Double-directional Radio Channel Measurements – What We Can Derive from Them

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Abstract: Double-directional is the feature of propagation that is utilized in multiple-input multiple-output (MIMO) systems with antenna arrays at both ends of the radio link. This contribution discusses which information can be derived from measured/estimated directions of arrival (DOAs) *and* directions of departure (DODs), and establishes a new parameter describing the multipath spread from both link-ends. We find that the ”multipath component separation” combines delay, Doppler, and (double-) angular dispersion. Evaluation of indoor and outdoor environments show the usefulness and the limits of the multipath component separation concept. We also show statistics of the number of multipath components in these environments. In many instances, we observe more than a single reflection/scattering point that a wave passes before reaching the receiver.

Introduction

The investigation of smart antennas has lead to better understanding of the radio channel, and to more accurate and realistic spatial channel models [1], [2]. To identify useful multipath components and to suppress undesired co-channel interference has great potential in smart antennas. Multi-element antennas at both link ends establish a spatial MIMO channel. We call this the *double-directional radio channel*, in contrast to the ordinary directional channel (Fig.1). A most exciting reason for investigating the MIMO channel is the huge potential for transmission capacity [3]. In recent simulations of this capacity [4], it turned out that the channel model chosen for such simulations bears great impact on the resulting capacity. The ”multipath richness” of an environment [5] is an important parameter for capacity assessment.

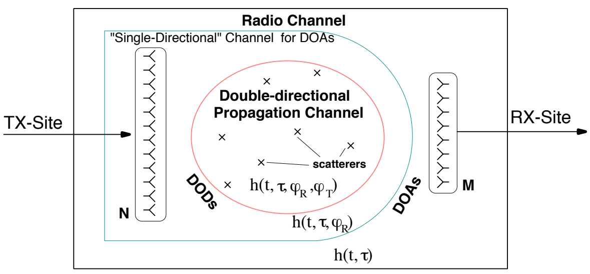

Figure 1. Double-directional channel concept

Statement of the problem

For scientific and for practical engineering reasons, we are interested in the nature of the multipath in mobile radio channels. Modeling these channels by stochastic means is a necessity, as long as our knowledge of the physical propagation mechanisms is insufficient. Ideally, we could make deterministic predictions of radio-wave propagation, even in mobile radio, given we have enough knowledge. By measuring the DOAs and the DODs [6], [7], [8] we certainly can come closer to this goal.

Specifically, we want to investigate the following questions in this paper:

(1) How many paths do exist in usual environments?
(2) Which power do they carry?
(3) Can they be separated?
(4) If so, in which domain?
(5) Which are dominant paths worth to look at, e.g. with a smart antenna?

Measurement set-up and estimation of directions

In addition to 5GHz measurements in Ilmenau, Germany [6], we measured an office and a factory environment in Vienna, Austria. The measurements were done at 2GHz with a bandwidth of 120MHz. The transmitter was a single omni-directional antenna that was re-located by software control over a straight line in steps of half a wavelength (Fig. 2). The receiver was an 8-element linear patch array spaced at half a wavelength, supporting an angle of view of about 120°. The antennas were directed in such a way that line-of-sight was blocked.

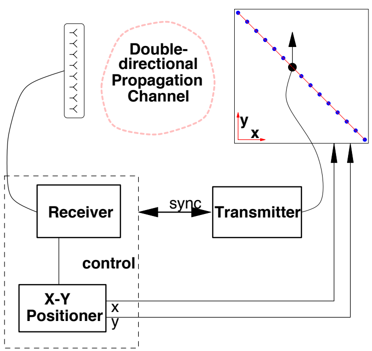

Figure 2. Measurement set-up

In the office the RX and TX antenna were placed in separate rooms with three other rooms in between. The factory hall measurement positions are shown in Fig. 3.

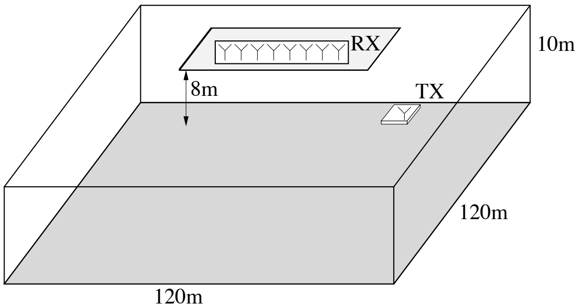

Figure 3. Antenna positions in the factory hall

Results

The number of paths that we could identify was surprisingly large. On the other hand, the power carried by a large number of them was rather low. Figure 4 shows the cumulative distribution function (cdf) of the power carried by the number of multipath components (MCP, x-axis) in two line-of-sight (LOS) and two non-line-of-sight (NLOS) scenarios (top and bottom lines, respectively).

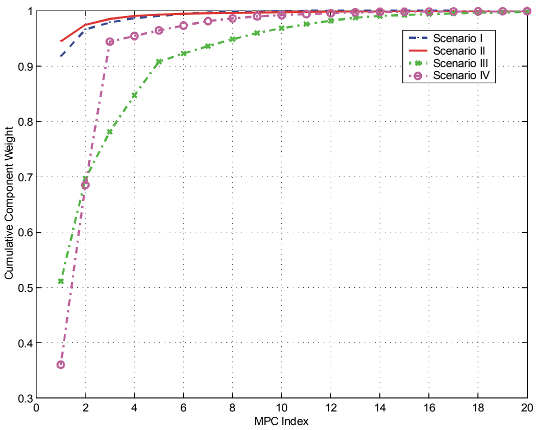

Figure 4. Cumulative power carried by MCPs

Multipath component separation

The mobile radio channel has been described as time dispersive (actually delay dispersive), corresponding to frequency selectivity; as Doppler dispersive, corresponding to time selectivity; more recently as angularly dispersive, corresponding to spatial selectivity. The reason for delay, Doppler and angular dispersion are different path-lengths, velocities of scatterers, and their angular displacement, respectively. So, all reasons for channel dispersion lie in the geometry of the wave propagation process, taking place via propagation paths. Evidently, *path* dispersion is generic for all kinds of dispersion and hence we need a measure to characterize it.

We propose the following measure to quantify the spread between any two individual multipath components, the *multipath component distance* (MCD)

$$MCD = \frac{1}{\sqrt{3}}\sqrt{\Delta x_R^2 + \Delta x_T^2 + \Delta\tau^2}\ ,$$

which is the radius of a hyper-sphere in the normalized multipath parameter distance space. The coordinates in this parameter space are the normalized delay-separation ($\Delta\tau$) and the normalized Euclidian distance between two points on a unit-sphere characterizing either the DODs ($\rightarrow \Delta x_T$) or the DOAs ($\rightarrow \Delta x_R$). The normalization is such that the maximum of either coordinate is unity and its minimum is zero.

A global measure for the analyzed environment is the *multipath component separation* (MCS) being the power-weighted mean of all individual MCDs,

$$MCS = \sqrt{\sum_k^N \sum_l^N MCD_{k,l}^2 P_{k,l} \Big/ \sum_k^N \sum_l^N P_{k,l}}\ .$$

The cross-power $P_{k,l} = \sqrt{P_k P_l}$ of paths k,l restricts the influence of low-power paths. Note that the sum can be extended over all MPCs since the k-th component has no contribution ($MCD_{k,k}=0$).

Figure 5 shows the MCDs for a sample scenario for various measurement settings.

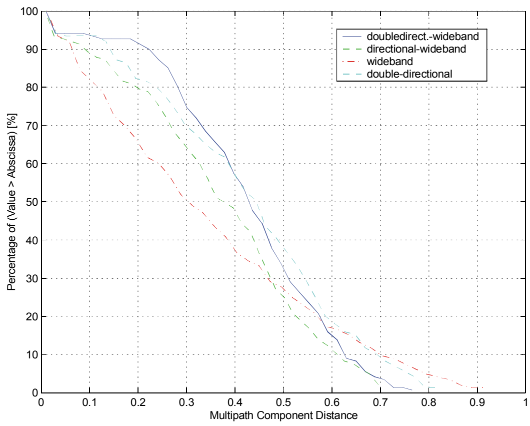

Figure 5. Multipath component distance

The great advantage of the MCS is that

i) it takes into account several dimensions. E.g. also the elevation would be interesting in a scenario in which the MPCs arrive from angles with elevation other than zero (eg [9]). In a highly dynamic scenario, also the Doppler shift could be included as a further coordinate in the parameter space;

ii) it combines the spreading in all considered physical dimensions into one single figure-of-merit;

iii) although normalized, the MCS is system-independent (!) and as such appropriate to characterize different environments for a variety of candidate systems;

iv) it is easy-to-use since only a value between zero and one is returned, and it can directly be used to consider the available diversity/beamforming gain or achievable data-rate through parallel channels.

The MCS tells us whether there are many dominant multipath components available at either end of the link that are useful to look at individually. Note, the higher the power of the paths to be separated the larger the MCS.

An interesting application of the MSC would be answering the question whether it is more useful to opt for beamforming or diversity processing either at TX or RX (which is higher?). In an actual application, the multipath component distance MCD helps in estimating the performance that will be achieved. This is feasible via relating the coordinates in the MCD to the antennas` apertures and the delay-resolution of the system. (Here, we take for granted that the measured delay resolution is better than that of a specific candidate system.)

Do the measurement results give information on MIMO capacity? Not directly, because our measurements yield a single realization of the stochastic channel. But to make predictions about MIMO channel capacity one can proceed like this [10]: To obtain different realizations of the channel one can ascribe a random phase to each multipath component. This phase is chosen independent for each multipath component, but completely correlated for all antenna elements. Repeating the procedure with different phases for the multipath components gives an ensemble of channel and capacity realisations.

Measurements for high-speed mobiles

Results obtained from a recent outdoor field trial in the 2GHz band are presented in this section. This trial focused on the time-variance introduced by mobile stations moving at high speed. In this trial, the double-directional channel parameters for the arrival- and departure angles are estimated using two antenna arrays. The transmitter employs a 15-element uniform circular array of monopoles mounted on a ground plane on top of a car driving at high speed (“UCA-15”, spacing 0.43 wavelength). The receiver uses a stationary uniform linear array of 8 patch elements (“ULA-8”, spacing 0.5 wavelength). The individual channel transfer functions between all 15x8 pairs of transmitting and receiving antenna elements are measured in a total bandwidth of 120MHz. The directions of arrival and departure are estimated sequentially in time as the car with the transmitter moves passed the receiver. To this aim, the conditional maximum-likelihood method is implemented. The method is based on nulling individually detected paths and solves the model-order problem along with the path parameters. The proposed method allows to resolve multiple paths in terms of their DOA and DOD from the two arrays and their temporal delays.

First results are shown in Figure 6. At the top of this figure, the estimates for DOA at the linear array are shown over time as the car moves at approximately 160 km/h past the receiving array. Several arrivals can be identified. In the middle, the estimates for DOD at the circular array are shown: a clear trajectory of the DOD is visible. At the bottom, the estimated path delays between transmitting car and receiving array are shown over time.

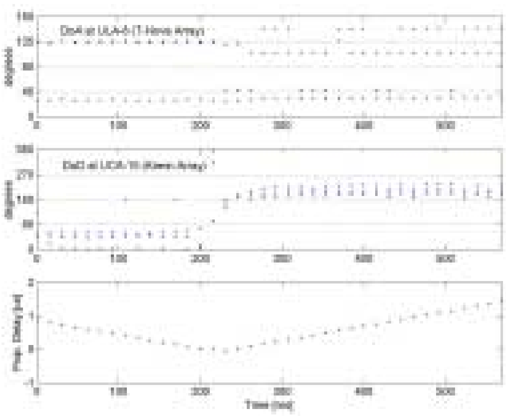

Figure 6: Estimates for DoA, DoD, and Delay

Summary and conclusions

Double-directional propagation is generic for spatial MIMO systems (=systems with multi-element antennas on both sides). We found that MPCs are measurable that underwent up to third order scattering/reflection. We conclude that single-bounce models of the mobile radio channel evidently are not adequate and have to be revisited. The concept of an ”angular spread” around a nominal DOA is too general when it comes to describe the microcellular propagation channel in detail. Multi-element antenna systems should aim to transmit only in directions offered by the channel as DODs that terminate at the receiving side as true DOAs.

We also proposed a new measure, the multipath component separation MCS, to characterize propagation apt for MIMO systems.

Acknowledgments
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