On the estimation of the Degrees of Freedom of In-door UWB channel

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I. INTRODUCTION

Considering the growing interest of Personal Communication beyond 3G, UWB communication is presented as a serious candidates and a support technology for this kind of application. UWB systems are often defined as systems that have a relative bandwidth that is larger than 25% and/or an absolute bandwidth of more than 500MHz (FCC). The UWB using large absolute bandwidth, are robust to frequency-selective fading, which has significant implications on both, design and implementation. Additionally, the spreading of the information over a very large frequency range decreases the spectral density and makes it compatible with existing systems. For designing and implementing any wireless system, channel sounding and modelling are a basic necessity. Several studies, theoretical and practical, have shown an extreme difference with respect to narrowband channels [1]. In previous work at Eurecom Institute, we characterized the second order statistics of indoor (UWB) channels and practical, have shown an extreme difference with respect to narrowband channels [1]. In previous work at Eurecom Institute, we characterized the second order statistics of indoor (UWB) channels and practical, have shown an extreme difference with respect to narrowband channels [1].

In order to estimate the true covariance matrix $K_h$, we use statistical averages based on observations from $(20 \times 50)$ positions.

III. ESTIMATION OF THE NUMBER OF DEGREES OF FREEDOM

A. Covariance matrix estimation

The sample covariance matrix is a maximum-likelihood estimate, under the assumption of a large number of independent channel observations which arise from the different transmitting and receiving antenna positions. The covariance matrix of measured channel samples, $h$, is written as

$$K_h = E[hh^H] = E[gg^H] + \sigma_n^2 I$$

where $g$ is a vector of samples of the noise-free channel process, and $I$ is the identity matrix. The maximum-likelihood covariance matrix estimate computed from $N$ statistically independent channel observation with length $p$ and $p < N$ is given by

$$R = K_h^N = \frac{1}{N} \sum_{i=1}^{N} h_{W,t} h_{W,t}^H.$$  (3)

In the context of our measurements, the multiple transmitter/receiver grid can equivalently be seen as a large$(50 \times 20)$ MIMO system.

B. Information theoretic criteria

Wax and Kailath [3] presented a new approach for estimating the number of signals in multichannel time-series and frequency-series, based on statistical classification criteria (AIC) and (MDL). The covariance matrix $R$ is Hermitian and positive definite. The (AIC) criterion is given by:

$$AIC(k) = -2 \log \left( \prod_{p=k+1}^{N} \lambda_i(h) \right) \frac{1}{p-k} \sum_{i=k+1}^{N} \lambda_i(h) + 2k(2p-k)$$

and in [4] the MDL criterion is given as follows:

$$MDL(k) = -2 \log \left( \prod_{p=k+1}^{N} \lambda_i(h) \right) \frac{1}{p-k} \sum_{i=k+1}^{N} \lambda_i(h) + \log(N) \frac{k}{2p-k}$$

where the $\lambda_i(h)$ are the eigenvalues of the covariance matrix $R$. The number of (DoF), possibly the number of significant eigenvalues,
is determined as the value of $k \in \{0, 1, ..., p - 1\}$ which minimizes the value of (4) or (5). In this work, the number of DoF represents the number of unitary dimension independent channels that constitute an UWB channel.

IV. RESULTS AND ANALYSIS ABOUT UWB CHANNEL

In this section, we present and analyze the results obtained from the UWB channel measurement conducted at Eurecom. Figure 1 considers LOS and NLOS measurement scenarios. We plot the (AIC) and (MDL) functions for two different bandwidths typically 200 MHz and 6 GHz. The minimum of (AIC) or (MDL) curves gives the number of significant eigenvalues. As a matter of fact, we see that the number of DoF increases with bandwidth but not linearly. Thus, for 200 MHz bandwidth, we capture 98% of the energy with 25 significant eigenvalues whereas for 6 GHz channel bandwidths the number of eigenvalues is 50. To illustrate the relationship between number of (DoF) and system bandwidth, we recall that for a signal with duration $T$ and frequency band $\Delta W$, the number of (DoF) of the signal space $N_{\text{DoF}}$ is given by [5]

$$\quad N_{\text{DoF}} = T \cdot \Delta W + 1. \quad (6)$$

Generally [6], we find that if one transmits a band limited and time limited signal over a fading channel with $\text{rms}$ delay spread behavior $T_d$, the channel (DoF) $N$ is approximately

$$\quad N = T_d \cdot \Delta W. \quad (7)$$

To investigate deeply the validity of this relationship for UWB channels, we measure the evolution of the $\text{rms}$ delay spread with the frequency bandwidth, for both LOS and NLOS cases, for one fixed threshold of received energy $-20 dB$ attenuation regarding the first arriving path. Then we plot, on figure 2, the computed number of (DoF) following equation (7). We then compare this result with the number of (DoF) obtained by (AIC) criterion from measurements. For 98% of the captured energy, we notice that the number of eigenvalues using the relationship in (7) increases linearly with the bandwidth for both LOS and NLOS case. In opposition, the number of eigenvalues calculated directly from measurements by (AIC) tends towards saturation beyond 2000 MHz frequency bandwidth for LOS case and beyond 1500 MHz frequency bandwidth for NLOS case. We remark also, that for lower frequencies (below 800 MHz for NLOS and 1500 MHz for LOS settings), the number of DoF by (AIC) is higher than that one obtained following equation (7). In fact, the measured number of (DoF) based on (AIC) is computed from the total channel impulse response obtained by IFFT while in the other case we focus on the time limited channel impulse response truncated at $T_d$. Hence the difference between both computed DoF comes from energy outside the $T_d$ interval.

V. CONCLUSION

In this work, we showed the (AIC) and the (MDL) are two techniques to estimate the number of (DoF) of an UWB channel in an in-door environment. We also studied the evolution of the $\text{rms}$ delay spread behavior $T_d$, as a function of frequency bandwidth based on a measurements campaign carried out at Eurecom Mobile Communication laboratory. We compared the (AIC) result with the number of (DoF) obtained by the product of $T_d$ by frequency bandwidth. This comparison, pointed out that the number of DoF for a given UWB channel saturates beyond a certain frequency and does not increase linearly.

REFERENCES