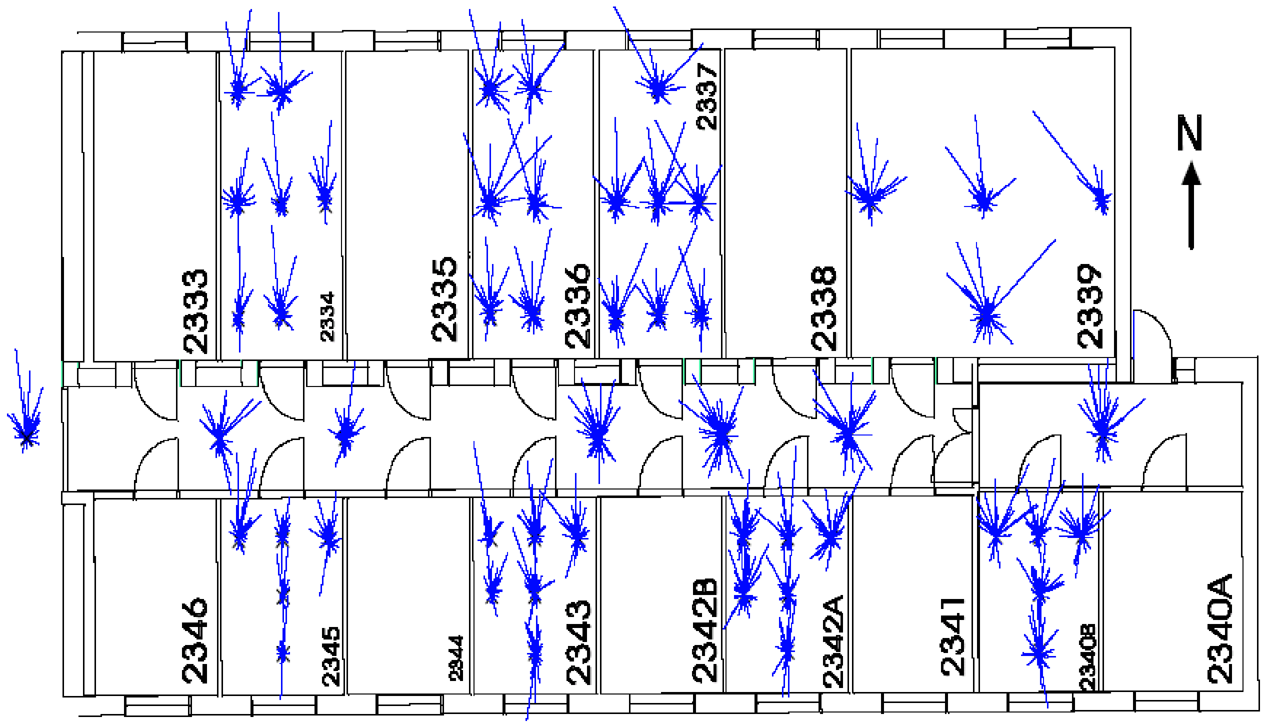


How does the signal leave the transmitter At the roof



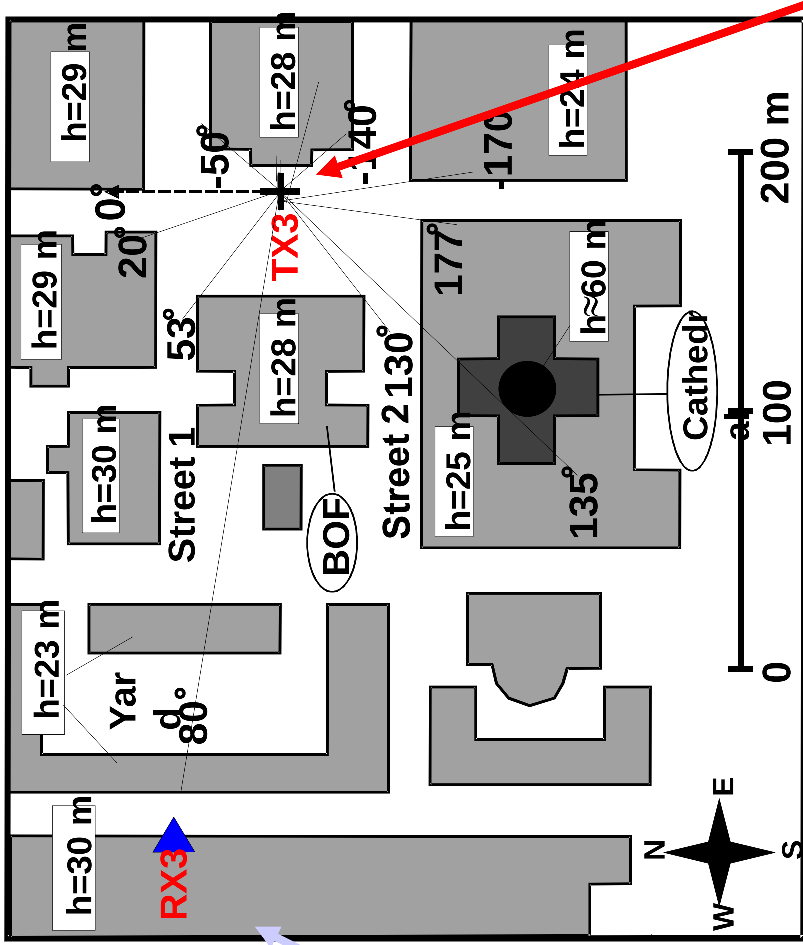
In all offices

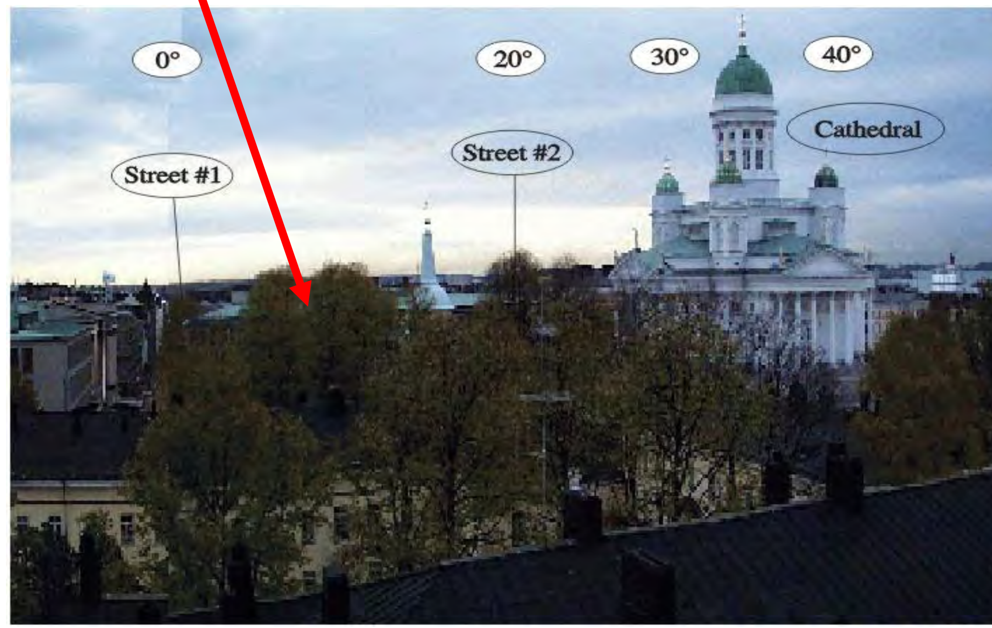




How does the signal reach the receiver outdoor urban

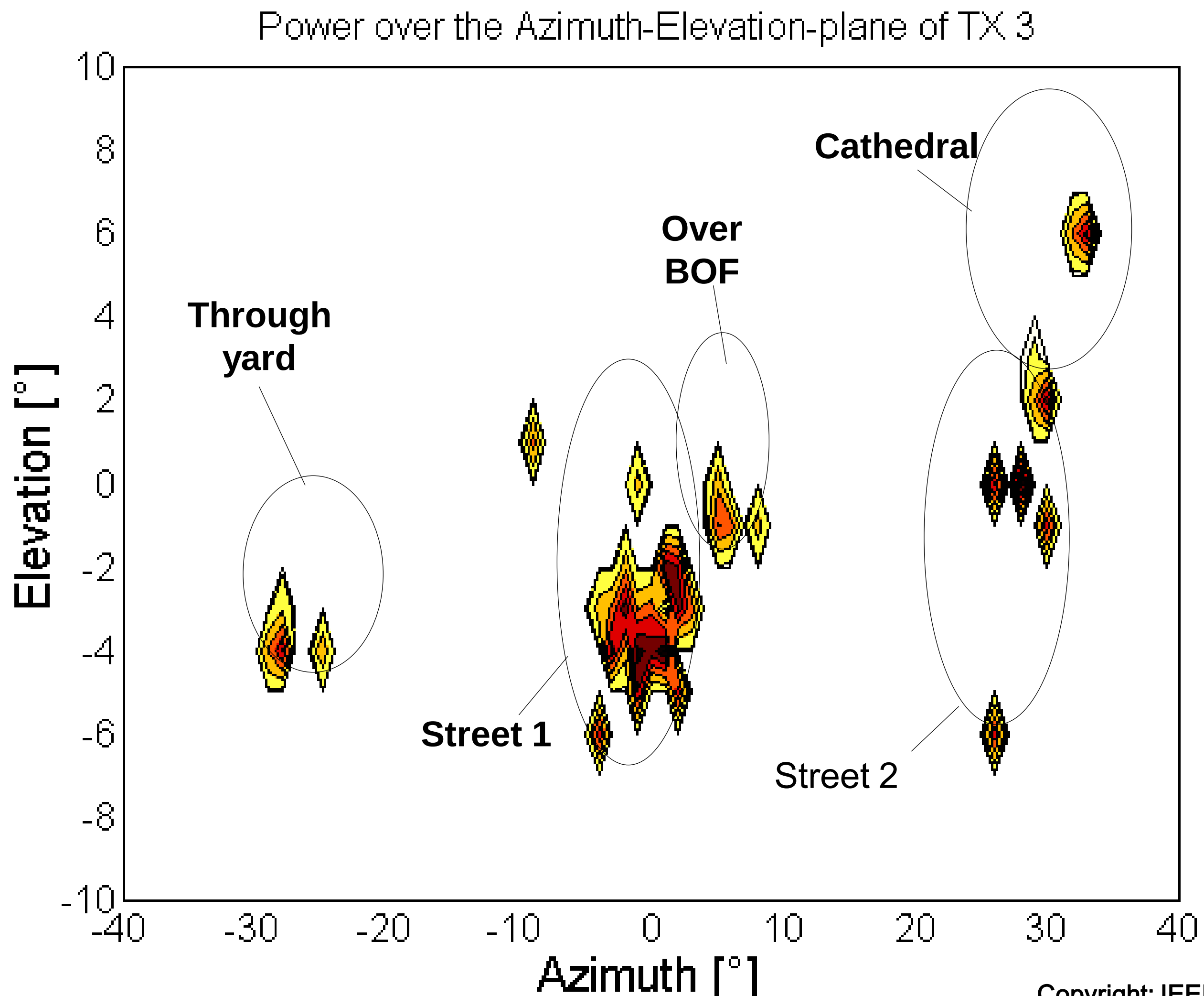
Transmitter





Mottagare

Signal arrives from some specific areas



Diffraction, reflection, scattering, transmission