Dynamic Wideband Measurement of Mobile Radio Channel with Adaptive Antennas

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Abstract – This paper presents dynamic radio channel measurement using a fast wideband complex radio channel sounder and an antenna array. Examples of continuous channels of a moving mobile are presented. The array reception allows the investigation of channel dispersion in both angle and time. In addition, wideband measurement gives information of the coherence bandwidth of the 2D channel, essential for downlink beamforming in FDD systems. Also correlation between the elements in the array is studied.

I. INTRODUCTION

It is widely accepted that successful implementation of adaptive antennas in future mobile radio communication systems requires knowledge of the two-dimensional radio channel including both the delays and the directions-of-arrival (DOAs) of the signal multipath components. This knowledge can be obtained either by prediction based on e.g. ray tracing simulations, or measurements of real channels. The former approach requires reliable simulation tools that, themselves, can be verified with measurement data. So far most of the reported two-dimensional channel measurements have assumed a static channel. 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, dynamic measurements are required. The measured channels can be used for e.g. adaptive algorithm evaluation or system simulators for adaptive BS antennas. 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.

II. 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 can be computed from the relative phases of the IRs from different array elements using Fourier transform or superresolution 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. Delay resolution, delay window, and corresponding maximum mobile speed and length of continuous measurement run with an 8-element linear array.

τ_{min} [ns]	τ_{max} [μs]	v_{max} [m/s]	s_{max} [m]
17	8.5	52	8.9
33	8.5	52	17.9
100	12.7	34.7	35.9
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.

III. DESCRIPTION OF MEASUREMENTS

The channel measurements presented in this paper were carried out in the campus area of Helsinki University of Technology in Espoo, Finland. The array connected to the receiver simulating the base station antenna was 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. The measurement was performed along three mobile routes of length of a few tens of meters.

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**
Carrier frequency	2154 MHz
Chip frequency of PN code	30 MHz
Sample rate	120 Ms/s
Code length	63
Delay resolution	33 ns
Delay window	2.1 µs
Element switching rate	238.1 kHz
Size of IR	504 bytes
Averaging factor	2
Maximum number of IRs	8322
Number of array elements	8
Maximum number of array IRs	1040
Samples / wavelength	4
Samples / m	28.7
Length of maximum continuous run	36.2 m
Mobile speed	0.4 m/s
BS antenna height: Route I BS antenna height: Routes II and III	15 m 11.5 m
MS antenna height	1.8 m

The slow mobile velocity of only 0.4 m/s is 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 180 m for Route I and 60 m for Routes II and III. Routes I and II were measured by combining the data from two continuous runs. Table 3 presents the lengths of the mobile routes and the number of impulse responses recorded along each route. The mobile routes together with the BS array location and its pointing direction are presented in Figure 1.

Table 3. Mobile routes

Route	**Route I**	**Route II**	**Route III**
Route length	63 m	47 m	34 m
Number of array IRs	1808	1349	976

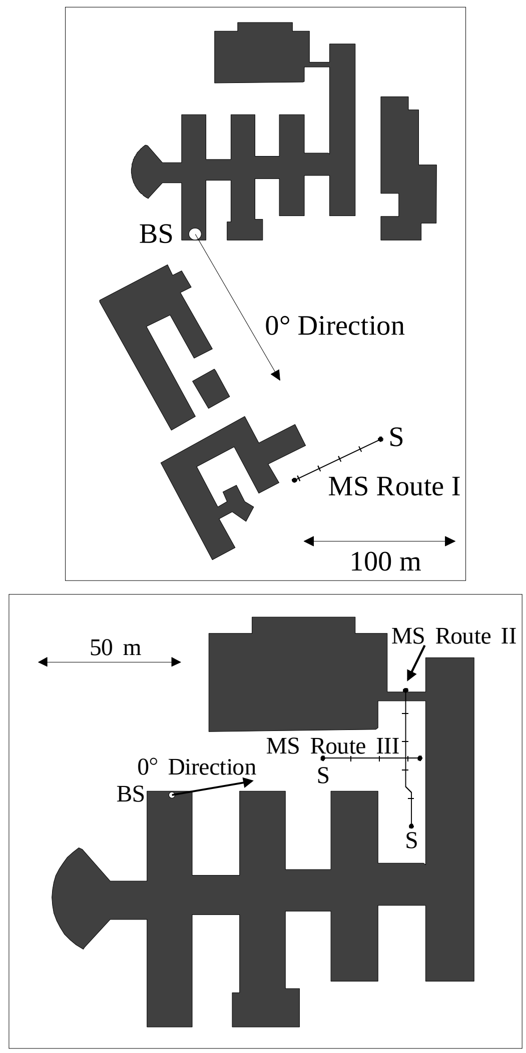

Figure 1. MS routes and BS array locations. The starting point of each route is marked with S.

The propagation environment at mobile Route I is typical suburban. The buildings have a maximum of 3 stories, and their surroundings consists mainly of lawns and small forest areas. At the LOS part of Route I there is one dominant reflection from the opposite building, see Fig. 1. A LOS–NLOS transition occurs when the mobile goes behind the building. The part of the building between the MS and BS has 2 stories and it is thus lower than the location of the BS antenna.

The propagation environment at MS Routes II and III differs from that of Route I. The building walls are closer and they form a more dense scattering environment. The geometry of the location resembles an intersection of two street canyons. At Route II there are two transitions when the LOS first appears and then disappears. Route III is a LOS case with reflecting walls at both sides.

IV. ANALYSIS OF MEASUREMENT RESULTS

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 15 m (Route I) or 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 non-idealities in the antenna and its feed network.

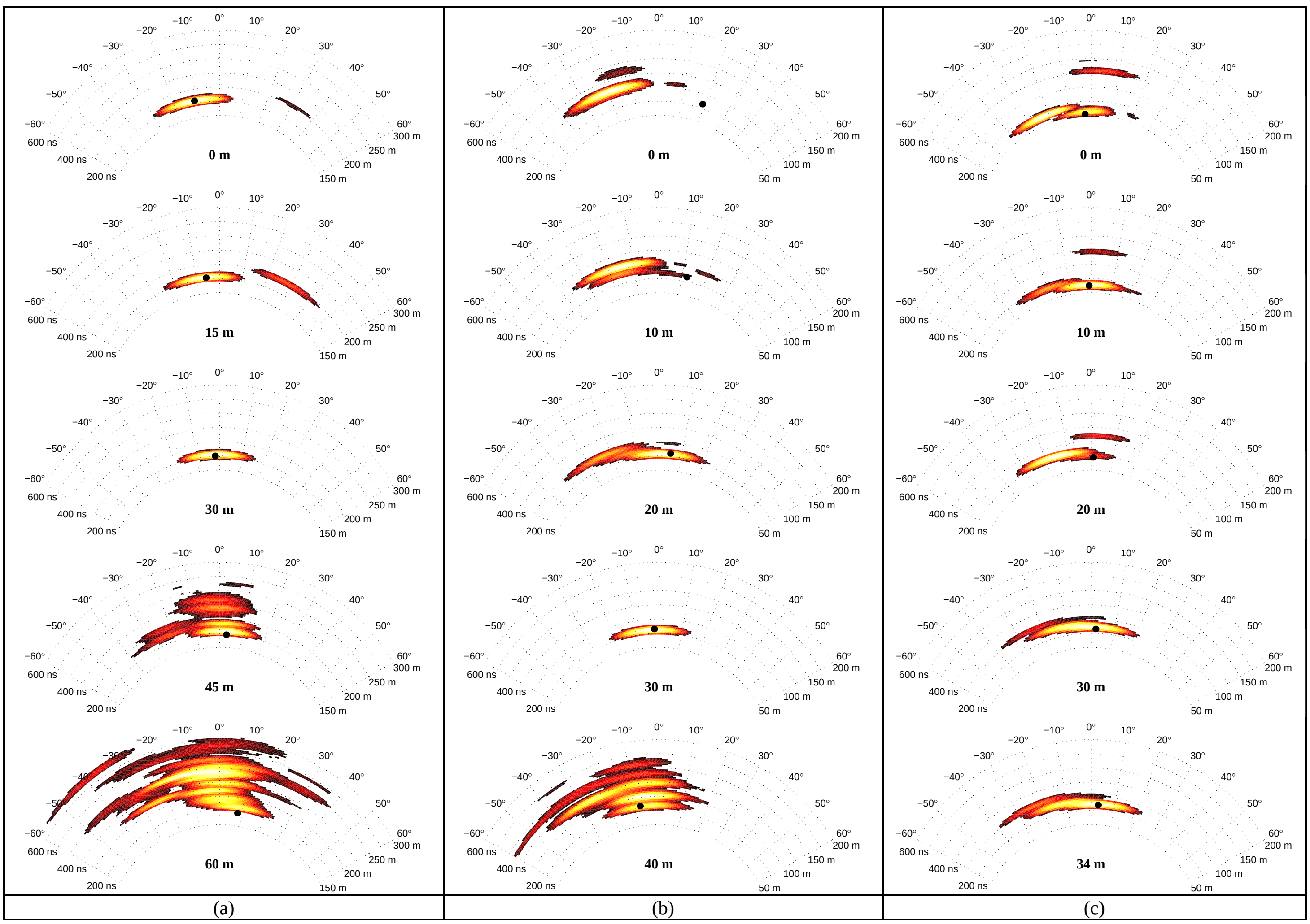

Figure 2. Examples of delay-DOA spectra. (a) Route I. (b) Route II. (c) Route III. The dot marks the MS location in each case. The amplitudes are normalized to the strongest component and the scale ranges from –20 dB (dark) to 0 dB (bright).

At mobile Route I, Fig. 2 (a), the signal consists mainly of two components, the LOS component and one reflection from the opposite building, at around 30° direction. At 30 m the ray no more meets the wall at appropriate angle to reach the BS, and only the LOS component is present. At 45 m the LOS is just about to disappear and the number of signal paths is already increased significantly. At least 6 separate components can be identified. At 60 m when LOS no more exists, the channel is widely spread in both angle and delay.

At mobile Route II, Fig. 2 (b), 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 III, Fig. 2 (c). 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 dispersible 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 each mobile route. 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 – III are 0.81, 0.89, and 0.95, respectively, with the average being 0.84. The measured mean delay and mean angular spreads for all routes together were 28.8 ns and 10.3°, respectively. For delay spread the value is typical for suburban environment, where no large objects exist acting as strong distant reflectors. The angular spread, however, is larger than typical suburban because of the short range that makes the local scattering area around the mobile to cover larger angular sector seen from the BS. It has to be noted, however, that the incapability of the system to measure small delay or angular spreads increase both the mean values.

The larger channel spread at Route I can be explained by the longer distance between the MS and BS, more open environment and thus free propagation of rays causing longer delays. The median of both delay and angular spread is approximately same for each route.

C. Frequency correlation

Due to the time dispersible 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.

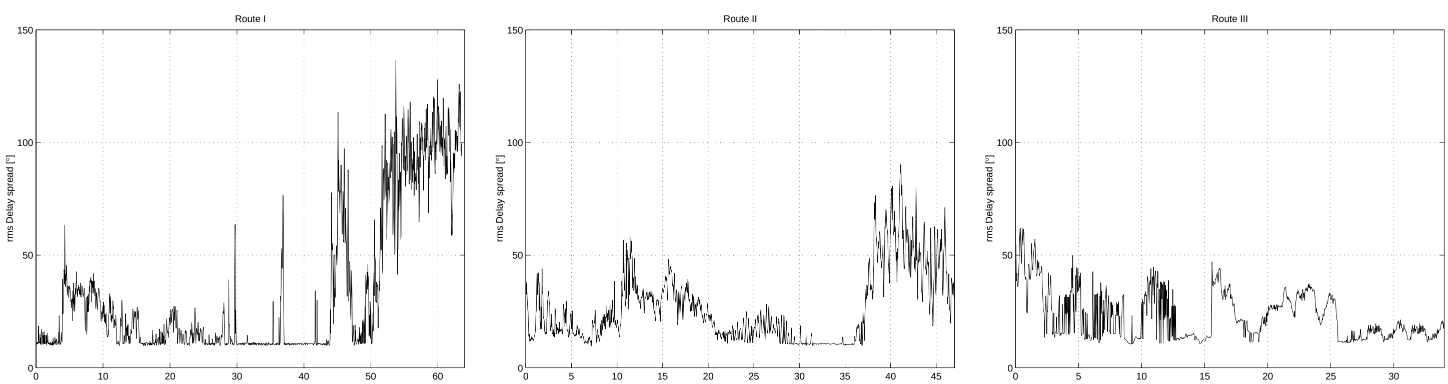

Figure 3. Delay spread of the channel at each mobile route.

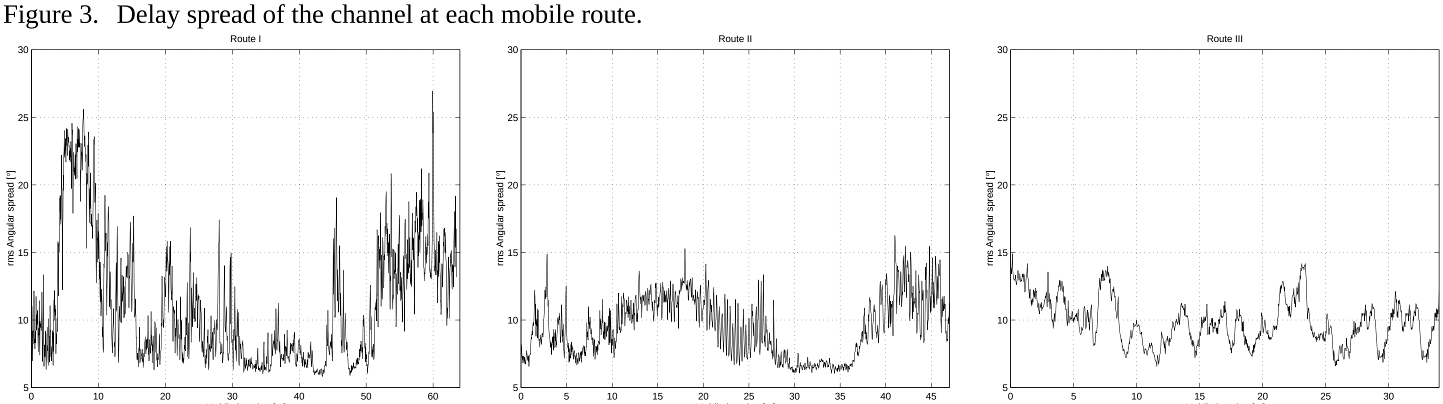

Figure 4. Angular spread of the channel at each mobile route.

Figure 5 shows the frequency correlation of the channel averaged over each measured mobile route. The correlation is presented inside the 3 dB bandwidth of the code only, because elsewhere the spectrum contains little energy.

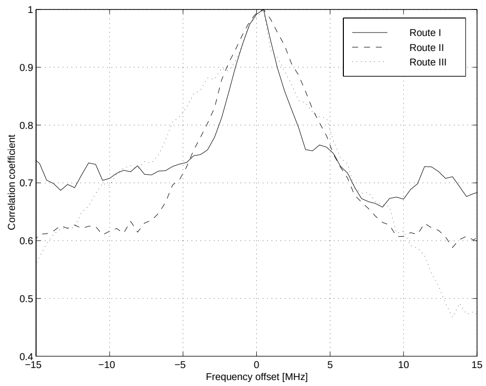

Figure 5. Frequency correlation of the measured channels.

The correlation is best for Route I, that is mostly LOS, which is reasonable. The correlation coefficient is still 0.7 at ±15 MHz off the center frequency. Although the correlation is weaker for Routes II and III, it indicates that the coherence bandwidth of the measured channels is more than 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.

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. Figure 6 presents the channel correlation as a function of the element separation averaged over each measured mobile route.

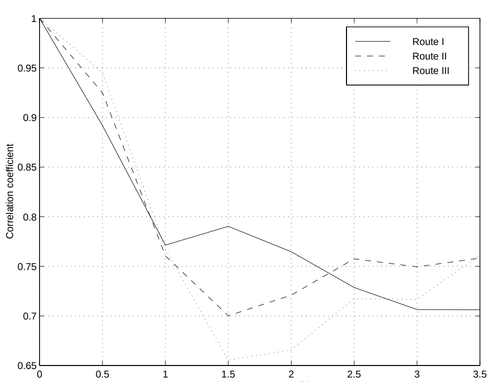

Figure 6. Spatial correlation of the measured channels.

As the frequency correlation, also the spatial correlation of the channel is strongest for Route I. This is comprehensible due to the simple propagating environment. At spatial element separation of 3.5 λ the correlation coefficient is still stronger than 0.7 for all routes, which is not enough to provide adequate diversity gain. Also this result is in good agreement with the existing information on spatial diversity.

V. CONCLUSIONS

The presented measurement system allows the investigation of the wideband dynamic mobile radio channel of adaptive antennas in realistic situations. This paper gives an overview of the channel characteristics that can be determined. They 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. Both polarizations can be included using dual-polarized elements with independent feeds.

In addition to signal propagation measurements, also different array configurations can be evaluated in realistic conditions. Both mobile and base station ends of the channel can be measured, due to the easily movable receiver. The measured channels can be used directly as input for system simulators of adaptive antennas or as statistical data for stochastic two-dimensional channel model development.

The system is currently being extended to 64 channels. Dual-polarized measurements with different array configurations at both ends of the channel will be conducted during 1998.

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