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Description of wireless MIMO measurements at 2GHz in various typical environments

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Abstract

This paper reviews four of *ftw.*'s MIMO radio channel measurements that were carried out in various environments in and around the city of Vienna, Austria, during a major measurement campaign in 2000/2001 . Center frequency is 2 GHz with a bandwidth of 120 MHz. Antenna arrays of varying geometry are used on both ends of the radio link.
The measurement data are available for download from ftw.'s home page http://www.ftw.at/mimo/measurements. Selected data sets from urban, suburban, and indoor environments are available.

1 Introduction

The wireless MIMO- (Multiple-Input Multiple-Output) channel has gained high interest in today's research. Measurements are one very important tool to get more information on the nature of the channel itself. Within the last year *ftw.* has collected a lot of measurement data and has decided do publish some of the measurements for scientific purpose.
Some evaluation results are also available. Investigations on the urban and suburban environment can be found in [1] and [2] respectively. Results on the indoor and rich scattering environment are given in [3, 4].
In the following the measurement equipment will be reviewed in Section 2 followed by a description on the necessary data modifications to get manageable file sizes. Section 4 explains the used data structure and a detailed description of the measurement scenarios is given in Section 5.

2 Measurement Equipment

The measurements were performed by the MIMO capable wideband vector channel sounder RUSK-ATM, manufactured by MEDAV [5]. The sounder was specifically adapted to operate at a center frequency of 2 GHz with an output power of 2 Watt. The transmitted signal is generated in frequency domain to ensure a pre-defined spectrum over 120 MHz bandwidth, and approximately a constant envelope over time. In the receiver the input signal is correlated with the transmitted pulse-shape in the frequency domain resulting in the specific transfer functions. Back-to-back calibration before each measurement ensured an unbiased estimate.

Also, transmitter and receiver had to be synchronized via Rubidium clocks at either end for accurate frequency synchronism and a defined time-reference.
For studies on MIMO systems, the double-directional nature of the channel must be exploited. Therefore two simultaneously multiplexed antenna arrays have been used at transmitter and receiver.
For the outdoor measurements the transmitter was placed on a trolley and moved through streets at speeds of about 3 to 6 kmh. The indoor measurements were performed by using a virtual array.

2.1 Antenna geometries

Transmit antenna array - Outdoor

At the mobile station, it is devised to cover the whole azimuthal range. To this end, a uniform circular array was developed by Fa. Krenn [7]. It consists of 15 monopoles mounted on a ground plane and was placed on top of a small trolley (Figure 1). The elements were spaced at 0.43λ (6.45 cm) resulting in a diameter of around 30 cm in the middle of the 90 cm ground-plane. Attention was paid on a height of the transmit antenna of about 1.5m above ground which fits the typical height of pedestrians using their phones. This also matches the COST259 [10] recommendations for mobile terminals.

Figure 1: Measurement setup at transmitter for outdoor measurements.

Positioning table - Indoor

An x-y positioning table with a monopole on top gives the most freedom on different antenna geometries. (Of course, one is limited to static scenarios by using such a virtual array.) In addition there is no coupling between the antenna elements and therefor there is no need to calibrate the virtual array.
For the indoor measurements, discussed in this paper, a 15-element linear array was used. The antenna spacing is λ half at the center frequency. The positioning table was used for both indoor measurements, the standard one as well as for the rich scattering environment.

Receive antenna array

The receiver was connected to a uniform linear array supplied by T-NOVA, Germany (Figure 2). The antenna is made of eight patch elements spaced at a distance of $\lambda/2$ (7.5cm). Two dummy elements on each side of the array ensure equal element characteristics for all elements.

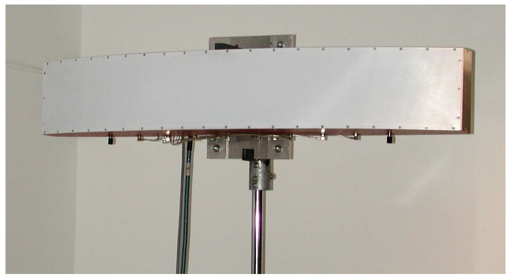

Figure 2: 8-element linear receive array (T-Nova).

Antenna calibration

Antenna calibration is a very important topic to reduce the coupling between the antenna elements and to ensure the correct phase of the signal at each element [8]. The result of an antenna calibration is the so called correction matrix $\mathbf{C}$ which is always a square matrix with the dimension of the number of antenna elements. Multiplying $\mathbf{C}$ with the receive data R results in the desired measurement data H. R and H is now a vector containing the receive values of each antenna element.

$$H = R\mathbf{C} \tag{1}$$

This had been done for the receive array but not for the circular transmit array due to problems with the calibration. However the coupling of the circular array is very low and the phases are nearly equal. In practice it had been shown that direction estimation at the transmit side is very difficult.
The virtual array itself, of course, does not need a calibration at all.

2.2 Antenna multiplexing

With above arrangement, consecutive sets of 15×8 transfer functions, cross-multiplexed in time, were measured. In the following the antenna multiplexing is explained in detail:

Outdoor

Due to the nature of the channel sounder the acquisition period of one snapshot was limited to $3.2\,\mu$s which corresponds to a maximum path length of about 1 km. A detailed time-line, including the antenna multiplexing, is given in Figure 3.

MIMO snapshots were taken each 21 ms. To measure all antenna combinations fast multiplexing was used at the receive array whereas the transmit array element was only changed after all receive elements had been used. An additional time gap of $3.2\,\mu$s between each antenna combination is used to ensure the multiplexer has switched to the next element before the next measurement starts. When switching the transmit elements an additional time interval is added.

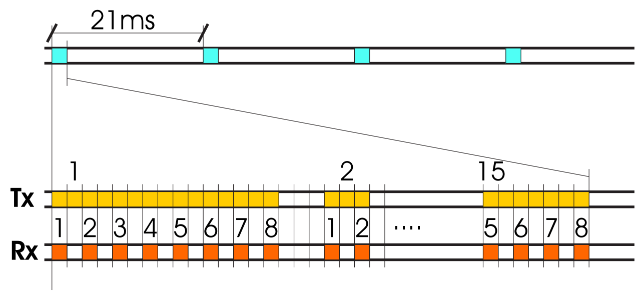

Figure 3: Antenna multiplexing: outdoor measurements.

Indoor

For the indoor measurements the acquisition period was set to $0.8\,\mu$s. Due to the higher attenuation and the small distances in indoor environments longer periods would only increase the amount of data but would not contain more information. A multiplexing time-line is given in Figure 4. Due to the positioning table at the transmitter the time between two different Tx

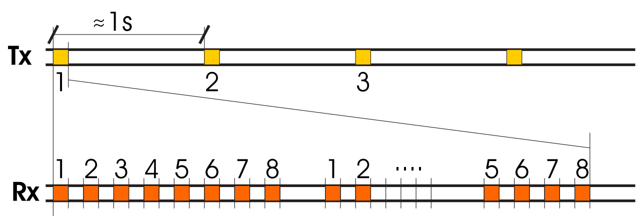

Figure 4: Antenna multiplexing: indoor measurements.

antenna positions is in the range of 1 s but not totally constant. For one Tx position 100 SIMO snapshots are taken.

3 Limitations on measurement data

Since a typical measurement file is in the range of several hundred mega-bytes, the files had to be modified to enable download on the Internet. In principle there are three different ways of limiting file sizes: using a smaller bandwidth, limiting the number of antennas or picking out a subset of MIMO snapshots in time. A limitation on antennas does not really make sense, especially for the circular array. Keeping the high bandwidth of 120 MHz may be important for some evaluations. Therefore we have decided to pick out a subset of the MIMO snapshots. Since the original data of the outdoor measurements was oversampled in space the first step is to pick out only each fourth snapshot for the suburban versus each second for the urban environment resulting in a snapshot resolution of 84 ms and 42 ms respectively. This is equivalent to a resolution in space of about λ half. In addition the movement was shrunk to the section of most interest. This is, for example, for the suburban environment the area around the pedestrian tunnel.
Furthermore to keep the files small the data is stored as *single* values. Summed up this results in manageable file sizes. The indoor files do not have to be modified.

4 File structure

All available measurement files are standard Matlab [9] files and are using a cell structure providing the following information:
Loading the data file into Matlab results in a new structured cell array called *ftw_mimo*. This cell contains two subcells *Data* and *Info*. The *Data* cell contains the measurement data itself as transfer functions using a four dimensional matrix. The four dimensions are as follows:

$$[Snapshots\,in\,time \;\times\; Frequency\,samples \;\times\; Rx\,antennas \;\times\; Tx\,antennas] \tag{2}$$

The subcell *Info* contains information on the data like the duration of snapshots in time, the measurement environment, bandwidth and so on.

5 Measurement scenarios

5.1 Urban area

The urban area measurements have taken place around the Technische Universität in Vienna. The Receiver was placed on top of one of the highest buildings in the surrounding, the so called *Freihaus*. This is a twelve storey high building whereas the neighbor buildings are around six floors high. Therefore we can assume almost every time a path that is diffracted over the rooftop. The exact route can be found in Figure 5 and includes a walk through a building. This detail can also be found in Figure 6. The walking speed of this sample was about 3 km/h.

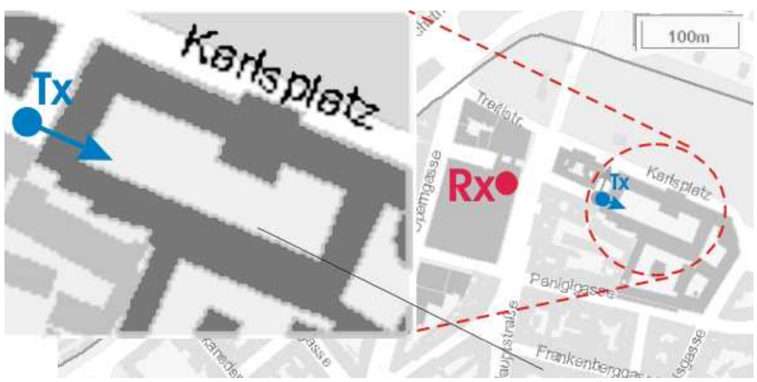

Figure 5: Measurement map of the urban environment.

5.2 Suburban area

About 50km north of Vienna we found a suburban area at the village of Weikendorf. The measurement area covers one-family houses with private gardens around them. The houses are typically one floor high. Such an area is typical for small villages around Vienna. In addition we also find a rail track in this area which breaks the structure of single placed houses.
To get a typical base station position we have used a lift to wind up the receiver to a height of about 20 m which is much higher than anything in the surroundings. Therefore the appearance of LOS is very high.
The most interesting measurement run within this area includes a walk through a small pedestrian tunnel below the railway. By entering the tunnel the propagation paths will change significantly. A map of the scenario is given in Figure 7 whereas a view from the receiver towards the tunnel is given in Figure 8

Figure 6: Transmitter start position, urban scenario.

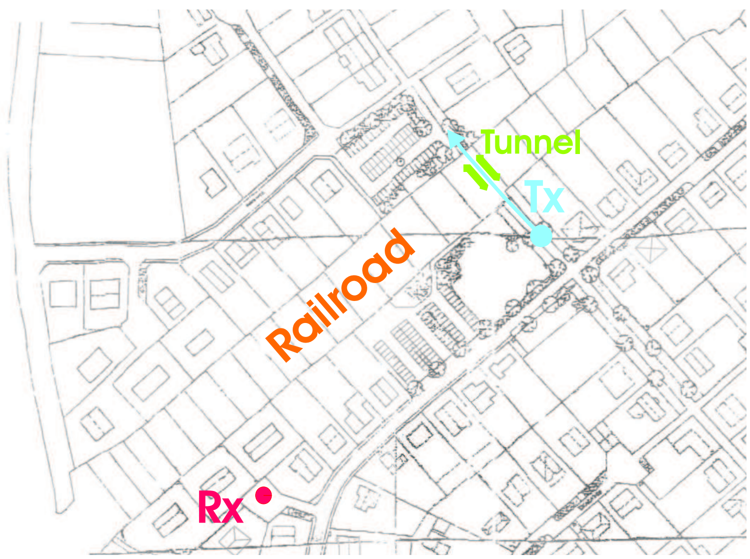

Figure 7: Measurement map of the Weikendorf scenario.

5.3 Indoor, office building

Since a positioning table was used for the indoor measurements there is no movement of the transmitter.
The indoor measurements were taken at the former office facilities of *ftw.* in the heart of Vienna. It is an old building with rooms of a height of about 4 m. One office has a size of about 20 to 30 m^2. A map of the measured area including the antenna positions is given in Figure 9.

5.4 Indoor, rich scattering

In addition to the standard measurements within our offices we have performed a second measurement including a lot of tin foil plugged onto the walls within the measurement area. Summed up about 35 additional tin foil scatterers with an area of about half a square meter were used.

Figure 8: View from the receiver towards the transmitter (Weikendorf scenario).

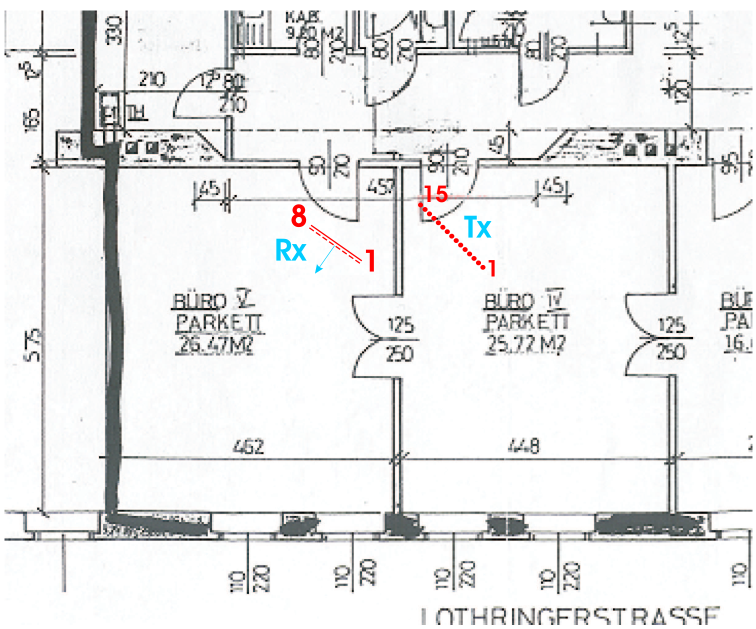

Figure 9: Antenna positions for the indoor measurements.

To avoid specular reflections from these elements the tin foil was wrinkled. Figure 10 gives an impression of this environment. The antenna positions were exactly the same as for the measurements without tin foil.

6 Summary

All measurements described in this paper are available for download at *ftw.*'s homepage *http: www.ftw.at/mimo/measurements* under the following conditions:

Figure 10: The rich scattering environment at transmitter and receiver.

- The data on this page may be used by everyone who has registered to our homepage, but only for scientific purposes.
- It is not allowed to share the data with third parties or any other subject that has not registered to our homepage.
- Within a company the data may be shared with other employees who have registered to our website. The data must not be downloded by each employee himself/herself.
- Any publication that uses at least parts of the measurements has to reference the homepage where the data can be found (http://www.ftw.at/Measurements). In addition a copy of the paper has to be sent to measurements@ftw.at.

7 Acknowledgement

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