3-D DIRECTIONAL WIDEBAND DUAL-POLARIZED MEASUREMENT OF URBAN MOBILE RADIO CHANNEL WITH SYNTHETIC APERTURE TECHNIQUE

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INTRODUCTION

Realistic spatial channel models are essential for development of future wideband mobile communication systems, particularly when adaptive antennas at the base stations are considered. Channel models are prerequisite for the performance evaluation of different adaptive antenna solutions and estimation of the obtained capacity gain. Realistic models require channel measurements to prove their assumptions and allow appropriate parameter selection. Considerations of different measurement techniques and an extensive literature list can be found in [1]. In this paper we present a novel concept for spatial radio channel measurements at the base station site in urban environment. It combines RF switching and synthetic aperture technique and allows the full 3-D channel characterization. A high-resolution 2-D Unitary ESPRIT algorithm is used for estimation of azimuth and elevation angles of the incoming waves, and a high delay resolution is obtained using a wideband channel sounder with 2154 MHz carrier frequency. The used dual-polarized microstrip patch array allows the separation of horizontally and vertically polarized wave components. Spatial measurements at the base station (BS) site with a planar array are especially interesting because the directions of arrival (DOA) are more discrete from the BS point of view. A measurement campaign was carried out using three different receiver array (base station) sites in urban environment (downtown Helsinki), below, at, and above the roof-top level. The antenna heights and positions correspond well to urban macro- and microcell antenna installations of the operational networks. 20-30 transmitter (mobile) locations at ground level were measured for each site. Transmitter using an omnidirectional discone antenna was always at 1.5 m above the street level. The main goal of the measurement campaign was to improve understanding of the urban propagation mechanisms, such as the roles of 'street-canyon-' and 'over-the-rooftop-' propagation. The measurement campaign is described in more detail in [2].

MEASUREMENT CONCEPT

Spatial measurements of time-variant channels require a multi-channel vector sounder which is able to receive signals in a coherent manner from all elements of an antenna array. The practically appropriate alternative is to connect the elements of the array via fast RF-switches to a single channel sounder, and perform the sounding sequentially for each sensor. If the channel can be assumed static over a certain period of time, the synthetic aperture technique can be used by moving a single sensor between predefined grid points, and measuring one channel impulse response (CIR) at each point. In this paper we present a novel sounding technique, combining RF-multiplexing and the synthetic aperture technique. The used physical array consisted of 16 dual-polarized microstrip patch elements and was installed in vertical

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orientation on a trolley with electrical motor, moving at constant speed of 0.3 m/s over metallic rails. The elements were arranged in a zigzag pattern (Fig. 1) to reduce mutual coupling. The spacing between the elements was λ/2 in both directions. During the measurements we collected "snapshots" over the physical array for every λ/2 distance moved by the trolley. The total number of collected snapshots (N) was 58, and thus the dimensions of the synthetic aperture were 8×29 wavelengths. Fig. 1 introduces the basic concept of the measurement and Fig. 2 shows the receiver array at the microcell site (RX1). The measurements were performed at night to minimize the effect of traffic on the time stability of the channel. We utilized the wideband channel sounder developed at HUT/IRC [3] using a carrier frequency of 2154 MHz. The I and Q branches of the received signal were sampled directly and the impulse response of the radio channel was computed using software post-processing. The chip frequency of the transmitted PN sequence was 30 MHz, and a sequence length of 255 chips was used. This leads to maximum delay of 8.5 μs with resolution of 33 ns. The measurement of one impulse response from all the 16 dual-polarized elements lasted 544 μs, corresponding to trolley movement of only approximately 0.001 λ. After calculating the impulse responses of all synthetic sensor positions we reorganized the data so that the post-processing could be performed for a normal planar structure. For each impulse response delay tap above a predefined threshold we estimated the DOAs using the subspace estimation based 2-D Unitary ESPRIT algorithm [4]. We then created an array steering matrix for each DOA to estimate the corresponding power. As an output we finally obtained DOAs (azimuth and elevation), delays, complex amplitudes, and polarization vectors of the incoming waves. The DOA estimation error was verified to be less than 1° with LOS measurements using exactly known transmitter positions.

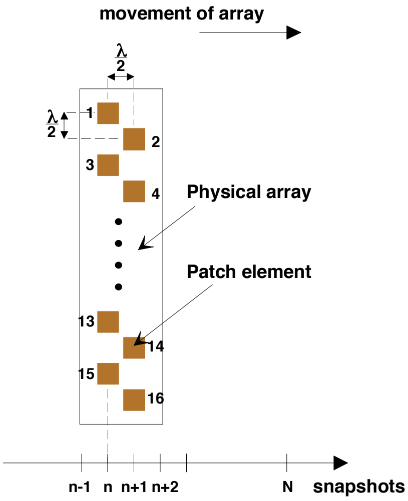

Fig. 1. Measurement concept

Fig. 2. Receiver array

MEASUREMENT ENVIRONMENT

We carried out the measurements in urban environment in downtown Helsinki. Three receiver array sites were used: RX1 on the second floor level below the roof-top, RX2 and RX3 at and above the roof-top level, respectively. The chosen positions correspond well to the real micro- and macrocell base station antenna installations in urban environments. Receiver sites are presented in Fig. 3. At site RX1 the environment is described by an open square ('Rautatientori'), to the right of the broadside of the antenna aperture, see Fig. 4. The characteristic feature of receiver position RX2 is the ('Kaisaniemenkatu') street approaching the receiver from left with the angle of –30° from the broadside, see Fig. 5. The height of the building blocks beside and in front of the receiver is equal to the antenna height. Only the tower of the theatre building on the northern side of Rautatientori square rises above the other environment. Receiver site RX3

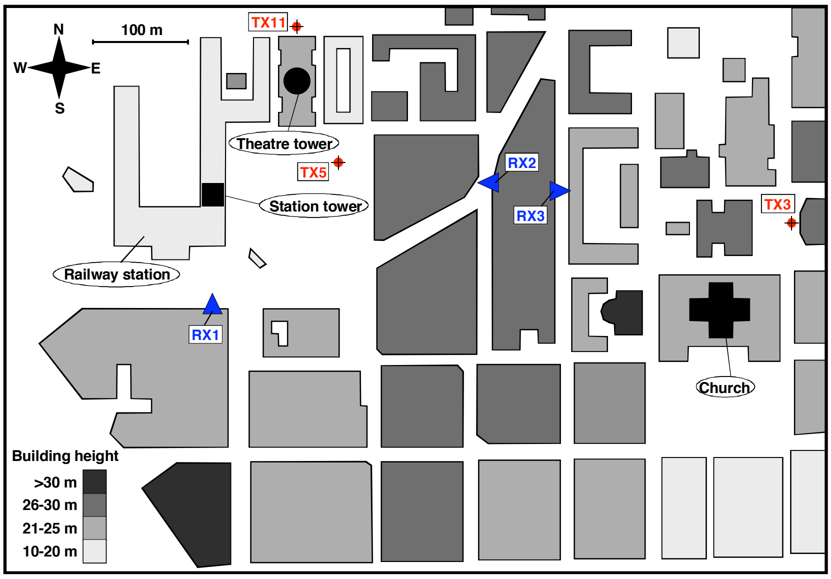

Fig. 3. Map of measurement sites

Fig. 4. View from site RX1

Fig. 5. View from site RX2

Fig. 6. View from site RX3

has the same height as RX2, but the buildings in the nearest blocks in front of the array are lower, and thus the environment seen by the base station is more open. The only building that rises clearly above its surroundings is the Lutheran Cathedral ('Church'), see Fig. 6.

RESULTS

During the measurement campaign about 70 transmitter positions were measured. In this paper we present only some sample results, describing the most typical observed propagation mechanisms. For receiver below roof-top level (RX1) we show transmitter position TX11, which situates on the street behind the building block on the northern side of the 'Rautatientori' square. Fig. 7 shows a detailed map of the surroundings of the transmitter and Figs. 8-9 show the total power for both polarizations in azimuth-elevation and azimuth-delay planes, respectively. The propagation is defined by the narrow street canyons on both sides of the theatre building (Fig.7). Most waves arrive with low elevation angles from the azimuth directions defined by parallel streets ('Street1'–'Street3'). The western street ('Street 1') dominates but some waves with short delays arrive also from 'Street 3'. However, we observe also components with relatively long delays which correspond to reflections from the park (north of the transmitter) and multiple reflections in the street canyons. In addition, some components with high elevation angles diffracted from the tower of the theatre ('Theatre tower') can be seen. For site RX2 at roof-top level we show transmitter position TX5, which is situated near the north-eastern corner of the open square. Fig. 10 presents a detailed map and the assumed propagation paths. Figs. 11-12 show the power in azimuth-elevation and azimuth-delay planes, respectively. The first signal component arrives over the roof-top from the direction of the transmitter ('Pseudo-LOS'). Only slightly delayed waves arrive from the azimuth angle of 13°, which corresponds to the reflections from the chimney stack on the roof of the opposite building. Waves reflected from the theatre tower and the white high-rising building in the corner of the square ('White tower', see Fig. 4) arrive simultaneously with the first components from the direction of the 'Kaisaniemenkatu' street ('Street canyon'). From this direction we see spreading in the delay domain because the multiple reflections from the buildings around the square are easily coupled to the street. Fig. 13 shows the surroundings of transmitter position TX3 for receiver site above roof-top level (RX3). The transmitter position is behind the building of Bank of Finland (BOF). Figs. 14-15 show the power in azimuth-elevation and azimuth-delay planes, respectively. The first components arrive along the street in the broadside direction ('Street 1'). Soon after that we see diffractions over the BOF building, and the first components from the direction of the first parallel street on the right ('Street 2'). Waves reflected from the Lutheran Cathedral ('Church') arrive with high elevation angles. The longest delays are associated with propagation through the inner yard of the low building in front of the array. Largest delay spreads are also here related to the waves propagated along the street canyons.

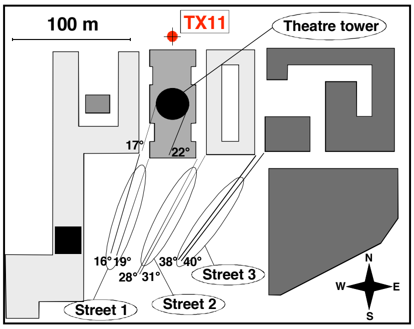

Fig. 7. TX11: Detailed map

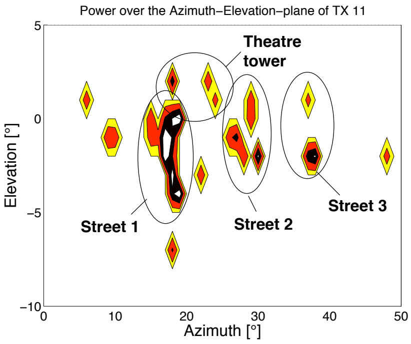

Fig. 8. TX11: Azimuth-elevation

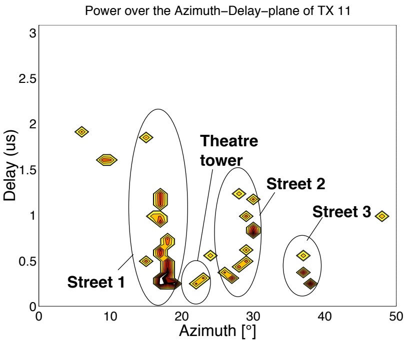

Fig. 9. TX11: Azimuth-delay

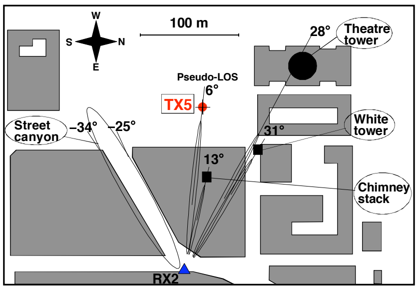

Fig. 10. TX5: Detailed map

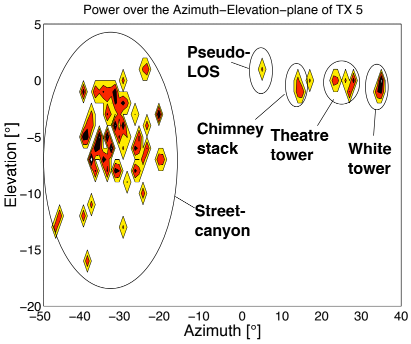

Fig. 11. TX5: Azimuth-elevation

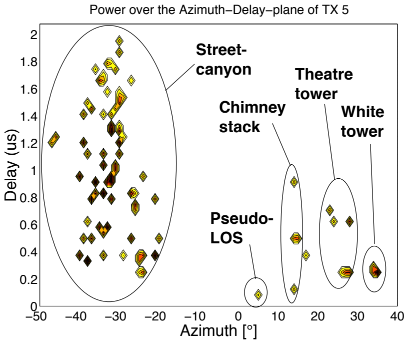

Fig. 12. TX5: Azimuth-delay

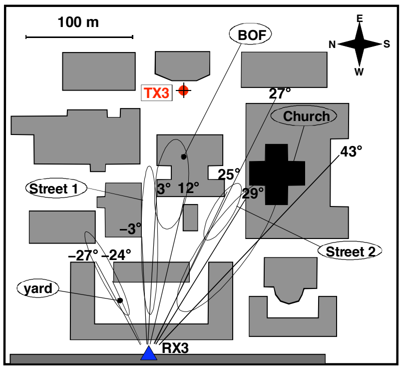

Fig. 13. TX3: Detailed map

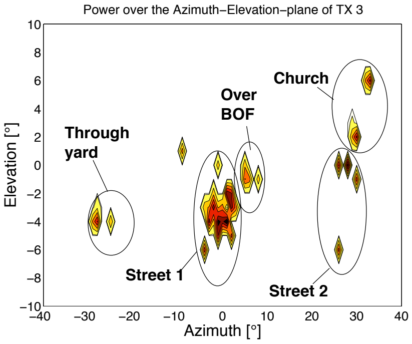

Fig. 14. TX3: Azimuth-elevation

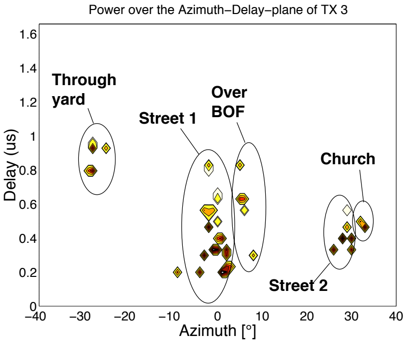

Fig. 15. TX3: Azimuth-delay

CONCLUSIONS

In this paper we present for the first time 3-D wideband mobile radio channel measurements at the base station using novel measurement technique. We are able to estimate the azimuth and elevation angles, delay, and polarization ellipse of the incident waves. During the measurement campaign we collected data using about 70 different transmitter positions, of which only some sample results have been presented. However, the following conclusions have been drawn after evaluating the whole measurement set. According to the results, the urban radio channel has a strong directional nature, where incoming energy is mainly concentrated in spatial clusters. The surroundings of the mobile have fairly little effect on the clusters seen by the base station. Thus, the environment seen by the base station strongly defines the propagation scenario, independently of BS antenna height. Propagation over roof-tops seems to be typically related to reflections from high-rising buildings in the surroundings, with LOS to BS. Directly diffracted components arriving with the shortest delays from the direction of the transmitter were always weak in our measurements. The presented measurement technique could be used to collect a dataset allowing efficient evaluation of existing ray tracing tools.

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