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Wireless Communications Channels Lecture 6: Channel Models

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Lecture contents

- Different modelling methods
- Okumura-Hata path loss model
- COST 231 model
- Indoor models
- Wideband models
- COST 207 (GSM/2G model)
- ITU-R model for 3G
- Directional channel models
- Multiple antenna (MIMO) models
- Ray tracing & Ray launching

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Modeling methods

- ❑ **Stored channel impulse responses**
  - ❑ **Channel sounder** based; thus realistic
    - ❑ Different from system-level field trials
  - ❑ Reproducible and thus reliable
  - ❑ Difficult to cover **all** scenarios
- ❑ **Deterministic channel models**
  - ❑ Based on Maxwell's equations
  - ❑ **Site specific** and computationally demanding
- ❑ **Stochastic channel models**
  - ❑ Describes **distribution** of the field strength over **an area**
  - ❑ Mainly used for design and system comparisons

Narrowband models Review of properties

- Narrowband models contain ”only one” attenuation, which is modeled as a propagation loss, plus large- and small-scale 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 ...
  (of amplitudes and not in dB-scale)

Standard models for path loss
Okumura’s measurements

Extensive measurement campaign in Japan in the 1960’s.

Parameters varied during measurements:

$$\mathrm{PL} = A + B \log_{10}(d) + C$$

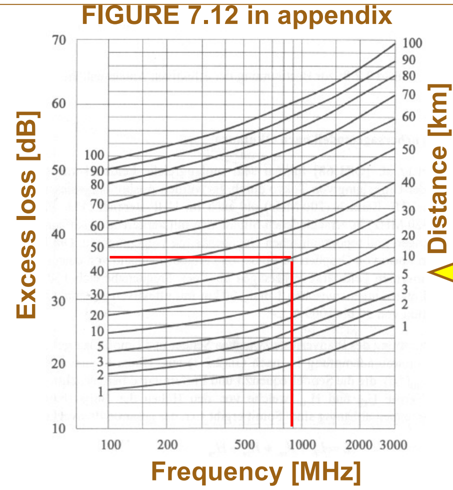
Dependent on the below factors

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.**

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

Okumura’s measurements
excess loss

FIGURE 7.12 in appendix



Example

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**

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The Okumura-Hata model
How to calculate prop. loss

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

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

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

h_b and h_m in meter

	$a(h_m) =$	$C =$
Metropolitan areas	$8.29\left(\log(1.54h_m)\right)^2 - 1.1$ for $f_0 \le 200$ MHz $3.2\left(\log(11.75h_m)\right)^2 - 4.97$ 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	$\left(1.1\log\left(f_{0\|MHz}\right) - 0.7\right)h_m - \left(1.56\log\left(f_{0\|MHz}\right) - 0.8\right)$	$-4.78\left[\log\left(f_{0\|MHz}\right)\right]^2 + 18.33\log\left(f_{0\|MHz}\right) - 40.94$

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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, is better suited 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**

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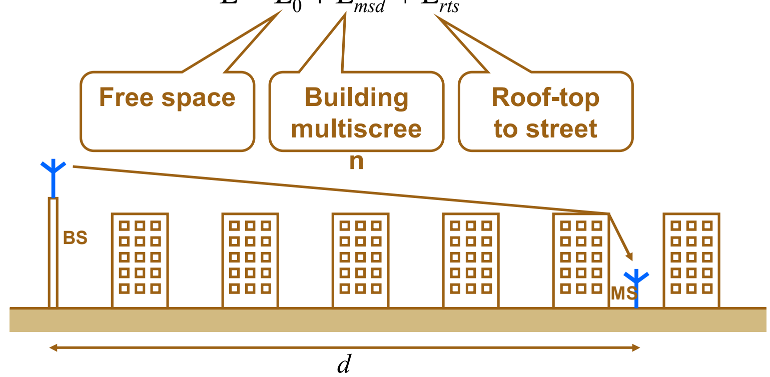
The COST 231-Walfish-Ikegami model How to calculate prop. loss

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



Details about calculations can be found in the appendix.

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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, since it is valid for a particular case

Wideband 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

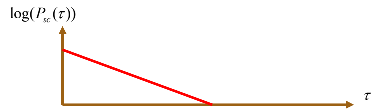
Mean tap power determined by the power delay profile

Power delay profile

Often described by a single exponential decay

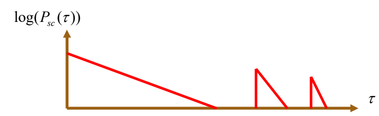
$$P_{sc}(\tau)=\begin{cases} exp(-\tau/S_{\tau}) & \tau\geq 0 \\ 0 & otherwise \end{cases}$$

delay spread



though often there is more than one "cluster"

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



Arrival time

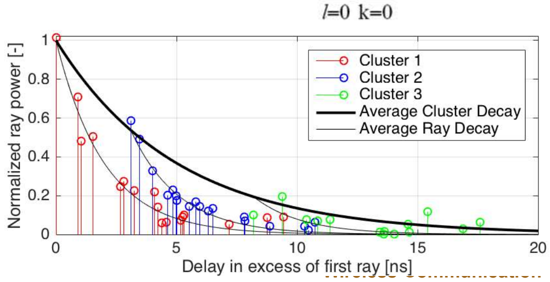
If the bandwidth is high, the time resolution is large so we might resolve the different multipath components

- Need to model arrival time
- The Saleh-Valenzuela model:

cluster arrival time (Poisson)

ray arrival time (Poisson)

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



Double-exponential ray power:

Wideband models
COST 207 model for GSM

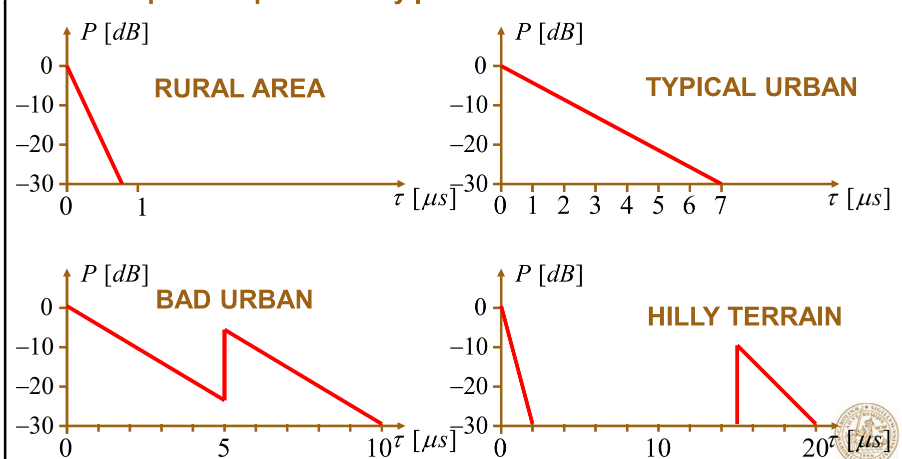
The COST 207 model specifies:

- FOUR power-delay profiles for different environments.
- FOUR Doppler spectra used for different delays.

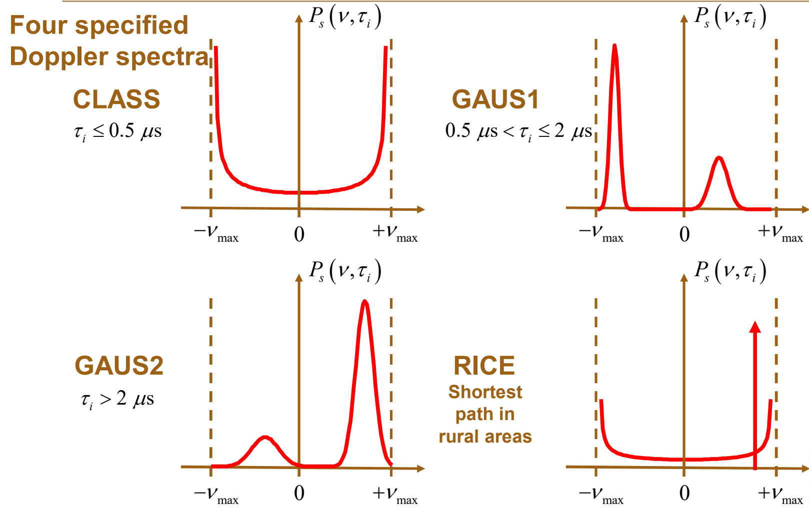
It does NOT specify propagation losses for the different environments!

Wideband models
COST 207 model for GSM

Four specified power-delay profiles



Wideband models
COST 207 model for GSM



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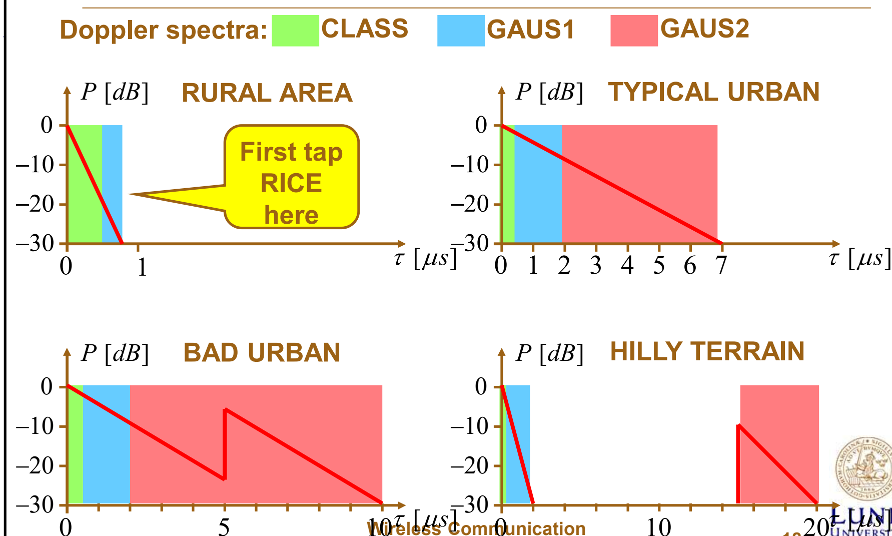
Wideband models
COST 207 model for GSM



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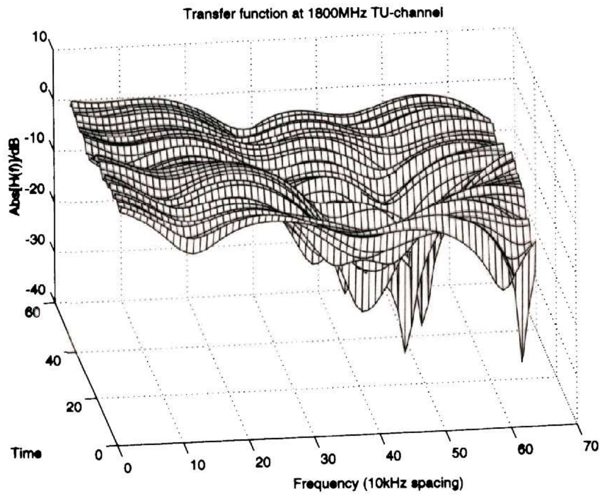
Transfer function, Typical urban



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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.

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Wideband models
ITU-R model for 3G

ns

Tap No.	delay/ns	power/dB	delay/μs	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 of specific antenna pattern

Double directional impulse response

TX position

RX position

number of multipath components for these positions

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

direction-of-arrival

delay

direction-of-departure

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

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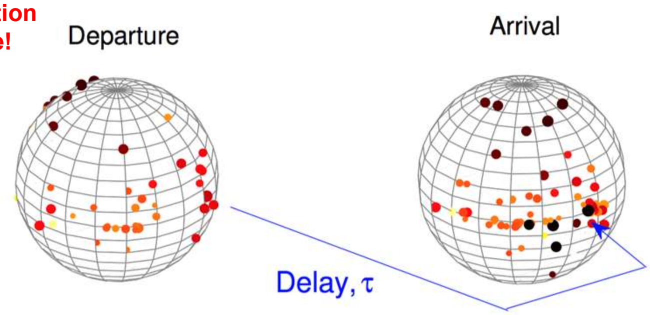
Double directional impulse response with slightly different notation:

$$h_p(\tau,\phi^{\mathrm{Rx}},\theta^{\mathrm{Rx}},\phi^{\mathrm{Tx}},\theta^{\mathrm{Tx}}) = \sum_{n=1}^{N} \alpha_n \delta(\tau-\tau_n)$$
$$\times\, \delta\left(\phi^{\mathrm{Rx}}-\phi_n^{\mathrm{Rx}}\right)\delta\left(\theta^{\mathrm{Rx}}-\theta_n^{\mathrm{Rx}}\right)\delta\left(\phi^{\mathrm{Tx}}-\phi_n^{\mathrm{Tx}}\right)\delta\left(\theta^{\mathrm{Tx}}-\theta_n^{\mathrm{Tx}}\right)$$

Time and location is omitted here!



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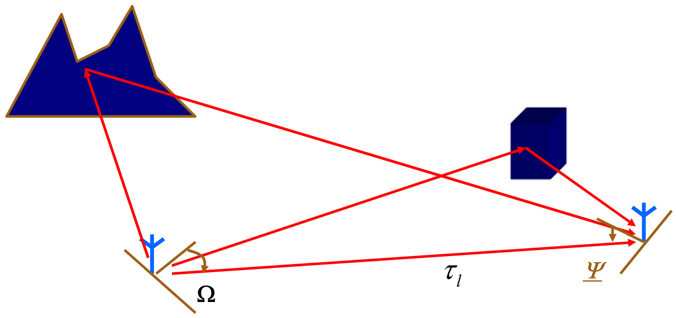
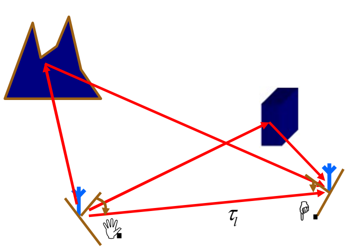
Physical interpretation



Angular spread

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



double directional delay power spectrum

$$DDDPS(\Omega,\Psi,\tau) = \int P_s(\Psi,\Omega,\tau,\nu)d\nu$$

angular delay power spectrum

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

angular power spectrum

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

power

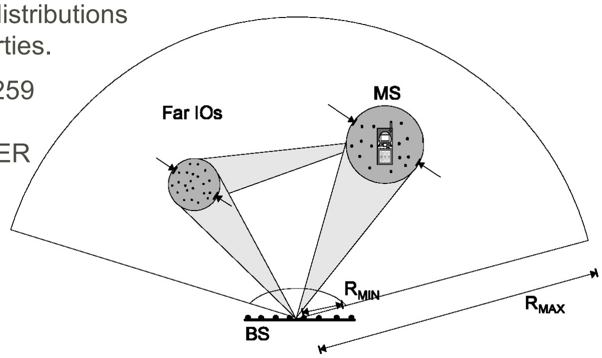
$$P = \int APS(\Omega)d\Omega$$

Geometry-Based Stochastic Channel Model (GSCM)

Assign positions for scatterers according to given distributions

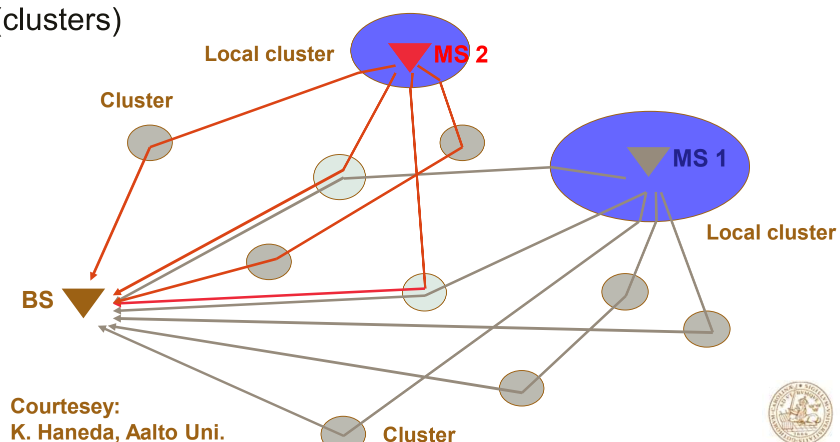
Derive impulse response given the scatterers and distributions for the signal properties.

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.

The MIMO channel

channel matrix

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

signal model

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

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

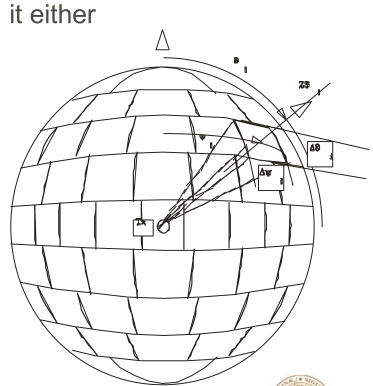
TX antenna sends out rays in different directions

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



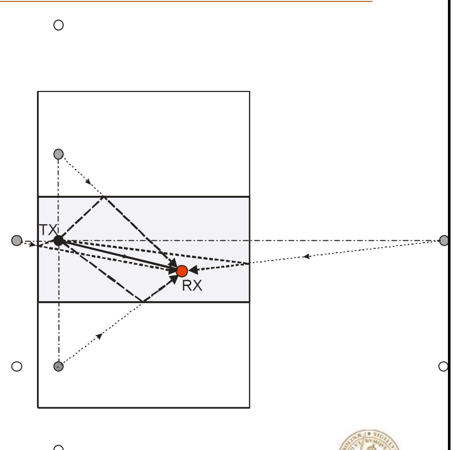
Predicts channel in a whole *area* (for one TX location)

Ray tracing

Determines rays that can go from one TX position to one RX position

- Uses imaging principle
- Similar to techniques known from computer science

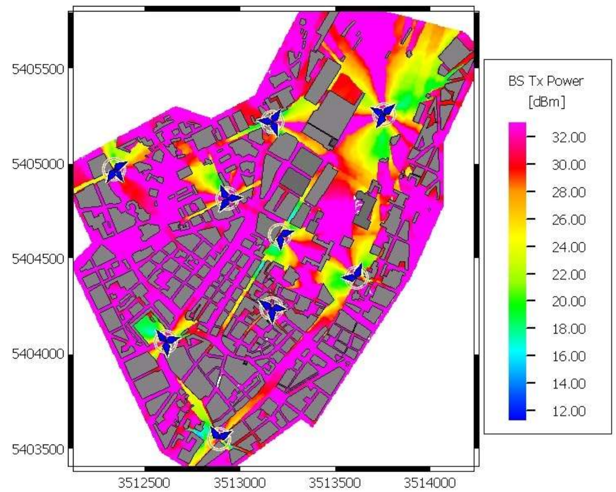
Then determine attenuation of all those possible paths



Example: Ray tracing

Required base station power to connect to a WCDMA cell phone. Example from Stuttgart.

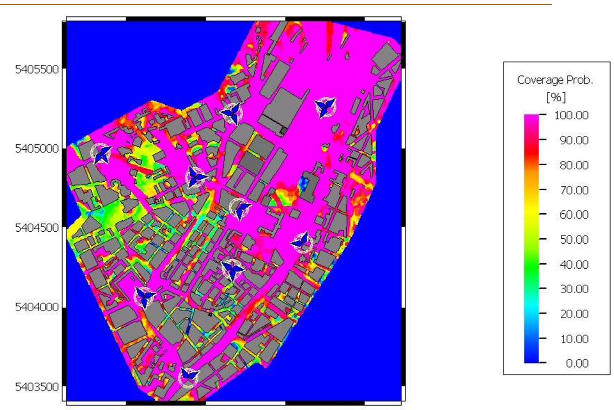
Courtesey: Awe-communications



Example: Ray tracing

Coverage for a WCDMA cell phone. Example from Stuttgart.

Courtesey: Awe-communications Propagation Models



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