ANTENNA MULTIPLEXING & TIME ALIGNMENT FOR MIMO CHANNEL SOUNDING

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ABSTRACT

This paper addresses real-time multiple-input-multiple-output (MIMO) radio channel sounding. To avoid expensive transmitter-receiver chains antenna multiplexing is well suited for that application. However, the sequential measurement principle entails different time lags between the antenna channels. We show how the observed impulse responses can be aligned using classical interpolation methods as long as the Nyquist criterion with respect to the time variance of the measured mobile radio channel is met. This is important since the time lags, if neglected, may lead to wrong results e.g. in ESPRIT based parameter estimates.

INTRODUCTION

For 3G and 4G mobile communication systems the application of multiple antennas at both the transmitter and the receiver site is considered to enhance the channel capacity [2]. The design of such systems requires profound knowledge of the wideband double-directional radio channel, in this context especially its time-variant characteristic in various radio environments is of interest. One promising way to get the time-variant complex multiple-input-multiple-output (MIMO) channel impulse responses for realistic link- and system-level simulations is to measure various real mobile radio scenarios. These measured complex MIMO impulse responses can than be used in link-level simulations directly [3], or parametric channel models can be derived from them. For the measurement of the MIMO impulse responses a MIMO channel sounder is required. The most obvious but expensive concept to realize such a sounder is to use multiple transmitter and receiver chains at both link ends. But aside from high costs, this concept has furthermore the drawback that the multiple analog transmitter and receiver chains will inevitably have different frequency responses, non-linear distortions, and so on. Therefore to circumvent these problems and of course to keep costs moderate the application of the fast multiplexing principle is very reasonable [1]. Such a channel sounder will sequentially measure the complex single-input-single-output (SISO) impulse responses between all combinations of transmit and receive antennas. All measured SISO impulse responses together yield the complex MIMO impulse response. But it is important that, due to multiplexing, every complex SISO impulse response of the whole MIMO impulse response is measured at a different time. This can be of course tolerated for static radio scenarios. But for the analysis of dynamic scenarios, the temporal offsets between the SISO IRs within one MIMO IR has to be considered. If the Nyquist criterion, with respect to the maximum Doppler bandwidth of the mobile radio channel measured, is met, time alignment of the SISO IRs within a MIMO IR can be implemented using classical interpolation algorithms. There are various reasons why this time alignment is necessary. Firstly if the measured MIMO channel impulse response shall be used in a link-level simulation, all symbols of all transmit chains have to be convolved with the complex SISO IRs at one time instance. Secondly, if we want to estimate channel parameters from the measurements with a super-resolution parameter estimator like the M-D ESPRIT (Estimation of Signal Parameters via Rotational Invariance Techniques) [4] algorithm it is required that all SISO IRs of one MIMO IR are available at the same time instance, since this algorithm is based on a signal model describing the whole channel at one time instance. Neglecting the time lags between the SISO IRs of the measurements, will lead to wrong parameter estimation results of the time-variant radio channel. Generally, for the application of an arbitrary parameter estimation algorithm the temporal offset between the CIRs has to be taken into account!

This paper describes the concept of fast antenna multiplexing for MIMO channel sounding. Furthermore useful interpolation methods for time alignment will be given. The performance of the interpolation will be shown using simulation examples. Finally some parameter estimation results using the ESPRIT algorithm are presented.

MULTIPLEXING PRINCIPLE

MIMO channel sounding requires multi channel acquisition based on multiple antennas at both link ends. Generally that would require parallel transmitter-receiver chains which have to be synchronized carefully. To circumvent this enormous effort a simple multiplexing principle can be used switching all antenna elements at the transmitter and receiver site sequentially. A realization example is shown below (Fig. 1).

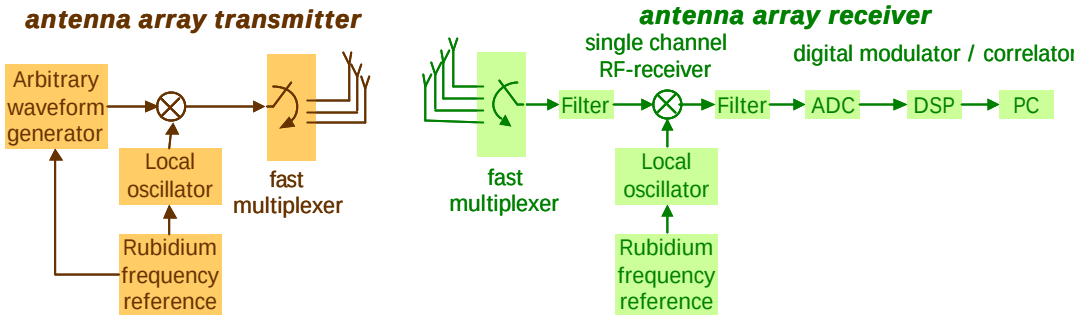

Fig. 1. Realization example of a MIMO channel sounder based on the multiplexing principle

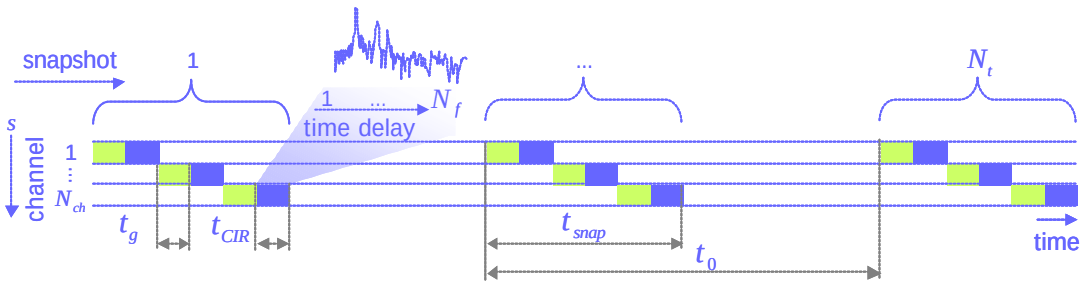

Fig. 2. Time scheme of the multiplexing principle

Fig. 2 shows the multiplexing time scheme in principle. For each transmit-receive antenna combination s (measurement channel index) a complex SISO impulse response of time length t_{CIR} is acquired. Between two neighboring channels a guard interval t_g (e.g. equal to t_{CIR}) is inserted ensuring the steady-state of the measurement system. Therefore to record a complete MIMO impulse response (containing N_{ch} SISO IRs) a total time of $t_{snap} = (t_g + t_{CIR})N_{ch}$ is required. Hence the minimum snapshot time interval t_0 is equal to t_{snap}.

TIME ALIGNMENT

Due to the multiplexing principle time lags between the SISO IRs result within a MIMO snapshot which can be aligned using interpolation methods, provided that the Nyquist sampling rate regarding the maximum Doppler- bandwidth $2a_{scen}$ in the measurement scenario is met. Hence, the snapshot time interval t_0 has to be chosen equal to or smaller than $(2a_{scen})^{-1}$. In other words the maximum measurable Doppler shift a_{meas} that is related to t_0 has to be equal or greater than a_{scen}. The relative time lags $t_{lag}(s)$ with respect to channel number one vary by the measurement channel index s:

$$t_{lag}(s) = (s-1)\frac{t_g + t_{CIR}}{t_0} \quad \text{with} \quad s = 1(1)N_{ch}. \tag{1}$$

An obvious method to align all channels is the interpolation of N_t snapshots in the Doppler frequency domain using suited interpolation filter transfer functions (e.g. rectangular shaped) as follows:

$$G_{\text{int}}(m,s) = e^{-j2\pi t_{lag}(s)\left(f_c t_0 + \frac{m}{N_t}\right)} \quad \text{with} \quad m = -\frac{N_t - 1}{2}(1)\frac{N_t - 1}{2}. \tag{2}$$

It is important to realize that the filter transfer function has to be designed with respect to the carrier frequency f_c. Alternatively the interpolation can be performed in the (snapshot) time domain. Applying a Fourier transform ($m \rightarrow n$) to (2) the following weighting functions of the interpolation filters (of odd length N_{taps}) result:

$$g_{\text{int}}(n,s) = e^{-j2\pi t_{lag}(s) f_c t_0} \operatorname{sinc}\left(n - t_{lag}(s)\right) \text{ with } n = -\frac{N_{taps}-1}{2}(1)\frac{N_{taps}-1}{2}. \tag{3}$$

In Fig. 3 a simple example for both methods is given. The interpolation filters can be improved by application of suited window functions if $a_{scen} < a_{meas}$.

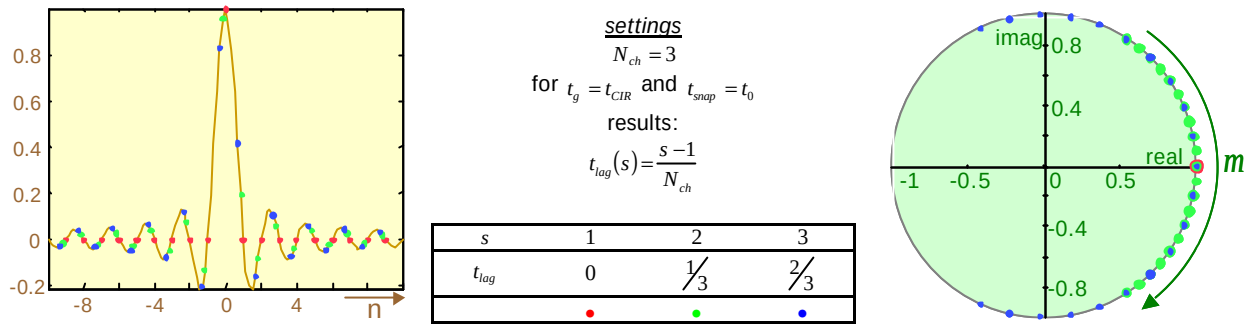

Fig. 3. Real-valued interpolation filter coefficients in time domain (left) and complex filter transfer functions (right) – (influence of the carrier frequency not shown)

SIMULATIONS

To demonstrate the performance of the discussed methods some simulation results will be given. For that purpose a simplified scenario has been simulated using an uniform linear array at the receiver site and a single antenna at the transmitter site (see Fig. 4). The transmit antenna was moved in various directions starting a fixed point. The *measurement* parameters have been set to typical (realistic) values. The motion speed has been varied at a fixed snapshot time interval t_0.

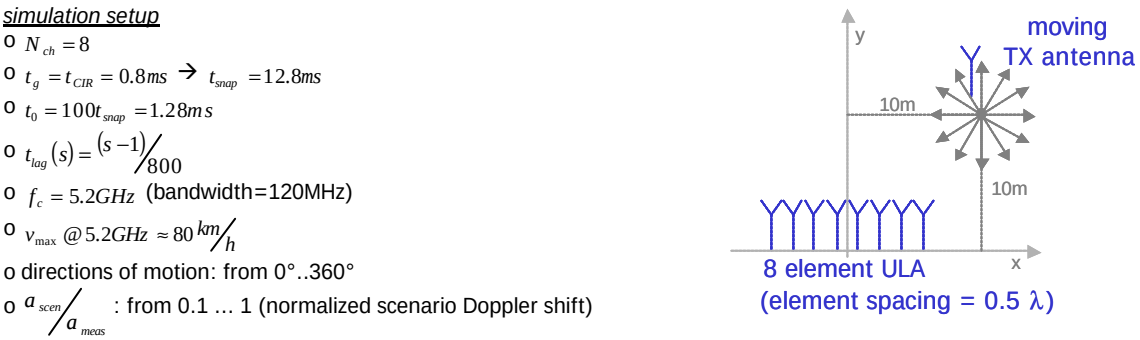

Fig. 4. Simulation setup parameter (left) and simulation scenario (right)

Using this setup multiplexed MIMO snapshots and additionally reference MIMO snapshots (based on a simultaneous acquisition) have been generated. The multiplexed MIMO snapshots were interpolated using sinc-filters of different length. After that a comparison between the reference and the interpolation result has been performed. For that purpose the rms deviation was calculated (cf. Fig. 5, left). It can be seen that significant deviations result for short filter lengths and large scenario Doppler shifts (corresponding to high motion speeds). Similarly the interpolation gain, depicted in Fig. 5 (right), behaves. For large filter lengths and medium scenario Doppler shifts an obvious improvement can be observed.

Furthermore the generated simulation data have been used to demonstrate the influences on the 2-D ESPRIT algorithm. In Fig. 6 the parameter estimation results are shown in dependence on the direction of motion and the normalized scenario Doppler shift. The upper row demonstrates the path parameters (time-delay, direction of arrival, magnitude of the path weight) that result if interpolation is not applied and the lower row if interpolation is applied. The red lines characterize the expected path parameters that are a result of the ESPRIT algorithm using the reference data. Due to the

multiplexing principle the simulation data were influenced in such a way that the ESPRIT algorithm identifies much more paths than included (real and additional virtual paths). In order to distinguish between strong and weak paths, the weaker ones have been marked by brighter colors (below –20dB).

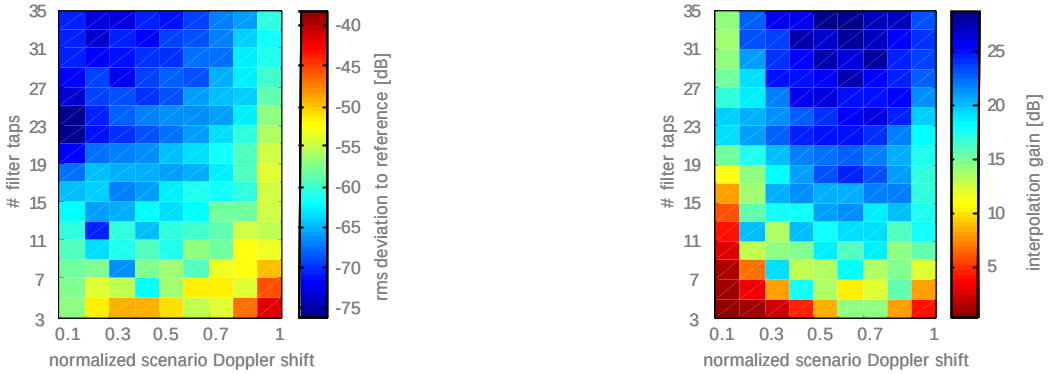

Fig. 5. rms deviation of the sinc-interpolated snapshots to the reference snapshots (left) and the interpolation gain (right)

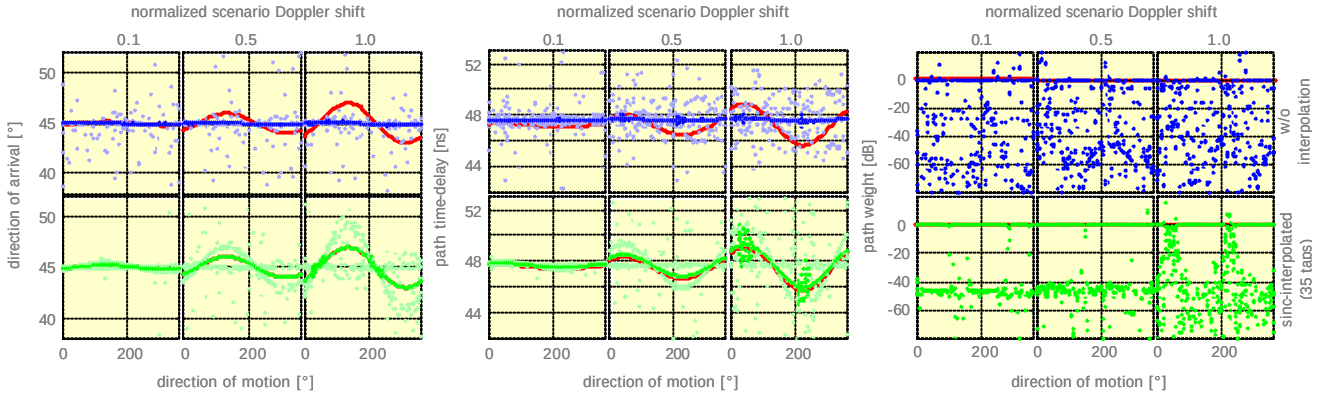

Fig. 6. Parameter estimation results using 2-D Unitary ESPRIT (red lines stand for expected parameters)

The ESPRIT parameter estimation results demonstrate the improvements if interpolation is applied. The directions of arrival and the time-delays match with the reference parameter mostly.

SUMMARY

This paper has described an antenna multiplexing principle for MIMO channel sounding application. It was shown that the resulting time lags can be aligned using suitable interpolation methods as long as the Nyquist criterion regarding the maximum scenario Doppler shift is fulfilled. Especially the influence on the M-D ESPRIT algorithm was demonstrated.

ACKNOWLEDGEMENTS

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