Exploiting Single SISO Impulse Responses to Predict the Capacity of Correlated MIMO Channels

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Abstract—A novel strategy of precalculating potential MIMO spectral efficiencies of correlated channels based on both, measured as well as appropriately modeled SISO channel impulse responses is presented. Besides capacity prediction, the model is capable of comprising the physical nature of the channel in form of its frequency response. The method is applied to indoor MIMO channels where the correlation is introduced mainly by a strong LOS signal component coinciding with low mobility. A spherical wave model is applied and the distributions of angle of arrival and angle of departure turn out to be important modeling parameters. The modeled MIMO capacities are compared to measured capacity records for verification, proving high accuracy.

I. INTRODUCTION

Multiple Input-Multiple Output (MIMO) transmission systems promise high channel capacity gains and reliability improvements for fixed bandwidth and transmit power [1], [2]. The in-room Line-Of-Sight (LOS) MIMO channel capacity depends on the geometrical antenna setup at transmitter (Tx) as well as receiver (Rx), i.e. the inter antenna element spacings within a particular antenna array as well as the orientation of the arrays towards each other [3]–[7]. This dependence can only be revealed correctly, if the channel is modeled by a spherical wave modeling approach [3], [4]. In the following, we address the modeling of such in-room LOS channels in terms of the prediction of their spectral efficiency using channel impulse responses (CIRs) which are known from Single Input-Single Output (SISO) measurements or modeling approaches1. Due to the comparatively short-range distances between Tx and Rx in in-room scenarios, we have to apply a spherical wave model to incorporate the signal correlations. The reference SISO channel impulse responses could have been obtained from measurements or from broadband modeling approaches that are compatible with LOS channels. In our paper we will derive the principle modeling strategy focusing on the derivation of the MIMO channel transfer matrix. We will prove the approach to deliver reasonable results for both, measured and modeled SRCIRs. The modeled SRCIR is exemplarily presumed to be developed according to Saleh’s widely accepted channel model [8], but also different indoor models could be utilized. Thus, we present a strategy of exploiting available SISO measurement data without carrying out new, laborious MIMO measurement campaigns. We aim at providing a possibility which enables the user to estimate the statistical distribution of the channel capacity across a certain environment without being limited to a certain SISO model. Here we treat the capacity for different Tx and Rx positions as a random variable which is analyzed based on cumulative distribution functions (CDFs). Modeling the time variance of the MIMO capacity, instead, is not a focus for the moment.

II. THE IN-ROOM MIMO CHANNEL AND ITS CAPACITY

A. Characteristics of the observed channels and scenarios

In this paper we limit ourselves to indoor channels with a strong and unobstructed LOS signal component. The model generally is able to cope with broadband channels. For the moment, we presume the amount of mobility within the scenario to be low and only caused by small-size objects which do not cover the first-order Fresnel-zone leading to considerable diffraction losses. For typical in-room Tx-Rx distances this presumption also is reasonable for moving persons. With respect to the antennas at Tx and Rx we exemplarily concentrate on uniform linear arrays (ULAs) as the commonly used antenna arrangement, but by increased complexity the results of course are also conferrable to more sophisticated antenna geometries.

B. The MIMO capacity as the objective modeling measure

According to [1] and [2] for a MIMO system consisting of $N$ transmit antennas and $M$ receive antennas the time invariant channel spectral efficiency $C$, which describes the channel capacity normalized by the transmission bandwidth (unit [Bit/sec/Hz])$^2$, in the absence of channel knowledge at the Tx is calculated according to

$$C = \frac{1}{B} \int_{B} \log_2 \left[ \det \left( I_M + \frac{\sigma_R^2}{\sigma_N^2} \mathbf{H}(f) \mathbf{H}^H(f) \right) \right] df. \quad (1)$$

Here, uncorrelated transmit signals and equal power at each Tx antenna are assumed for the frequency selective MIMO-channel. $B$ denotes the transmission bandwidth, $I_M \in \mathbb{R}^{M \times M}$ is the identity matrix, $\mathbf{H}(f)$ denotes the mean transmit power that is allocated to each transmit antenna and $\sigma_N^2$ denotes the noise power per receive antenna. Moreover, $(\cdot)^H$ abbreviates the complex conjugate transpose. In this paper we follow the strategy of working with the ratio $\sigma_R^2/\sigma_N^2$ instead of the SNR at the Rx inputs. Consequently, we leave the measured channel transfer functions (CTFs) within the channel transfer matrix $\mathbf{H}(f)$ unchanged with respect to their incorporated path loss.

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1We denote these CIRs “SISO reference CIRs” (SRCIRs).

2we use the terms “capacity” and “spectral efficiency” synonymously, here
This convention is to be mentioned here, as it is different from normalizing $H(f)$ by factoring out the path loss and finally replacing $\sigma_\nu^2/\sigma_\eta^2$ by the SNR at the receiver inputs, as it is commonly done. We use this strategy as it has several advantages with respect to the evaluation of measured data (see [5] for details). Nevertheless, our convention is not crucial for the basic results which this paper is dedicated to.

### III. Description of the Modeling Strategy

#### A. The SISO Channel Impulse Response

With respect to the initial a priori information for our modeling approach we distinguish between two cases: a known SRCIR or its appropriate model.

1) **measured SRCIR**: Starting with the description of a measured SRCIR, the CIR $h(t)$ of a time invariant, frequency selective channel in baseband notation is usually modeled

$$h(t) = \sum_{k=0}^{K} a_k \delta(t - \tau_k) = \int_{-\infty}^{\infty} H(f) \ e^{j2\pi ft} \ df$$

$$= \int_{-\infty}^{\infty} \sum_{k=0}^{K} A_k(f) e^{j2\pi ft} \ df,$$

where $a_k$ describes the complex valued path amplitude of propagation path $k$ and $\tau_k$ its propagation delay. $\delta(t)$ denotes the Dirac-pulse at time instance $t = 0$ and $H(f)$ is the frequency selective SISO channel transfer function. The CIR consists of $K+1$ physical propagation paths where the path number $k = 0$ denotes the LOS signal component. The path gain $|a_k|$ of a single propagation path within the transmission bandwidth $B$ is calculated according to

$$a_k = \int_{B} A_k(f) e^{j2\pi ft} (t - \tau_k) df,$$

$$A_k(f) = \frac{C_0}{4\pi L_k f} \prod_{d=1}^{D(k)} r_{d,k}(f) = \frac{1}{4\pi L_k \tau_k} \prod_{d=1}^{D(k)} r_{d,k}(f).$$

Here $L_k$ denotes the path length of propagation path $k$ and $r_{d,k}(f)$ is the complex valued, frequency dependent reflection factor for a single contact of wave $k$ with reflection layer $d$. Each wave $k$ is assumed to be reflected $D(k)$ times, where the value of $D(k)$ varies for the different paths, but is generally unknown from the CIR solely. Furthermore, for the LOS signal part as well as short reflections in equation (3) the path loss can be approximately calculated substituting $f$ by the center frequency of the transmission band $f_c$ which introduces a suitable simplification presuming the relevant bandwidth $B << f_c$. In fact, the $K$ physical multipath components described by the parameter set $\{a_k, \tau_k\}$ can only be temporally resolved for a sufficiently large measurement bandwidth. Thus, the limited bandwidth $B$ of any measurement system which has been used to accomplish the SRCIRs, results in a limited temporal resolution of the measured CIRs. Moreover, from

the nature of the measurements we normally obtain a sampled version of the CIR

$$h_{meas}(t) = \sum_{p=0}^{\infty} a_p \cdot \delta(t - p \cdot T_a),$$

where the sampling period is $T_a$ and $a_p$ denotes the complex path amplitude of the band-limited, time continuous CIR at sampling time instance $t = p \cdot T_a$. This particularly means that different, consecutive propagation paths with respect to their propagation delays are probable to merge into a single sample of our measured CIR. Thus, they can not be distinguished. This is a shortcoming for the modeling strategy as no complete information on the $K$ physical multipath components is available in general. As no additional a priori information on the SRCIR is available besides the time samples, this basic information has to be sufficient for our MIMO model.

2) **Modeled SRCIR**: Differently, a modeled SRCIR regards the true, physical multipath components instead of measured CIR samples. Such a SISO indoor channel model of high impact is Saleh’s well known approach [8]. Thus, we will exemplarily refer to this channel model throughout the derivation of our MIMO model in this paper, but we will add a LOS signal component which originally has not been included. This strategy seems to be reasonable in order to exemplify how the (LOS) MIMO model is derived, based on a particular SISO approach. Nevertheless, the MIMO modeling approach is applicable independently from the underlying SISO model. This fact will become more vivid at a later stage. To provide some basic information on Saleh’s channel model: it is a cluster based approach, assuming the different physical transmission paths to arrive at the Rx in temporally disjoint clusters. Each cluster $l$ out of $L$ clusters itself incorporates $K(l)$ multipath components, where $K(l)$ as well as $L$ generally are not upper bounded. Hence, the complex, low-pass CIR model of the multipath channel is given by $h_{mod}(t) = h_0(t) + h_{NLOS}(t)$, where the NLOS part is modeled according to Saleh [8]

$$h_{NLOS}(t) = \sum_{l=0}^{L-1} \sum_{k=0}^{K(l)-1} a_{lk} \delta(t - T_l - \tau_{lk}).$$

The part $h_0(t)$ incorporates the LOS signal into the model. The $l$–th cluster arrives at time $T_l$ at the receiver, and the $k$–th multipath component (MPC) belonging to the $l$–th cluster arrives at time $\tau_{lk}$ measured in reference to the cluster $l$. The complex coefficients $a_{lk}$ consist of a real valued random amplitude factor and a phase angle $\varphi_{lk}$, i.e.

$$a_{lk} = |a_{lk}| \cdot e^{j\varphi_{lk}}.$$ The phase angles are uniformly distributed, statistically independent random variables over $[-\pi, \pi]$. With respect to the generally time variant behavior of the channel, the arrival times $T_l$ and $\tau_{lk}$ are described by two independent interarrival exponential probability functions $f_{T_l}(T_l|T_{l-1})$ and $f_{\tau_{lk}}(\tau_{lk}|\tau_{lk(l-1)})$ with parameters $\Lambda$ and $\lambda$, respectively. Both parameters can be accomplished from specified analysis of measured data [8]. The clusters are determined mainly by

$^3$In fact, by the term "MPC" we refer to the NLOS signal parts, only.
the environment, i.e. the macrostructure of the location, as for example the walls or large objects. For the MIMO model verification based on measured data, which follows in section IV, we in a first step had to derive the Saleh modeling parameters in order to fit the measured CIRs or the measured spatial power delay profile (SPDP). The SPDP denotes a power delay profile which is derived in spatial domain instead of temporal domain. Under several presumptions it can be obtained from a number of SISO measurements covering the area of interest (see also [10]). The SPDP parameter derivation is not further discussed in the paper at hand. We assume to be prepared by a proper SRCIR, which in this paper has been derived according to Saleh’s approach.

B. Modeling the \( M \times N \) SRCIRs of the MIMO system

The basic idea of the MIMO modeling approach deals with the construction of typical, frequency selective MIMO channel transfer matrices which incorporate the spherical wave modeling scheme, the antenna configurations and the properties of the particular environment. Here the main focus is directed towards the exactness of the precalculated channel capacity as a random variable. According to equation (1) the channel capacity depends on the correlation between all \( M \times N \) CIRs forming the MIMO channel. Thus, the correlation of the LOS signals as well as the reflections and, consequentially, the geometrical setup of the antennas within the environment are the most important aspects of the modeling procedure. This fact marks a big difference compared to statistical modeling approaches and is a key feature of the proposed scheme.

Starting with the MIMO modeling procedure, firstly a MIMO antenna configuration is constituted, particularly the numbers \( M, N \) of the antennas, their inter antenna array spacings \( d_T, d_R \) as well as the orientation of the Tx and the Rx antenna array towards each other are fixedly chosen. As an intermediate step, we again have to distinguish between measured reference CIRs and modeled reference CIRs.

1) Case 1: modeled SRCIR: Here we start with \( h_{\text{mod}}(t) \) which is assumed to be a CIR realization derived from the chosen (LOS) reference model for the environment of interest. For the modeling approach the SRCIR is denoted according to

\[
h_{\text{SRCIR}} = \sum_{i=0}^{I} a_i \delta(t - \tau_i),
\]

where \( i \) runs about the existing \( I \) MPCs and \( i = 0 \) again corresponds to the LOS signal. The notation of the SRCIR is independent from the underlying SISO channel model and takes into account simply all the MPCs which are observed. With respect to Saleh’s model, for example, we obtain \( I = \sum_{i=0}^{L-1} K(l) \).

2) Case 2: measured SRCIR: In section III-A it has been discussed that complete knowledge on each delay \( \tau_k \), the corresponding reflection factors \( r_d^{(k)}(f) \), \( d = \{1, ..., D^{(k)}\} \) and both the number of reflections \( D^{(k)} \) and their particular propagation paths would enable the user to correctly determine the CIRs of the MIMO system solely based on a single CIR for one combination of Tx-Rx antenna elements. In practice such complete information can never be obtained and even if that was possible, the calculation would be impracticable. Therefore, we propose a different strategy in order to deal with the limited information provided by the SRCIR: we assume to be prepared with a measured SRCIR \( h_{\text{meas}}(t) \) which has been derived using a particular Tx-Rx antenna element pair out of the \( M \times N \) Tx-Rx antenna element combinations possible for a \( M \times N \) MIMO system. Usually, this SRCIR has been obtained within the environment of interest utilizing the identical measurement bandwidth which is presumed for the investigated MIMO system (or has been filtered accordingly) and it is available in time discrete form at a sampling period \( T_a \). As it has been described in section III-A the SRCIR does neither give insight into the exact number \( K_1 \) of MPCs nor their delays \( \tau_k \). Instead, each sample at \( t = (p_0 + p) \cdot T_a, \ p = \{0, ..., P - 1\} \) is influenced by an unknown number of MPCs which themselves have to be regarded in the remaining CIRs of the MIMO systems. Here \( p_0 \) denotes the first non-zero sample of the CIR which usually includes the LOS signal component. The last sample, which can be distinguished from the noise, has index \( P - 1 \), where \( P = \lfloor \tau_K / T_a \rfloor \). Now, the basic simplification of the proposed modeling method is introduced by the treatment of each sample of the CIR: We assume the sample to be equivalent to a single MPC although in reality it is influenced by a couple of unknown MPCs.

In the model the \( M \times N \) MIMO CIRs are created from the single SRCIR with particular regard to the geometrical settings of the antennas and the location. Thus, each tap of the SRCIR has to regard this geometrical conditions because all the true delays, which affect such a single tap, are results of the antenna arrangement themselves.

Hence, the resulting MIMO model does not represent exactly the physical reality, but characterizes an “artificial” MIMO channel which correctly reflects the channel correlation and, consequentially, the MIMO channel capacity.

In order to present a unified modeling description for both cases of SRCIRs, in the following we substitute variable set \( \{p, P\} \), which has been used to describe the samples of the measured SRCIRs, by the set \( \{i, I\} \). Consequently, we obtain

\[
h_{\text{SRCIR}} = \sum_{i=0}^{I} a_i \delta(t - p_0 \cdot T_a - i \cdot T_a), \ I = P,
\]

where \( i = 0 \) is assigned to the LOS signal part. Hence, we obtain an identical notation for both cases, modeled and measured SRCIR. In the following, we will also denote the \( i \)-th sample as “\( i \)-th multipath component” for simplicity. Finally, for illustration figure 1 depicts a measured SRCIR compared to the true propagation paths forming the channel. Additionally, the MPCs are denoted according to Saleh’s approach to illustrate the nomenclature.

Having introduced a unified notation for the SRCIRs, the following procedure is identical for both of the discussed cases. Beyond the SRCIRs, as a second and third a priori information, a concrete positioning of the Tx and Rx antenna arrays has to be presumed and sufficient knowledge of the angles of
arrival (AOAs) $\Theta_i^T$, $\Phi_i^R$ and the angles of departure (AODs) $\Theta_i^R$, $\Phi_i^T$ must be available. The AOAs and AODs, are very important modeling parameters as they constitute the phase angle relations between the MIMO channel transfer matrix entries. Information on these angles is typically available in form of probability distributions and can be obtained from measurements or from the literature (see again [9] and the references therein).

In a first modeling step $h_{\text{SRCIR}}(t)$ is assigned to one of the Tx-Rx antenna element pairs of the MIMO system\(^4\). The $M \times N$ MIMO CIRs are created from $h_{\text{SRCIR}}(t)$ with particular regard to the geometrical settings of the antennas and the location. Thus, each MPC of the SRCIR has to regard this geometrical conditions itself. Now, for each SRCIR MPC

\[ D_i^{mn} = \frac{(D_i^{11} - (m - 1) d_R \cos \Theta_i^R) - (n - 1) d_T \cos \Theta_i^T}{(m - 1) d_R \cos \Phi_i^R - (n - 1) d_T \sin \Phi_i^T} \]

In fact, a dependence of the distances $D_i^{mn}$ on the particular antenna assembly has to be introduced. At first, the assembly is characterized by the positions of all Txs and Rx antennas, which in the following we abbreviate by the vector

\[ \nu = \begin{bmatrix} -T_1, \ldots, -T_N, -R_1, \ldots, -R_M \end{bmatrix} \]

Secondly, distances are influenced by the AOAs and AODs. We abbreviate these angles by the ensemble $\Psi_i = \{\Theta_i, \Phi_i, \Phi_i^R, \Phi_i^T\}$. Having calculated each distance $D_i^{mn}(\nu, \Psi_i)$ and the corresponding delay $\tau_i^{mn}(\nu, \Psi_i)$, consequently, the path amplitudes $a_i^{mn}(\nu, \Psi_i)$ have to be derived. They are based on the respective amplitudes $a_i^{11}(\nu, \Psi_i)$ of the SRCIR which itself results either from measurements or is found according to the modeling prescrips of the underlying SISO model. Establishing the MIMO model, the remaining amplitudes $a_i^{mn}(\nu, \Psi_i)$ are derived by scaling $a_i^{11}(\nu, \Psi_i)$ according to the path length difference between the considered path $D_i^{mn}(\nu, \Psi_i)$ and the reference path $D_i^{11}(\nu, \Psi_i)$ incorporating the signal correlations in the channel matrix, i.e.

\[ a_i^{mn}(\nu, \Psi_i) = a_i^{11}(\nu, \Psi_i) \cdot D_i^{11}(\nu, \Psi_i)/D_i^{mn}(\nu, \Psi_i). \]
The path gains \( a_{0}^{mn}(\vec{v}_0) \) and propagation delays \( \tau_{0}^{mn}(\vec{v}_0) \) related to the LOS part \( h_0(t, \vec{v}_0) = a_{0}^{mn}(\vec{v}_0) \cdot \delta(t - \tau_{0}^{mn}(\vec{v}_0)) \) of the CIR are calculated according to the antenna positions applying again the spherical wave model,

\[
h_0(t, \vec{v}_0) = \frac{c_0}{|4\,\pi\,f_0 D_0^{mn}(\vec{v}_0)|} \delta(t - D_0^{mn}(\vec{v}_0)/c_0). \tag{10}
\]

The distance \( D_0^{mn}(\vec{v}_0) = \|\vec{v}_0^R - \vec{v}_0^T\|_2 \) denotes the shortest distance between Tx antenna \( n \) and the \( m \)-th Rx antenna.

**Note:** \( \vec{v}_0 \) describes the exact positioning of the Tx and the Rx antenna arrays, as for the LOS case the virtual positioning (previous paragraph) meets the physical reality. Hence, \( \vec{v}_0 \) is sufficient to describe the initial Tx-Rx setup, particularly the geometrical arrangement of Tx and Rx towards each other.

Moreover, it is important to be aware that especially the LOS signal part, which typically carries the major part of the signal energy, is to be exactly calculated from the geometrical arrangement utilizing the spherical wave assumption. This strategy is a noteworthy step in order to incorporate the dependence of the MIMO capacity on the geometrical arrangement [3]–[7] into the model. If this aspect is neglected, the rank of the channel matrix will be underestimated in most high-RSS scenarios leading to a gap between measured and modeled channel capacities (see fig’s. 3, 4).

If the utilized SRCIR already incorporates a LOS signal part it is therefore suggested to replace it by the exact LOS signal calculated according to the array geometry, as described before. If we deal with a measured SRCIR, instead, we only know about the LOS signal part that it is included in the first arriving, nonzero sample. Due to the limited time resolution, usually this sample is also influenced by one or a couple of reflected waves which impinge circuitously at the Rx. As the LOS component carries the main part of the signal energy and as it is usually much stronger than any reflected wave we solely model the LOS signal part while neglecting the reflected parts, which we anyway do not have any information available about. Therefore, we omit the first sample at time instance \( t = p_0 \cdot T_a \) from the SRCIR and model the LOS signal again strictly according to the ULA arrangement (equation (10)).

Hence, the modeled MIMO channel transfer matrix \( H(f, \vec{v}_0, \{\vec{v}, \Psi\}) \in \mathbb{C}^{M \times N} \) dependent on the particular Tx-Rx positioning \( \vec{v}_0 \) and the randomly chosen ensemble \( \{\vec{v}, \Psi\} = \{\{\vec{v}_i, \Psi_i\}|i = 1...I\} \) can be delineated\(^5\). It consists of entries

\[
H^{mn}(f, \vec{v}_0, \{\vec{v}, \Psi\}) = H_0^{mn}(f, \vec{v}_0) + H_0^{mn}\{\vec{v}, \Psi\} + \sum_{i=1}^{I} a_1^{11}(\vec{v}_i) D_1^{11}(\vec{v}_i) e^{-j 2\pi f D_0^{mn}(\vec{v}_i, \Psi_i)/c_0}. \tag{11}
\]

It is used to determine the spectral efficiency of the MIMO system according to equation (1). Finally - as it is insufficient to use only one realization of the ensemble \( \{\vec{v}, \Psi\} \) - a lot more realizations are obtained creating a statistic at the investigated \( \vec{v}_0 \) in order to calculate the expected value of the spectral efficiency \( E(C(\vec{v}_0, \{\vec{v}, \Psi\})) \) as the modeling result, i.e.

\[
C(\vec{v}_0) = E_{\{\vec{v}, \Psi\}} \left\{ \frac{1}{T} \int_B \log_2 \left| \det \left( I + T(f, \vec{v}_0, \{\vec{v}, \Psi\}) \right) \right| \right\} df \tag{12}
\]

\( T(f, \vec{v}_0, \{\vec{v}, \Psi\}) = \frac{\sigma_e^2}{\lambda^2} H(f, \vec{v}_0, \{\vec{v}, \Psi\}) H^H(f, \vec{v}_0, \{\vec{v}, \Psi\}) \).

Of course also different statistical analyses based on \( C(\vec{v}_0, \{\vec{v}, \Psi\}) \) could basically be performed.

Next, a brief summary on the overall procedure is provided:

1. Choose an antenna arrangement \( \vec{v}_0 \).
2. Derive the SRCIR for \( \vec{v}_0 \) according to a SISO model or derive it from measurements.
3. If the reference model incorporates a LOS signal component, remove it from the model.
4. Calculate the LOS propagation paths exactly according to the antenna arrangement and independently from the SRCIR.
5. Draw an ensemble of AOAs/AODs \( \Psi \) from an appropriate angular distribution (\( \Psi_i \) for each MPC \( i \)).
6. For each MPC obtain the virtual antenna arrangement \( \vec{v}_i \) that corresponds to its delay as well as to the chosen \( \Psi_i \).
7. For each MPC include the channel correlation by calculating the channel transfer matrix relations according to the virtual antenna arrangement.
8. Model or calculate the amplitude coefficient for each MPC in the SRCIR.
9. Scale the amplitudes and phases for all MIMO antenna combinations according to their propagation delays relating to the reference antenna pair.
10. Calculate the channel capacity for the MIMO system.
11. Repeat steps 4-10 in order to obtain a statistic over \( \Psi \), the more information on \( \Psi \) is available the better the result fits reality.
12. Repeat steps 1-11 to cover different antenna arrangements \( \vec{v}_0 \) and, thus, obtain a spatial capacity statistic.

### IV. Model Verification Utilizing Measured Data

In order to validate the model, we performed indoor measurements in different locations where Tx and Rx have been placed within the same room. The legends of figure 3 and
4 provide basic information on the measurement parameters. The measured positions and crucial modeling assumptions. A more detailed and illustrated description of the scenarios, the antenna arrangements as well as the measurement equipment can for example be found in [5] in coincidence with a basic discussion of the results. Focusing solely on the LOS signal part, the two chosen antenna arrangements covered the case, where we obtain only a rank-deficient channel transfer matrix (CTM) (perpendicular setup, denoted "pp.") as well as the case where we can obtain high-rank channel transfer matrices (broadside antenna array arrangement, denoted "br."). The distance \[ D_0^{\text{cen}}(\mathbf{v}_0) = D_0^{\text{cen}} \forall \mathbf{v}_0 \] was kept constant for all measured positions \( \mathbf{v}_0 \) in order to leave the LOS path loss unchanged and, therefore, ease the statistical analysis. This way we stressed the impact of the MPCs on the channel capacity in order to check the modeling quality for those MPCs. This seemed to be of highest interest, as the LOS signal part is calculated correctly anyway according to the setup. Nevertheless, fixing the Tx-Rx distance clearly is not a general restriction. For the model verification based on a modeled SRCIR we in a first step applied Saleh’s SISO model to the data in order to derive the SRCIR (see [10] details). The capacity modeling results for this case are depicted in figure 4, which also includes the corresponding Saleh modeling parameters in the framed boxes. Furthermore, figure 3 displays the MIMO modeling results based on measured SRCIRs. Both figures distinguish between a spherical and a plane wave assumption for the LOS signal part as well as the MPCs. As can be observed, the modeling approach generally delivers very accurate results, if the spherical wave assumption is presumed especially for the LOS signal part which delivers the major part of receive signal energy. Contrarily, for the reflected signals the results in case of the spherical wave model only slightly differ from that for the plane wave model. Observing the results in fig. 4 the CDFs also indicate very accurate modeling results for the slope of the curves as well as for the predicted C-values. Again the spherical wave model is supported and it is shown to even have a more crucial impact on the modeling accuracy than for the case of a measured SRCIR. With respect to the angular distribution of the reflections at the Rx, we chose a uniform distribution \( \mathcal{U} [-\pi, \pi] \) of \( \Theta^R_i \) and \( \Theta^L_i \) what fits very well to our location as indicated by the close fit of measured and modeled CDFs. A more detailed analysis in [9], which presents results from joint angle of arrival and angle of departure measurements within the investigated environments, further proves the uniform distribution for the reflected waves to be correct. Generally, the choice of the angular distribution is a key parameter of the modeling approach and has a crucial impact on the modeling accuracy. This is further discussed [10] based on additional computer simulation.

V. CONCLUSION

A simple, but accurate strategy for the prediction of the statistical channel capacity distribution within a particular indoor environment has been presented. The underlying frequency selective, multipath-channel is characterized by a strong Line-of-Sight signal component. The model originates from a known SISO reference channel impulse response which is obtained from measurements or SISO modeling approaches. The auxiliary information for the model is mainly the antenna arrangement and spacing at Tx and Rx as well as the distributions of the AOAs and AODs within the environment. For the prediction of the capacity a spherical wave model is to be applied to assure sufficient accuracy. The model has been verified utilizing measured spectral efficiencies and very good accuracy can be reported. Hence, the modeling approach enables an elementary prediction of MIMO capacities in correlated (LOS) channels from available SISO channel information, incorporating correct information about the multipath characteristics of the channel.

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