Narrowband MIMO Channel Modeling for LOS Indoor Scenarios

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ABSTRACT

Herein, a line-of-sight (LOS) multiple input multiple output (MIMO) channel model is presented based on 5.2 GHz indoor MIMO channel measurements. The signal from the dominant direction is estimated and removed from the channel data. The residual part is shown to be Rayleigh distributed and its covariance matrix can be well approximated by the Kronecker product of the covariance matrices seen from the transmitter and receiver respectively. Therefore we model the whole narrowband LOS indoor MIMO channel as a static rank one matrix plus a statistical model based on Rayleigh distribution with a multiplicative covariance structure.

1 INTRODUCTION

It was reported in [1, 2] that multiple-input-multiple-output (MIMO) system can provide high channel capacity as long as there is sufficient rich scattering around. To design high performance MIMO communication systems, one of the necessary requirements is to have a model that can describe MIMO channels reasonably well. In [3], a narrowband model was presented for non-line-of-sight (NLOS) indoor scenarios based on a multiplicative structure of the channel correlations. In [4], a similar wideband model was proposed based on the correlation between the power of the different channel coefficients. More examples of MIMO channel modeling can be found in [5, 6, 7]. In general, most of the models depend on the assumption that the MIMO channel coefficients are Rayleigh distributed, which is reasonable in NLOS scenarios as long as there are no dominant paths. However, many scenarios can be described as line-of-sight (LOS), where the direct path between the receiver and transmitter dominates the channel. In such cases, the channel is Ricean distributed rather than Rayleigh distributed. In this paper, we present a narrowband model for LOS indoor MIMO channels based on 5.2 GHz wideband MIMO channel measurements conducted under the EU IST SATURN project.

2 MEASUREMENT SETUP

The test site was the Merchant Venturers Building of the University of Bristol. The general layout of the test site includes office rooms, computer labs, corridors and open spaces. The entire measurement includes 15 transmitter locations and 3 receiver locations. Both LOS and NLOS cases were measured. Note that in this paper, all the results are from two LOS measurements, where both the transmitter and receiver were located in the lobby with LOS path between them.

The measurements were carried out using the Medav RUSK BRI vector sounder, which had an 8-element omnidirectional uniform linear array (ULA) at the transmit side and an 8-element ULA with 120° beamwidth at the receive side. The distance between two neighboring antenna elements was half wavelengths for both arrays. The transmitter and receiver were synchronized by a cable to get coherent measurements. The measurements had a bandwidth of 120 MHz. The excess delay window was set to $0.8\mu s$, corresponding to 97 narrowband frequency subchannels. For each transmit element, one ‘vector snapshot’ (one measurement from each receive element) was taken by the receiver through switching control circuitry. The sampling time for one complete MIMO snapshot (8 vector snapshots) was 102.4μs, which is well within the coherence time. One complete measurement includes 199 blocks with 16 MIMO snapshots within each blocks, therefore there are 3184 complete MIMO snapshots in total for each frequency subchannel. The time delay between two neighboring blocks was 26.62ms. This means the total time for a complete measurement was 5.3s. The measurements were performed using a multi-tone sounding signal and the estimated channel responses were saved directly in the frequency domain. During the measurements, people were moving around.

3 MEASUREMENT ANALYSIS

3.1 Data Model and Channel Capacity

Assume there are m transmit elements and n receive elements. For a narrowband MIMO channel, the input-output relationship can be expressed in the baseband as $\mathbf{y}(t) = \mathbf{H}\mathbf{s}(t) + \mathbf{n}(t)$, where $\mathbf{s}(t)$ is the transmitted signal, $\mathbf{y}(t)$ is the received signal and $\mathbf{n}(t)$ is additive white Gaussian noise. $\mathbf{H}$ here is an n by m channel matrix.

It is well known when the transmitted power is equally allocated to each transmit element, the normalized channel capacity can be expressed as [1]

$$C = \log_2 \det(\mathbf{I}_n + \frac{\rho}{m}\mathbf{H}\mathbf{H}^*), \tag{1}$$

where $\mathbf{H}$ is the normalized channel matrix, ρ is the average signal-to-noise-ratio (SNR) at each receiver branch and $(\cdot)^*$ denotes complex conjugate transpose.

3.2 Kronecker Structure

It was reported in [3] that for a narrowband NLOS Indoor MIMO channel, the channel covariance matrix can be well approximated by the Kronecker product of the covariance matrices seen from the transmit and receive side respectively, i.e.

$$\mathbf{R}_H = \mathbf{R}_H^{Tx} \otimes \mathbf{R}_H^{Rx}, \tag{2}$$

where $\mathbf{R}_H$ is the covariance matrix of the vectorized channel matrix, $\mathbf{R}_H^{Tx}$, $\mathbf{R}_H^{Rx}$ are the covariance matrices at the transmit and receive side and '$\otimes$' denotes the Kronecker product. Suppose the channel coefficients are complex Gaussian, then it is easy to show from equation (2), as in [5], that

$$\mathbf{H} = (\mathbf{R}_H^{Rx})^{1/2}\mathbf{G}[(\mathbf{R}_H^{Tx})^{1/2}]^T, \tag{3}$$

where $\mathbf{G}$ is a stochastic n by m matrix with independent and identically distributed (IID) complex Gaussian elements and $(\cdot)^T$ is transpose. Here $(\cdot)^{1/2}$ denotes any matrix square root such that $\mathbf{R}^{1/2}(\mathbf{R}^{1/2})^H = \mathbf{R}$.

3.3 Deterministic Maximum Likelihood (DML) Method

The DML method is used to estimate the impinging direction of the LOS path and the associated complex path gain from the channel data at the receive side. Assume there are d point sources, the estimated 'vector snapshot' $\hat{\mathbf{h}}$ of the received channel responses, i.e. the column vector of the measured channel matrix $\mathbf{H}$, can be modeled as

$$\hat{\mathbf{h}}(t) = \sum_{i=1}^{d} \gamma_i(t)\mathbf{a}(\theta_i) + \mathbf{n}(t) = \mathbf{A}(\theta)\gamma(t) + \mathbf{n}(t), \tag{4}$$

where θ_i is the angle of arrival (AOA) associated with the ith point source, $\mathbf{A}(\theta) = [\mathbf{a}(\theta_1), \mathbf{a}(\theta_2), \ldots, \mathbf{a}(\theta_d)$ is the steering matrix, $\gamma(t) = [\gamma_1(t), \gamma_2(t), \ldots, \gamma_d(t)]^T$ is the complex gain vector for different paths and $\mathbf{n}(t)$ is the noise vector.

Assume that $\mathbf{n}$ is complex white Gaussian noise, by minimizing the negative likelihood function, the DML estimates can be found by solving a non-linear squares problem. The reader may refer to [8] for more details about the DML estimation.

4 MEASUREMENT RESULTS

Although people were moving around during the measurements, it has been found that the estimated channels are fairly static and therefore for NLOS cases [3], we average both over the frequency and spatial domains to get sufficient data to study the channel statistics. However, this is not the case in LOS scenarios since the dominant part is static and therefore should not be averaged.

One approach to solve this problem is to estimate and remove the dominant part from the channel data and then model these two parts separately. In this work, the dominant direction is found by using the DML method on the vector of received channel responses as stated in section 3.3 and the signals impinging from this direction are separated from the signals coming from other directions by projecting the channel data to the null space of this dominant direction. In the following part, we will consider one pair of transmitter and receiver location as an example, similar results are found for another measurement.

By employing 2-dimensional search (i.e. search 2 AOAs simultaneously, one for the dominant direction and another from the strongest reflector), the dominant direction in this case is found to be $-12°$ apart from the bore-sight of the receive array (orthogonal). Projecting the channel data to the null space of this direction, we get the residual channel. By averaging the residual channel over both the frequency and spatial domain, the residual part is shown to be Rayleigh distributed and its covariance matrix can be well approximated by the Kronecker product of the covariance matrices seen from both ends respectively. Therefore this part can be modeled as shown in (3). Furthermore, it is found that the signals impinging from the dominant direction amount to about 70% of the total power. Even within the main incoming azimuth direction, the channel gain is frequency dependent, which may be explained by multipath reflections in the ceiling and floor, and possibly in the wall behind the transmitter from the same azimuth direction. However, it is still sufficient to model the dominant part as a rank one matrix, for each frequency subchannel, to obtain a Rayleigh distributed residual channel. Therefore the whole narrowband LOS indoor MIMO channel can be modeled as

$$\mathbf{H} = \mathbf{H}_D + \mathbf{H}_R = \mathbf{a}(\theta_D)\mathbf{g}_D^T + (\mathbf{R}_{H_R}^{Rx})^{1/2}\mathbf{G}[(\mathbf{R}_{H_R}^{Tx})^{1/2}]^T, \tag{5}$$

where $\mathbf{H}_D$ is the dominant part of the MIMO channel, $\mathbf{H}_R$ is the residual channel, θ_D is the dominant direction and $\mathbf{g}_D$ is a complex gain vector with the estimated dominant channel gain from each transmit elements as its elements.

Monte-Carlo simulations are used to generate 5000 MIMO channel realizations according to (5) with 2x2 setup. The normalized narrowband MIMO channel capacity is calculated and compared with the ideal IID MIMO channel based on the cumulative density function (CDF). Fig. 1 shows the results from two typical frequency subchannels. Since the dominant part is frequency dependent in this case, choosing $\mathbf{H}_D$ from different frequency subchannels may give different channel capacity. The subplot at the right-hand side shows the result when the dominant part is much stronger than the residual part while the subplot at the left-hand side shows the result that the dominant part is comparable to the residual channel. In [9], it was reported that for one narrowband subset of data, the LOS environment (empty room) provides more scattering than the mixture of NLOS and LOS environment. This result may correspond to the subplot at the left-hand side. However, if taking the received signal power into account, the measured LOS scenarios can always provide higher capacity comparing with the NLOS scenarios due to the higher SNR at the receiver branch.

5 CONCLUSIONS

In this paper, we access data collected from 5.2 GHz measurements for LOS indoor scenarios. We use the DML method to estimate and remove the dominant part from the channel data from the receive side. It is shown that the residual part is Rayleigh distributed and can be modeled statistically based on the Kronecker Structure of the covariance matrix. Therefore the narrowband LOS MIMO channel can be modeled as a static matrix plus the above statistical model. Finally we use this model to show some capacity characteristics of narrowband LOS MIMO channels.

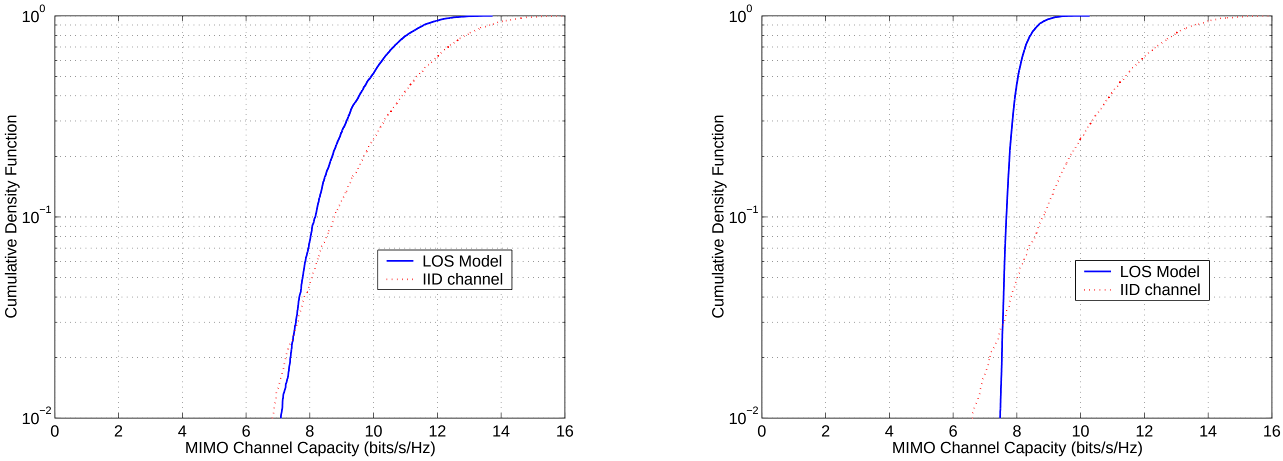

Figure 1: CDF of narrowband channel capacity (normalized) for narrowband LOS MIMO channel model and IID MIMO channel. Power is equally allocated to the transmit elements, the SNR at each receiver branch is 20dB.

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