Channel Modelling – ETIN10

Lecture no: 6

Channel models

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- Multiantenna (MIMO) models
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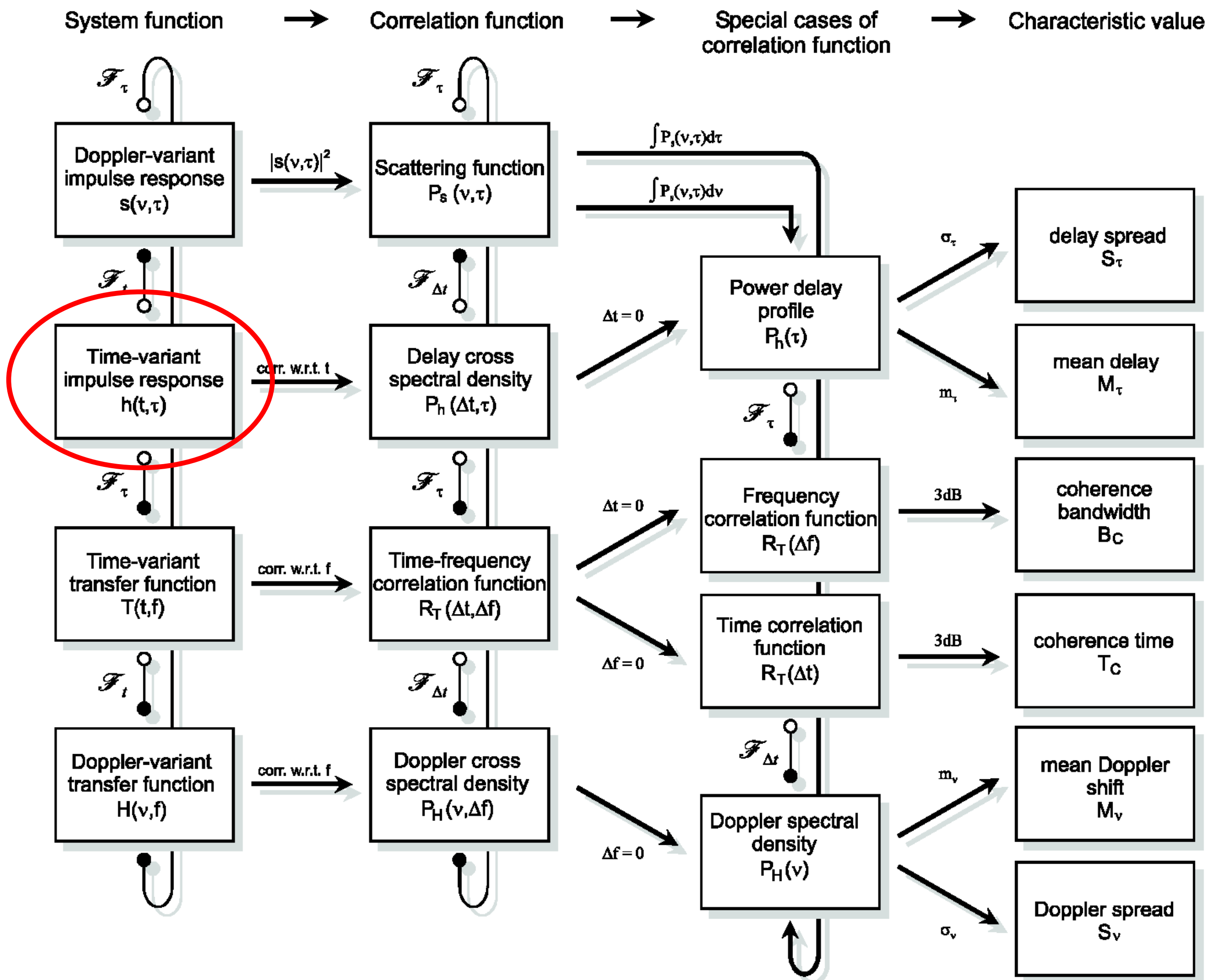
Channel measures



Modeling methods

- Stored channel impulse responses
  - realistic
  - reproducible
  - hard to cover all scenarios
- Deterministic channel models
  - based on Maxwell's equations (or approximations: ray tracing)
  - site specific
  - computationally demanding
- Stochastic channel models
  - describes the distribution of the field strength etc
  - mainly used for design and system comparisons
  - example: the Rayleigh-fading model

Narrowband models
Review of properties

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

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

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

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

Okumura’s measurements

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
Environment	medium-size city, large city, etc.

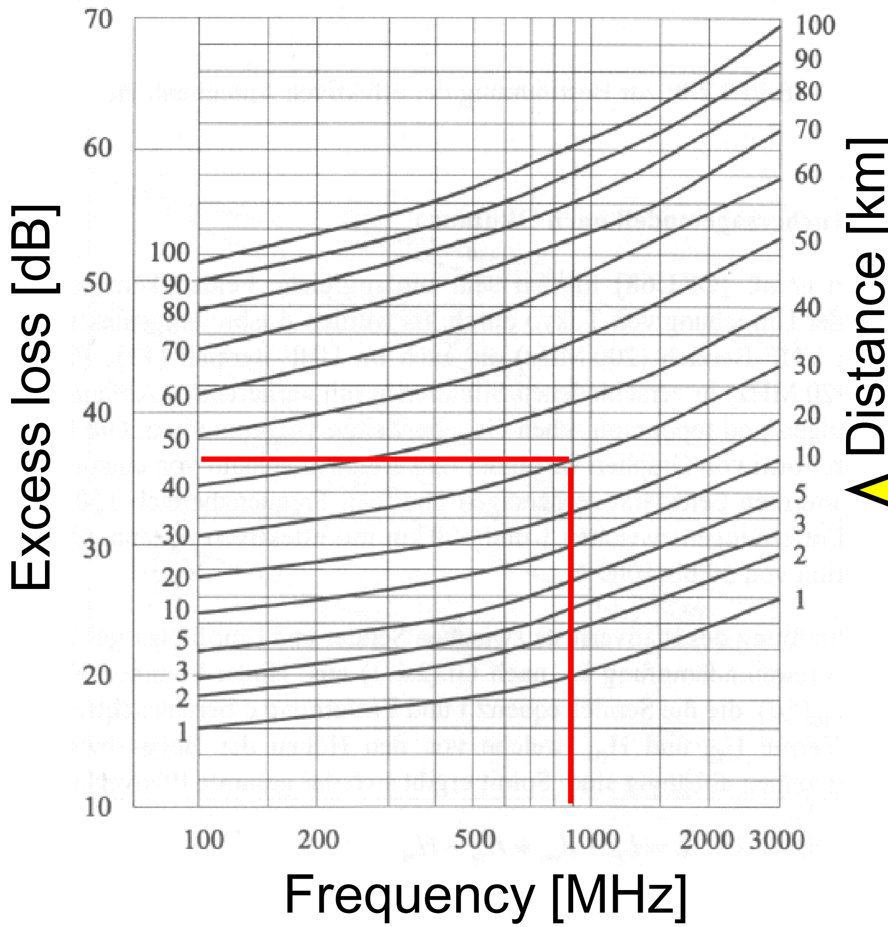
Propagation loss is given as **median** values (50% of the time and 50% of the area).

Results from these measurements are displayed in figures 7.12 – 7.14 in the appendix.

Okumura's measurements excess loss

Example

FIGURE 7.12 in appendix



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

900 MHz and
30 km distance

The Okumura-Hata model Background

In 1980 Hata published a parameterized model, based on Okumura's measurements.

The parameterized model has a smaller range of validity than the measurements by Okumura:

Frequency	150 – 1500 MHz
Distance	1 – 20 km
Mobile station height	1 – 10 m
Base station height	30 – 200 m

It doesn't encompass the 1800 MHz frequency range. This problem was solved by the COST 231-Hata model.

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	$\left(1.1\log\left(f_{0\vert MHz}\right) - 0.7\right)h_m - \left(1.56\log\left(f_{0\vert MHz}\right) - 0.8\right)$	0
Suburban environments	$\left(1.1\log\left(f_{0\vert MHz}\right) - 0.7\right)h_m - \left(1.56\log\left(f_{0\vert MHz}\right) - 0.8\right)$	$-2\left[\log\left(f_{0\vert MHz}/28\right)\right]^2 - 5.4$
Rural areas	$\left(1.1\log\left(f_{0\vert MHz}\right) - 0.7\right)h_m - \left(1.56\log\left(f_{0\vert MHz}\right) - 0.8\right)$	$-4.78\left[\log\left(f_{0\vert MHz}\right)\right]^2 + 18.33\log\left(f_{0\vert MHz}\right) - 40.94$

The COST 231-Walfish-Ikegami model

The Okumura-Hata model is not suitable for micro cells or small macro cells, due to its restrictions on distance (d > 1 km).

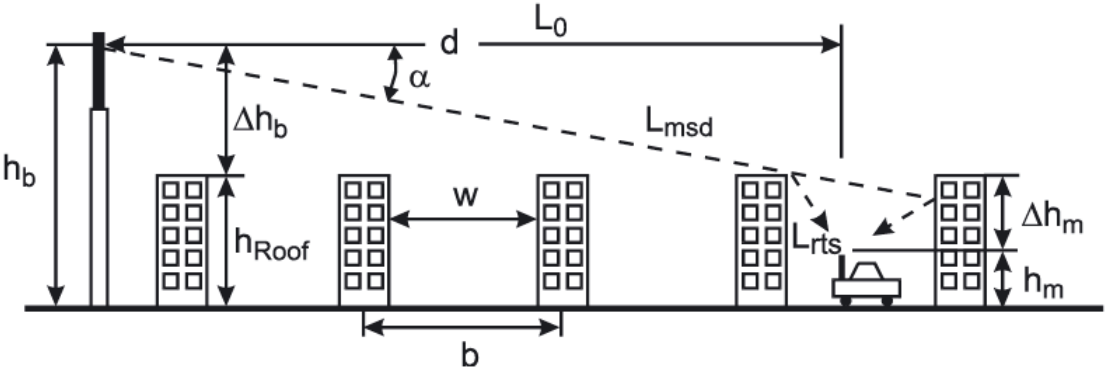
The COST 231-Walfish-Ikegami model covers much smaller distances, and it is better suitable for calculations on small cells and covers the 1800 MHz band as well.

Frequency	800 – 2000 MHz
Distance	0.02 – 5 km
Mobile station height	1 – 3 m
Base station height	4 – 50 m

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

$$L = L_0 + L_{msd} + L_{rts}$$

Free space | Building multiscreen | Roof-top to street



Assumptions: - a Manhatten grid, constant building height, and a flat tarrain.
- the effect of waveguiding through street canyons is not included

L_0 is a function of d (KM),f_0(MHz)
L_{msd} is a function of Δh_b, d, f_0, b
L_{rts} is a function of w, f_0, Δh_m, the orientation of the street

Details about calculations can be found in the appendix.

Motley-Keenan indoor model

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

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

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 => requires the location of BS, MS, and the building plan.
- Neglects propagation paths that go around the walls (through corridors)

Wideband models (Tapped Delay Line Models)

- Tapped delay line model often used

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

- Often Rayleigh-distributed taps, but might include LOS and different distributions of the tap values
- Mean tap power determined by the power delay profile

- Popular cases:

N=2, no LOS => the *two-path channel*, the simplest delay-dispersion model

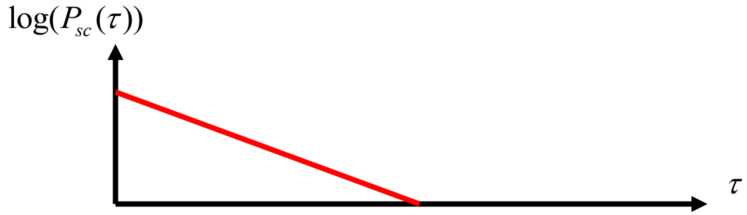
LOS + one fading tap => widely used for satellite channels

Models for the Power Delay Profile

- Often described by a single exponential decay

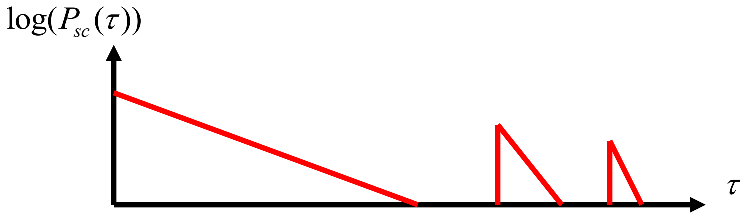
$$P_{sc}(\tau) = \begin{cases} exp(-\tau / S_\tau) & \tau \geq 0 \\ 0 & otherwise \end{cases}$$

delay spread



- though often there is more than one “cluster”

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



where *k* is the cluster’s index

arrival time

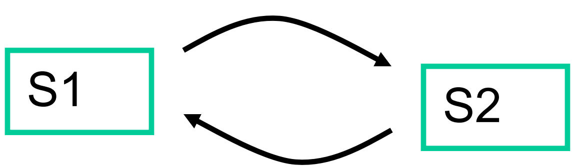
- If the bandwidth is high, the time resolution is large so we might resolve the different multipath components
- Need to model arrival time
- The Saleh-Valenzuela model:

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:



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

Standardized Channel Models
COST 207 model for GSM

The COST 207 model specifies:

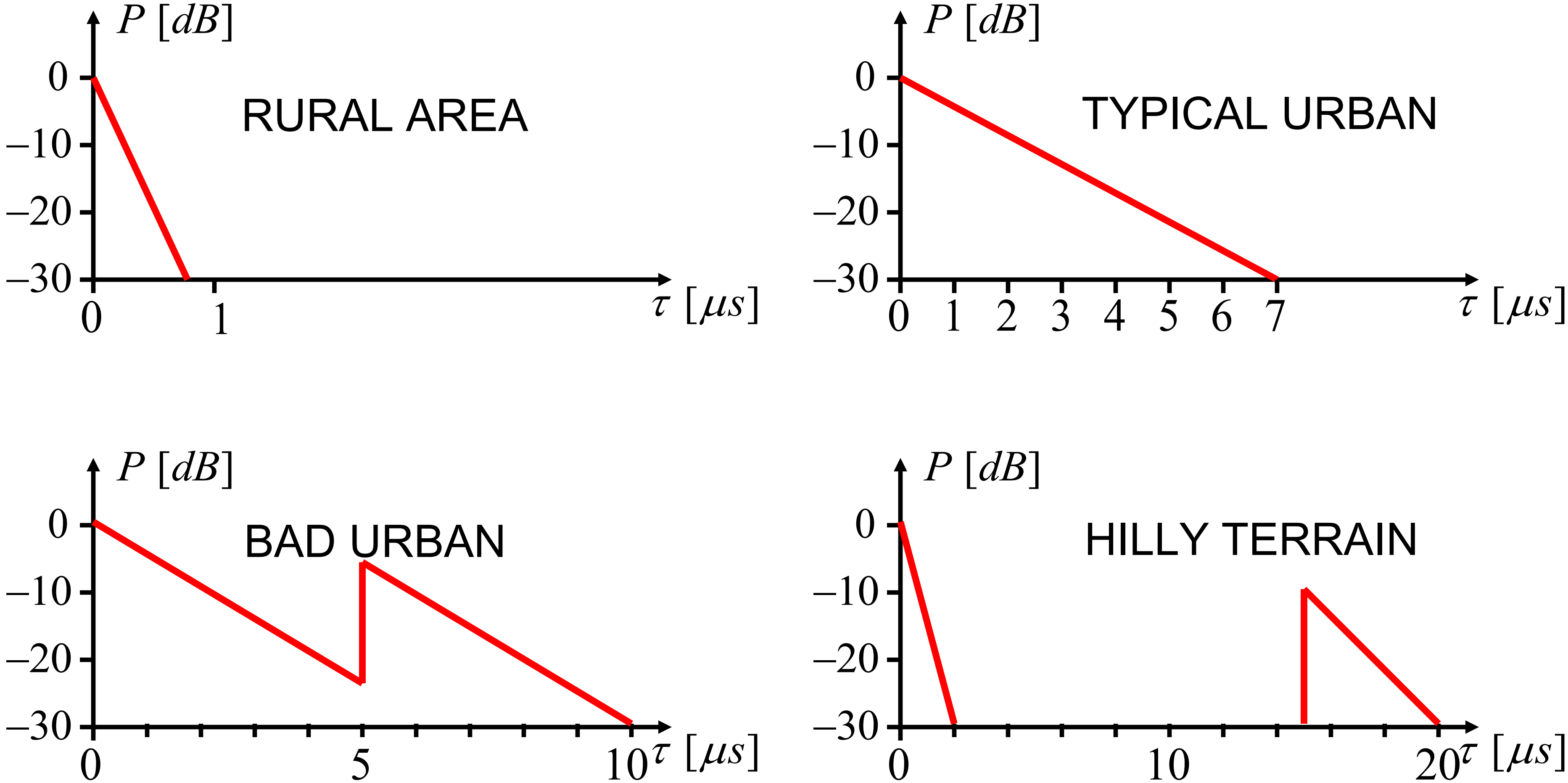
FOUR power-delay profiles for different environments.

FOUR Doppler spectra used for different delays.

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

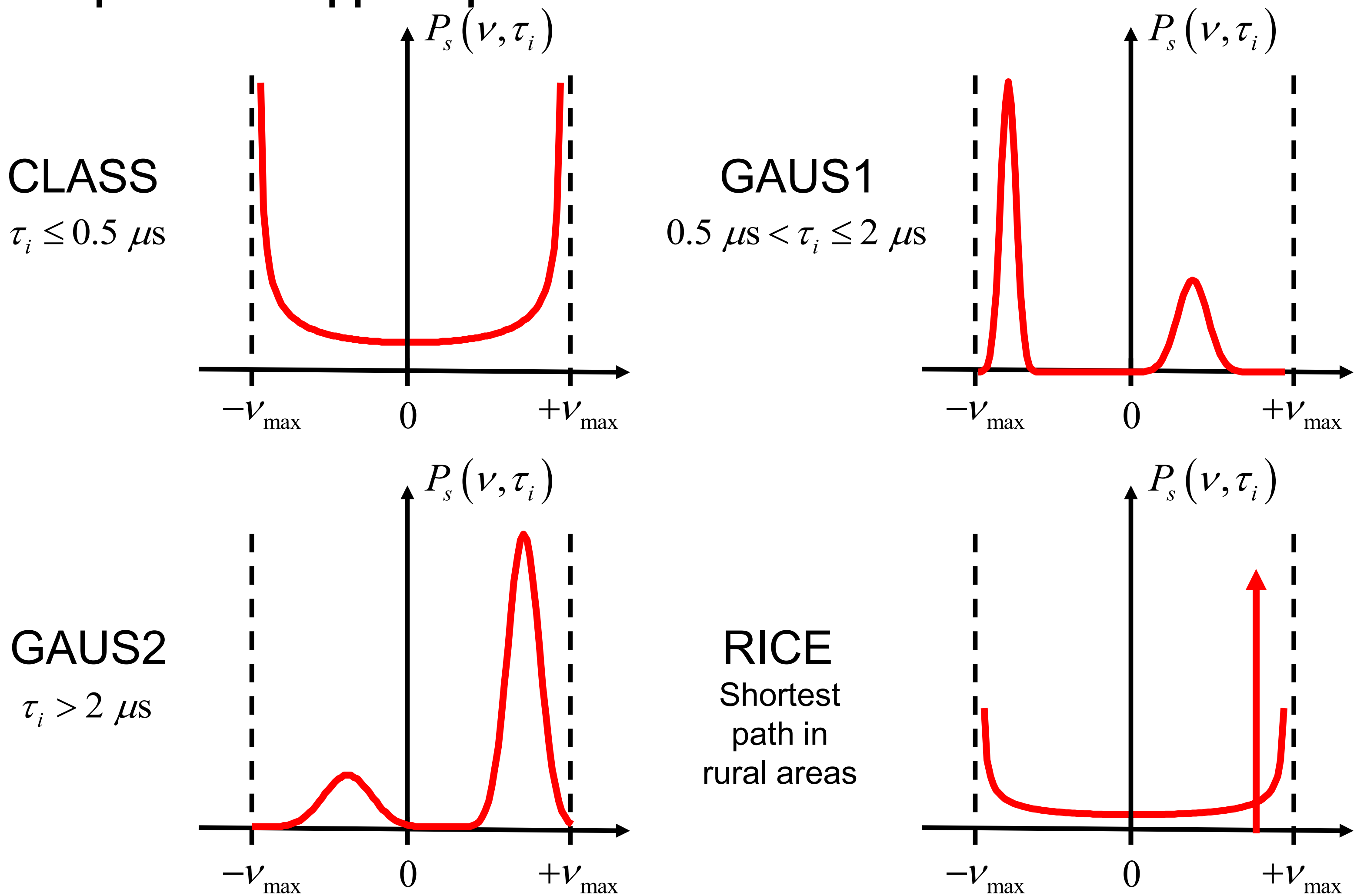
Wideband models
COST 207 model for GSM

Four specified power-delay profiles

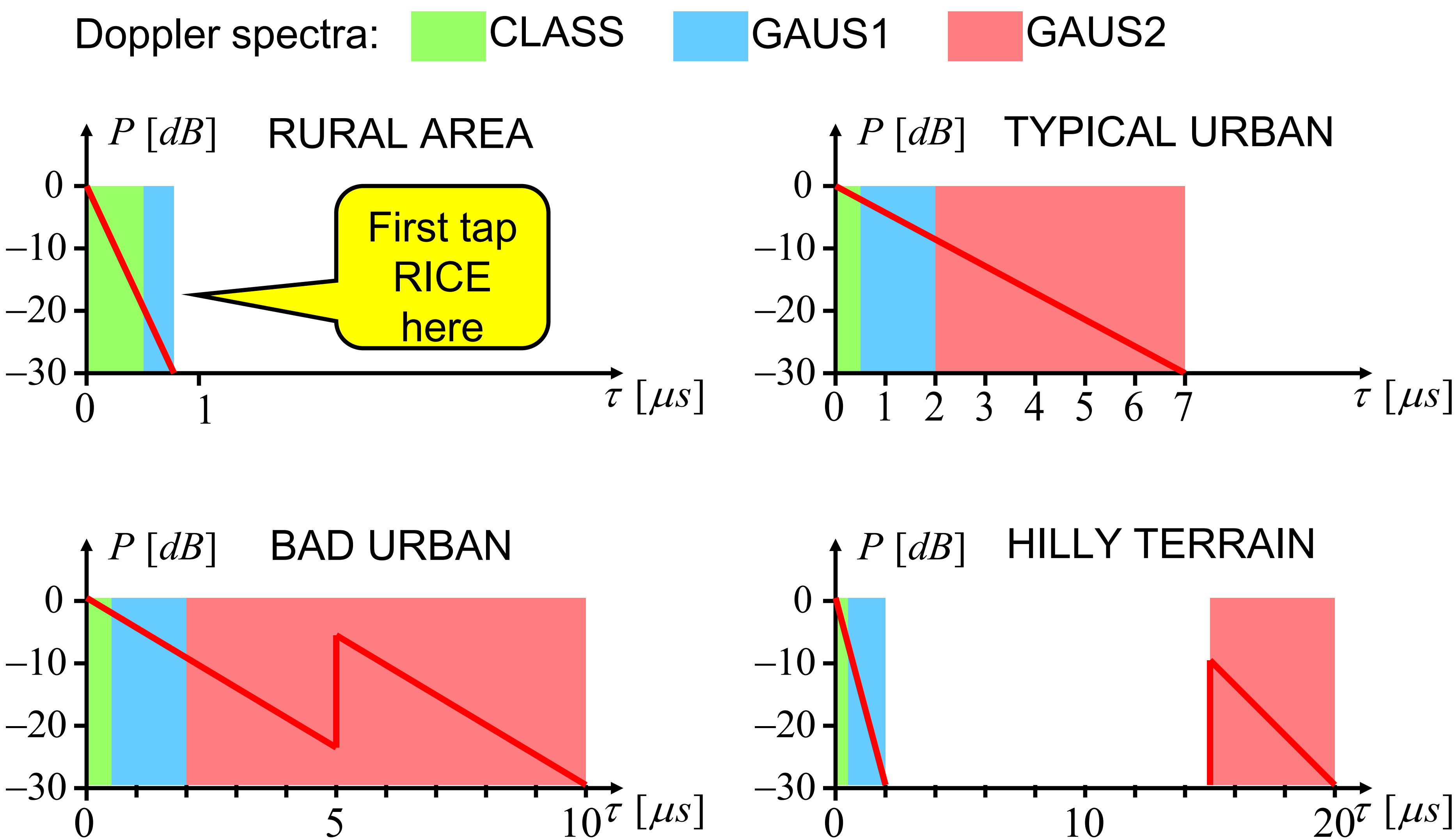


Wideband models
COST 207 model for GSM

Four specified Doppler spectra

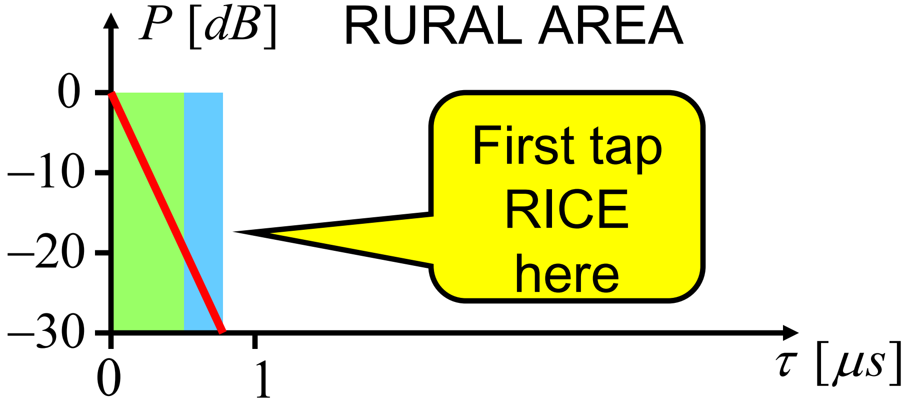


Wideband models
COST 207 model for GSM



Wideband models
COST 207 model for GSM

Doppler spectra: CLASS GAUS1 GAUS2



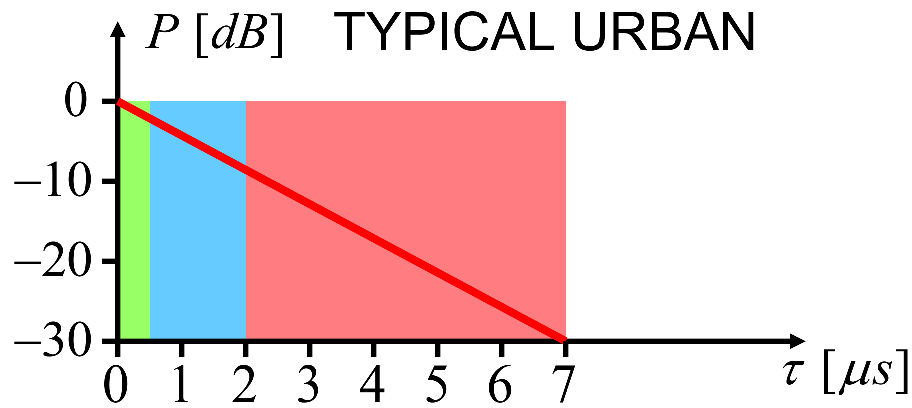


Table 7.3 Parameters for rural (non-hilly) area (RA)

Tap#	Delay [μs]	Power [dB]	Doppler category
1	0	0	RICE
2	0.2	-2	CLASS
3	0.4	-10	CLASS
4	0.6	-20	CLASS

Table 7.4 Parameters for urban (non-hilly) area (TU)

Tap#	Delay [μs]	Power [dB]	Doppler category
1	0	-3	CLASS
2	0.2	0	CLASS
3	0.6	-2	GAUS1
4	1.6	-6	GAUS1
5	2.4	-8	GAUS2
6	5.0	-10	GAUS2

Wideband models
ITU-R model for 3G

The ITU-R model specifies:

SIX different tapped delay-line channels for three different scenarios (indoor, pedestrian, vehicular).

TWO channels per scenario (one short and one long delay spread).

TWO different Doppler spectra (uniform & classical), depending on scenario.

THREE different models for propagation loss (one for each scenario).

The standard deviation of the log-normal shadow fading is specified for each scenario.

The autocorrelation of the log-normal shadow fading is specified for the vehicular scenario.

Wideband models
ITU-R model for 3G

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

Directional channel models

- The spatial domain can be used to increase the spectral efficiency of the system
  - Smart antennas
  - MIMO systems
- Need to know directional properties
  - How many significant reflection points?
  - Which directions?
  - Model incoming angle (direction of arrival) and outgoing angle (direction of departure) to scatterers
- Model independent from specific antenna pattern

Double directional impulse response

TX position

RX position

number of multipath components for these positions

$$h(t,\vec{r}_{\mathrm{TX}},\vec{r}_{\mathrm{RX}},\tau,\Omega,\Psi) = \sum_{\ell=1}^{N(\vec{r})} h_\ell(t,\vec{r}_{\mathrm{TX}},\vec{r}_{\mathrm{RX}},\tau,\Omega,\Psi)$$

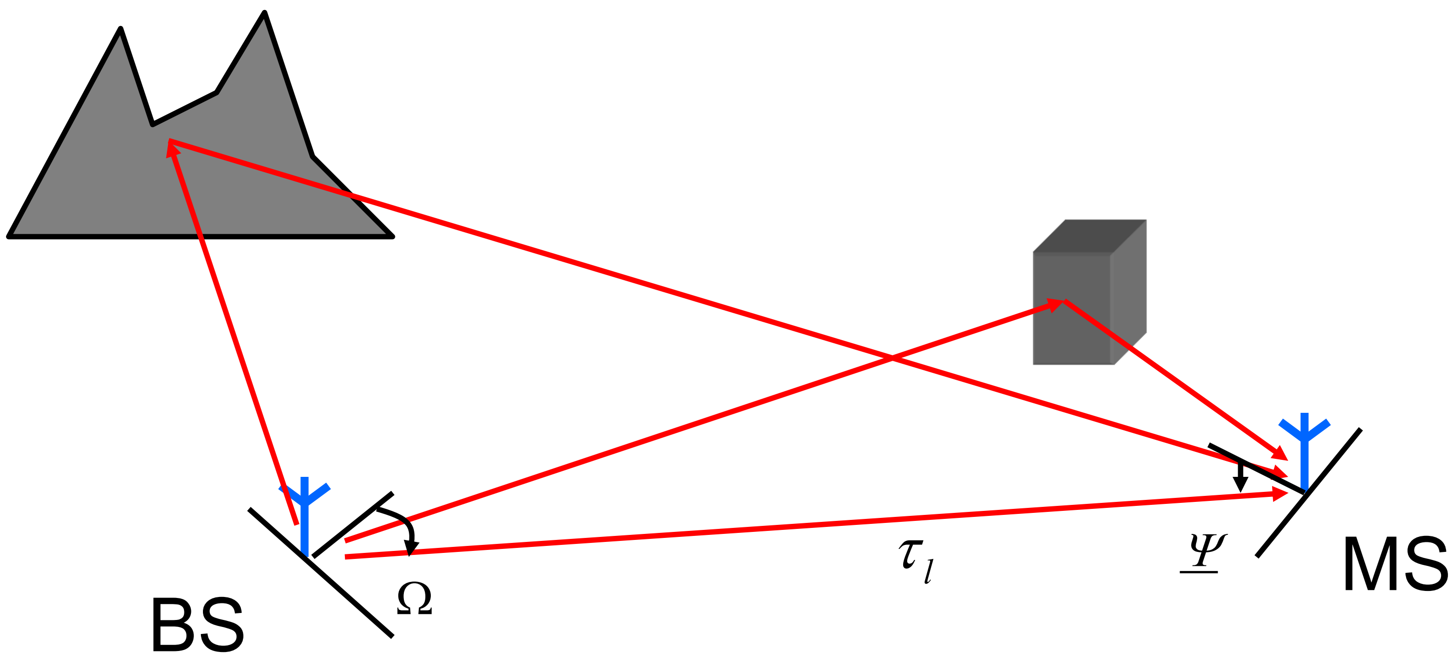
direction-of-arrival

delay

direction-of-departure

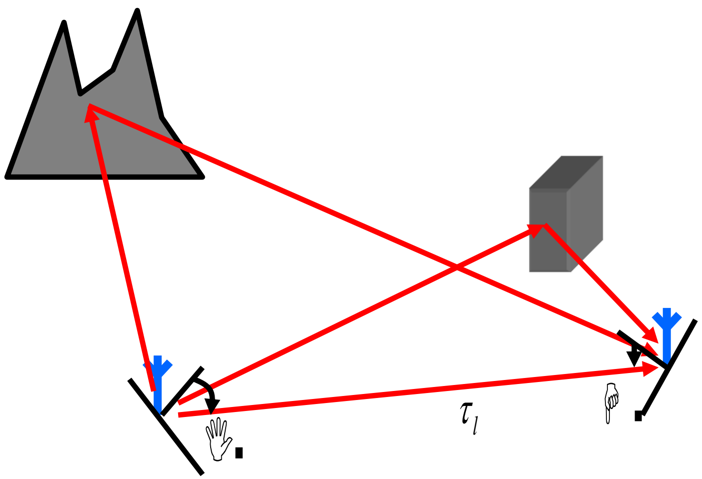
$$h_\ell(t,\vec{r}_{\mathrm{TX}},\vec{r}_{\mathrm{RX}},\tau,\Omega,\Psi) = |a_\ell| e^{j\varphi_\ell}\delta(\tau-\tau_\ell)\delta(\Omega-\Omega_\ell)\delta(\Psi-\Psi_\ell)$$

Physical interpretation



Angular spread

$$E\{s^*(\Omega,\Psi,\tau,v)s(\Omega',\Psi',\tau',v')\} = P_s(\Omega,\Psi,\tau,v)\delta(\Omega-\Omega')\delta(\Psi-\Psi')\delta(\tau-\tau')\delta(v-v')$$



double directional delay power spectrum

$$DDDPS(\Omega,\Psi,\tau) = \int \mathrm{P_s}(\Psi,\Omega,\tau,v)\mathrm{d}v$$

angular delay power spectrum

$$ADPS(\Omega,\tau) = \int DDDPS(\Psi,\Omega,\tau)G_{\mathrm{MS}}(\Psi)d\Psi$$

angular power spectrum

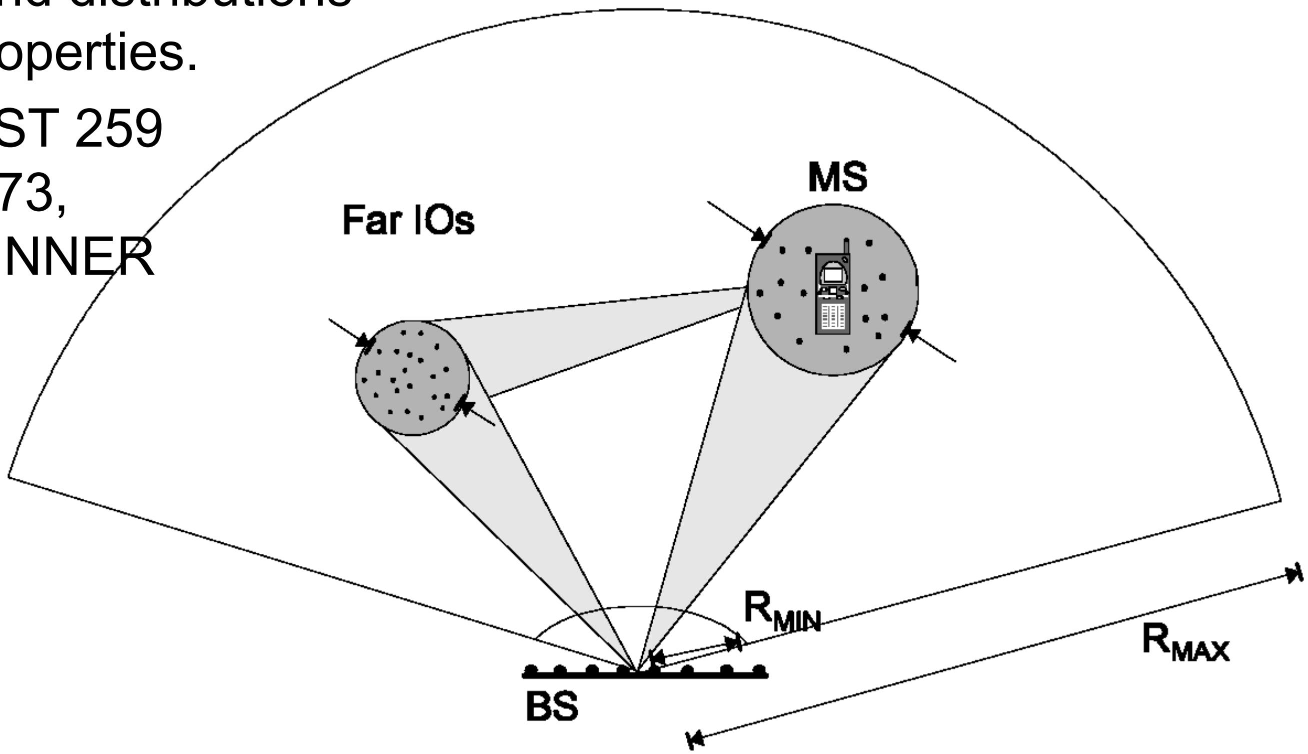
$$APS(\Omega) = \int \mathrm{APDS}(\Omega,\tau)\mathrm{d}\tau$$

power

$$P = \int \mathrm{APS}(\Omega)\mathrm{d}\Omega$$

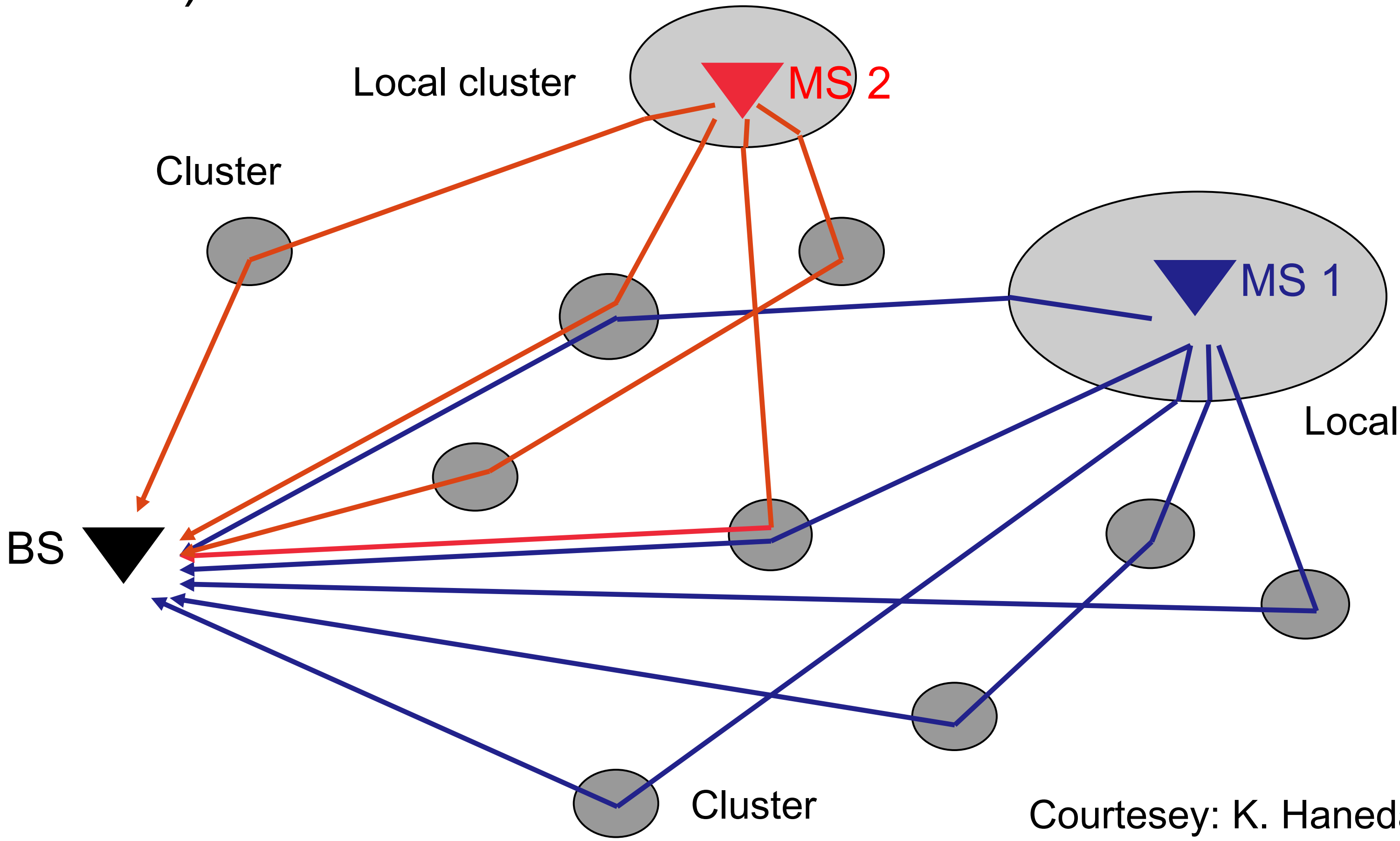
Geometry-based stochastic channel models

- Assign positions for scatterers according to given distributions
- Derive impulse response given the scatterers and distributions for the signal properties.
- Used in the COST 259 model, COST 273, COST 2100, WINNER 3GPP/3GPP2



Geometry-Based Stochastic Channel Model (GSCM)

- Create an ”imaginary” map for radio wave scatterers (clusters)



Courtesey: K. Haneda, Aalto Uni.

MIMO channel models

- Channel matrix

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

- Signal model

$$y(t) = \sum_{\tau} h(\tau)x(t-\tau)$$

- Kronecker model

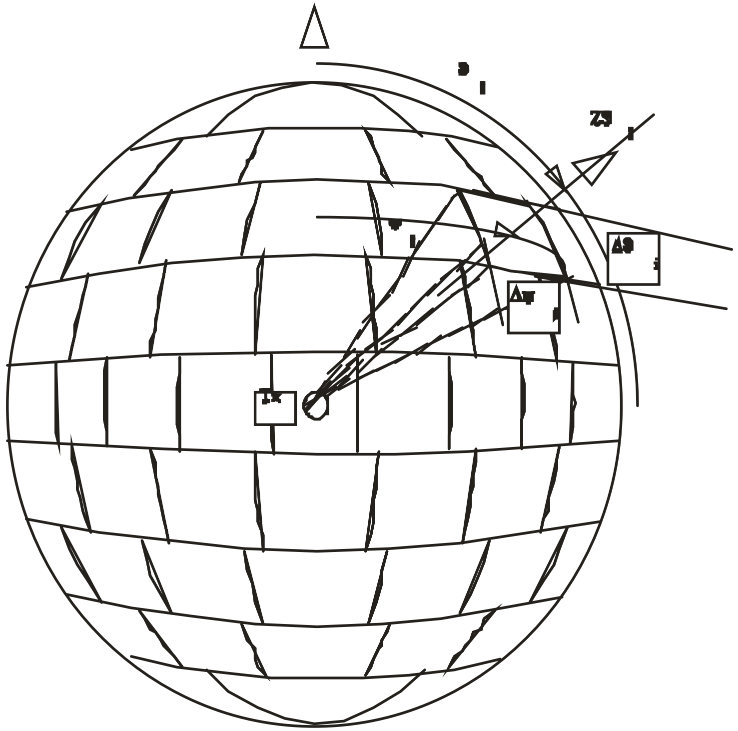
$$H = \frac{1}{E\{tr(HH^*)\}} R_{Rx}^{1/2} G_G R_{Tx}^{1/2}$$

Deterministic modeling methods

- Solve Maxwell's equations with boundary conditions
- Problems:
  - Data base for environment
  - Computation time
- "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.

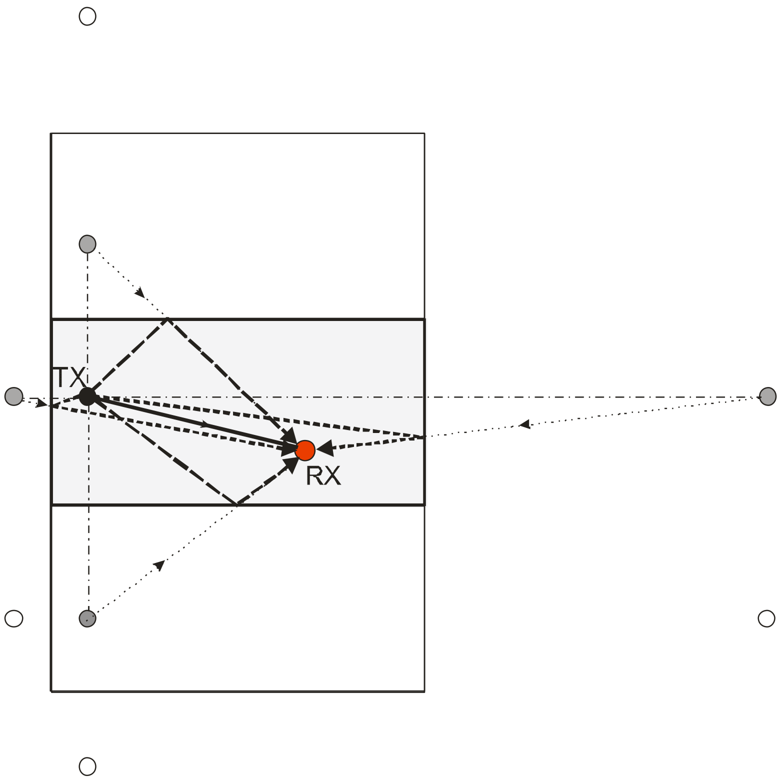
Ray launching

- TX antenna sends out rays in different directions
- We follow each ray as it propagates, until it either
  - Reaches the receiver, *or*
  - Becomes too weak to be relevant
- Propagation processes
  - Free-space attenuation
  - Reflection
  - Diffraction and diffuse scattering: each interacting object is source of multiple new rays
- Predicts channel in a whole *area* (for one TX location)

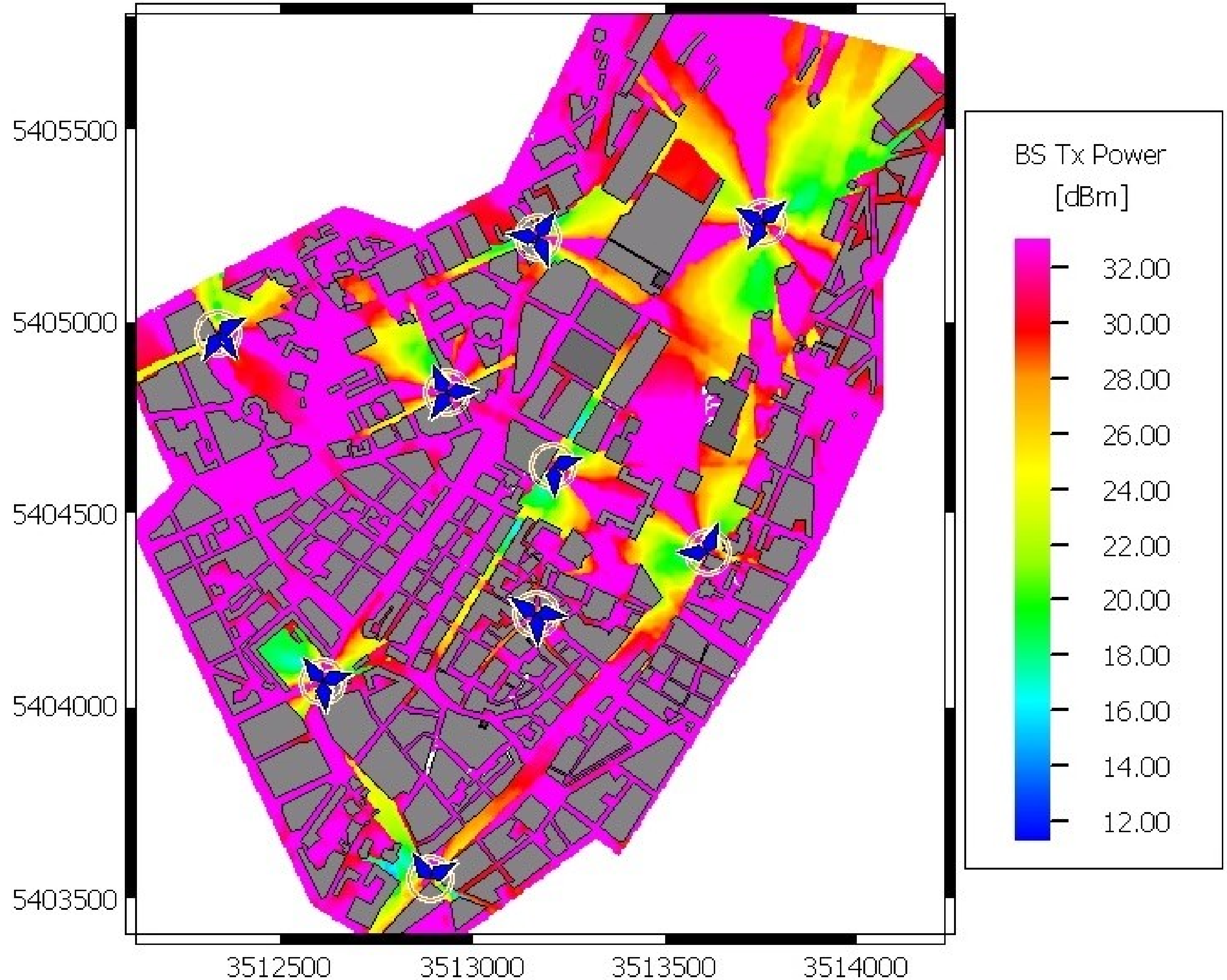


Ray tracing

- 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

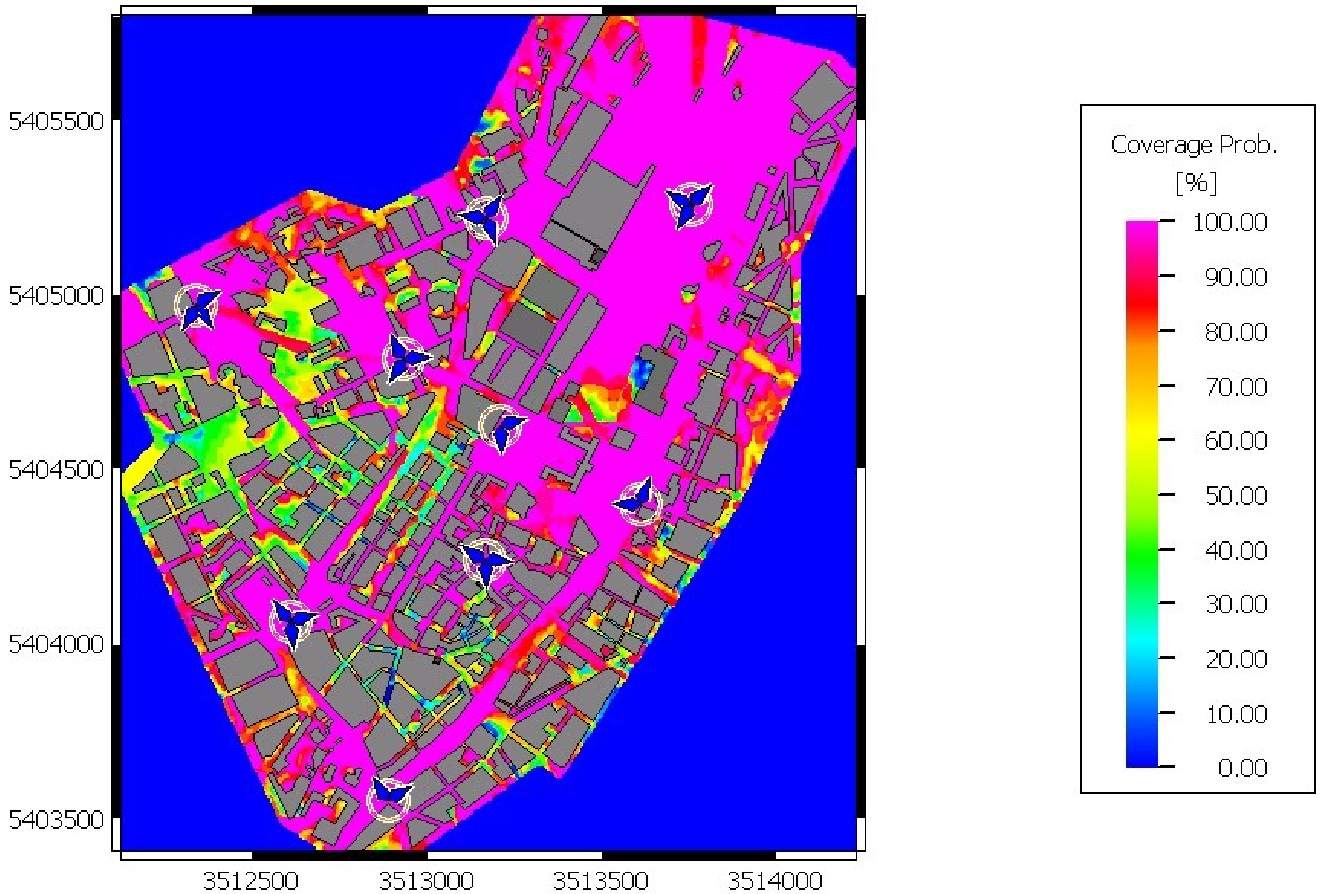


Example: Ray tracing



Required base station power to connect to a WCDMA cell phone. Example from Stuttgart. Courtesey: Awe-communications

Example: Ray tracing



Coverage for a WCDMA cell phone. Example from Stuttgart. Courtesey: Awe-communications Propagation Models