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On the Relevance of Dense Multipath Components in a Micro Cell Scenario

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On the relevance of dense multipath components in a micro cell scenario

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Abstract - A novel model for radio channel parameter estimation describes the channel using two components. One part of the channel is approximated using specular or more precisely concentrated propagation paths and the other part is modeled as a stochastic process describing the dense multipath components. Using measurements in a micro cell scenario we show in this temporary document that both components are relevant. Both, the concentrated propagation paths as well as the dense multipath components can dominate the propagation mechanisms in some situations.

I. Introduction

A radio channel model which is generally accepted approximates the narrow band radio channel with the superposition of a finite number of propagation paths. This data model is valid if we want to generate a realization of the radio channel, as long as the apertures are finite. The necessary information for this channel model, we have to provide, is a statistic of the path parameters. The accuracy of the model, provided the path parameter statistics are valid, can be controlled by the number of propagation paths used to generate the channel. Altogether we can say the synthesis problem is solved if we have the parameter statistics of the propagation paths.

One way to derive parameter statistics for the propagation paths is to measure the radio channel with a channel sounder and estimate the path parameters from the channel observations using a parameter estimator. These estimates can subsequently be used to derive sufficient statistics for the radio channel, i.e. the propagation path parameters. Generally speaking the problem to solve is an analysis problem. Again we need a channel model, this time for the parameter estimator, to describe the observations of the radio channel measured with the channel sounder. A fact we can not ignored is, that the restrictions for the analysis model are stronger than for the synthesis model. The problem is that every observation contains a finite amount of information about the radio channel only. Hence we have to construct a model for the channel observations, whose parameters can be estimated form the measurement data and which is up to the observations uncertainty, usually determined by the measurement noise, sufficiently accurate. Whether or not the parameters of given model can be estimated from an observation can be calculated using the Fisher-Information-Matrix and the Cramér-Rao-Lower bound (CRLB). Assuming no hyper-efficient estimator exist for the given data model, we can say, that the CRLB gives the minimum variance for any unbiased estimator we construct to estimate the parameters of a given data model. The chosen model is too complex for the amount of information contained in an observation if the lower bound on the variance of one or several model parameters is higher than the parameter itself. Consequently we can not simply use the number of propagation paths to adjust the accuracy of the radio channel model if we want to solve the analysis, e.g. channel parameter estimation, problem.

For this reason we have proposed in [3] to extend the data model (sum of deterministic propagation paths) for the analysis problem by an additional component describing the dense multipath components of the radio channel. This model is based on the experience from measurements that a radio channel observation has to be described by the superposition of some strong concentrated propagation paths and a large number of small propagation paths. We call the contribution of the small propagation paths as dense multi-path. In this paper we discuss the relevance of the specular (concentrated) propagation paths and of the dense multipath components in micro-cell scenarios. In the next section we provide a summary of the mathematical data model.

II. General Data Model

Let use denote a single observation of the radio channel as $\mathbf{x}$. Furthermore we introduce the vector valued function $\mathbf{s}(\boldsymbol{\theta}_p)$ to express the contribution of a single propagation path to the observation in dependence of the path parameters $\boldsymbol{\theta}_{sp}$. There exist various ways to parameterize a propagation path, a general model is provided for example in [4]. For the dense multipath components (DMC) $\mathbf{d}_{DMC}$ we use our model described in [3]. The vector $\mathbf{d}_{DMC}$ is a circular Gaussian process with the covariance matrix $\mathbf{R}(\boldsymbol{\theta}_{DMC})$. Up to now no reliable information about the spatial structure of the DMC is available, hence we assume they are spatially white and correlated in the frequency domain only. Hence the covariance matrix has the structure

$$\mathbf{R}(\boldsymbol{\theta}_{DMC}) = \mathbf{I} \otimes \mathbf{R}_f(\boldsymbol{\theta}_{DMC}) \otimes \mathbf{I}.$$

The covariance matrix in the frequency domain has Toeplitz structure an is given by

$$\mathbf{R}_f(\boldsymbol{\theta}_{DMC}) = \mathrm{toep}\left(\boldsymbol{\kappa}(\boldsymbol{\theta}_{DMC}), \boldsymbol{\kappa}(\boldsymbol{\theta}_{DMC})^H\right),$$

whereby the spectrum or better the correlation function in the frequency domain is given by

$$\boldsymbol{\kappa}(\boldsymbol{\theta}_{DMC}) = \frac{\alpha_{DMC}}{M_f}\begin{bmatrix}\frac{1}{\beta_{DMC}} & \frac{\mathrm{e}^{-\mathrm{j}2\pi\tau_{DMC}}}{\beta_{DMC}+\mathrm{j}2\pi\frac{1}{\mathrm{M_f}}} & \cdots & \frac{\mathrm{e}^{-\mathrm{j}2\pi(\mathrm{M}_f-1)\tau_{DMC}}}{\beta_d+\mathrm{j}2\pi\frac{M_f-1}{\mathrm{M}_f}}\end{bmatrix}^T.$$

The parameters τ_{DMC}, α_{DMC} and β_{DMC} are the base time delay, the minimum attenuation and the normalized coherence bandwidth of the dense multipath components see [3] for a more detailed description of the parameters. Since every covariance matrix can be factorized into

$$\mathbf{R}(\boldsymbol{\theta}_{DMC}) = \mathbf{L}(\boldsymbol{\theta}_{DMC}) \cdot \mathbf{L}(\boldsymbol{\theta}_{DMC})^H$$

we can generate the process $\mathbf{d}_{DMC}$ using

$$\mathbf{d}_{DMC} = \mathbf{L}(\boldsymbol{\theta}_{DMC}) \cdot \mathbf{w}_1$$

where

$$\mathbf{w}_i = \mathcal{N}(0, \tfrac{1}{2}\mathbf{I}) + \mathrm{j} \cdot \mathcal{N}(0, \tfrac{1}{2}\mathbf{I})$$

is a multivariate i.i.d. circular Gaussian process. Altogether one channel observation can be modeled as

$$\mathbf{x} = \sqrt{\alpha_0} \cdot \mathbf{w}_0 + \mathbf{s}(\boldsymbol{\theta}_{sp}) + \mathbf{d}_{DMC}$$

whereby α_0 is the variance of the measurement noise.

The RIMAX algorithm described in [4] is an efficient estimator for the parameters $\boldsymbol{\theta}_{sp}$ and $\boldsymbol{\theta}_{DMC}$. It estimates the radio channel parameters jointly and is based on the maximum likelihood approach, it provides furthermore a mean to estimate the number of propagation paths. Using the parameter estimates one can determine an estimate of the total power of one channel observation using

$$\hat{P}_c = \mathbf{x}^H \mathbf{x} - M \cdot \hat{\alpha}_0 = \|\mathbf{x}\|_F^2 - M \cdot \hat{\alpha}_0 ,$$

whereby M is the length of the observation vector $\mathbf{x}$. Furthermore the contribution of the specular paths to the channel transfer function can be estimated using

$$\hat{P}_{sp} = \left\| \mathbf{s}\left(\hat{\boldsymbol{\theta}}_{sp}\right) \right\|_F^2 .$$

Finally the contribution of the dense multipath components to the given observation can be calculated using

$$\hat{P}_{DMC} = \left\| \mathbf{x} - \mathbf{s}\left(\hat{\boldsymbol{\theta}}_{sp}\right) \right\|_F^2 - M \cdot \hat{\alpha}_0 .$$

Using these three estimates we are able to calculate a measure of the relevance of the specular- and the dense multipath components as

$$\frac{\hat{P}_{sp}}{\hat{P}_c} \text{ and } \frac{\hat{P}_{DMC}}{\hat{P}_c} .$$

We will use these ratios in the subsequent sections to evaluate the relevance of the DMC for a given channel.

III. Measurement setup

Our channel measurements have been performed with the RUSK DoCoMo wideband channel sounder at the 5.2 GHz (WLAN band) with a bandwidth of 100 MHz [1], [2]. The channel sounder contains a fast multiplexing controller, which can be used to switch fast, within the coherence time of the channel, between the antenna elements of the antenna arrays throughout the channel measurement [1]. At the mobile transmitter an omni-directional antenna has been used, illuminating the radio channel with a transmit power of 40 dBm. At the fixed receiver, playing the role of the BS, an 8 element uniform linear array (ULA) has been used.
The channel sounder uses a strictly band-limited periodic broadband signal (multi-sinus) to excite the radio channel. The burst duration of the multi-sinus-sequence was chosen as 6.4 µs. Since the channel sounders inserts only a blank of the same time-length to allow the antenna multiplexer and receiver to settle, all channel impulse responses between the single TX-antenna and the RX-antenna array elements can be measured in a short time interval at one measurement point. The measurement of all 8 channel impulse responses takes 102.4 µs. For Doppler shift resolution the measurement of the 8 channel impulse responses was repeated 4 times consecutively. The total measurement time of such a complete channel snapshot is approx. 410 µs (see **Figure 1**).

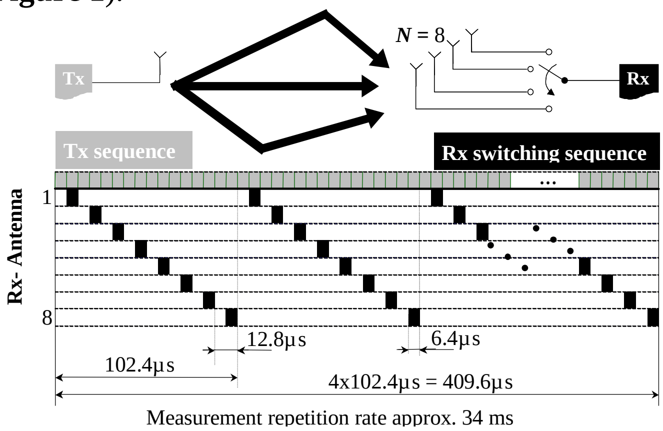

Figure 1: Measurement sequence

IV. Measurement Scenario

During summer 2001 a measurement campaign has been carried out in the major street Chuo-Dori (Chuo-Avenue) downtown Tokyo, which can be characterized as typically urban with a regular street grid and high-rise buildings at both sides of the street. The street is situated in the district Nihonbashi. A measurement with a static BS position and a moving MS was conducted. Figure 2 shows a view on the scenario from the BS and Figure 3 shows a map of the measurement area.

Figure 2: Photo taken at the position of BS antenna

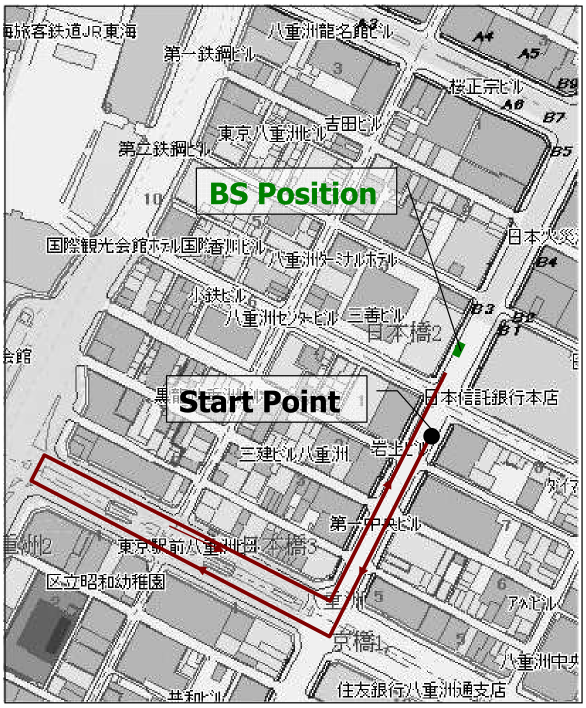

Figure 3: Map of the scenario

At the beginning of the measurement drive and at the end the LOS path could exist. In the middle part, after the car has turned off, no LOS path could exist. Altogether approx. 11000 channel observations have been measured during the whole measurement.

V. Parameter Estimation Results

The RIMAX algorithm described in [4] has been applied to estimated the parameters $\hat{\boldsymbol{\theta}}_{sp}$ and $\hat{\boldsymbol{\theta}}_{DMC}$ for all channel measurements. Figure 4 (left) shows the estimates of the three parameters $\hat{P}_c$, $\hat{P}_{sp}$ and $\hat{P}_{DMC}$ for all channel observations. In Figure 4 (right) the estimated base delay of the DMC is shown. Since the base delay is closely related to the distance between MS and BS we can use it to distinguish between sections in the measurement where the MS was moving and the section where the MS had to stop, for example for the traffic light. Figure 5 shows the number of propagation paths estimated by RIMAX (left) and the dependence of the coherence bandwidth of the DMC on their base delay, i.e. the distance between MS and BS (right). Figure 6 (left) shows how much power the *p*-th propagation contributes in 80%, 95% and 99% percent of the ~11000 observations to the total power of the channel transfer function. In 99% of the cases the 30th path contributed less than 22dB to the channel transfer function. The right hand side of the same figure shows the ratio between $\hat{P}_{DMC}$ and $\hat{P}_c$.

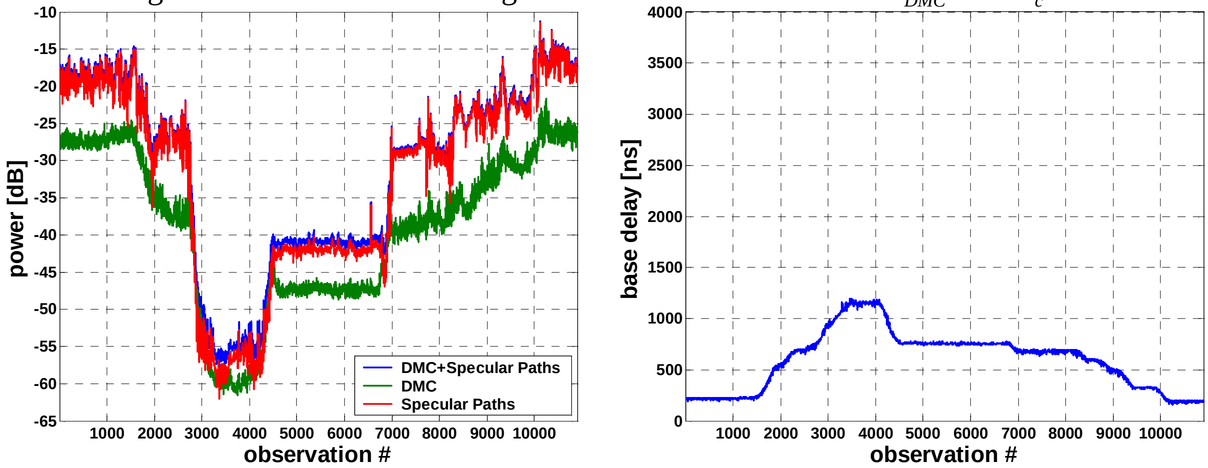

Figure 4: The parameters $\hat{P}_c$, $\hat{P}_{sp}$ and $\hat{P}_{DMC}$ for the whole measurement drive (left) and the estimated base delay of the DMC (right).

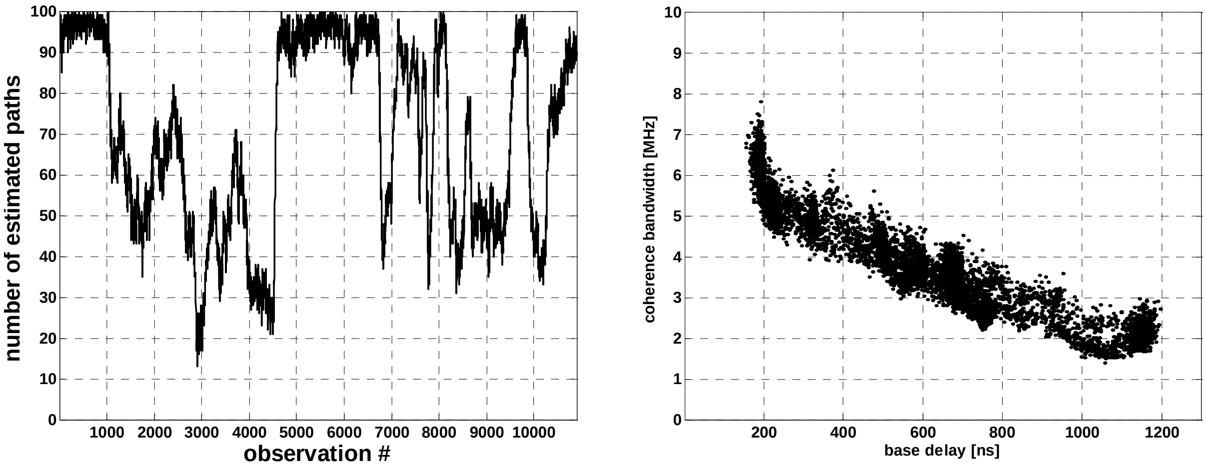

Figure 5: The number of propagation paths estimated by RIMAX (left) and the dependence of the coherence bandwidth on the base delay (right) for the whole measurement

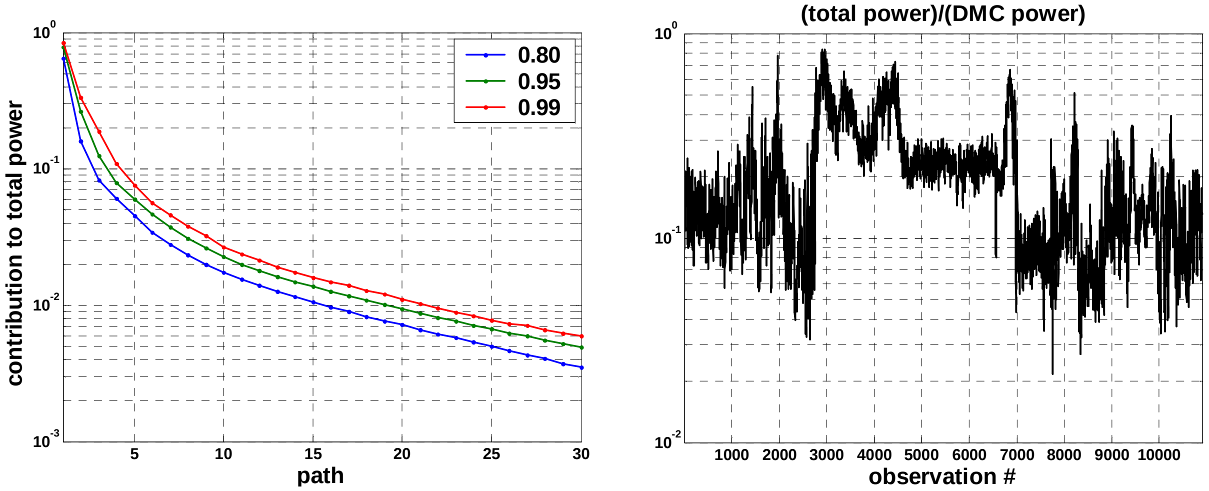

Figure 6: The contribution of the propagation paths to the channel transfer function (left) and the ratio $\hat{P}_{DMC} / \hat{P}_c$ (right) over the whole measurement

To get more insight into the statistics of the parameters at first the stand still positions of the MS has been removed from the observations. In the second step the measurements was split into two parts. The first part contains sections 1 and 3 of the measurement drive, i.e. the sections where the LOS-path could exist, and the second part contains the section where the LOS-path could not exist. Figure 7 and Figure 8 shows the parameters of the part of the measurement where MS and BS was in the same street and Figure 9 and Figure 10 shows the estimated parameters of the middle part of the measurement (MS and BS not in the same street). Whereas the specular components dominates the propagation in section 1 and 3 the DMC dominate the propagation in section 2. It is important to note, that in section 1 and 3 the LOS was often obstructed by a car. Furthermore the contribution of the specular propagation paths in section 1 and 3 decays clearly faster than in section 2. We can say the number of propagation paths necessary to model the radio channel for a scenario where both MS and BS are in the same street is significantly smaller than in a scenario where BS and MS are not in the same street.

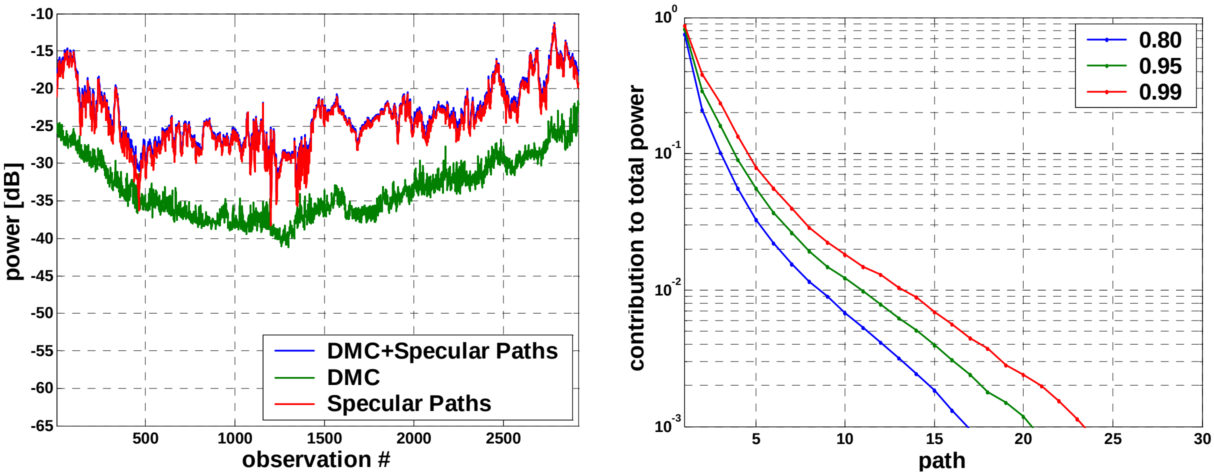

Figure 7: The parameters $\hat{P}_c$, $\hat{P}_{sp}$ and $\hat{P}_{DMC}$ (left) and contribution of the propagation paths to the channel transfer function (right) for section 1 and 3 of the measurement drive without static positions.

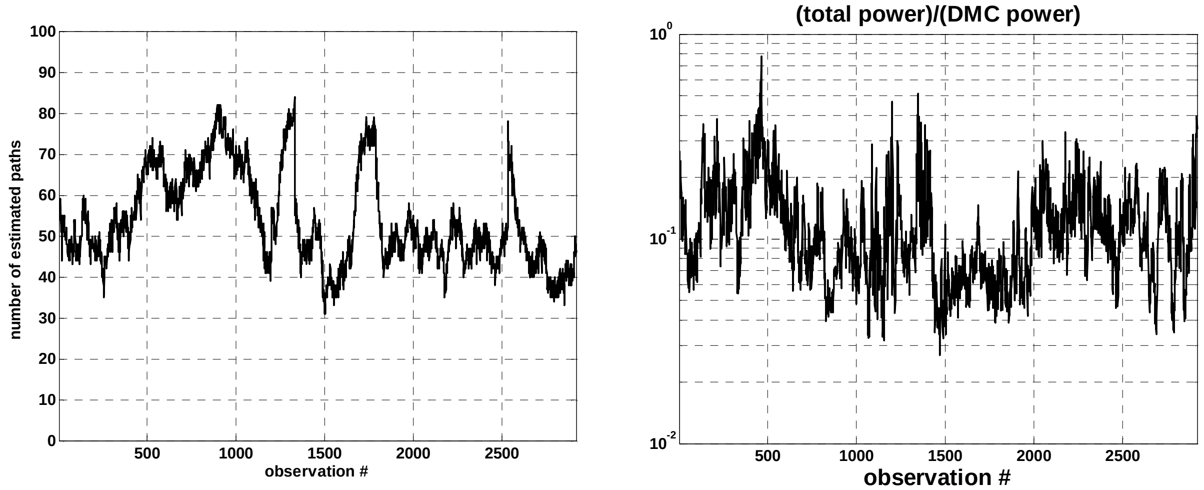

Figure 8: The number of propagation paths estimated by RIMAX (left) and the ratio $\hat{P}_{DMC}/\hat{P}_c$ (right) for section 1 and 3 of the measurement drive without static positions.

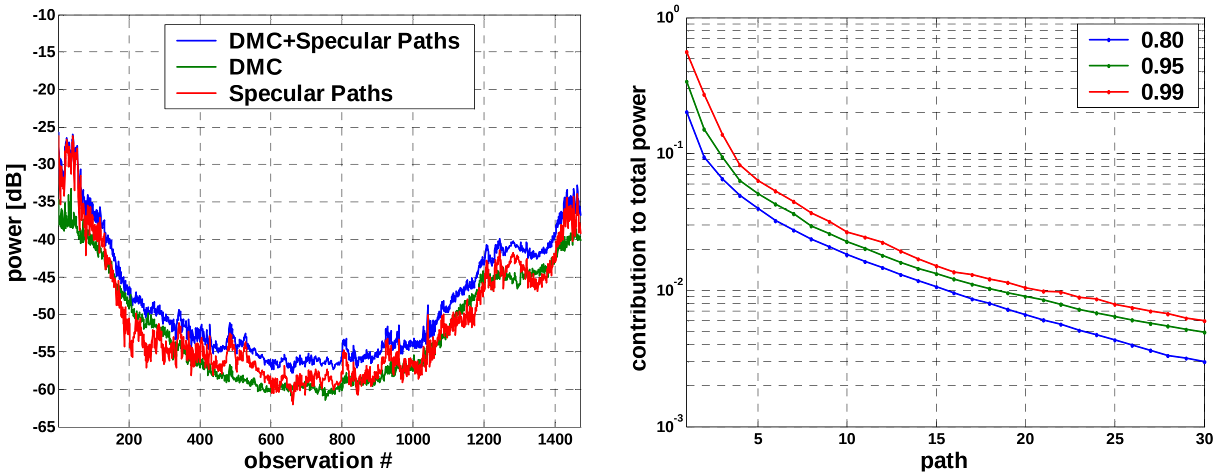

Figure 9: The parameters $\hat{P}_c$, $\hat{P}_{sp}$ and $\hat{P}_{DMC}$ (left) and contribution of the propagation paths to the channel transfer function (right) for section 2 of the measurement drive without static positions.

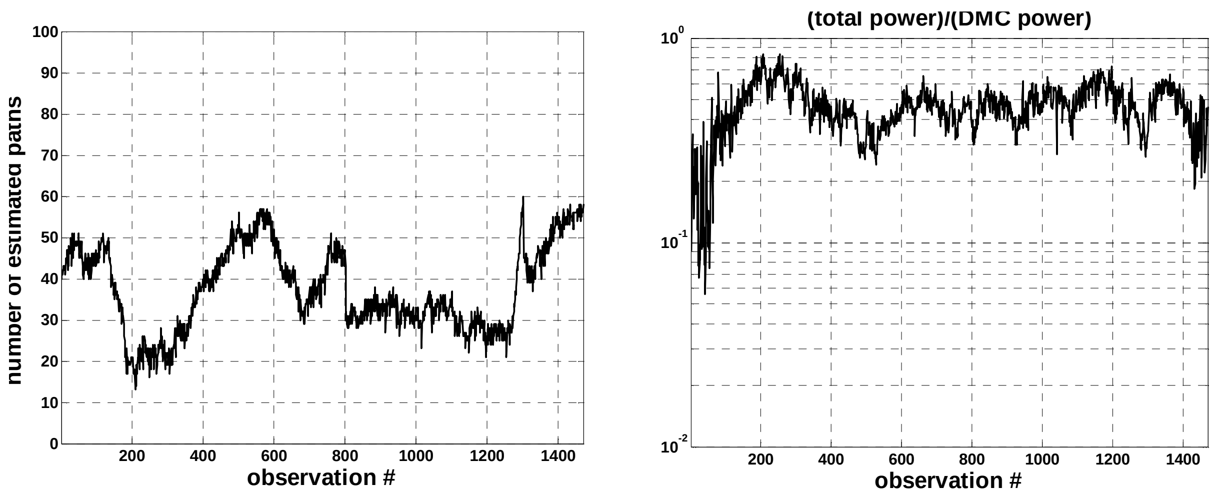

Figure 10: The number of propagation paths estimated by RIMAX (left) and the ratio $\hat{P}_{DMC}/\hat{P}_c$ (right) for section 2 of the measurement drive without static positions

VI. Conclusion

We have shown using parameter estimation results from channel sounding measurements that the dense multipath components are relevant in the micro cell scenario. In non line of sight situations propagation mechanism mainly depends on the DMC whereas in line of sight situations the specular paths clearly dominate the radio propagation between MS and BS. An observation which is also important is that the coherence bandwidth and the base delay of the DMC are strongly correlated. In the same context it is important to note that the power of the DMC is less time variant than the total power, i.e. the power of the specular propagation paths.

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