Channel Sounding

S-72.4210 PG Course in Radio Communications

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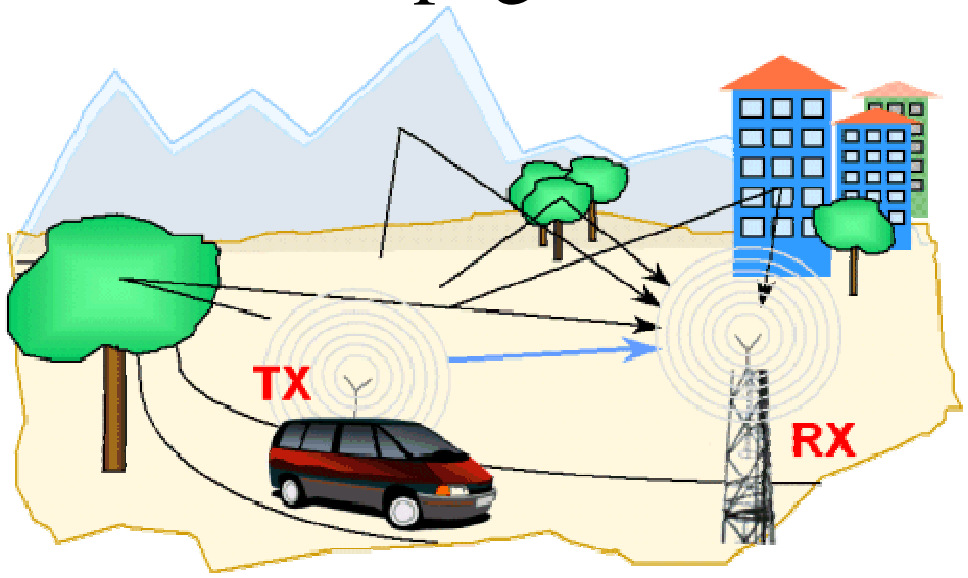
Outline

- Introduction.
- Propagation Scenario and MIMO Channels
- Double-directional model.
- MIMO Channel Sounding.
- Real-World Antenna Arrays.
- Measurements Principle.
- Multidimensional Estimation Algorithms.
- Examples of Measurement Campaign and Scenarios.
- Conclusions.

Introduction

- 3G and 4G mobile communication systems consider multiple antennas at both receiver and transmitter → enhanced channel capacity and QoS.
- Perfect design of this systems requires profound knowledge of the radio channel:
  - time-variant characteristics.
- For precise characterization of the radio channel:
  - Vector Channel Impulse Response (VCIR).
- In MIMO system the VCIR is measured for each transmitting antenna to a configured RX antenna array.
- The time variance of the radio channel requires high speed recording of VCIRs with respect to the maximum Doppler frequency.
- The measurement data can be used directly (stored radio channel) or indirectly (derived channel model) for realistic link- and system- level simulation.

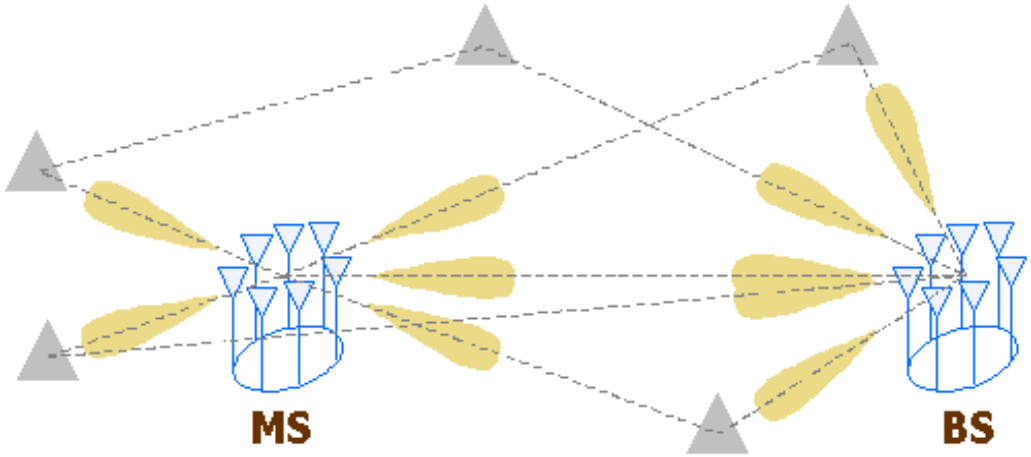
Radio Wave Propagation Scenario



- Multiple propagation paths:
  - Line-of-Sight (LoS), scattering, reflection, diffraction.
- In case of multipaths, the wireless channel may become:
  - Frequency dependent, time dependent and position dependent.

MIMO Channels

- MIMO channel have been investigated by theoretical studies.
- Major benefits: high channel capacity, range extension, interference reduction.
- Spatial signal processing may increase the bit rate at the same bandwidth by exploiting the rich scattering environments and multipath propagation.
- Multi-channel measurements are essential for validating the theoretical approaches under practical conditions.
- Multipath parameters:
  - Direction-of-Departure (DoD)
  - Direction-of-Arrival (DoA)
  - Time Delay
  - Doppler Shift
  - Complex Polarimetric Path Weight Matrix

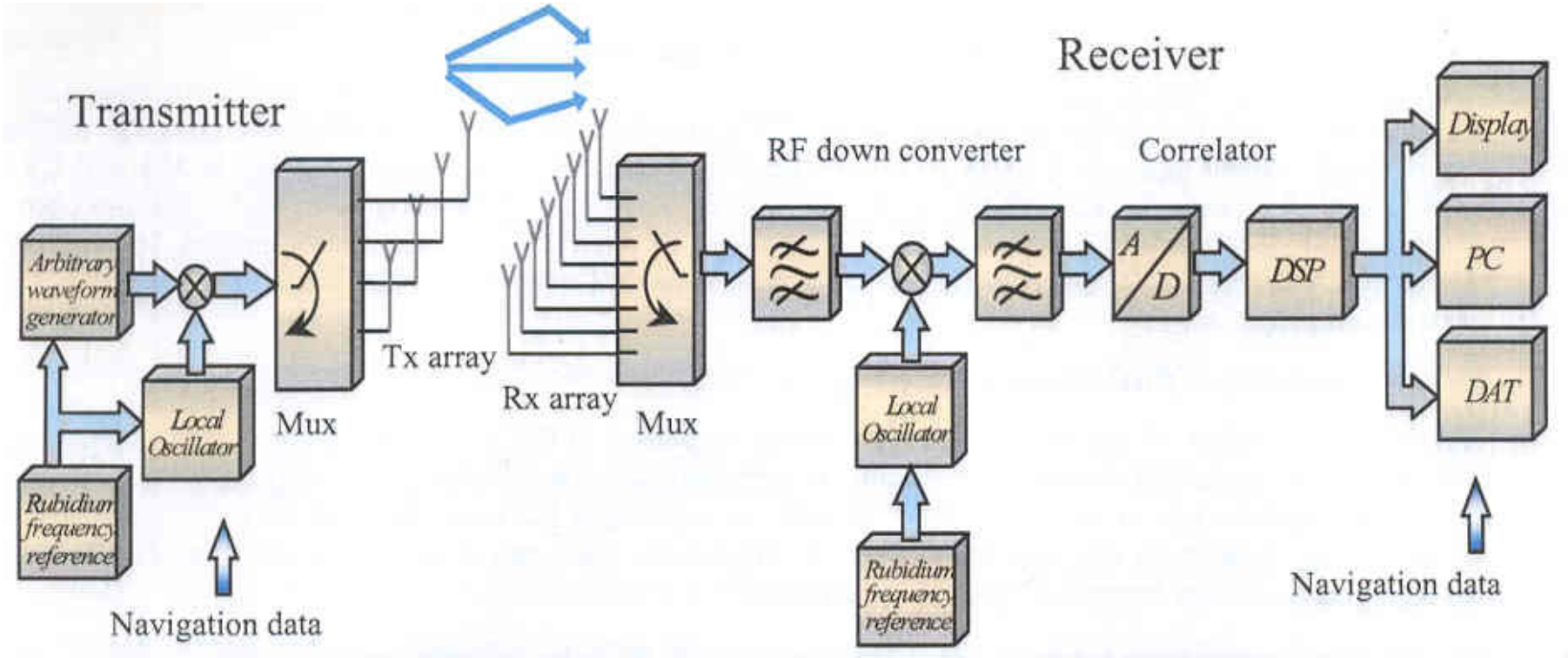


MIMO Channel Sounding

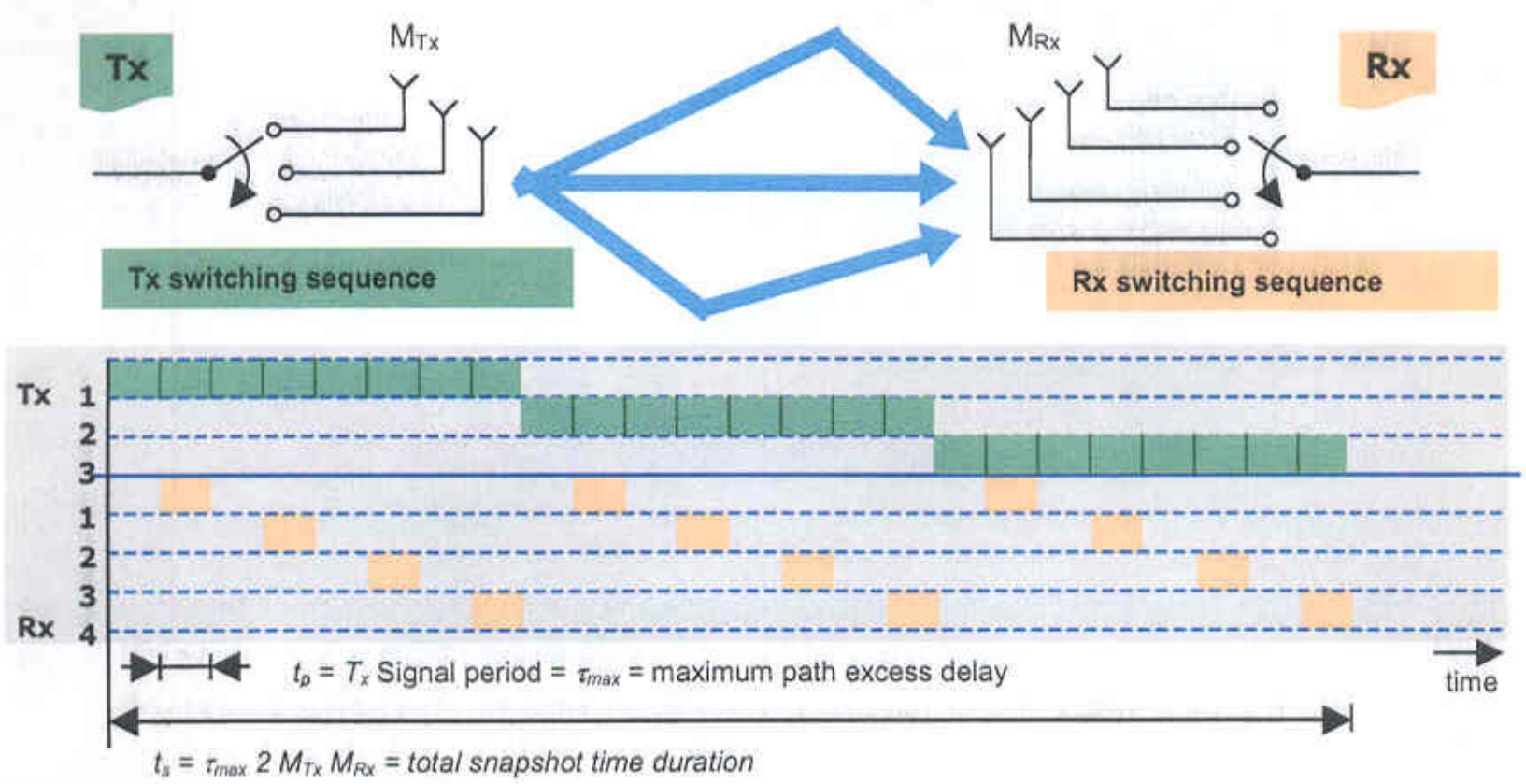
- The presented broadband MIMO channel sounder applies correlation technique.
- The radio channel is excited by a broadband multi-tone test signal.
- Real-time acquisition of the VCIR is required for correct estimation of the Doppler-shifted paths and for complete retrieval of path statistics.
- The transmitter provides a periodic test sequence.
- At the receiver the arriving test signal is correlated with a local copy of the test sequence.
- Due to the impulse-like auto correlation function of the test sequence, the correlator output provides the measured channel impulse response.

MIMO Channel Sounding

- Block diagram of a RUSK MIMO channel sounding by MEDAV.



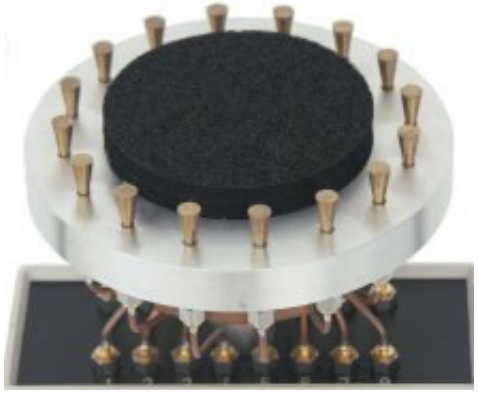
Measurements Timing



VIDEO

Real-World Antenna Arrays

PULPA: Polarimetric Uniform Linear Patch Array, N=8 elements.

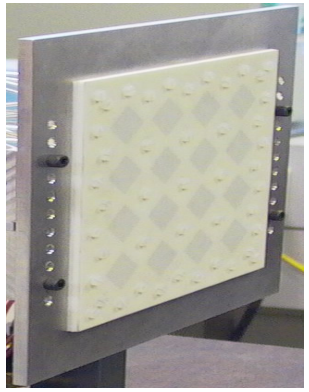


UCA: Uniform Circular Array, N=16 elements.

SPUCPA: Stack Polarimetric Uniform Circular Patch Array, N=96 elements.

Real-World Antenna Arrays

CUBA: Circular Uniform Beam Array, 6 beams.



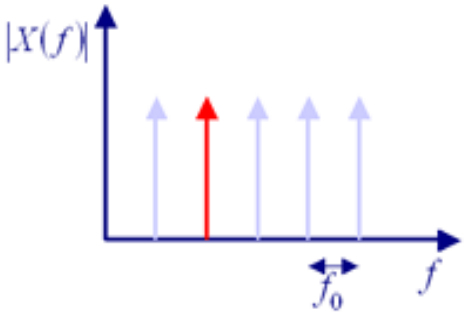
PURPA: Polarimetric Uniform Rectangular Patch Array, N=16 elements.

PSSPA: Polarimetric Semi-Spherical Patch Array, N=21 elements.

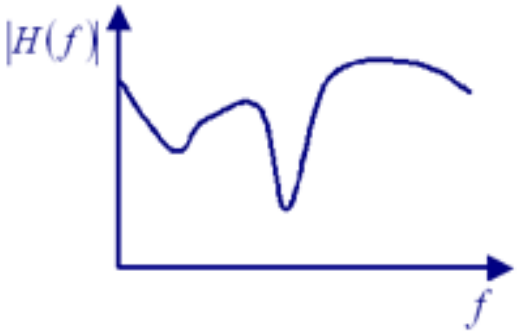
PSPA: Polarimetric Spherical Patch Array.

Measurements Principle: Basic Idea

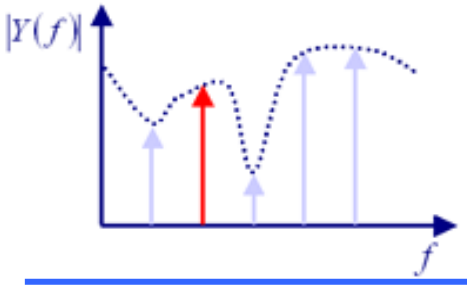
- The measurement principle of the RUSK channel sounders is here described.



- A single sine wave is used for exciting the test circuit. One at a time, all the frequencies within the bandwidth of interest are used.



- The test circuit can be a general unknown system → the radio channel. It shows both magnitude and phase variations due to multipath propagation.

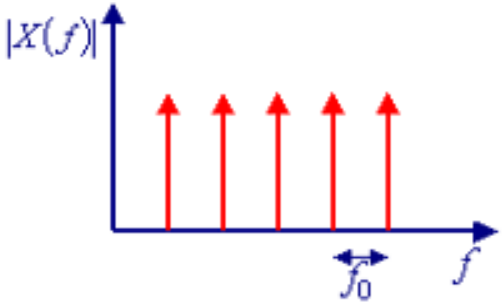


- Hence, the complex frequency response is:

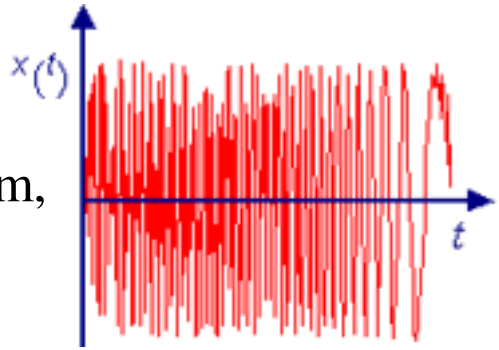
$$H(f) = \frac{Y(f)}{X(f)}$$

Measurements Principle: Test Signal

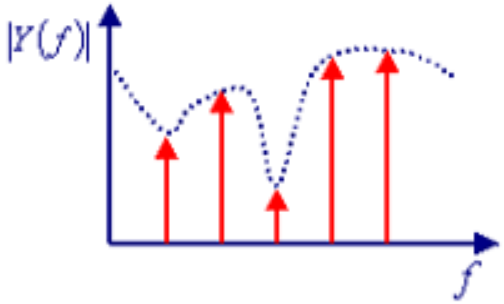
- The sequential frequency testing is too slow → the channel may change rapidly.



- A RUSK channel sounder excites all frequencies simultaneously → test signal.



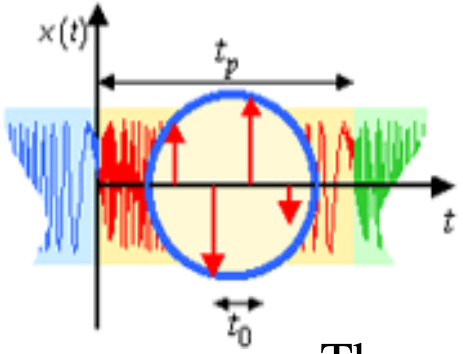
- For avoiding linear power amplifier problem, the phases of the spectral lines have to be optimized→ crest factor can be minimized.



- With this test signal, the frequency response for all frequencies can be measured simultaneously → frequency domain correlation process.

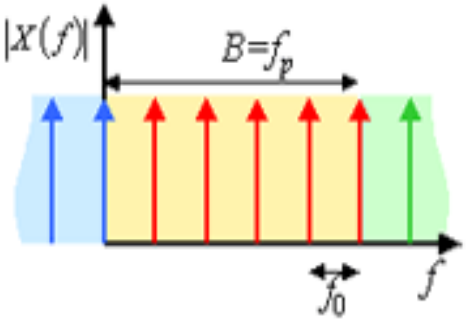
Measurements Principle:

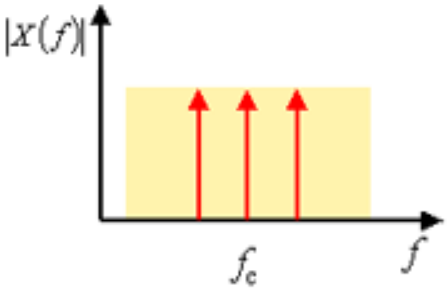
- Relationship between the propagation scenario and the test signal's parameters.



- The test signal is periodic in time. The period must be longer than the duration of the channel´s impulse response → capture the delayed multipaths.

- The required frequency spacing fo=1/t_p can be then computed. The bandwidth B is equal to the minimum sampling rate f_p .

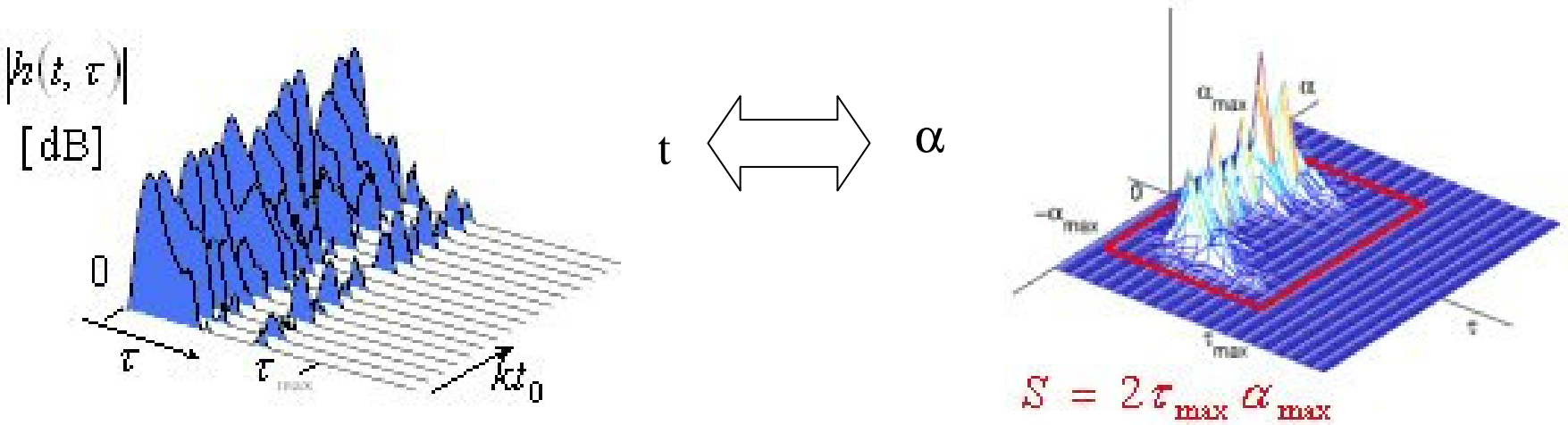




- The excited RF bandwidth can be reduced by omitting the outermost spectral line → easier implementation design.

Measurements Principle:

- At this point we drop the assumption of a time-invariant channel and look at the consequences for the channel sounder's operation.

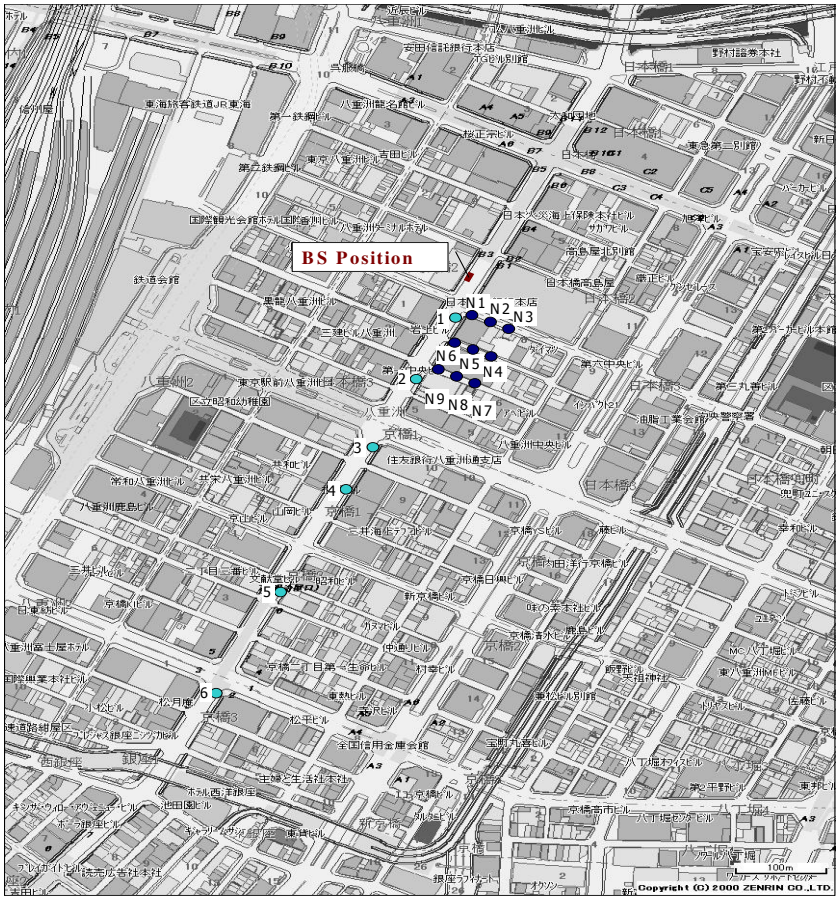


Multidimensional Estimation Algorithms

- Since we have parameterized the radio channel, we have to use estimation algorithm, which exploits the multidimensionality of the data.
- Examples of Multidimensional Estimation Algorithms:
  - Multidimensional ESPRIT
  - SAGE-based algorithms
  - RiMAX
  - RARE
  - Extended Kalman Filer-Based algorithm for Parameter Tracking

Example of Measurement Campaign

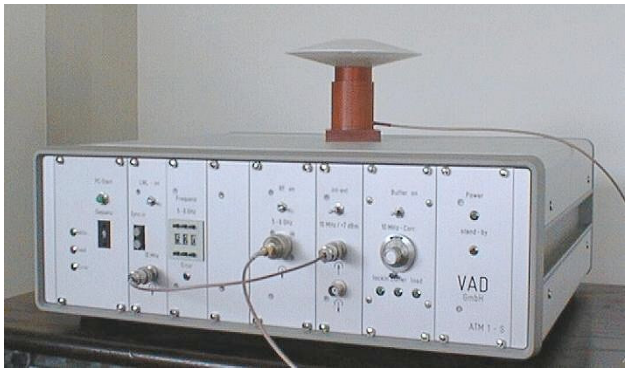
- The field experiments has been carried out in Chuo-Dori Nihonbashi Tokyo from 6.-9. August 2001 [4].
- Measurement frequency: 5.2 GHz
- Measurement bandwidth: 100 MHz
- MS-Antenna: Omni directional
- BS-Antenna Array: 8 Elements ULA

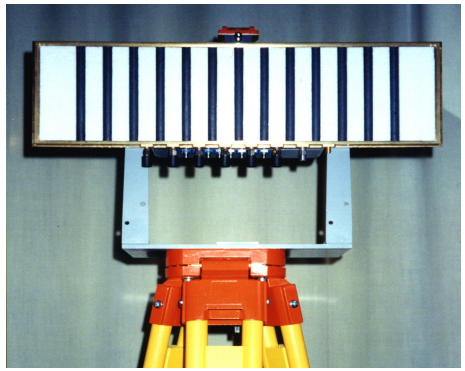


Measurement Hardware/Setup

- Channel Sounder:
  RUSK DoCoMo
- Synchronization:
  2 High Stable Atomic References
  for the Transmitter and Receiver respectively
- Maximum Tx-Power:
  40dBm @ 5.2GHz
- Data-Storage:
  Hard-disk

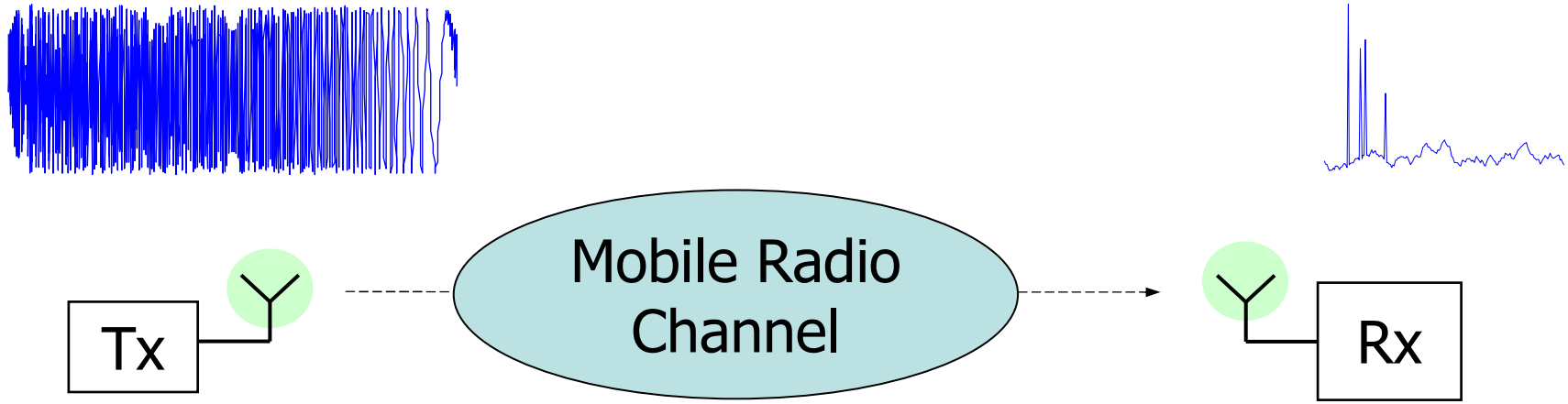
Analog Receiver Unit &
Digital Receiver Unit





Digital Transmitter Unit &
Analog Transmitter Unit

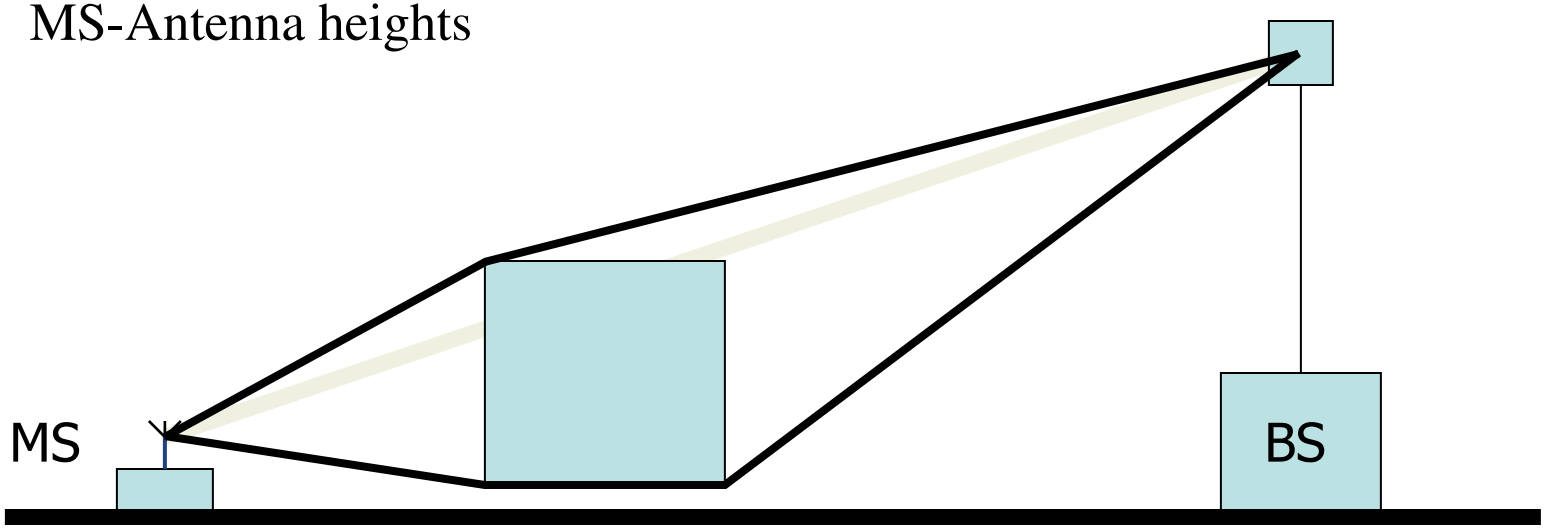
Channel Sounding Principles



- Transmit signal: periodic broadband signal (multi-sinus sequence)
- The channel impulse response can be estimated from the received signal using correlation processing

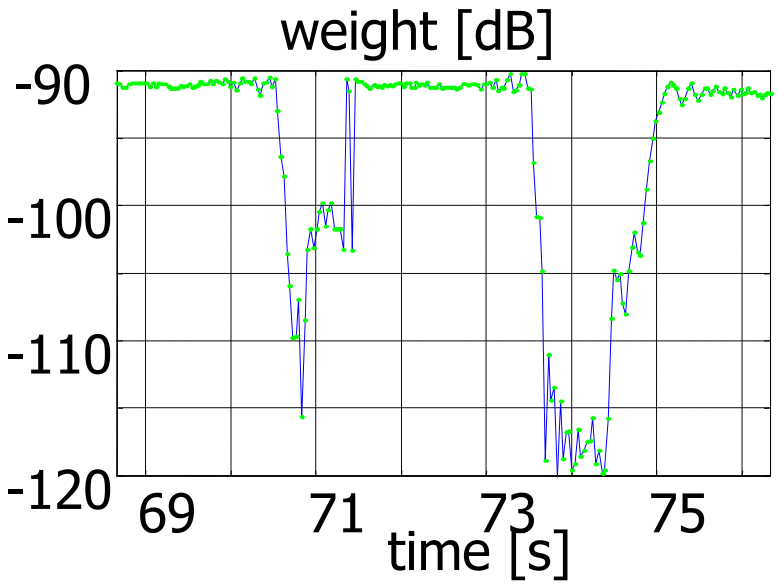
Shadowing

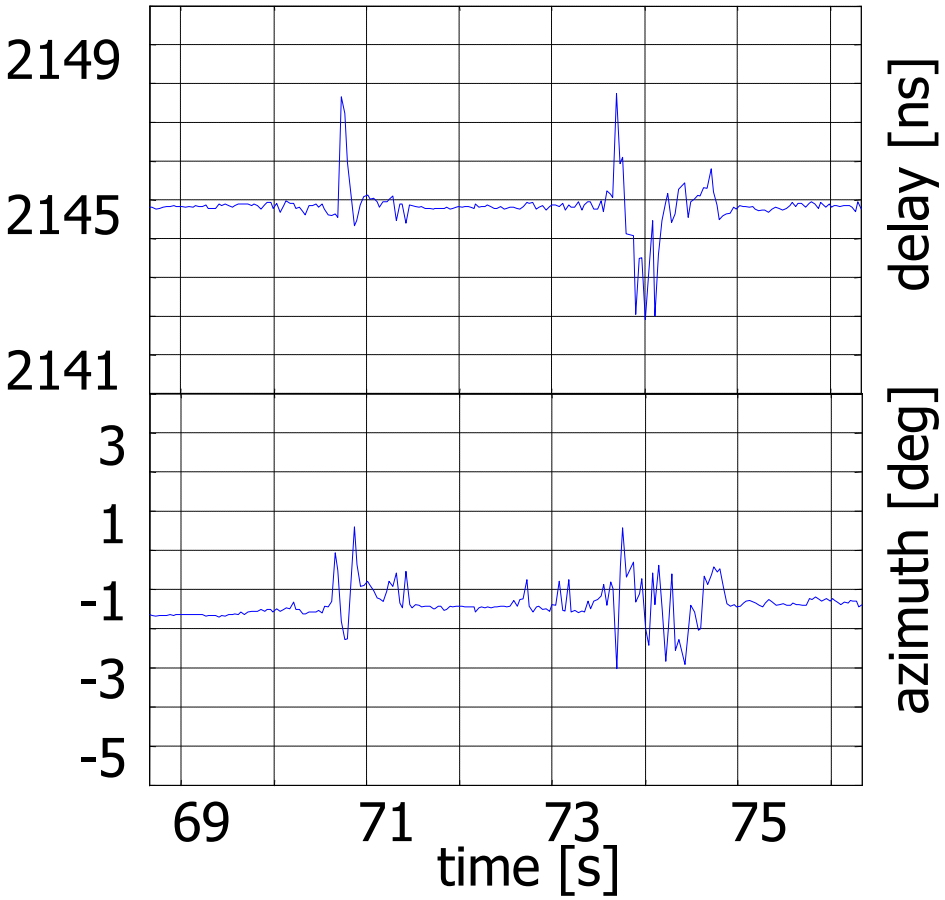
- The received power in shadowed ray condition depends on [4]-[5]:
  - Car size and position relative to BS and MS
  - BS-Antenna heights
  - MS-Antenna heights



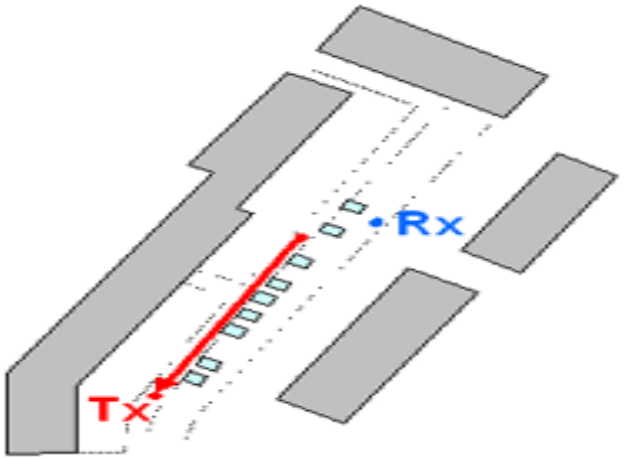
Parameter Change during Shadowing

- Example for estimation of time delays, receive azimuth and path magnitude of a propagation path during two consecutive shadowing events.



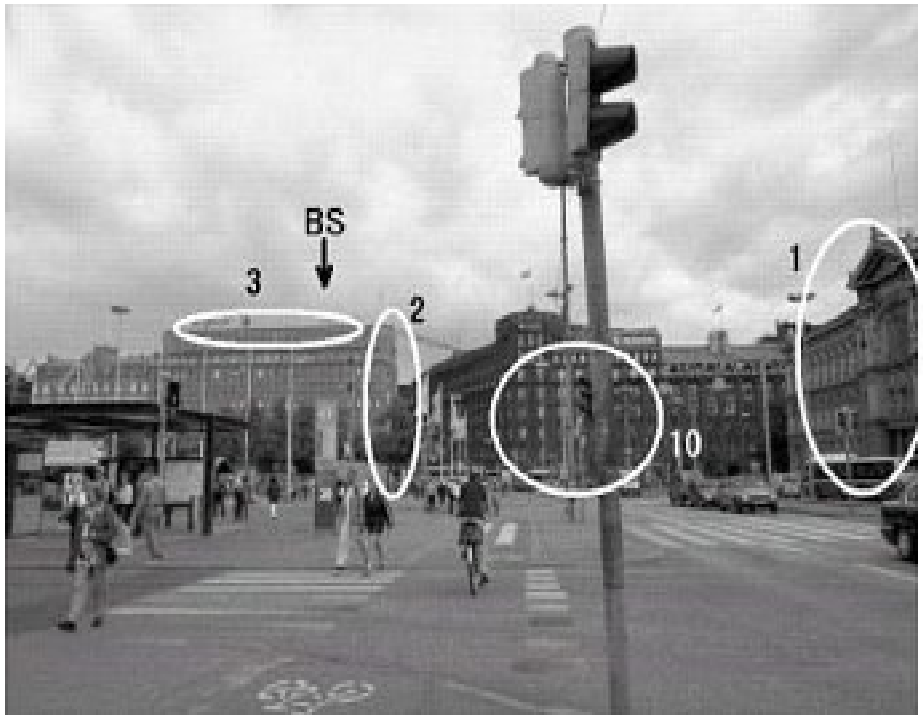


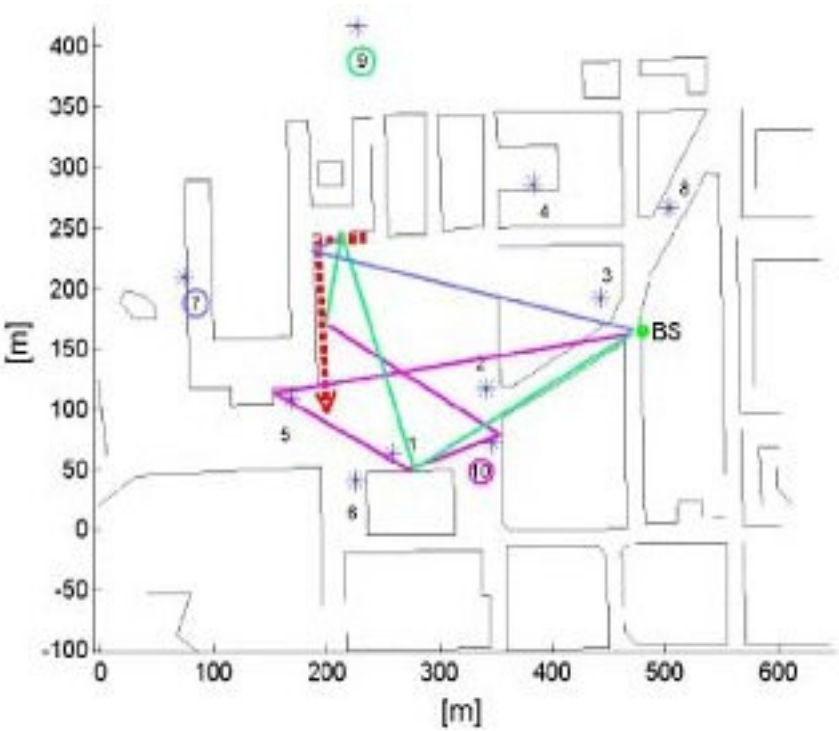
Examples of Measurement Scenario



- TX: transmitter
- RX: receiver
- Location: TU-Ilmenau, Germany.

Examples of Measurement Scenario





- Location: downtown, Helsinki, Finland.

Conclusions

- Multi-channel measurements are essential for validating the theoretical MIMO approaches under practical conditions.
- Channel Sounding is a technique used for :
  - learning the behaviour of the radio channel.
  - building more and more accurate model of the wireless channel.
  - Improving and testing algorithms.
- The measurement data can be used directly (stored radio channel) or indirectly (derived channel model) for realistic link- and system- level simulation.

References

[1] www.channelsounder.de

[2] www.channelsounder.de/medavdocs/RUSK-MIMO-Produktinfo-E_W701WI.096_.pdf

[3]www.tkk.fi/Units/Radio/research/rf_applications_in_mobile_communication/radio_channel/radio_channel_characterization.html

[4] Richter, A.; "Estimation of Radio Channel Parameters: Models and Algorithms". PhD Thesis Dissertation, Technische Universität Ilmenau (TU-Ilmenau), Germany, 2005.

[5] Pesavento, M.; "Fast Algorithm for Multidimensional Harmonic Retrivial", Ph.D. Thesis Dissertation, Electrical Engineering and Information Sciences, Ruhr-Universität Bochum, Germany, 2005.

[6] Haardt, M.; "Efficient One-, Two-, and Multidimensional High-Resolution Array Signal Processing", Ph.D. Thesis Dissertation, Technische Universität Ilmenau (TU-Ilmenau), Germany, 1997.

Homework

- Let us have a car moving at 10 m/sec and transmitting a signal at 5.2 GHz. The channel has a Delay Spread (τ_{max}) of 1.2 μsec. Which is the maximum number of channel which could be measured by the presented MIMO channel sounder?

  Hint: first compute the Doppler Spread α_{max}. Hence, use the inverse of the formula on slide 14.