EXPERIMENTAL CHARACTERISATION OF MIMO PROPAGATION CHANNELS

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ABSTRACT

This paper describes the experimental characterisation of MIMO propagation channels. The requirements for the measurement system are discussed and the developed system is described. At the second part of the paper the analysis methods of MIMO measurement results are introduced and results are presented both for outdoor and indoor for several different antenna configurations. The significance of large scale propagation effects like shadowing on MIMO capacity gain is shown. It seems also obvious that the antenna directivity is an important factor for the fluctuation of the achieved MIMO capacity.

INTRODUCTION

This paper describes the approach for experimental characterisation of MIMO (multiple-input-multiple-output) propagation channels. Recent results from information theory have predicted high data rates for MIMO mobile radio systems (e.g [1]). However, the achievable capacity is defined by the availability of parallel propagation channels in the multipath environment. For example the keyhole effect [2] could reduce the theoretical capacity. Obviously, radio channel measurements are needed to investigate the existence and characteristics of parallel separate propagation paths [3]. Both detailed understanding on the most important propagation phenomena and information on the statistical properties of the channel are needed to support the development of MIMO radio systems. Essential properties of the MIMO channel measurement system are:

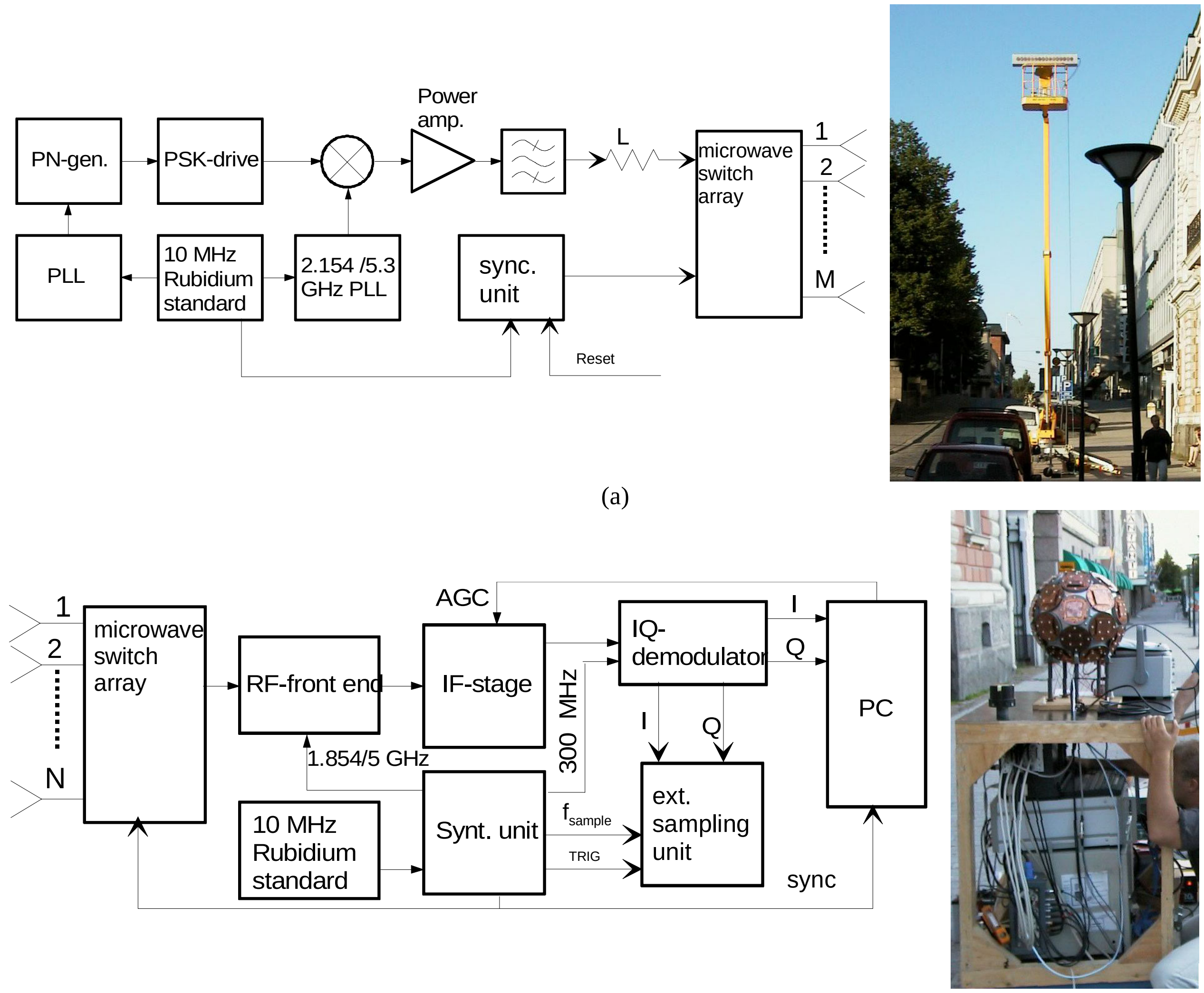
- Good angular resolution to distinguish directions of arrival (DOA) and departure (DOD). It is useful to be able to separate the effect of the antenna configuration and the propagation environment in the system analysis. The ultimate goal would be to separate all significant waves. At least in the mobile end there should also be some angular measurement capability in the elevation domain. The angular resolution can be improved by suitable super resolution methods, whose utilisation requires adequate signal-to-noise radio, i.e. transmitted power.
- Polarisation measurement capability to determine the usefulness of orthogonal polarisations as parallel channels.
- Capability to record the channel continuously to investigate the behaviour of the multipaths along the route of the mobile. Critical locations can be expected to be for instance street crossings in urban environments, where line-of-sight (LOS) may occur and the signals travelling to the crossing street are diffracted from a few street corners possibly acting as “keyholes”. Continuous coherent measurement gives also the possibility to use Doppler domain in the signal analysis.

This paper describes the approach taken at Helsinki University of Technology, where a 16×64 dual-polarised MIMO measurement system has been developed for 2 GHz frequency range and used for measurements in several environments. In the next chapter the measurement system and after that the data analysis are described. Finally in the last chapter the performed measurements, some of their results and conclusions are presented.

MEASUREMENT SYSTEM AND DATA ANALYSIS

Measurement system

The measurement setup presented in this paper is based on the 2.15 GHz sounder system described in [4, 5] and recently extended to MIMO measurements [6]. The block diagram and photographs of the system are shown in Fig. 1. An external sampling unit is used, which can store 2×20 Mbyte/s stream of complex data to 2×9 Gbyte hard disks. The factor 2 indicates the separate samplers for the I and Q components of the signal. Microwave switches are used at both ends of the radio link to measure sequentially the wideband channel (pseudonoise code with 30 MHz chip frequency is used corresponding to delay resolution of about 33 ns or 10 meters) between each pair of antenna elements. The size of the channel matrix in the current system is $M \times N = 16 \times 64$ (TX × RX). The spherical array used at the mobile receiver end consists of 32 dual-polarised patch antennas with separate feeds for θ- and φ-polarisations [5] and the linear array at the fixed transmitter end has 8 dual-polarised patch antennas. Due to power handling capability of the TX switch, the transmitted power had to be limited to +26 dBm, which reduces the maximum measurement distance and limits the use of the system mainly to pico, micro, and small macrocells. However, these environments can be expected to be an important application area of high data rate systems potentially employing MIMO configurations.



(a)

(b)

Fig. 1. MIMO measurement system. a) Fixed transmitter. b) Mobile receiver.

When four samples per wavelength of 0.14 m are recorded, the maximum continuous route length is about 300 m. The measurement time of the channel matrix is about 9 ms and the wait time between two consecutive measurements is 63 ms. The moving speed is about 0.5 m/s, so the mobile moves 4.3 mm during the complete channel matrix measurement, which can be considered small compared to the wavelength and causes an error of only a fraction of a degree in the angular domain analysis [5].

PROPAGATION CHANNEL, ANTENNA AND CAPACITY ANALYSIS

The measurement results can be utilised in the analysis of MIMO systems in several ways:

1. By selecting certain antenna elements from the spherical and linear arrays to obtain some realistic MIMO antenna configuration. In this case one can estimate the capacity in a straightforward manner for the selected antenna configuration from the measured channel matrix.
2. By performing direction-of-arrival (DOA) analysis to obtain an estimate of the distributions of waves at both ends of the link [7]. By using far-field assumption one can calculate the received signals of any arbitrary antenna configuration whose size is of the order or smaller than that of the measurement array [8].
3. The measurement results can be used to create channel models (empirical, statistical), which are then used for system analysis.

This paper deals with the first two options, the third one is the subject of further analysis. To get the capacity estimates according to the first option, autocorrelation matrices of the narrowband channel between each antenna element have been determined as a function of time to identify different parallel channels. The number of different channels is related to the number of significant eigenvalues of the autocorrelation matrix [9].

Maximum spectral efficiency [bits/s/Hz] has been calculated based on these eigenvalues and the Shannon capacity theorem [10] and e.g the water-filling scheme was used in transmission [11].

$$C = \sum_{i=1}^{N,M} \log_2\left(1+\frac{\lambda_i P_i}{\sigma}\right) \tag{1}$$

Here λ_I are the eigenvalues, P_i the normalised powers allocated for each parallel channel, σ is the noise power, and the summation is performed over N or M eigenvalues, whichever of N or M is smaller. The normalisation of the power levels or i.e. the signal-to-noise ratios (SNR) can be performed in many ways. Typically it is assumed that the total transmitted power is constant as the number of TX antennas M changes. In reception the common approach is to use some average SNR for the receiver channels. This works well, if all receiver antenna elements have essentially the same radiation pattern like in the case of a linear array. However, with the spherical receiver array this is not very feasible as some of the elements (typically those close to the poles) receive very low power and would thus decrease the average SNR and increase the obtained spectral efficiency though not really contributing to the MIMO reception. Thus we use another approach where one of the receiver channels is connected to a vertically polarised discone antenna with dipole pattern and about 2 dBi gain and the average (over a few metres and all TX elements) SNR of the “pilot” channel between vertically polarised TX elements and the discone is defined to be constant (10 dB in this paper).

To study the implementation of the second option above for the MIMO propagation analysis, the DOA estimations are performed for the spherical antenna by employing a beamforming algorithm [5]. Furthermore, a calculation method has been developed to “remove” the spherical array by solving the fields for the reference point located in the middle of the array. After that new signal phases and amplitudes can be calculated for arbitrary antenna configurations. For 3D configurations with dipole antennas the declaration of the effective length of the antenna has been used for the calculation of the captured signal. For the linear TX array we have in this paper used the selection option as it provides typical realistic basestation antenna configurations.

MEASUREMENTS AND CONCLUSIONS

The described system has been used for measuring MIMO channels in indoor and outdoor-indoor office environments, and in outdoor urban microcellular and small macrocellular environments with the total length of the routes of several kilometers. The analysis of the results is ongoing and in this paper some of the first results are discussed. In these examples the water-filling scheme is not used but instead equal TX power is employed for all parallel channels. The first example shown in Figure 2 is a continuous measurement along a crossing street in microcellular environment. The fixed TX antenna height is 13 m and the antenna configuration considered according to option 1 (selection) contains 3 adjacent dual-polarised elements (M = 6) selected from the linear array. In the mobile RX spherical antenna (height 1.7 m) 4 dual-polarised close-by elements have been chosen (N = 8). These are directed 90 degrees right from the traveling direction towards the fixed antenna. The results indicate the importance of continuous measurements as the line-of-sight (LOS) part of the route is clearly visible at 700 – 1300 snapshots. Here the MIMO capacity is highest at the LOS part though the number of significant eigenvalues is low. One can also see from the results at the end of the route that the multielement antenna is useful only if it can be directed towards the main DOA of the signals. The single-input-single-output (SISO) capacity of the “pilot” channel shown as a reference has the average spectral efficiency of about 3.5 bits/s/Hz due to selected 10 dB SNR.

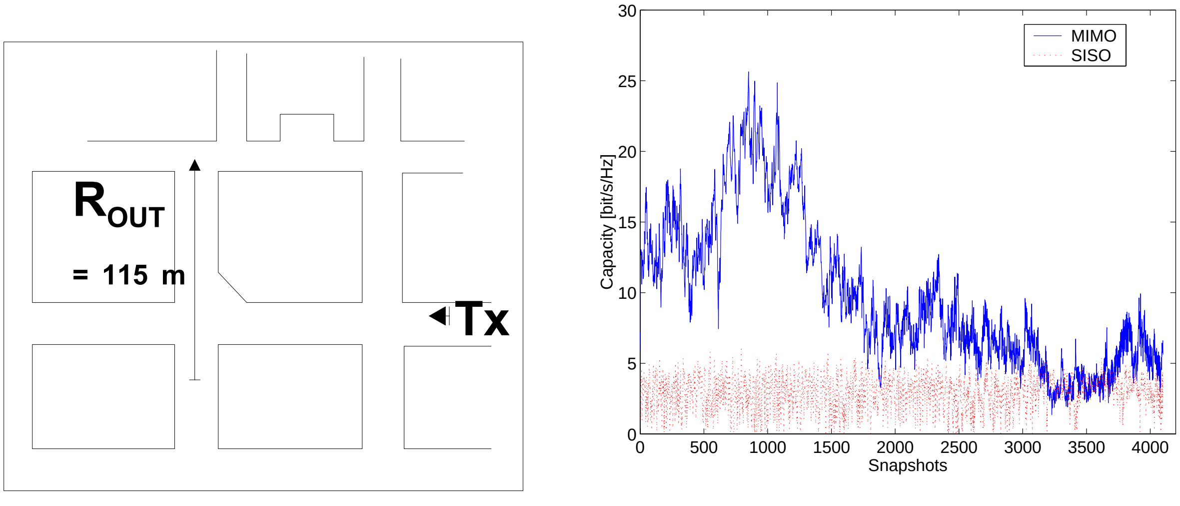


Fig. 2. Spectral efficiency (capacity/bandwidth) along a street in a microcellular environment.

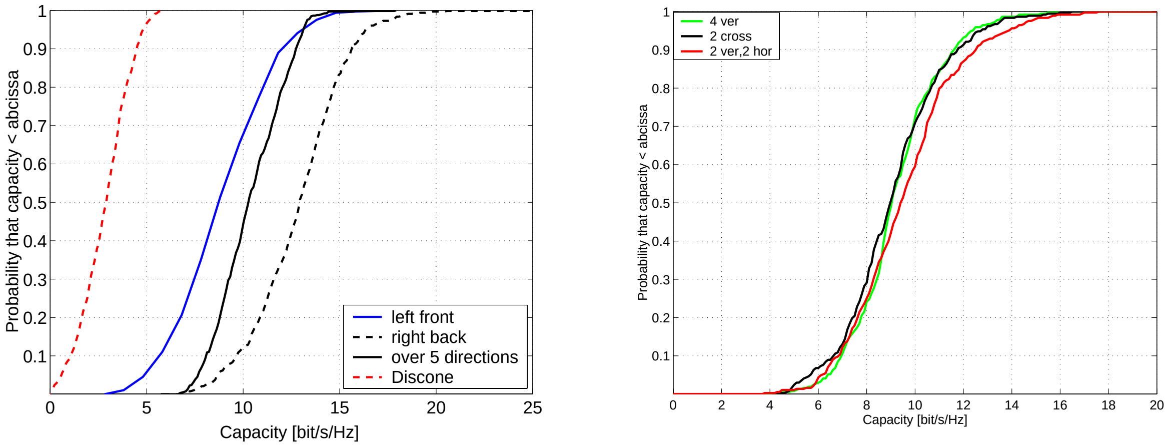


Fig. 3. Spectral efffiency distributions in an indoor environment. (a) Four patch elements chosen from the spherical antenna. (b) Computational results for different configurations of four dipole antennas.

The second example (Figure 3) is from an indoor office environment where the measurement was performed in a large open courtyard-type space at the center of the building. Here we compare the results obtained by selecting antenna elements and those obtained computationally by “removing” the spherical antenna and locating dipoles into the respective space. The fixed antenna height is about 5 m and the antenna configuration contains 2 dual-polarised elements (M = 4). In the receiving spherical antenna (height 1.7 m) 4 vertically or horizontally polarised close-by elements have been chosen (N = 4) in the selection option and 4 dipoles with 3 different configurations (4 vertical dipoles, 2 x 2 crossed dipoles with 45 degree slanting or 2 vertical + 2 horizontal dipoles) have been used in the computational case (N = 4). All mobile antenna configurations in this example have been thought to be possible on a laptop computer or similar device. The average spectral efficiency is around 3 times higher than for the SISO (discone) case. It can be noticed that with the omnidirectional dipole antennas (Figure 3 b) the capacity is almost independent on the antenna configuration. The use of orthogonal polarisations seems to provide parallel channels but the same capacity is obtained also with co-polarised antennas. However, with the directive patch configuration (Figure 3 a) the average capacity is the same as with dipoles, but dependency on the direction of the antenna is substantial. This means that additional “slow fading” appears in this case and should be taken into account in network planning.

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