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EXAMPLES OF DYNAMIC WIDEBAND MOBILE RADIO CHANNEL MEASUREMENTS WITH AN ANTENNA ARRAY

Abstract: **This paper presents examples of real-time wideband multichannel measurements of the radio channel of a moving mobile. The measurement method allows the investigation of the wideband dynamic mobile radio channel of adaptive antennas in realistic situations with normal mobile speeds. The number of recorded channels is at the moment 8, but it is being extended to 64 in the near future. This corresponds to e.g. 32 dual-polarized elements. The bandwidth can be up to 60 MHz. The channel characteristics that can be determined based on the data include amplitude, phase, excess delay, DOA and Doppler spectrum for each signal multipath component. Also the correlation between array elements and frequency correlation of the channel can be studied. The measured channels can be used for wave propagation studies and evaluation of different multichannel antenna and receiver configurations in different environments. Both mobile and base station ends of the channel can be measured due to the easily movable receiver.**

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1. Introduction

The required capacity in third generation mobile cellular systems sets high demands for the system. Wideband transmission together with different diversity schemes (spatial, frequency, polarization) or spatial user separation with adaptive antennas are considered as possible solutions. In micro- and picocells, where most capacity is needed, the radio environment is most difficult. Both delay and angular dispersion occurs, and the channel changes rapidly. The implementation of a system that successfully copes with the complex environment requires knowledge of the two-dimensional radio channel including both the delays and directions-of-arrival (DOA's) of the signal multipath components. This knowledge can be obtained by deterministic methods, such as ray-tracing, or measurements of real channels. The former approach requires reliable simulation tools that themselves must be verified with measurement data. So far most of the stochastic two-dimensional radio channel models have been based on static measurements. The DOA measurements have been based either on rotating a narrow-beam antenna [1] or simulating an antenna array by moving a single antenna [2,3]. However, to gather more realistic information about the behavior of the channel including Doppler characteristics, LOS-NLOS transitions etc., dynamic measurements are required. The straightforward way of doing dynamic channel measurements is to use a parallel system of N receivers behind N antenna elements [4]. This is the most realistic but also the most complex method, especially if wideband measurements are required and the number of elements is large. In this paper we use a more simple and flexible system with a single receiver and an N - channel switching unit. Real-time measurements of the dynamic two-dimensional radio channel corresponding to continuous routes of a moving mobile are presented. The measured channels can be used e.g. in system simulators for adaptive antennas, adaptive algorithm evaluation, wave propagation studies, and evaluation of different array configurations.

2. Measurement system

The used measurement system is based on a complex wideband radio channel sounder and a fast RF switch to record the channel impulse responses (IR) from multiple antenna elements [5]. The bandwidth of the receiver of the sounder is 100 MHz at carrier frequency of 2154 MHz. The chip frequency of the modulating PN-code in the transmitter can be selected between 2.5 and 60 MHz. The received demodulated signal is divided into I- and Q- branches and sampled with two 120 Ms/s A/D -converters. The signal samples from every antenna element are then stored for off line processing to obtain the complex IR of the channel. The angular dimension of the channel can be computed from the relative phases of the IRs of different array elements using Fourier transform or super-resolution techniques. The maximum mobile speed is determined by the desired accuracy of the directions of the signal components and limited by the maximum measurement rate of the sounder. The length of a continuous measurement run is limited by the size of the memory buffer of the sampling card (currently 2×4 Mbytes for I and Q) and depends on the length of the used PN-code in the transmitter. The maximum mobile speed (v_{max}) and length of continuous measurement run (s_{max}) of the moving mobile corresponding to a practical delay window (τ_{max}) for different delay resolutions (τ_{min}) are presented in Table 1. The criterion for the angular accuracy is ±5% of the half-power beamwidth of the antenna array. Four IRs per wavelength are measured and sampled with two samples per chip.

Table 1. Chip frequency (f_c), delay resolution, delay window, and corresponding maximum mobile speed and length of continuous measurement run with an 8-element linear array.

f_c [MHz]	τ_{min} [ns]	τ_{max} [µs]	v_{max} [m/s]	s_{max} [m]
60	17	8.5	52	8.9
30	33	8.5	52	17.9
10	100	12.7	34.7	35.9
2.5	400	12.4	35.6	147.2

The system is flexible as it allows channel measurements with different antenna arrays having both polarizations. Currently the number of channels is 8 but it is being extended to 64. The system is easily movable and thus allows measurements at both base station and mobile ends of the channel. The wideband operation (chip frequency up to 60 MHz) allows the investigation of the frequency correlation properties of the channel. Benefits of downlink beamforming in FDD systems can be studied using this information.

3. Description of measurements

The measurements presented in this paper were carried out in the campus area of Helsinki University of Technology in Espoo, Finland. A linear array was used as a BS antenna. It was connected to the receiver of the sounder through the element switching unit and located at fixed position while the transmitter simulating the mobile was positioned on a cart moving at constant velocity. Impulse responses were recorded from each element of the array while the cart was moving. Two examples of measured mobile routes are presented. The base station antenna array was a vertically polarized 8-element array of microstrip patch elements with $\lambda/2$ spacing [5]. The beamwidth of the element limits the maximum sector of view of the array to approximately 120°. An omnidirectional discone antenna was used at the mobile. The transmitter power level was 41.8 dBm. The measurement parameters are given in Table 2. The maximum number of recorded impulse responses is determined by the memory buffer of 8 Mbytes, which is used to store the signal samples before transferring to a hard disk.

Table 2. Measurement parameters

Parameter	Value	Parameter	Value
Carrier frequency	2154 MHz	Maximum number of array IRs	1040
Chip frequency of PN code	30 MHz	Samples / wavelength	4
Sample rate	120 Ms/s	Samples / m	28.7
Code length	63	Length of maximum continuous run	36.2 m
Delay resolution	33 ns	Mobile speed	0.4 m/s
Delay window	2.1 µs	BS antenna height	11.5 m
Element switching rate	238.1 kHz	MS antenna height	1.8 m
Size of IR	504 bytes	Measured array IRs: MS Route I	1350
Averaging factor	2	Measured array IRs: MS Route II	990
Maximum number of IRs	8322	Length of MS Route I:	47 m
Number of array elements	8	Length of MS Route II:	34.5 m

The slow mobile velocity of only 0.4 m/s was selected as a practical speed of the cart. The limitation for the mobile speed in the measurement becomes from the phase rotation due to Doppler shift that can not be separated from the DOA. The time required to record one IR from every element is only 8×2.1 µs = 16.8 µs, and practically the same measurement could thus have been done at mobile speeds up to 200 m/s (in theory). The base station antenna array was located on the roof of the 3-

storey building of the Department of Electrical and Communications Engineering. At the time of the measurement there were no moving objects in the environment other than the mobile. The average distance from the transmitter to the receiver was 60 m. MS Route I was measured by combining the data of two continuous measurement runs. The mobile routes together with the BS array location and its pointing direction are presented in Figure 1. The geometry of the location resembles an intersection of two street canyons. At Route I there are two transitions when the LOS first appears and then disappears. Route II is a LOS case with reflecting walls at both sides.

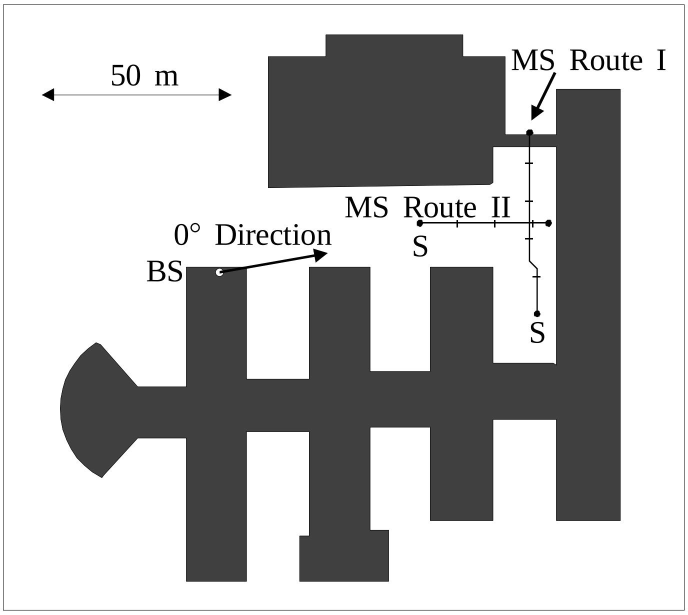

Figure 1. MS routes and BS array location. The starting point of the route is marked with S.

4. Examples of measured channels

For each received multipath component the following parameters can be solved: amplitude, phase, excess delay, direction-of-arrival and Doppler spectrum. Also the frequency correlation properties of the channel can be analyzed as well as correlation between channels corresponding to different array elements.

A. Delay-DOA spectrum

The DOAs of the multipath components are calculated by Fourier processing [5]. Chebychev amplitude weighting for 25 dB sidelobe level is applied to enhance the dynamic range. The resulting antenna beamwidth and thus angular resolution of the measurement is approximately 15° with the used 4 λ-long array.

Series of measured 2D impulse responses, i.e. delay-DOA spectra of the channel are presented in Figure 2. The snapshots are taken by averaging over 20 subsequent IRs (5 λ) at every 10 m along the mobile routes, beginning at the starting point of the route (see markers in Fig. 1). Also the physical location of the mobile is presented in each case. The dynamic range of the DOA measurement is approximately 20 dB due to the sidelobes in the array pattern. They are higher than the ideal value of 25 dB because of nonidealities in the antenna and its feed network.

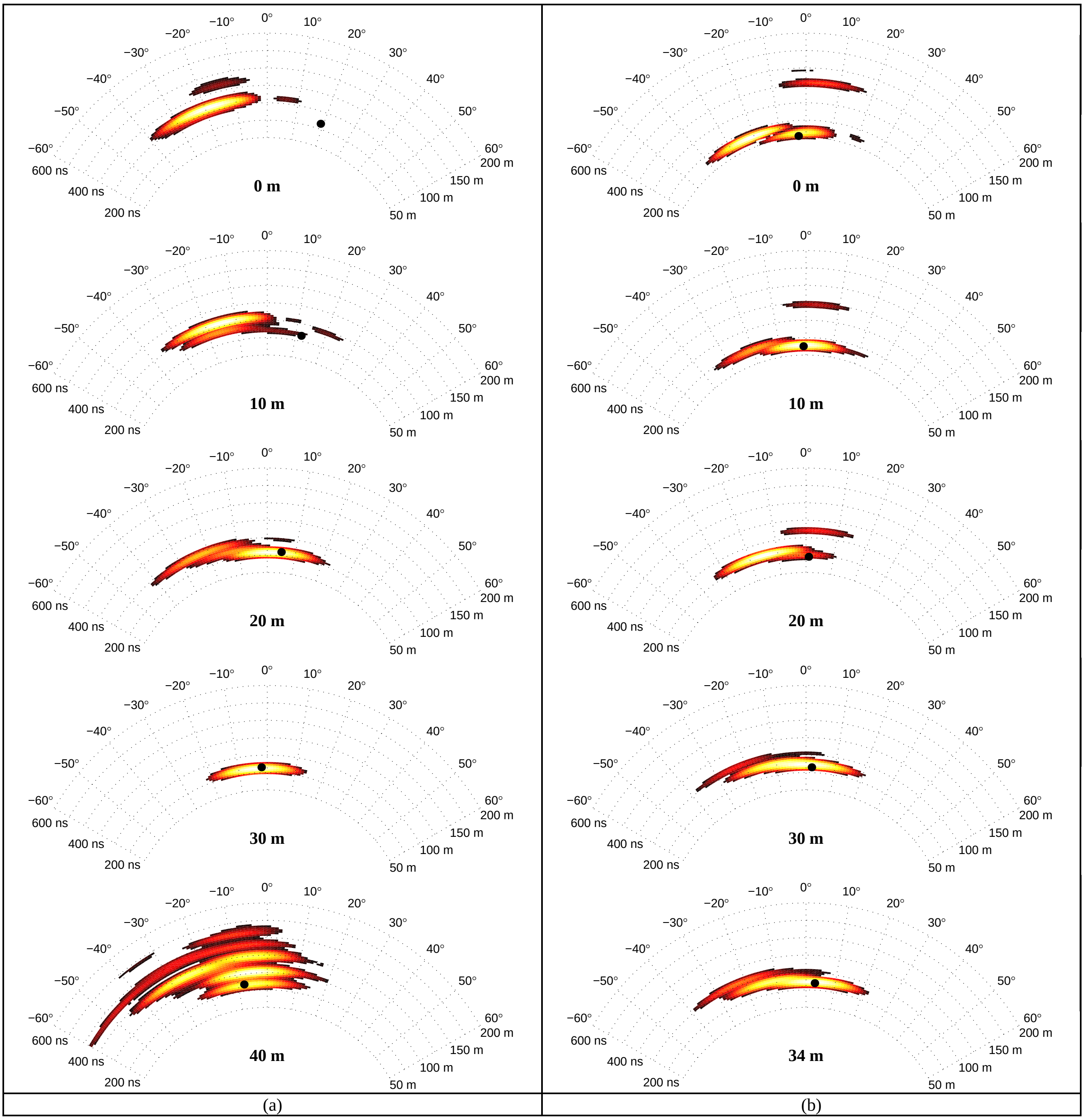

Figure 2. Examples of delay-DOA spectra. (a) Route I. (b) Route II. The dot marks the MS location in each case. The amplitudes are normalized to the strongest component and the scale ranges from –20 dB (dark) to 0 dB (bright).

At mobile Route I, Fig. 2 (a), the strongest reflection is received from a large uniform wall at direction around –20°. At MS locations 0 m and 10 m, for which LOS does not exist, one corner diffraction and two reflections (one single and one double) are observed. At 20 m, the reflection from the wall is still present, now accompanied by the LOS component. At 30 m, the angle of incidence at the wall is too small for the ray to be reflected to the receiving antenna. Only one component is now visible, because the back reflection can not be separated due to its small excess delay. The LOS exists throughout the mobile Route II, Fig. 2 (b). Also the reflection from the wall at left is visible at every measurement spot. In addition, the back reflection from the opposite wall is present until it can no more be separated from the LOS component, at 30 m.

B. Time and angle dispersion

The dispersive properties of the radio channel can be investigated with two figures: delay spread and angular spread, defined as the square root of the second central moment of the power delay profile and power angular profile, respectively. Figures 3 and 4 show the delay and angular spread of the channel for both mobile routes. The resolution of the measurement system limits the minimum measurable values to 10 ns for rms delay spread and 7° for rms angular spread. The results clearly indicate that when the LOS disappears, both the delay and angular spread increase rapidly. Based on the data, the correlation between delay and angular spread of the channel is clear. The correlation coefficients for Routes I and II are 0.89 and 0.95, respectively.

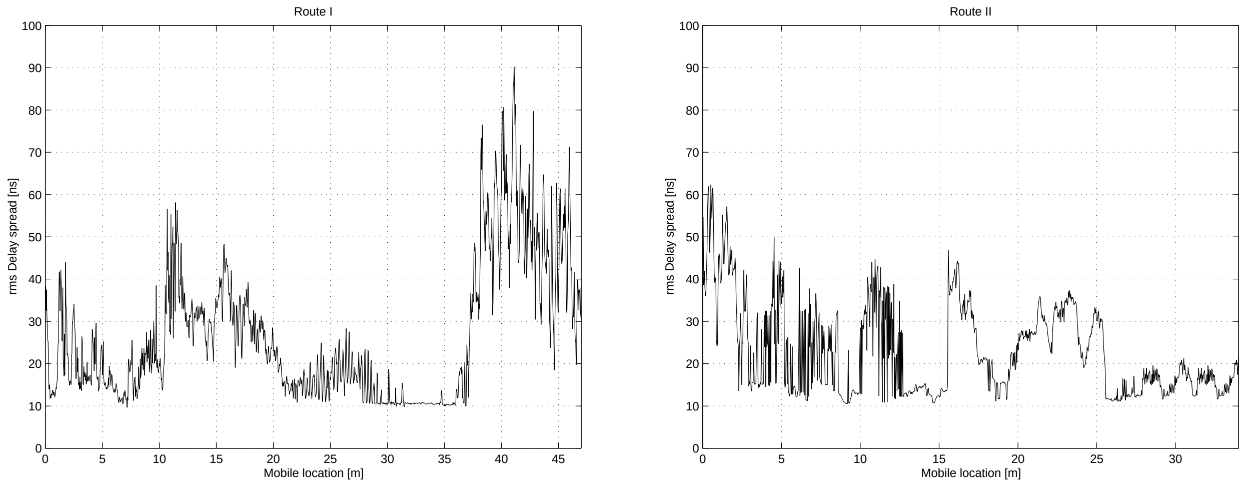

Figure 3. Delay spread of the channel at both MS routes.

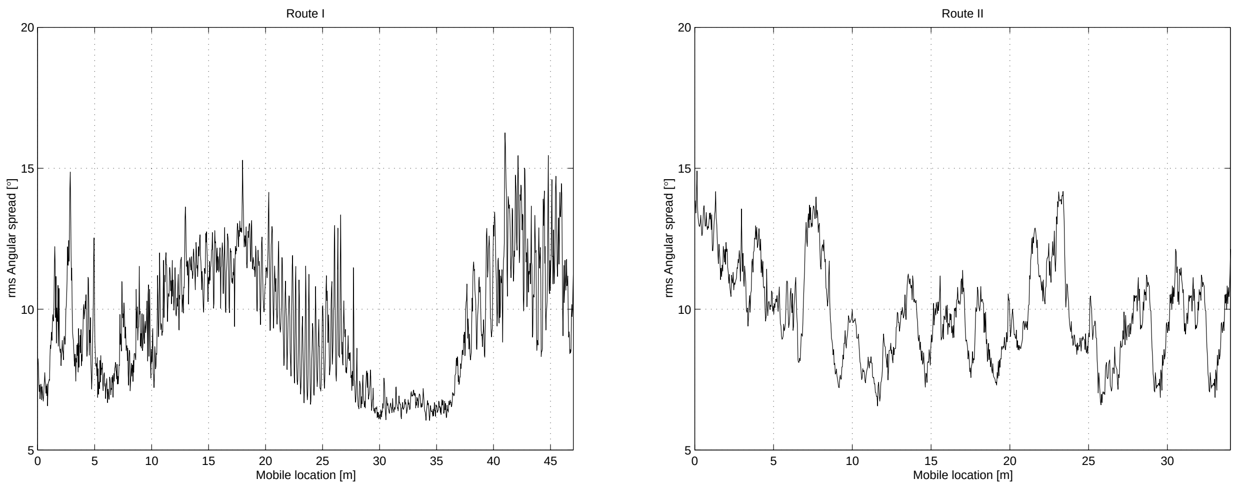

Figure 4. Angular spread of the channel at both MS routes.

C. Frequency correlation

Due to the time dispersive nature of the multipath radio channel, it is also frequency dependent. Wideband measurements allow the investigation of the frequency correlation of the channel up to the bandwidth of the modulating PN code. Figure 5 shows the complex frequency correlation of the channel as a function of frequency separation averaged over both measured mobile routes. The correlation is presented inside the 3 dB bandwidth of the code only, because elsewhere the spectrum contains little energy. Although the correlation decreases to 0.6 by ±10 MHz frequency separation, it indicates that the coherence bandwidth of the measured channels is at least 30 MHz, if a typical definition of 0.5 correlation is used. The limited coherence bandwidth of the channel is a particular problem for adaptive antennas in FDD systems. It is widely stated that the signal weights obtained in uplink are not applicable to downlink with frequency transform only. A wideband array measurement provides the means for studying the frequency correlation of channels of adaptive arrays.

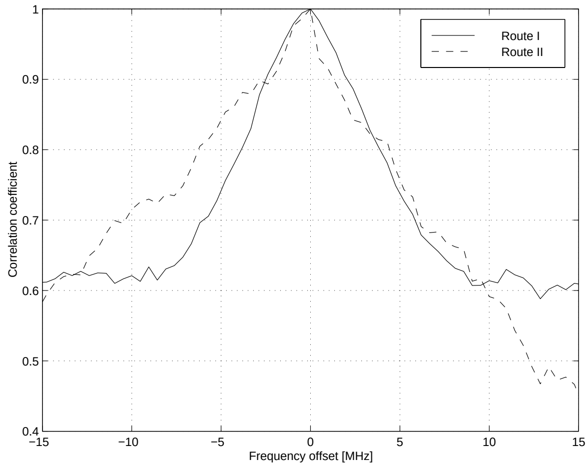

Figure 5. Complex frequency correlation of the channel averaged over the measured mobile routes.

D. Element correlation

Low correlation between the radio channels corresponding to different antenna elements is essential, if diversity reception is desired. The channel correlation as a function of the element separation can be investigated in case of array measurements. The complex channel correlation as a function of the element separation in the BS array and the location of the mobile for both measured mobile routes is presented in Figure 6. By comparing Fig. 6 to Figs. 3 and 4 it is clear that the spatial correlation is strongly connected to the channel dispersion. This means that when the channel is spread in delay and/or angle, the spatial correlation along the BS array is decreased. Pure LOS with no reflections leads to the strongest correlation. Figure 7 shows the average correlation between the array elements for both mobile routes. At spatial element separation of 3.5 λ the correlation coefficient is still stronger than 0.7 for both routes, which is not enough to provide adequate diversity gain. This result is in good agreement with the existing information on spatial diversity.

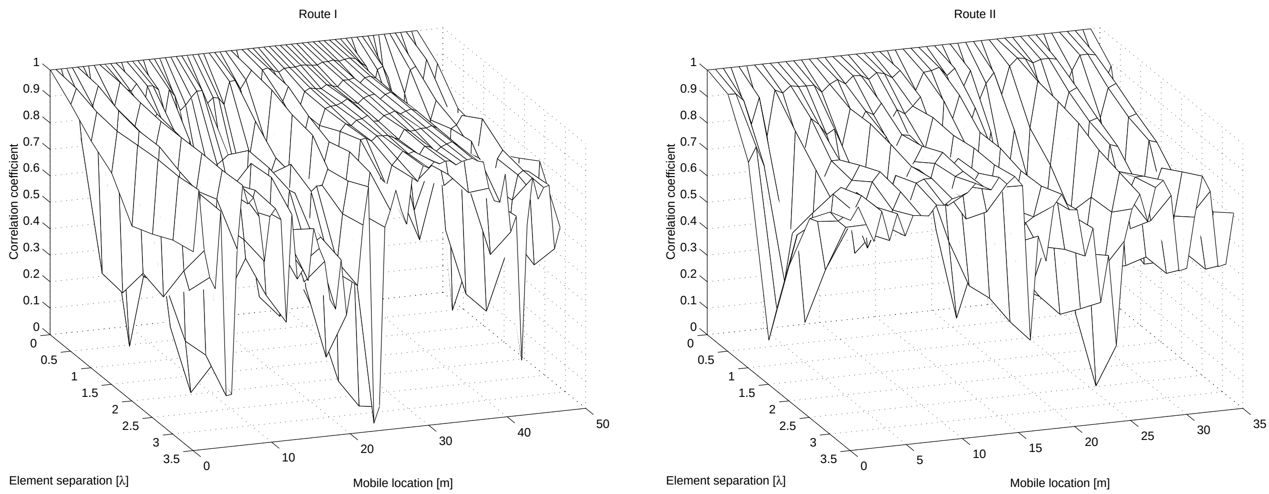

Figure 6. Complex channel correlation as a function of element separation in the BS array and mobile location.

5. Conclusions

This paper presents examples of real-time wideband multichannel measurements of the mobile radio channel of a moving mobile. The measurement method allows the investigation of the wideband dynamic mobile radio channel of adaptive antennas in realistic situations with normal mobile

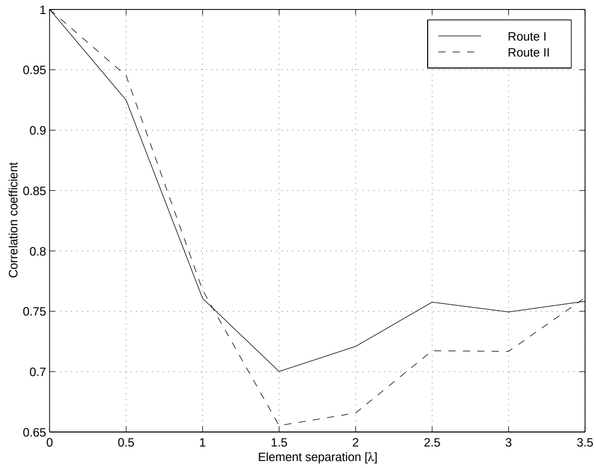

Figure 7. Complex channel correlation as a function of element separation in the BS array averaged over the measured mobile routes.

speeds. The number of recorded channels is at the moment 8, but it is being extended to 64 in the near future. This corresponds to e.g. 32 dual-polarized elements. The bandwidth can be up to 60 MHz. Both mobile and base station ends of the channel can be measured, due to the easily movable receiver. The channel characteristics that can be determined based on the data include amplitude, phase, excess delay, DOA and Doppler spectrum for each signal multipath component. Also the correlation between array elements and frequency correlation of the channel can be studied. The measured channels can be used as input data for wave propagation studies and stochastic two-dimensional channel model development. Also different multichannel antenna and receiver configurations can be evaluated in different environments by using system simulators. Dual-polarized measurements in different environments with different array configurations will be conducted during 1998. Possible candidates for the array geometry consist of e.g. long linear arrays for good angular resolution, planar arrays for three-dimensional angle space, and cylindrical arrays for full azimuth coverage.

Acknowledgments

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