

# MIMO Vector Channel Sounder Measurement for Smart Antenna System Evaluation

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## Abstract

For the simulation and design of smart antenna transmission principles in mobile radio, precise knowledge of the time-variant directional multipath structure in various radio environments is required. In this paper a new broadband multiple-input-multiple-output (MIMO) vector radio channel sounder is described which uses multiple antennas at the transmitter as well as at the receiver position. The proposed MIMO measurement principle can be effectively exploited to decorrelate multiple propagation paths and, thus, enhance resolution. With the multidimensional Unitary ESPRIT-algorithm applied, joint superresolution estimation of the direction of departure (DOD), the time-delay of arrival (TDOA), and the direction of arrival (DOA) of the propagating waves becomes possible. The measured results can also be used directly for the simulation of combined transmit-receive diversity (MIMO-) transmission principles and space-time (ST) adaptive receivers in a multiuser scenario. Results are referenced which are based on measurements in different locations including a complicated indoor environment as it is typical for industrial WLAN applications.

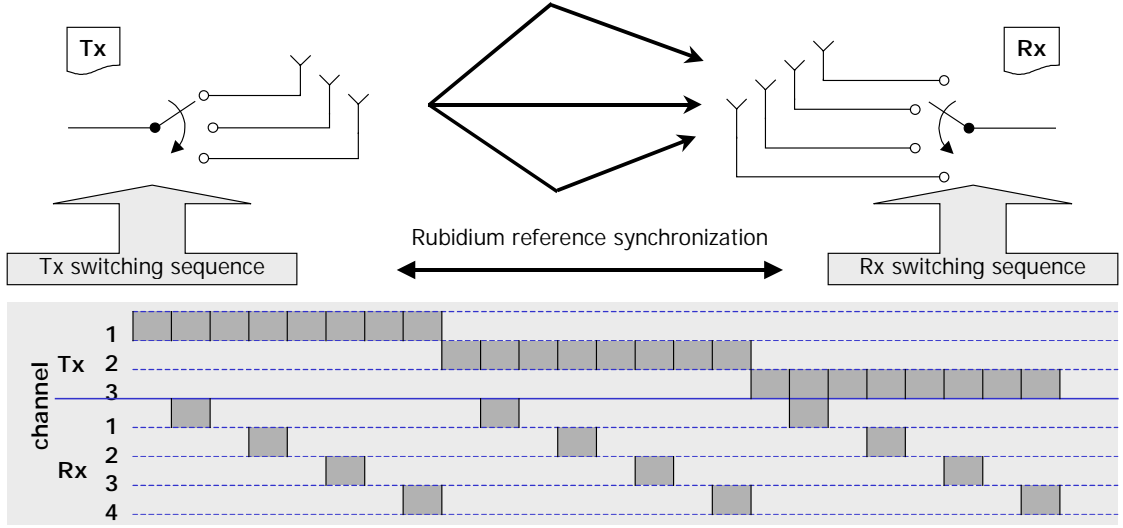
## 1 Introduction

Space-time processing is considered to enhance system performance of 3G and 4G mobile radio systems. High performance systems will be able to use multiple antennas at both the receiver and the transmitter site. The expected benefits include increased capacity and well defined quality of service as a result of diversity gain, source separation, interference reduction, and joint space-time equalization. Proper design, simulation, and performance evaluation of ST adaptive processors, however, require profound knowledge of the radio channel impulse response (CIR) statistics. Although various modeling approaches have been developed, sophisticated measurement methods are definitely required not only to evaluate these models but also to produce CIR data which can be directly used for simulation in a realistic radio environment. Simulation based on measured data has been shown to be absolutely realistic w.r.t. the channel influence as long as the statistics of the time-variant multipath propagation is completely reproduced by the recorded channel response data. This requires a high measurement repetition rate and a long time record capability of the channel sounding measurement equipment.

Also the arrangement of the antenna arrays at the Tx and the Rx position is very important. For the direct simulation approach, it should exactly correspond to the simulated target transmission system. If channel modeling is more important, the antennas should be arranged in a way that channel model parameters can be resolved which describe the environment as accurate and as general as possible.

## 2 Status of SIMO channel sounding

Broadband vector radio channel sounders are already well known for single-input-single-output (SISO) [2] and single-input-multiple-output (SIMO) measurements. In the latter case, a uniform linear antenna array (ULA) is typically used at the measurement receiver that plays the role of the base station (BS) [1]. The most effective measurement devices rely on periodic multifrequency excitation signals, real-time sampling and correlation processing. The highest possible measurement repetition rate for a channel with a maximum path excess delay  $\tau_{max}$  is  $1/\tau_{max}$ . Its lower limit is given by the Doppler bandwidth  $B_{max}$



**Fig. 1** Basic principle of sequential MIMO channel sounding.

which determines the Nyquist sampling frequency of the fast fading CIR taps. Since the delay-Doppler spreading factor  $S = \tau_{\max} B_{\max}$  of typical mobile radio channels is well below 1%, fast sequential acquisition of the antenna outputs is possible for real-time recording of the SIMO – CIR in case of reasonable array dimensions [3]. Superresolution of the channel parameter sets  $(\tau_p, \theta_p)$  which describe the path TDOA and azimuth DOA, is achieved by the subspace- and least squares-based 2D unitary ESPRIT algorithm [4]. Subsequently, the sequence of the instantaneous path weights are estimated by a least squares solution from the time-variant SIMO – channel response data snapshots. Obviously, the angular resolution capability of SIMO channel sounding is limited to the DOA dimension at the Rx only since DOD is not resolved. Omnidirectional antennas are typically used at the Tx which plays the role of the mobile station (MS).

Finally, it has been shown that precise device calibration is required in order to actually achieve the desired superresolution gain especially for coherent channel paths. This is most important in order to reduce the influence of the mutual antenna element coupling [6], [7]. A multipath environment has to be considered as coherent if the paths can not be resolved in the joint delay and angular domain within the limits given by the inverse of the measurement bandwidth and array size, respectively. Therefore, path decorrelation is required in order to enhance the rank of the data matrix which is a prerequisite for resolution. If the parameters are to be estimated from only one single instantaneous snapshot in time (or if the environment is partly static) the only way to achieve spatial path decorrelation at the receiver array is subarray smoothing. However, if two paths are closely spaced in azimuth, the spatial correlation period may be much

larger than the available Rx array dimension. This strongly decreases the efficiency of that procedure. Therefore, even in the case of very small calibration errors, the resolution may be severely limited.

The vector channel sounder measurement results can be directly interpreted as an instantaneous (time dependent) estimate of the channel frequency response  $H(t, f, s)$  resolved in the spatial domain  $s$  [1]. A 3-D Fourier transform (partly or completely realized by the ESPRIT algorithm) results in the joint Doppler/delay/azimuth resolved impulse response  $h(\alpha, \tau, \Theta)$ . If the channel response has to be considered as a stochastic process, further insight is gained by second order correlation analysis. The WSSUS channel model helps to define a 3-D correlation/spectral relation by assuming stationarity in time, frequency, and space  $(t, f, s)$ . That corresponds to uncorrelated behavior w.r.t Doppler shift, delay, and azimuth  $(\alpha, \tau, \Theta)$ :

$$\begin{aligned}
 r(\alpha, \tau, \theta) &= E\{|h(\alpha, \tau, \theta)|^2\} \\
 \bullet R(\Delta t, \Delta f, \Delta s) &= E\{H(t, f, s)H^*(t + \Delta t, f + \Delta f, s + \Delta s)\}
 \end{aligned} \tag{1}$$

The transform relation is a 3-D Fourier transform This result can be used, e.g to evaluate joint or integrated Doppler, delay or angular spreads as well as joint or integrated time-, space-, or frequency-dependent correlation.

### 3 MIMO Channel Sounding

The stated limitations of SIMO channel sounding may be overcome by a MIMO extension which includes multiple antennas at the transmitter as well. For that



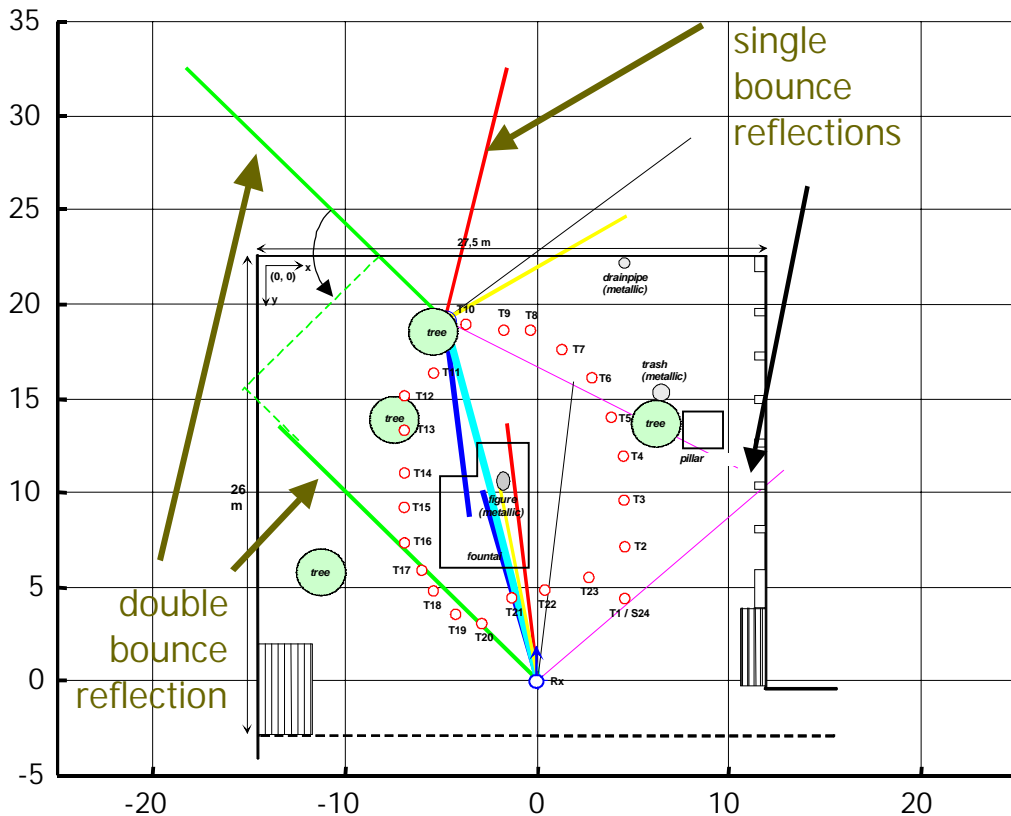


Fig. 3 Joint DOD/DOA/TDOA-estimation result

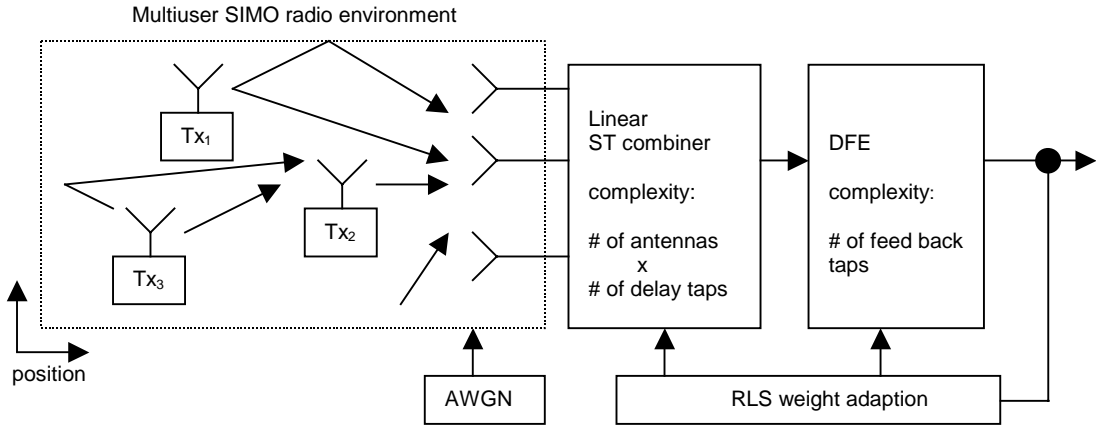
tary ESPRIT application.

The DOD/DOA angles are indicated by the path line orientation at the Rx and Tx position resp. The line length (split up equally to Tx and Rx) gives the TDOA and the line width indicates the path magnitude relative to LOS. Fig. 3 clearly indicates the presence of double bounce reflections which can be identified by the path lines that can not be mirrored to a triangle with the top indicating the reflection point.

## 5 MIMO Link-Level Simulation

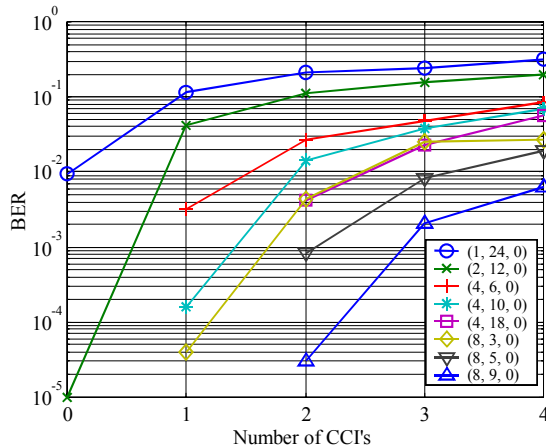
In the design flow of wireless systems it is very important to assess the link performance in a realistic radio environment. Most often, simulation is based on statistical channel models with idealized conditions such as uncorrelated scattering, and perfect tap timing and delay window timing of the receiver. Therefore, the estimated performance figures may be far away of what can be expected in real life. That is even more true if the performance in a multiuser scenario is concerned which causes cochannel interference. On the other hand, a performance test based on a demonstrator tends not only to be very expensive, but in general it will be limited by restrictions in flexibility and availability as well since the variety of different fac-

tors of impact cannot be tested due to expensive hardware and real-time software manipulations. Simulation based on the measured CIR sequences, however, can be much more flexible and informative since the variety of different ST processor principles (e.g. whether it is linear or nonlinear, fractionally or symbol spaced), the tap adaptation rules, the complexity (number of spatial and temporal taps), the timing and synchronization mechanisms, etc. can be tested. MIMO channel sounding gives even more power to measurement based link-level simulation. So in order to simulate a multiuser scenario, some kind of MIMO measurement is required. First investigations have been carried out that still are based on the SIMO sounding principle. The simulated modem principle supposes ST processing at the receiver only and multiple users are supposed to be spread out randomly in the whole radio cell. In this case the strict real-time Tx channel synchronization of the setup in Fig. 1 (which is crucial for DOD estimation as described above) may be released. Then the channel inputs which correspond to the multiple users can simply be taken from consecutive SIMO measurements at different locations of the Tx antenna. In [8], a simulation of an adaptive ST processor in an industrial environment based on real-time CIR measurements has been reported. The simulation scenario is given in Fig. 4 and the channel impulse response statistics has been



**Fig. 4** Principle of Multiuser SIMO measurements and simulation

analyzed in [5]. The simulation results in **Fig. 5** and **6** show very impressively how the performance of a ST processor for equalization and cochannel interference reduction depends on its complexity. Both Figures show uncoded bit error rates for a different number of cochannel interferers (CCI) and varying complexity of the ST-processor with perfect power control simulated for the multiple users. **Fig. 5** and **6** indicate the performance degradation in case of a different number of CCI's. Obviously, reasonable BER can be only be reached if the number or antennas is at least about two times higher than the number of CCI's.

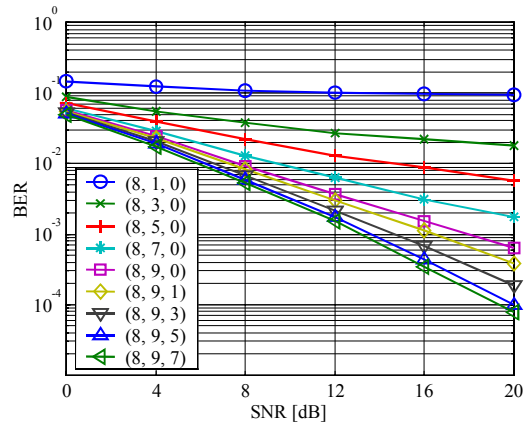


**Fig. 5** BER of a linear ST receiver in an industrial environment in an obstructed LOS scenario (SNR = 20 dB). The numbers given in brackets indicate (# of antennas, # of delay-feed-forward taps, # of decision-feed-back taps).

It should be noted, however, that the number of incoming waves is still much higher than the number of the antennas because of the "multipath richness" of the environment (the angular spread was in the order of 60 degrees azimuth). On the other hand, a minimum number of feed forward delay taps is required in this case (note that the BER performance of a ST-processor completely breaks down if the number of

antennas is smaller or equal to the number of the CCI's even in case of a very high number of feed-forward delay taps). It was also observed that the ability of the linear ST-processor does not depend on the DOA separation between the user-of-interest and the CCI's. This is in strong contrast to the performance of simple beamforming in the angular space only. Therefore, joint space-time beamforming can be considered as very effective for user separation at least in case of a radio environment showing strong multipath and high angular spread. It is even expected that high multipath complexity of the radio environment supports the ability of the ST processor to suppress CCI.

The results in **Fig. 6** show that some additional BER gain is possible if an additional decision-feed-back equalizer (DFE) is used consecutive to the linear ST-combiner.



**Fig. 6** Average BER of a linear ST receiver with consecutive DFE in an industrial environment in an obstructed LOS scenario with 2 CCI's at fixed positions.

Since the DFE is one-channel or scalar only, whereas the ST-combiner is multichannel, this can be considered as a reduced complexity structure which takes advantage of the source separation ability of the linear

ST-combiner and of the equalization ability of a nonlinear DFE.

## 6 Conclusions

The well known sequential SIMO vector radio channel sounder principle can be extended to MIMO measurements. The advantage is the enhanced parameter resolution by improved path decorrelation and additional direction of departure estimation. The measured results can also be used for realistic simulation of adaptive space-time processors in a multiuser SIMO environment. The results clearly show the BER performance in a real radio environment. Further investigations are in progress which include optimization of ST-processing (both linear and nonlinear methods including MLSE) and investigations of MIMO-systems for singles-user capacity enhancement [14].

## 7 Acknowledgements

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