Measurements and Modelling of the Small Scale Effects of Radio Channels for Rural and Suburban B3G Wireless Communications

Xiongwen Zhao, Tommi Jämsä, Juha Meinilä, Pekka Kyösti, Jukka-Pekka Nuutinen, Daniela Laselva, and Lassi Hentilä

***Abstract*—The power delay profiles (PDPs), tap Ricean factors, and tap Doppler spectra due to channel small scale effects are derived and studied in this paper based on the wideband measurements performed in rural and suburban with 100 MHz bandwidth at 5.25 GHz and 2.45 GHz for beyond 3G (B3G) link and system level simulations.**

***Index Terms*—B3G, wideband, PDPs, Ricean factor, Doppler spectrum, taps, Rayleigh and Rice distributions.**

I. INTRODUCTION

The radio channel measurements and modelling beyond 3G are under studying in European IST WINNER (Wireless World Initiative New Radio project). The link and system level models and parameters together with the WINNER model implementation are being (and will be) derived and developed by the work package 5 (WP5). Furthermore, the implementation of the 3GPP SCM model [1] has been completed by the WP5 [2]. The bandwidth of the 3GPP SCM model is around 5 MHz, but the WINNER model bandwidth will be up to 100 MHz. The 3GPP SCM model is only for urban and suburban environments, while the WINNER model will include more environments as urban, suburban, indoor, rural, hotspots etc. The input parameters of the 3GPP SCM model were based on many assumptions, however in WINNER the model is based on the real channel measurements. To study the small scale effects is a bit difficult, since the radio channels should satisfy the WSSUS condition. A window length is needed to divide the whole measured impulse responses (IRs) along a mobile route into several data sets. Within a data set, the channel does not change considerably and can be regarded as stationary. In this paper, we will focus on the modelling of the PDP, Ricean K-factors per tap and tap Doppler spectra.

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II. MEASUREMENT SYSTEM SETUP AND CAMPAIGNS

The measurements analyzed in this paper were carried out in Oulu region, Finland with 100 MHz bandwidth at 5.25 and 2.45 GHz for MIMO and single-input single-output (SISO) radio channels by using the Elektrobit multidimensional channel sounder [3] in which direct sampling (DS) technique was used. In this paper only SISO measurements are considered. In SISO measurements the dipole antennas were used at the both terminals with gain of 1 dBi and 2 dBi at 5.25 GHz and 2.45 GHz, respectively. The scenarios include rural and suburban with base station (BS or Tx) antenna heights of 17.6 m, 7.6 (11.7) m, and with the mobile station (MS or Rx) antenna heights of 1.7 m and 1.8 m, respectively. In the suburban measurements, the BS station antenna heights of 11.7 m and 7.6 m were for macro- and microcellular measurements, respectively. The rural measurement is almost in line-of-sight (LOS), only near the end of the measured route it is NLOS (non-line-of-sight) due to the obstruction of the forest. The characterization of the rural measurement environment can be found in Fig. 1. The suburban environment shown in Fig. 2 is a typical suburban residential area in Oulu region with mainly 4-6 floor buildings in surroundings (1-2 floor buildings in the measurement route) and narrow streets. The street grid is rather regular, and no open areas can be found between the buildings of the measured route. The suburban measurements were mainly in LOS. In the pictures, the BS stations are indicated by the red arrows.

III. PARAMETERS AND MODELS CAUSED BY SMALL-SCALE EFFECTS

In the following sections we choose 20 dB and 17 dB as the dynamic ranges of the impulse responses (IRs) to do the noise cut for 5.25 GHz and 2.45 GHz, respectively. The IRs were normalized to remove large scale effect (path loss).

A. Power delay profiles (PDPs)

To satisfy the stationary requirement of the radio channel, the measured IRs should be divided into different sets with window lengths of 3.2 m and 1.5 m for rural and suburban, respectively. Fig. 3 shows the PDPs for rural and suburban environments with 2.45 GHz and 5.25 GHz measurements. If we choose 20-25 dB dynamic range for the final PDPs, it can be seen that the PDPs have minor difference between 2.45 and 5.25 GHz band. Moreover, the PDPs do not attenuate as monotonic exponential function [1], thus more than one clusters can be found. The urban measurements at 2.45 GHz were failed because of the interference of the nearby operating WLAN. It is seen from Fig. 3(b) that the PDPs are almost the same for lower delays or short dynamic range, however far scatterers or large excess delays can be observed in the macrocell case. If we choose a specific dynamic range and consider the number of delay bins as the number of taps, the TDL models for rural and suburban environments can be developed based on the PDP's. The link level TDL models can be used as the calibration model for system level simulations. For this specific measurement system, the spacing of two adjacent delay bins is 5 ns, and the time resolution is 10 ns [3].

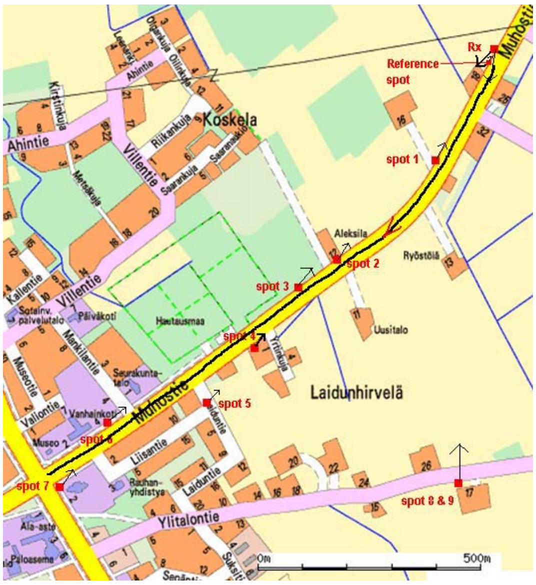

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Fig. 1 Rural measurement environments. (a) map of the measurement venue. (b) picture of the measurement venue.

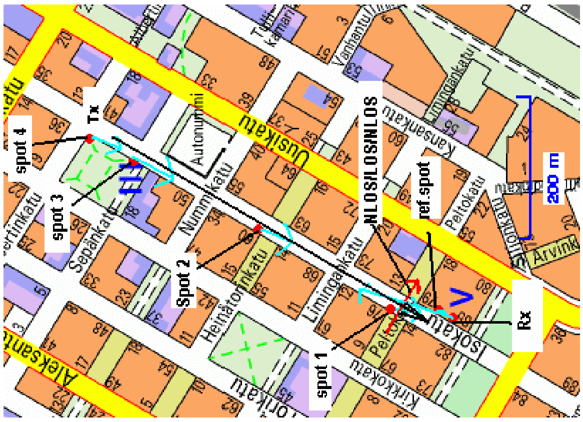

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Fig. 2 Suburban measurement environments. (a) map of the measurement venue. (b) picture of the measurement venue.

B. Narrowband Ricean K-factors for the taps

Ricean K-factors can be derived by using different methods, e.g. the method of moments (MoM) [4], maximum likelihood (ML) method, μ-based and γ-based methods, and also by the traditional least square error (LSE) method [5]. In this paper we use the MoM for the tap wise Ricean K-factor derivation. A tap is defined as a delay bin with 5 ns uniform tap intervals. Tap excess delays and amplitudes can be derived from the PDP's. For a TDL model, we need also tap Ricean K-factors, amplitude distributions, and tap Doppler spectra [6]. In derivation of Ricean factors [4][5], the measured IRs should have lower correlations in time, otherwise the derived K-factors will be not accurate. If a mobile speed is low and measurement rate is fast, the measured IRs have high correlations in practice. To get low correlation IR's, we use 10 IRs as the window length to average the original IRs first, then we use 40 IRs (after averaging) to calculate K-factor for a specific distance point in both environments. Fig. 4 shows the K-factors derived from the rural and suburban (microcell) measurements, respectively. It can be seen that the strong LOS component exists along the measured routes, and the K-factors in suburban are smaller than in rural LOS route.

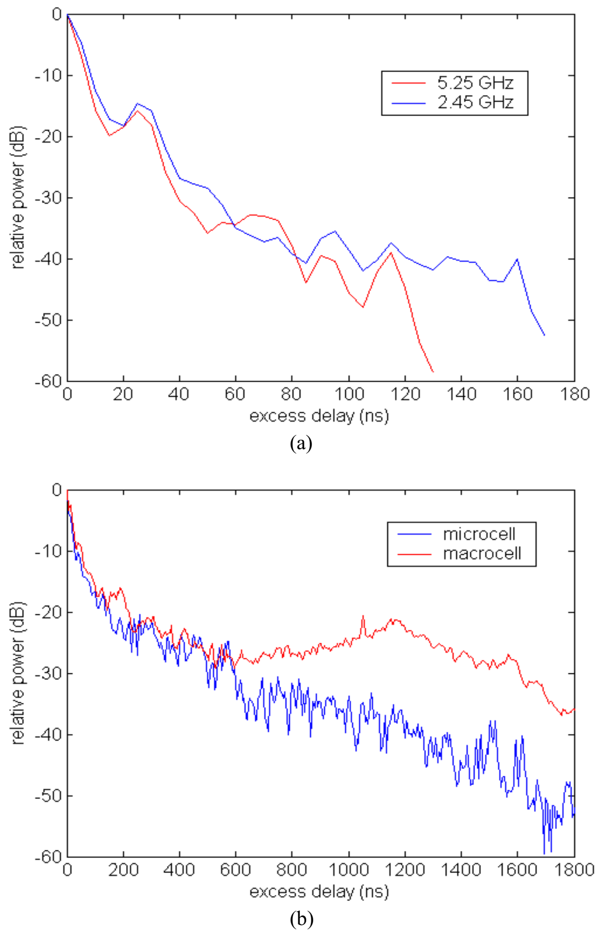

Fig. 3 Mean PDPs. (a) rural. (b) suburban at 5.25 GHz.

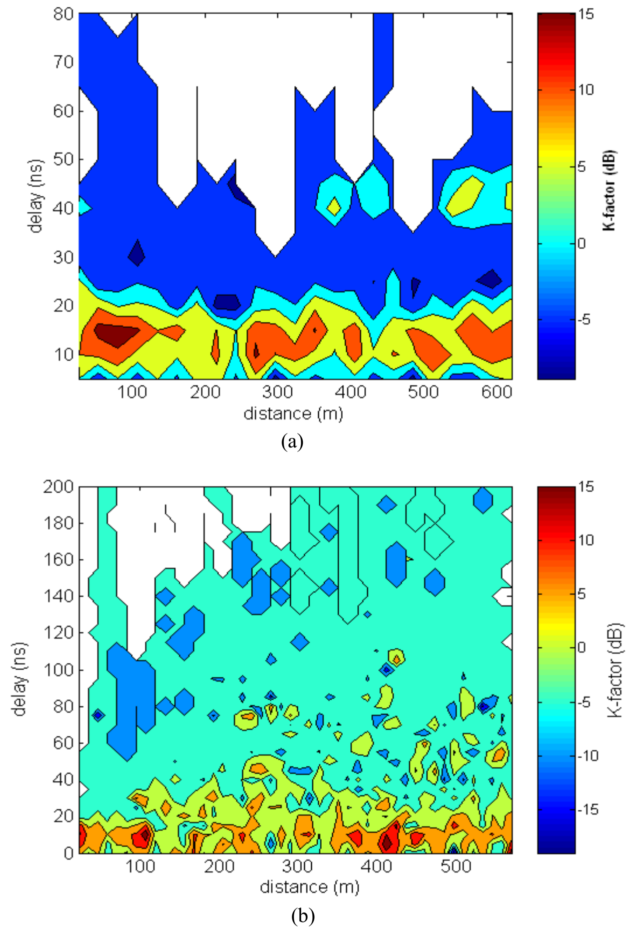

Fig. 4 K-factors along the measured routes at 5.25 GHz. (a) rural. (b) suburban.

Fig. 5 shows the tap amplitude distributions. The blue curves are for the measured data, and the red curves are Rice and Rayleigh fits by using the tap K-factors summarized in Table 1. It can be seen that the tap amplitude follows approximately Ricean distributed for the few first taps. However, most of the later tap amplitudes are Rayleigh distributed. From the same figure it can also be seen that good fit between measured data and Rice and Rayleigh distributions exist. Fig. 6 shows the linear relationship between the K-factor for the LOS component and the mobile distance. If a LOS component exists, it is always with the highest K-factor.

C. *Tap Doppler spectra*

Let us take the same tap definition as in Section III *B*, namely we consider a delay bin as a tap. As defined in Section III *A*, we take 3.2 m and 1.5 m as the window length to divide the whole measured IRs as different sets of IRs to satisfy the stationary requirement of the radio channel. Fig. 7 shows the Doppler spectra along the measured routes for rural macrocell and suburban microcell, respectively. It can be seen that the Doppler spectra are quite narrow throughout measurement routes.

Fig. 8 shows the tap Doppler spectra which are more narrow than the Jake's bucket-shape spectrum where the angle-of-arrivals (AoAs) of the received waves are assumed to be uniformly distributed in $(0,2\pi]$. The narrow Doppler spectra observed here are due to the received waves confined in a narrow angular range or due to the existence of a strong component plus weak scattering waves [6]. In the 3GPP SCM model, the tap Doppler spectra were assumed as Jake's, but the conducted measurement campaigns show that the shapes change according the measured environments [6][7]. The narrow Doppler spectra can be fitted by Gaussian, Laplacian or other distribution.

IV. Conclusions

The parameters related to channel small scale effects were derived and studied based on wideband measurements carried out in rural and suburban environments. The PDPs are useful when developing link level TDL calibration models. The MoM is efficient and accurate to derive tap Ricean K-factors in case of low sample correlations. The tap Doppler spectra are quite narrow compared to the Jake's, which can be caused by narrow angle-of-arrivals of the received waves or the existence of a strong component.

ACKNOWLEDGEMENTS

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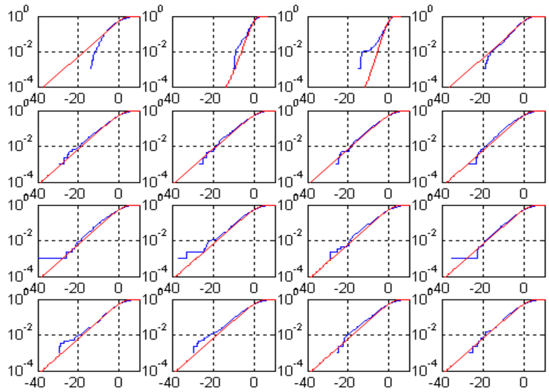

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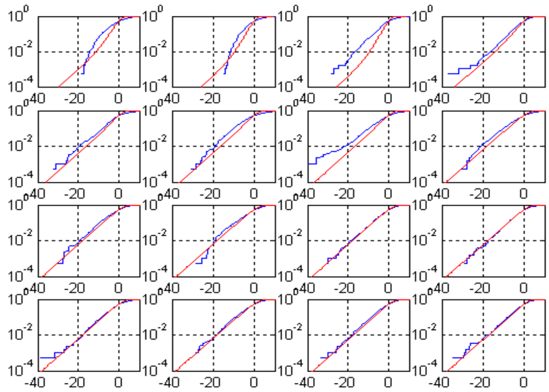

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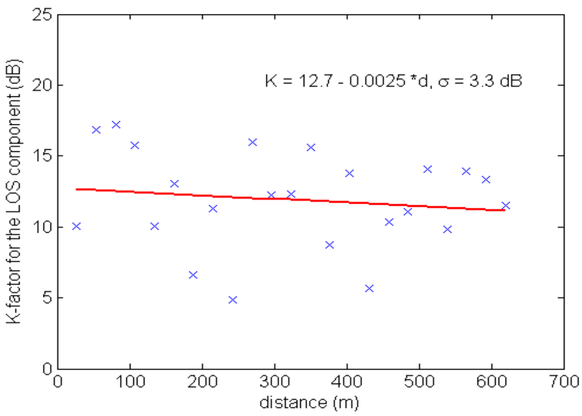
Fig. 5 Amplitude distributions at 5.25 GHz for the first 16 taps. The axes are for tap amplitudes relative to the median value (horizontal) and the CDFs (vertical). (Blue lines: measured. Red lines: curve fitting). (a) rural. (b) suburban.



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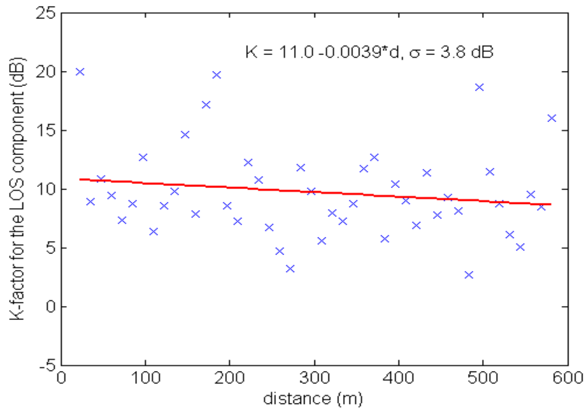

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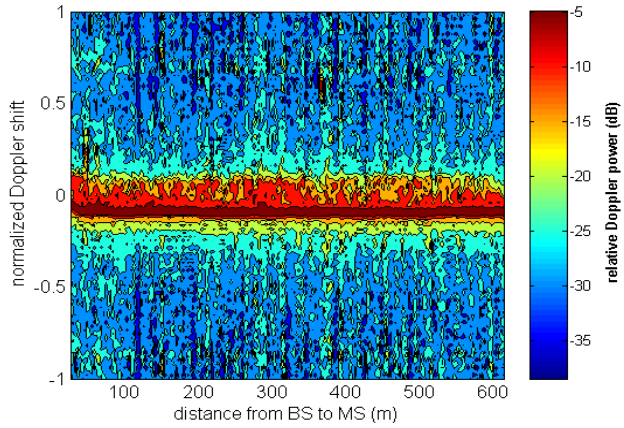
Fig. 6 Linear relationship between the K-factor and MS-BS distance for the LOS component at 5.25 GHz. (a) rural. (b) suburban.



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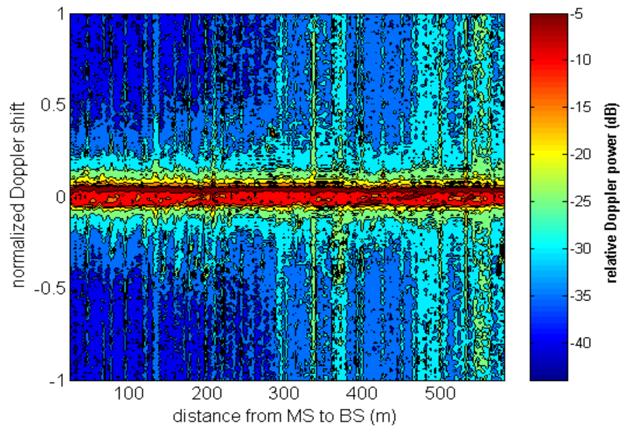

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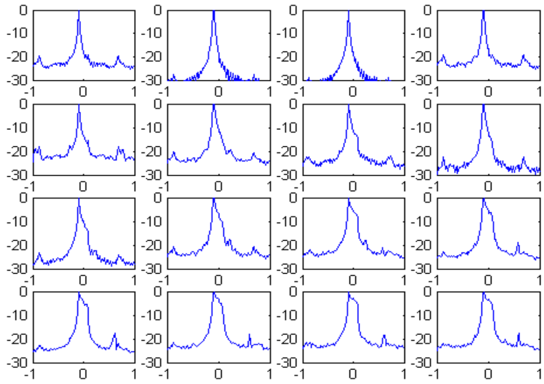
Fig. 7 Doppler spectra along the measured routes at 5.25 GHz. (a) rural. (a) suburban

TABLE 1 RICEAN K-FACTORS (IN dB) FOR THE FIRST 16 DELAY BINS AT 5.25 GHZ

Rural	1.5	9.9	10.7	2.6	-2.3	-1.8	-1.7	0.8	0.1	-0.8	-0.3	-0.3	-0.2	-0.2	-0.3	-0.3
Suburban	3.3	5.7	7.1	4.3	2.7	1.4	0.8	-0.4	-0.9	-0.3	-0.1	-0.6	-1.4	-1.9	-0.1	0.4



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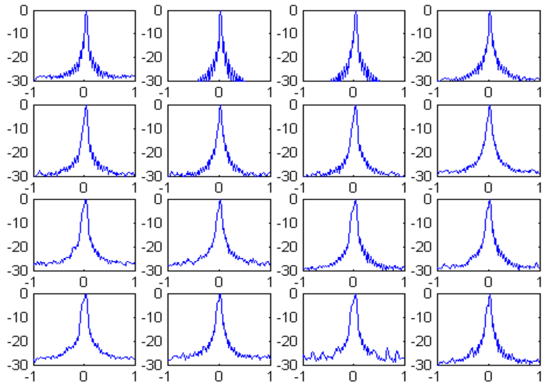

(b)

Fig. 8 Tap Doppler spectra at 5.25 GHz. The axes are for Doppler shift (horizontal) and relative power (vertical). (a) rural. (b) suburban.

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