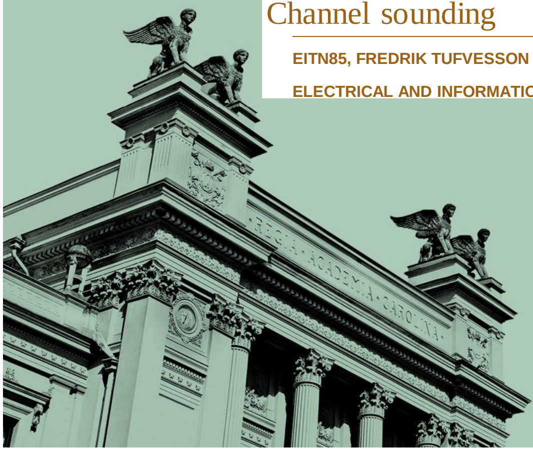
Wireless Communication Channels
Lecture 7: Directional channel models
Channel sounding

EITN85, FREDRIK TUFVESSON

ELECTRICAL AND INFORMATION TECHNOLOGY



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

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

direction-of-arrival

delay

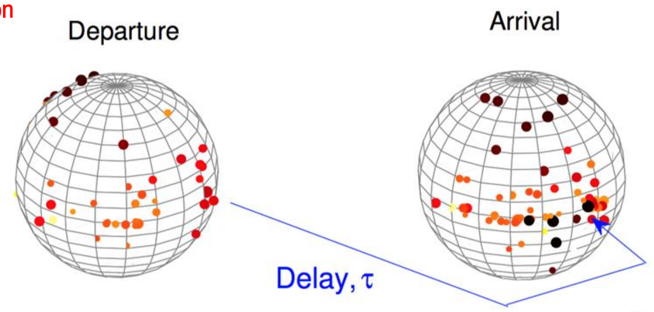
direction-of-departure

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

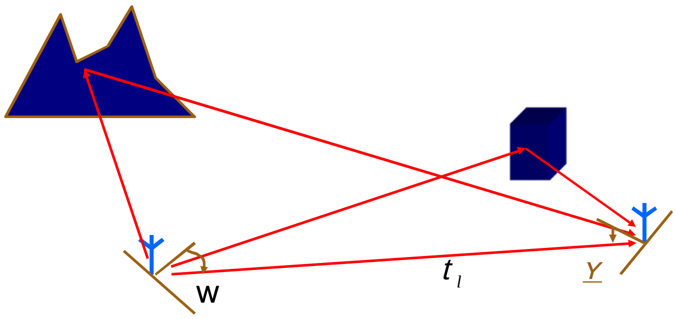
Double directional impulse response with slightly different notation:

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

Time and location is omitted here!



Physical interpretation

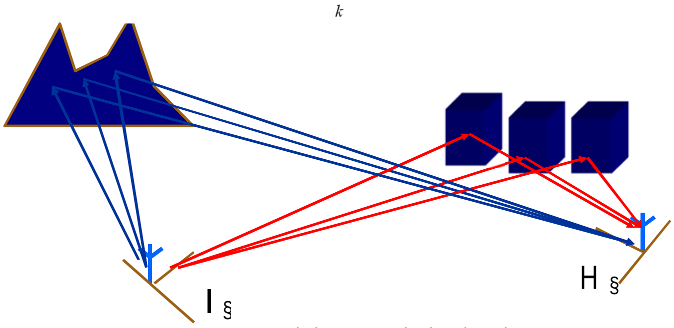


Directional models

- The double directional delay power spectrum is sometimes factorized w.r.t. DoD, DoA and delay.

$$DDDPS(\Omega,\Psi,\tau) = APS^{\mathrm{BS}}(\Omega)APS^{\mathrm{MS}}(\Psi)PDP(\tau)$$

- Often in reality there are groups of scatterers with similar DoD and DoA – clusters $DDDPS(\Omega,\Psi,\tau) = \sum_k P_k^{\mathrm{c}} APS_k^{\mathrm{c,BS}}(\Omega)APS_k^{\mathrm{c,MS}}(\Psi)PDP_k^{\mathrm{c}}(\tau)$



Angular dispersion

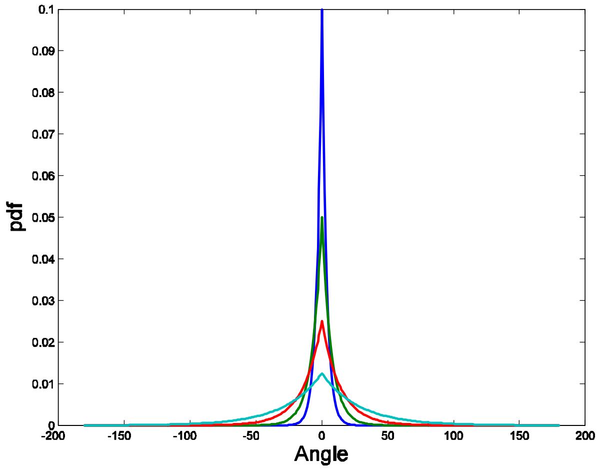
- At the base station the angular spread is often modeled as Laplacian

$$APS(\phi) = \exp(-\sqrt{2}\frac{|\phi - \phi_0|}{S_\phi})$$

- Typical rms angular spread:
  - Indoor office: 10-20 deg
  - Industrial: 20-30 deg
  - Microcell 5-20 deg LOS, 10-40 deg NLOS
  - Rural: 1-5 deg

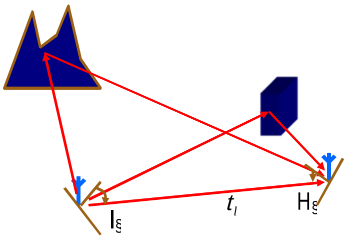
Laplacian distribution, example

Angular spreads 5, 10, 20, 40 degrees



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

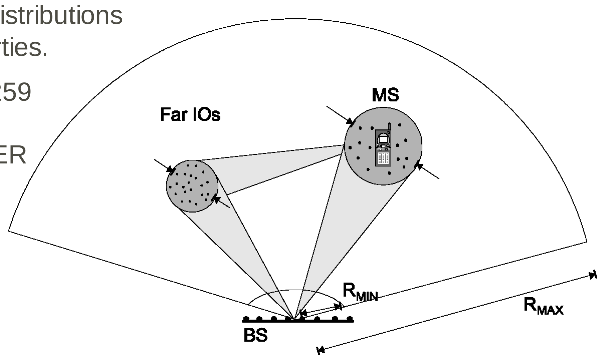
$$P = \int APS(\Omega)d\Omega$$

Geometry-Based Stochastic Channel Model (GSCM)

Assign positions for scatterers according to given distributions

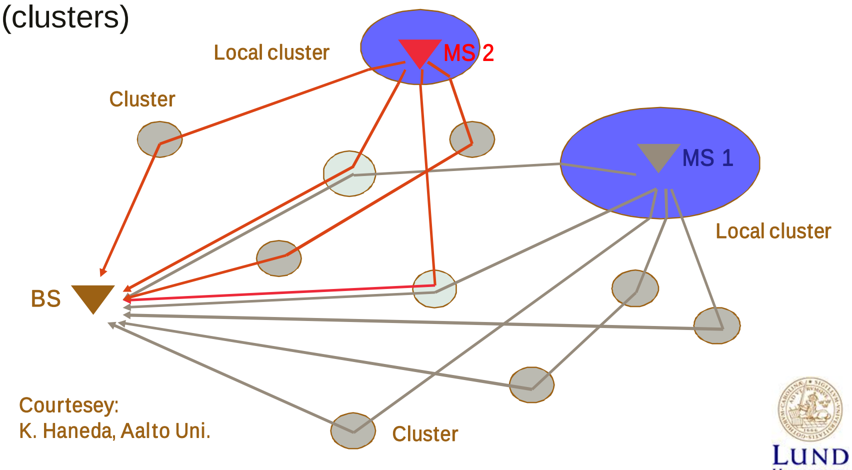
Derive impulse response given the scatterers and distributions for the signal properties.

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)



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MIMO channel

channel matrix

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

signal model

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

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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

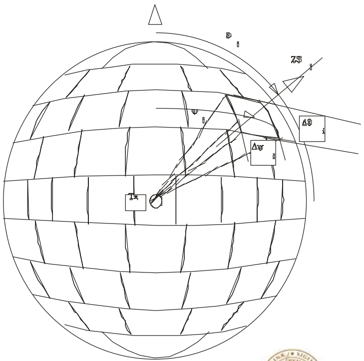
TX antenna sends out rays in different directions

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



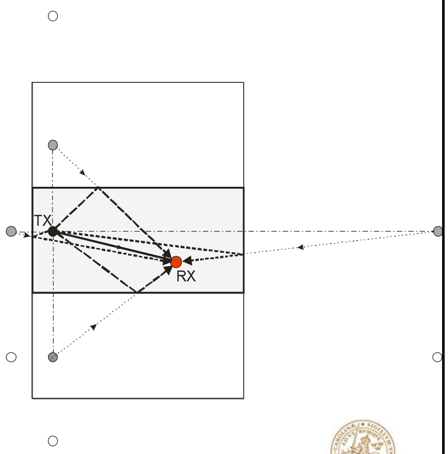
Predicts channel in a whole *area* (for one TX location)

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

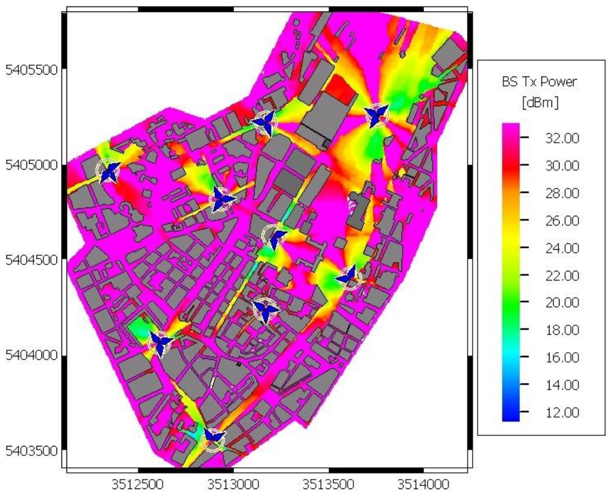
Then determine attenuation of all those possible paths



Example: Ray tracing

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

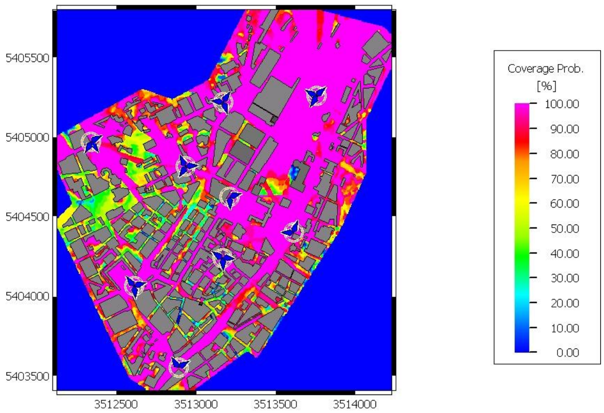
Courtesey: Awe-communications



Example: Ray tracing

Coverage for a WCDMA cell phone. Example from Stuttgart.

Courtesey: Awe-communications Propagation Models



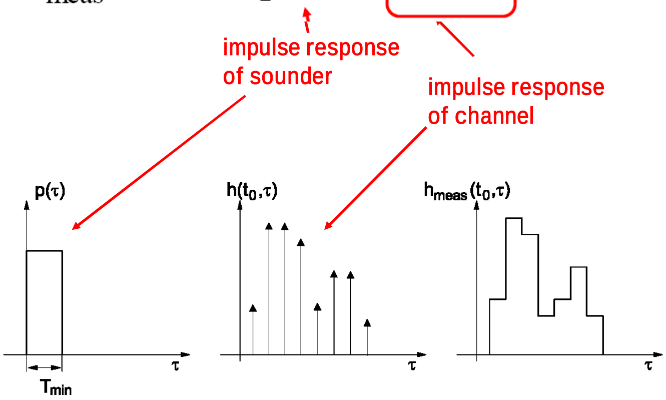
Channel measurements

In order to model the channel behavior we need to measure its properties

- Time domain measurements
  - » impulse sounder
  - » correlative sounder
- Frequency domain measurements
  - » Vector network analyzer
- Directional measurements
  - directional antennas
  - real antenna arrays
  - multiplexed arrays
  - virtual arrays

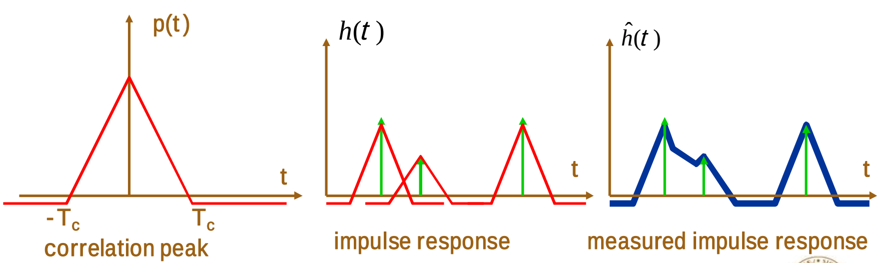
Impulse sounder

$$h_{\text{meas}}(t_i,\tau) = \tilde{p}(\tau) * h(t_i,\tau)$$



Correlative sounder

- Transmit a pseudo-noise sequence and correlate with the same sequence at the receiver
  - Compare conventional CDMA systems
  - Correlation peak for each delayed multipath component



Frequency domain measurements

Use a vector network analyzer or similar to determine the transfer function of the channel

$$H_{meas}(f) = H_{TXantenna}(f) * H_{channel}(f) * H_{RXantenna}(f)$$

- Time domain properties via FFT
- Using a large frequency band it is possible to get good time resolution
- As for time domain measurements, we need to know the influence of the measurement system

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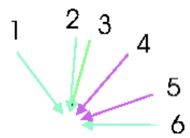
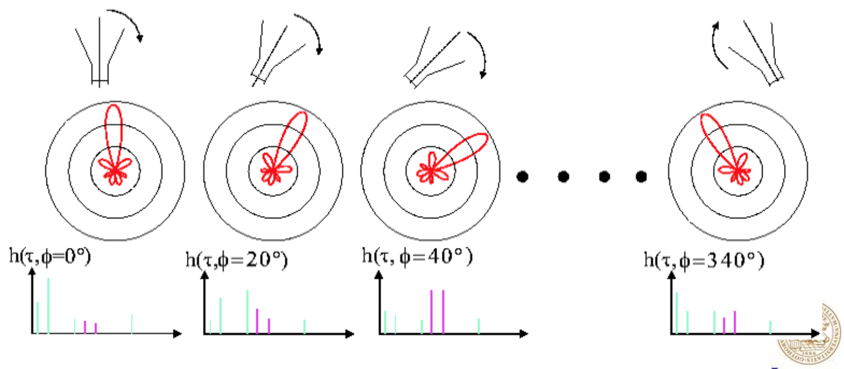
Channel sounding – directional antenna

- Measure one impulse response for each antenna orientation





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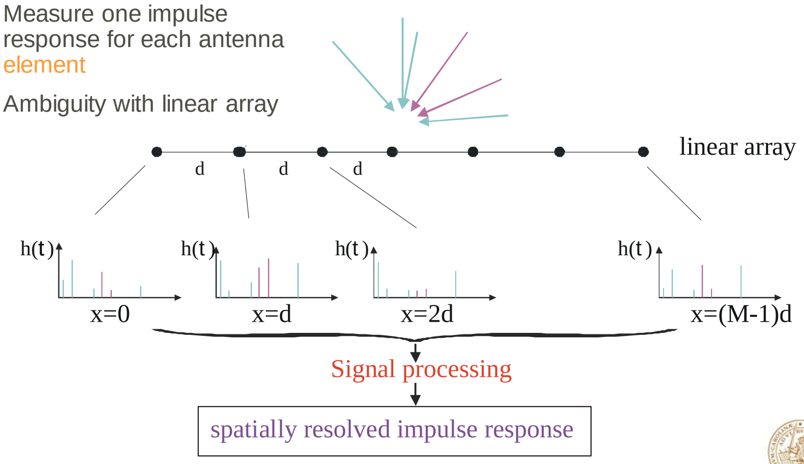
Channel sounding – antenna array

- Measure one impulse response for each antenna element
- Ambiguity with linear array



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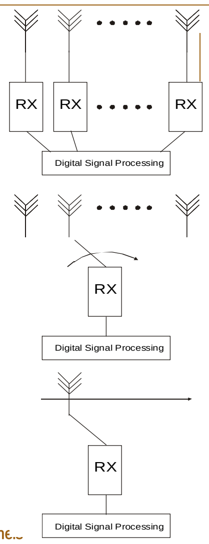
Real, multiplexed, and virtual arrays

- Real array: simultaneous measurement at all antenna elements
- Multiplexed array: short time intervals between measurements at different elements
- Virtual array: long delay

  no problem with mutual coupling



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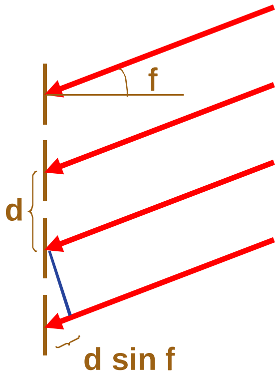
Directional analysis



The DoA can, e.g., be estimated by correlating the received signals with steering vectors.

$$\vec{a}(\phi) = \begin{pmatrix} 1 \\ \exp(-jk_0 d\cos(\phi)) \\ \exp(-j2k_0 d\cos(\phi)) \\ \vdots \\ \exp(-j(M-1)k_0 d\cos(\phi)) \end{pmatrix}$$

An element spacing of d=5.8 cm and an angle of arrival of f =20 degrees gives a time delay of $6.6 \cdot 10^{-11}$ s between neighboring elements

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High resolution algorithms

- In order to get better angular resolution, other techniques for estimating the angles are used, e.g.:
  - MUSIC, subspace method using spectral search
  - ESPRIT, subspace method
  - MVM (Capon's beamformer), rather easy spectral search method
  - SAGE, iterative maximum likelihood method
- Based on models for the propagation
- Rather complex, one measurement point may take 15 minutes on a decent computer

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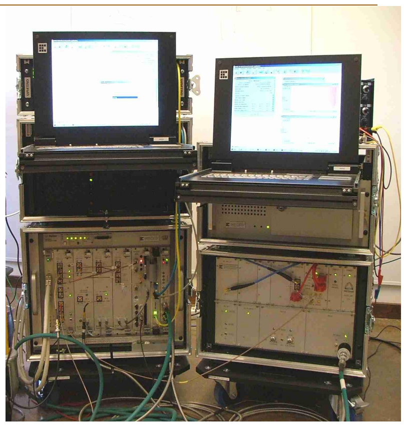
RUSK LUND, our broadband MIMO channel sounder

- A fast switched measurement system for radio propagation investigations at 300 MHz, 2 GHz and 5 GHz.
- Financed by Knut and Alice Wallenbergs stiftelse, FOI and LTH
- MIMO capacity limited by the switches, currently 32 elements at each side.



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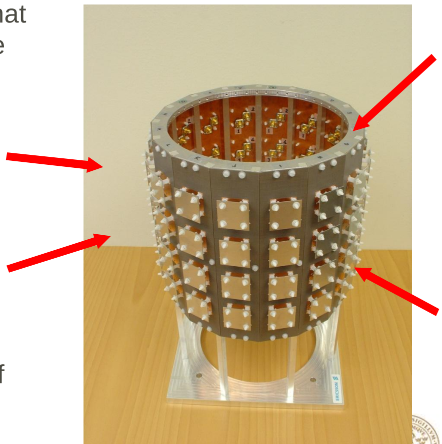
It's all about measuring some delays...

In MIMO systems we use the fact that there are several paths between the transmitter and receiver

These paths are characterized by a

- time delay,
- phase shift,
- attenuation,
- angle of departure and
- angle of arrival

The angle of departure and angle of arrival result in a slight difference in time delay for each of the antenna elements



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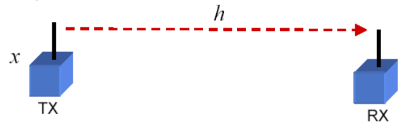
It's all about measuring some delays...

- In practice we measure the transfer functions between each of the antenna elements, and we calculate the parameters of interest



No diversity (SISO):

$$y = hx + n$$

TX&RX diversity (MIMO):

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_{1,1} & h_{2,1} \\ h_{1,2} & h_{2,2} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix}$$

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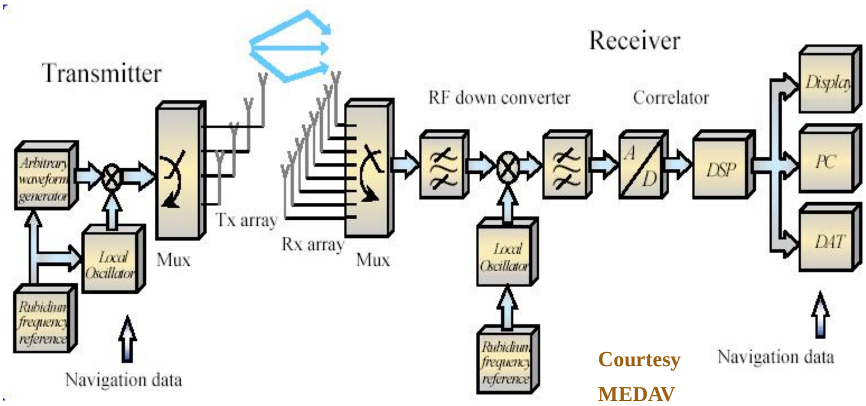
Working principle



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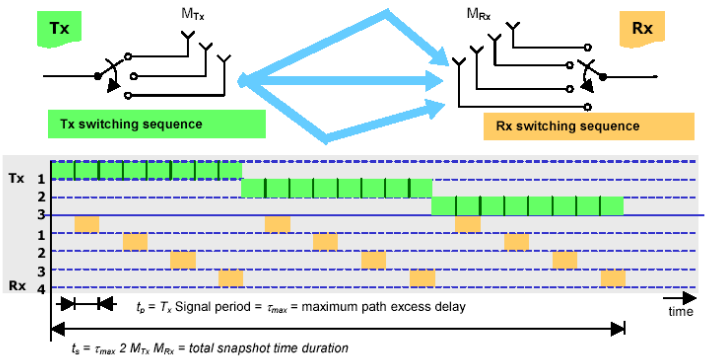
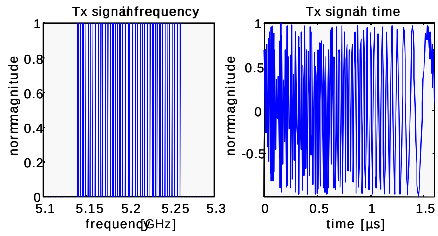
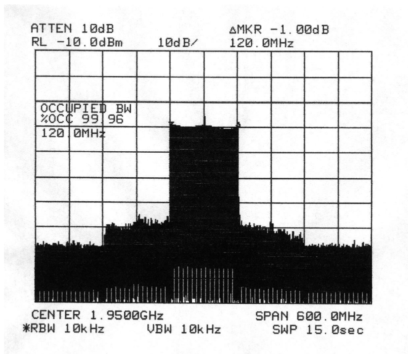
Timing diagram



Test signal – Multicarrier spread spectrum





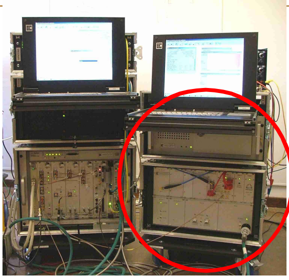
MSSS - Test Squence

- **periodic broadband Signal**
- **high Correlation Gain**
- **low Crest Factor**
- **inherently band limited**
- **flexible in generation**
- **multiband possibility (Up- /Downlink)**

The measurement system

- 200 kg of batteries to allow for 6 hours of mobile measurements
- 640 MHz sampling frequency, to allow high Doppler frequencies
- 2 separate PCs to manage the data flow from the A/D converters
- Oven controlled rubidium clocks to maintain synchronization during wireless measurements
- GPS and wheel sensors to position the system
- Broadband patch antennas with 128 antenna ports at 2.6 GHz
- Circular 300 MHz antennas with a diameter of 1.5 m

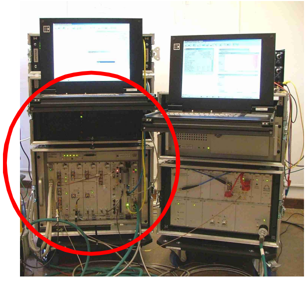
RUSK LUND transmitter



- bandwidths: up to 240 MHz
- frequency grid 10 MHz
- max. power 500 mW, with possibility for 10 W external amplifier
- carrier frequency ranges
  - 2200 – 2700 MHz,
  - 5150 – 5750 MHz
  - 235-387 MHz (20W)
- Power Supply 24 V DC and 230 V AC

- Baseband (Arbitrary Wave Form) Signal Generator
- Frequency Synthesizer
- Rubidium Reference
- Modulator
- Power Amplifier
- MIMO Control Unit
- GPS

RUSK LUND receiver



- GPS Receiver
- Odometer Interface
- total amplification 72 dB
- AGC dynamic range 51 dB , adjustable in 3 dB steps,
- intermediate frequency 160 MHz
- bandwidth 240 MHz
- Spurious free dynamic range 50 dB

- RF-Tuner
- High Speed ADC
- Automatic Gain Control (AGC)
- MIMO Control Unit
- Rubidium Reference
- High Speed Data Recorder 320 MByte/s, 500 GByte

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Antennas

To get good resolution we want large size arrays

4x16 dual polarized circular patch array

4x8 dual polarized rectangular array

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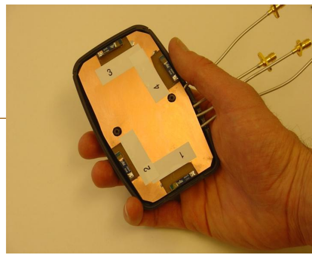
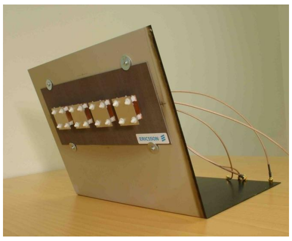
Antennas cont.

300 MHz 7+1 circular sleeve antenna array



PDA device



laptop device

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RUSK LUND, Key Parameters

- RF carrier frequency range
  - 235-387 MHz
  - 2200 – 2700 MHz,
  - 5150 – 5750 MHz
- RF carrier frequency grid:
  - 1 MHz (300 MHz)
  - 10 MHz (2 and 5 GHz)
- Measurement bandwidth up to 240 MHz (null-to-null bandwidth)
- MIMO capability:
  - 16 TX antennas and 8 RX antennas (300 MHz)
  - 32 TX antennas and 32 RX antennas simultaneously (2 and 5 GHZ)
- Power: TX
  - 20 W (300 MHz)
  - 500 mW and 10 W high power extension (2 and 5 GHz)
- Antennas:
  - 7+1 circular monopole antenna array (300 MHz),
  - 4x8 element planar array, dual polarized (2 GHz)
  - 4x16 element circular array, dual polarized (2 GHz)
  - various application specific antennas

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Some real world examples

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