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Multi-Dimensional Wideband Radio Channel Characterisation for 2-6 GHz Band

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Abstract

Future wireless communication systems employ higher carrier frequencies and wider bandwidths than the 2G/3G systems. Moreover, dual-polarised antenna arrays will most probably be employed for improved coverage and higher data rates. As a result multi-dimensional knowledge of the mobile radio channel with fine resolution becomes available for adaptive utilisation of the channel capacity. At the same time there is a tendency that cell sizes in new wideband radio access systems will be smaller and thus, the 3D radio scattering environment plays a major role. Therefore, it can be stated that effective development and specification of these novel wireless systems will require multi-dimensional radio channel modelling in such detail which is not widely available for current 2G/3G systems.

The current study reports preliminary results on multi-dimensional channel characterisation with 100 Mchip/s bandwidth at 5.25 GHz carrier frequency. The results in indoor office environment indicate that future multi-antenna systems employing MIMO or beamforming techniques may have a significant benefit from utilising the effects of polarization. Future research aims at developing advanced link and system level radio channel models in co-operation with interested parties from academia and industry.

1. Introduction

Future wireless communication systems will apply 2-6 GHz carrier frequencies with bandwidths wider than the current cellular systems. However, extensive radio channel measurement campaigns have been carried out mostly in frequency bands of 800 MHz-2.5 GHz. Those measurements are typically narrow-band and only few of them include multiple antennas at both the transmitter and the receiver side. Existing radio channel campaigns and models have been discussed e.g. in [1-7]. Frequently used channel models such as those specified by ITU are strongly based on the narrow-band measurement campaigns. However, despite of some measurement campaigns at 5 GHz (e.g. in EC project FLOWS), it can be stated that knowledge of the radio channel characteristics at 3-6 GHz in different radio environments is rather limited. Indeed, realistic, measurement based radio channel models do not exist for evolving future generation wireless communication systems operating with wide bandwidths at high carrier frequencies. The lack of wideband radio channel models is evident for example in the current 4G research which is aiming at very high data rates and good spectral efficiency using multi-antenna techniques. New multi-antenna schemes such as MIMO (Multiple-Input-Multiple-Output) systems require updated correlation based channel models even for 2-2.5 GHz band, for which the 3GPP/3GPP2 forum has recently specified the so-called SCM (Spatial Channel Model) model for the UMTS evolution in 2003 [8].

The need for multi-antenna transmitters and receivers in future wireless systems is two-fold: both improved coverage and capacity are needed. As carrier frequencies get significantly larger than 2GHz it is more difficult to reach good coverage for high data rates in cellular communications due to large path loss. One well-known solution is to apply multiple transmit antennas in a form of sectorisation and diversity antennas at the receiver to improve the transmission range. At the same time higher data rates for a single user and increased system throughput are required. Radio channel capacity and spectral efficiency can be increased by MIMO techniques in which user data is transmitted using multiple parallel data streams from multiple antennas simultaneously. Moreover, with increasing number of antenna elements, the MIMO capability can be accompanied by higher-order diversity schemes and/or beam forming techniques for improved signal levels or for suppression of interference. Consequently, the improved signal levels can be applied for improved MIMO capacity or for solving the coverage problem. It is also possible that the increased number of antenna elements of the antenna array can be employed adaptively in a way that the maximum data rate is compromised for improved coverage. In general, it can be stated that the utilisation of multi-antenna techniques becomes more and more feasible as the carrier frequencies get larger due to the fact that the size of antenna elements gets smaller.

The paper is organised as follows. After introduction the method and tools of multi-dimensional radio channel characterisation are described in Section 2 including also the scenario of the measurement environment. In Section 3 preliminary measurement results are reported. Finally, summary of the work and future research topics are discussed in Section 4.

2. Method

2.1 Measurement system

The current study employed the PropSound[1] radio channel sounder which enables fast wideband multi-channel characterisation of the radio channel. The sounder includes switches by which multi-antenna channel sounding is possible and makes it especially suitable for MIMO studies. Moreover, the sounder can be applied in wide range of frequency bands including for example the 1.7-2.7 GHz, 3.4-4.2 GHz, 4.4-5.0 GHz, and 5.1-5.9 GHz bands. The channel sounding is based on CDMA techniques using pseudo-random codes with variable spreading factors. The chip rate of the probing signal can be adjusted from 0.5 to 100 Mchip/s and up to 1056 time-multiplexed channels can be recorded. The post-processing tools of the sounder are based on standard Matlab format. Figure 1 depicts the block diagram of the multi-dimensional radio channel sounding system.

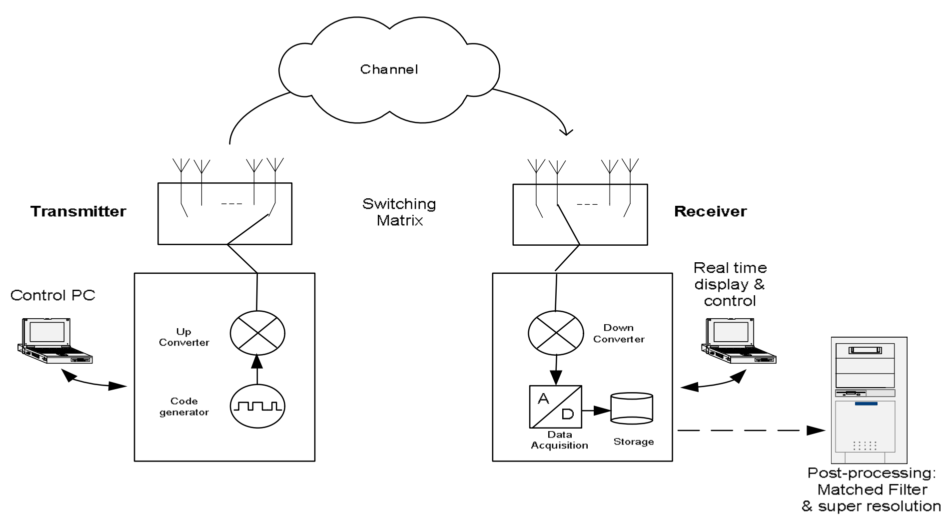

Figure 1. Block diagram of the multi-dimensional radio channel sounding system.

[1] Trade mark of Elektrobit Group Plc.

2.2 TX and RX Antenna Arrays

With high carrier frequencies the number of radiating elements in the antenna array can be large which allows the characterisation of signal paths with high resolution in multiple dimensions. Figure 2 (left) illustrates a 3D antenna array with 32 dual-polarised patch elements. The antenna elements are positioned in a way that allows omni-directional channel probing in azimuth direction and almost full measurement in the elevation angle. Only a small cone in space angle along the supporting pole of the array cannot be covered. In the present study the 3D antenna array was employed in an omni-directional mode, in which 2x9 dual-polarised elements were covering the entire 360-degree view in azimuth. A 4x4 dual-polarised planar array (Figure 2, right) was applied as a receiver antenna. The normalised power patterns of the radiating elements of the arrays are depicted in Figure 3.

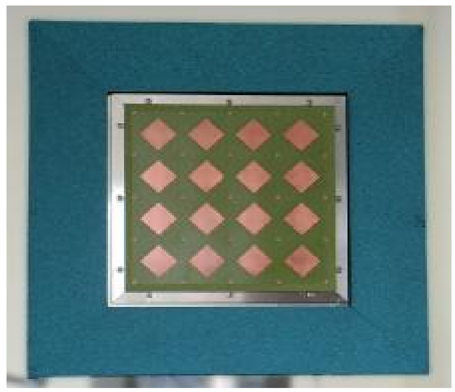

Figure 2. Dual-polarised antenna arrays for 5.25 GHz channel probing. The 3D antenna array on the left was applied as a transmit antenna and the 4x4 array on the right was used at the receiver.

2.3 Test Environment and Measurement Parameters

Measurements were carried out in indoor office environment. The floor plan is illustrated in Figure 4. The nine transmitter locations were selected in a way that allowed both Line-Of-Sight (LOS) and Non-Line-Of-Sight (NLOS) conditions with various signal-to-noise ratio (SNR) levels. The transmitter locations are denoted by a red arrow in Figure 4. Each arrow indicates also the reference direction of the transmitter antenna array. The receiver position was kept constant throughout the measurement. The height of the transmitting antenna arrays was approximately at table level (1 m) while the RX antenna was positioned at 2.5 m to mimick an indoor base station antenna. The maximum distance between the TX and RX antennas was 50 m, approximately. The walls inside the building have a light structure.

The channel sounding measurements were conducted in a static environment. The transmit power was 200 mW and data were collected at each measurement position for more than 1 minute. The main measurement parameters are listed in Table 1.

Table 1. Measurement parameters.

Carrier frequency	5.25 GHz
Chip frequency	100 MHz
Radio environment	LOS / NLOS
No. Tx antennas	9 dual-polarised
No. Rx antennas	16 dual-polarised
Code length	2.55 µs

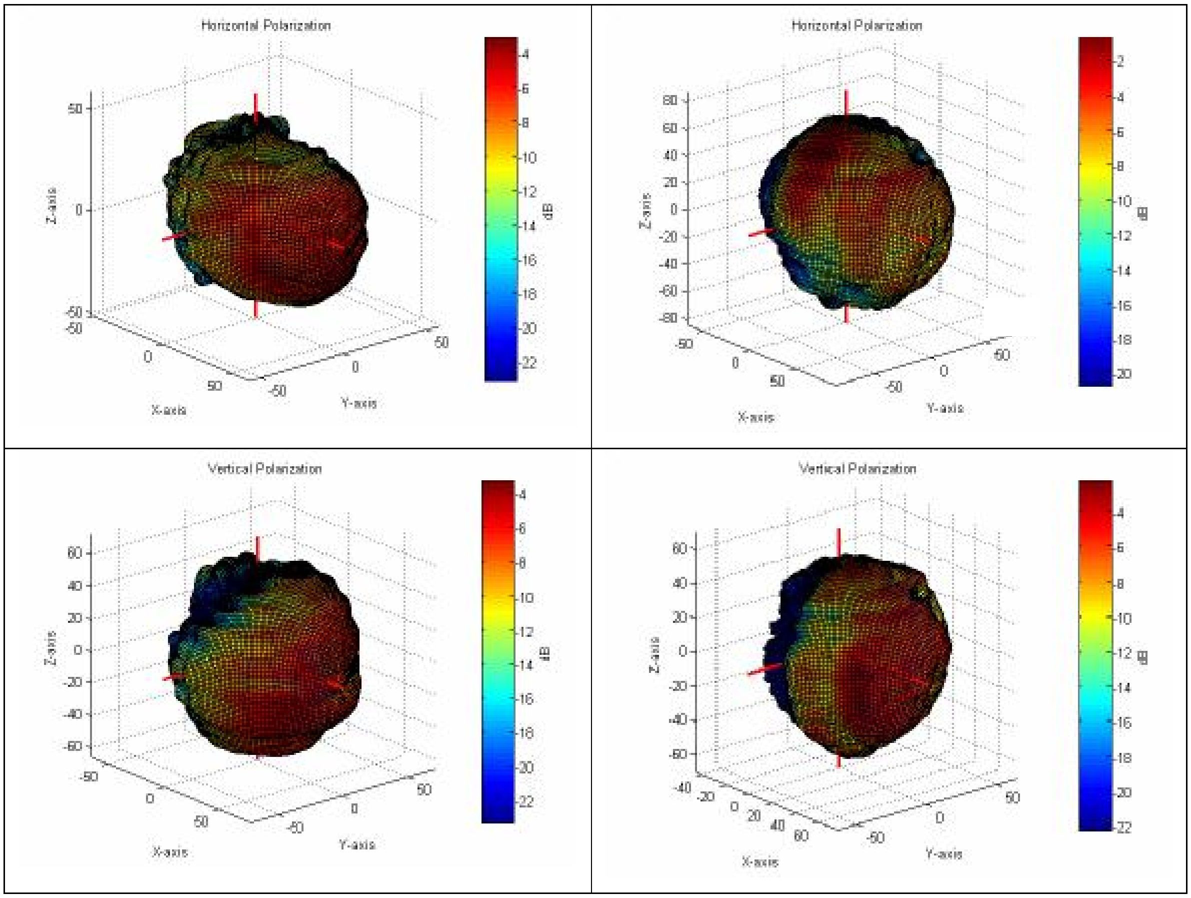

Figure 3. Normalized power patterns for the dual-polarised antenna arrays for 5.25 GHz channel probing (left column: TX antenna element, right column: RX-antenna element). Horizontal polarization is depicted on top row and vertical polarization on bottom row.

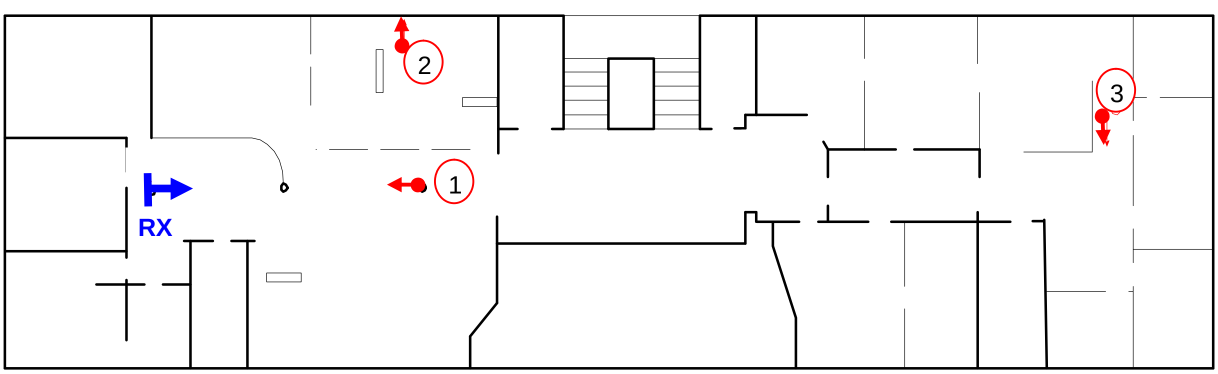

Figure 4. Floor plan of the measurement environment.

2.4 Post-Processing of Measurement Data

The properties of the signal propagation paths can be studied in multiple dimensions including the time, delay, frequency, azimuth, elevation, and polarization domains. From MIMO point of view it is also possible to calculate various correlation properties between the above mentioned signal dimensions.

In this study the SAGE algorithm (e.g. [9, 10]]) was applied for multi-dimensional detection and post-processing of the received signals. The SAGE algorithm employs super-resolution techniques in which the parameter estimation is based on a signal model [9]. In MIMO application the SAGE algorithm enables for example the estimation of the following characteristics of the wideband radio channel:

- Number of significant propagation paths
- Doppler frequency
- Propagation delays
- Angle of arrival at the receiver, AoA, i.e. both elevation and azimuth
- Angle of departure at the transmitter, AoD, i.e. in both elevation and azimuth
- Polarization matrix of the propagation paths
- Rotation direction of polarization

In current study the all the above characteristics except the Doppler frequency was estimated. The maximum number of propagation paths to be estimated was set to 20. Of course, the actual number of reliably detected paths depends on the signal-to-noise ratio.

3. Results

In the current experiment an especially interesting issue was to get an initial impression of path-wise polarization properties in indoor environments using super-resolution techniques. In basic MIMO approach spatial multiplexing is applied in order to increase the spectral efficiency of the radio link. This approach requires de-correlated radio channels from different antennas. The spatial separation of antennas is a well-known solution to decrease the channel correlations but, unfortunately, a separation of several wavelengths is often needed for acceptable correlation levels. Polarization diversity provides a competitive alternative for spatial diversity and linearly polarized +/-45 degrees slanted base station antennas are commonly used in mobile communications systems. Polarization MIMO measurement results in mobile communication environment were proposed already in 1972 in [11].

While usage of signal polarization provides means to mitigate correlation between channels, it may also provide additional benefits. It is known, for example, that conventional spatial multiplexing techniques are sensitive to LOS when co-polarized antennas are applied. However, if dual-polarized antennas are employed, then static component in LOS channel preserves its polarization and channels between orthogonally polarized antennas remain separated. At the same time leakage between differently polarized antennas is minimized. This phenomenon has been briefly studied, for example, in [12], where measurements on a suburban environment at 2.5 GHz were investigated. However, more measurements and modeling work are needed for higher carrier frequencies.

In the current study with wideband multi-dimensional channel sounder it is possible to study the phenomena of polarization with higher resolution than before. Indeed, the super-resolution technique of the SAGE algorithm makes it possible to investigate the polarization properties of each resolved propagation path separately [10]. In Figures 5-7 below the following radio channel characteristics are depicted: impulse responses, path-wise Angle-of-Departure (AoD) at the transmitter, path-wise Angle-of-Arrival (AoA) at the receiver, path-wise polarization with AoA at the receiver, and path-wise polarization with AoD at the transmitter. Moreover, the illustration of AoA and AoD contains also the information of the length of each propagation path in meters.

3.1 Line-Of-Sight Case

In the first scenario a simple LOS situation with high SNR was studied (position 1 in Figure 4). Impulse responses demonstrate high SNR conditions. From the result it is also obvious that the azimuth and elevation angles of the propagation paths at the receiver are concentrated in the direction of the line-of-sight component and the angular spread is small. AoD's at the transmitter have a larger distribution in azimuth due to the omni-directional TX antenna and thus some wall reflections reach the receiver. Blue and red ellipses illustrate the RX polarization for TX polarizations 1 and 2, respectively, and the size of the ellipse corresponds to the strength (path loss) of the particular propagation path. Moreover, the ellipses marked with

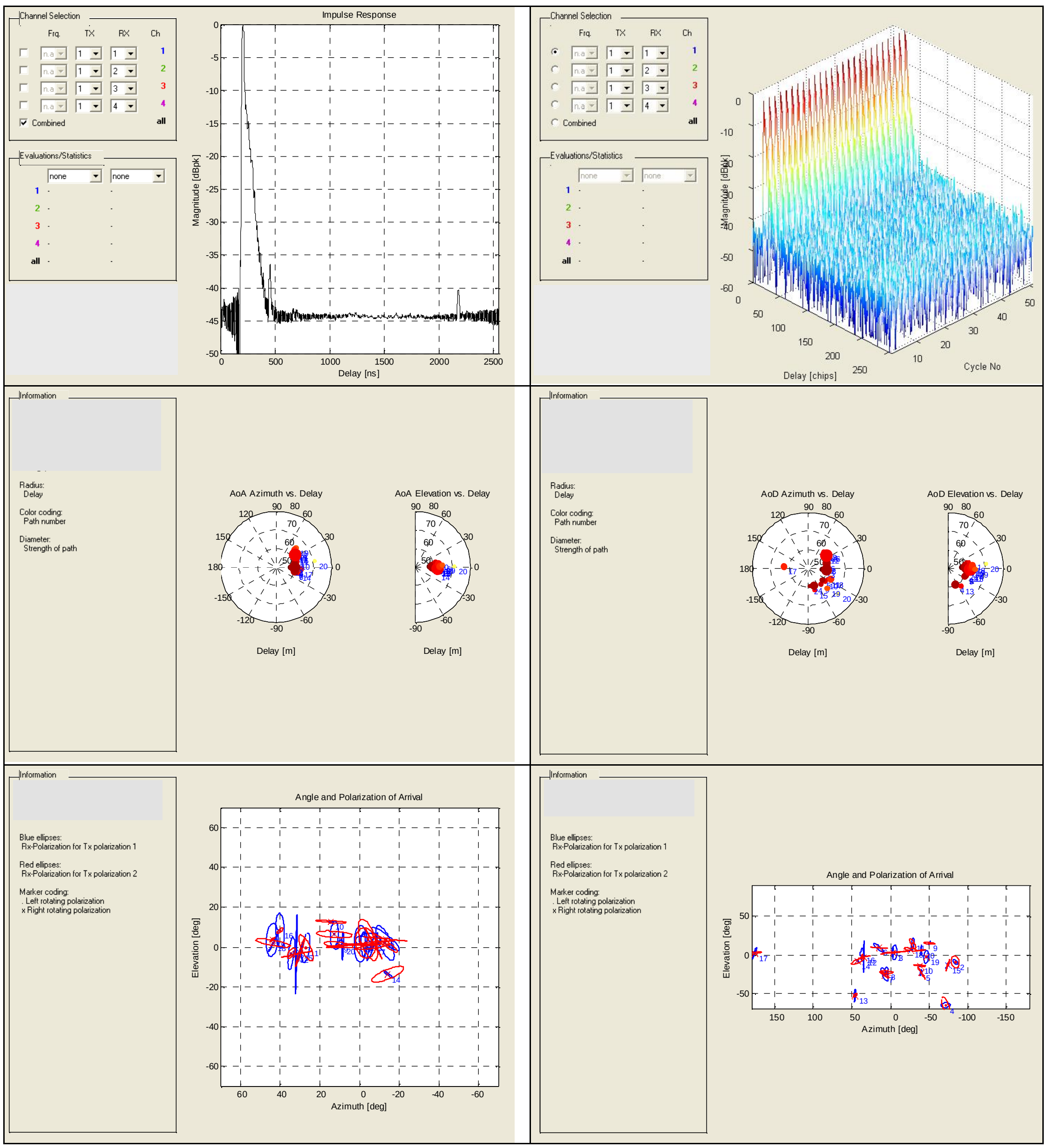

Figure 5. Impulse response measured in position 1 (LOS case, top left), waterfall representation of it (top right), angles of arrival in polar display (middle left), angle of departure (middle right), polarization (and angle) of arrival (bottom left), and polarization (and angle) of departure (bottom right).

'x' and '.' refer to right and left rotating polarizations, respectively. It can be also seen that in general the polarization branches are in balance and the polarization is well preserved.

3.2 Non Line-Of-Sight Case

In Figure 6 a NLOS scenario with high SNR was studied (position 2 in Figure 4). In this case the azimuth angles of the propagation paths have a larger distribution also at the receiver. The strongest AoD

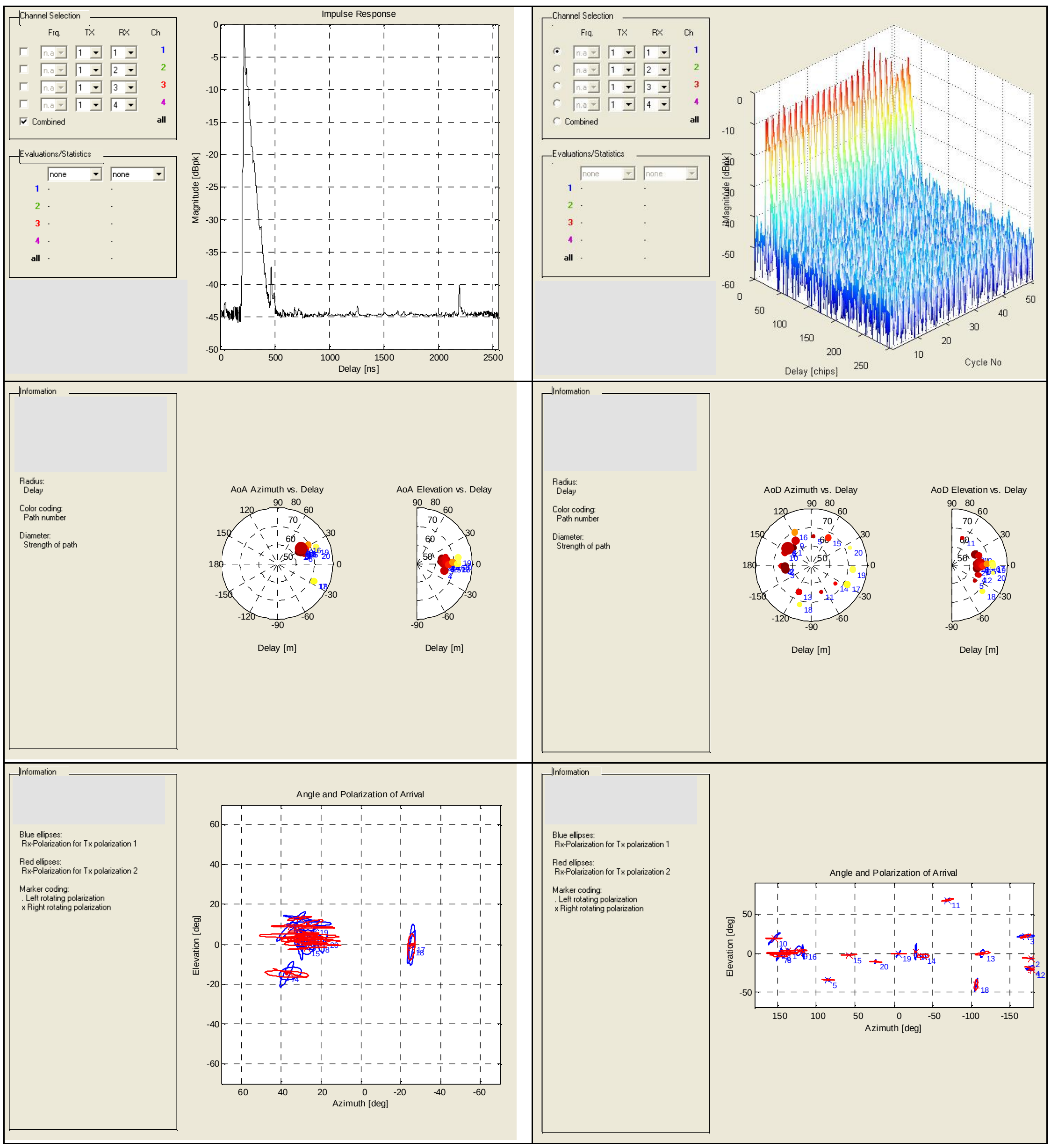

Figure 6. Impulse response measured in position 2 (NLOS case, top left), waterfall representation of it (top right), angles of arrival in polar display (middle left), angle of departure (middle right), polarization (and angle) of arrival (bottom left), and polarization (and angle) of departure (bottom right).

at the transmitter points towards the receiver but otherwise the AoD's are spread practically over the entire 360 degree range. Due to high SNR all the 20 strongest signal paths could be identified. Although some variation exists the polarization is well preserved.

In Figure 7 NLOS scenario with low SNR was studied (position 3 in Figure 3). In this case only two strongest propagation paths could be reliably resolved. From the azimuth angles it is clear that both resolved paths coincide with the shortest physical distance of the transmitter and the receiver. It can be also seen that the polarization branches are in balance and the polarization is well preserved. The mutual interference between orthogonally polarized signals is low. This experiment indicates that with wide bandwidth at 5 GHz carrier frequency it may be feasible to utilise the obstructing structures in indoor environment for the benefit of polarisation and beamforming. The control of interference may be feasible in the same manner.

4. Discussion and proposed research areas

It is evident that the characteristics of wideband radio channels at high carrier frequencies are not well explored. Even the basic behaviour with respect to path loss and fading statistics is not fully understood for example in the 5-6 GHz band. The need for extensive radio channel measurements and characterisation becomes even more obvious if different multi-antenna schemes such as the MIMO approach and the polarization dimension are taken into account. Above results indicated that antenna solutions based on intelligent use of channel polarization may have a great potential in striving for higher bit rates and better spectral efficiency with multi-antenna systems.

From above considerations it can be stated that the development and standardisation of evolving and future wideband wireless communication systems require that their system performance can be evaluated using realistic assumptions about the radio channel. Indeed, efficient exploitation of the radio channel demands that the transmitter and the receiver have to be matched to the instantaneous radio propagation environment. Thus the future efforts in wideband radio channel characterisation for carrier frequencies larger than 2 GHz shall include

- Extensive multi-dimensional wideband measurement campaigns
- Development of refined, efficient estimation techniques for channel parameter estimation
- Development of multi-dimensional wideband link level radio channel models for 2-6 GHz bands
- Development of multi-dimensional system level radio channel models for future wireless systems

Channel modelling research plays an important role in the development of future wireless communication systems and this role has been discussed also in the WWRF forum [e.g. 13-14]. It would probably be beneficial to initiate a white paper within WWRF for multi-dimensional radio channel modelling. This white paper might have common interests with the one related to smart antennas [15]. It is evident that the above listed research efforts require close co-operation and efficient work sharing between academia and industry.

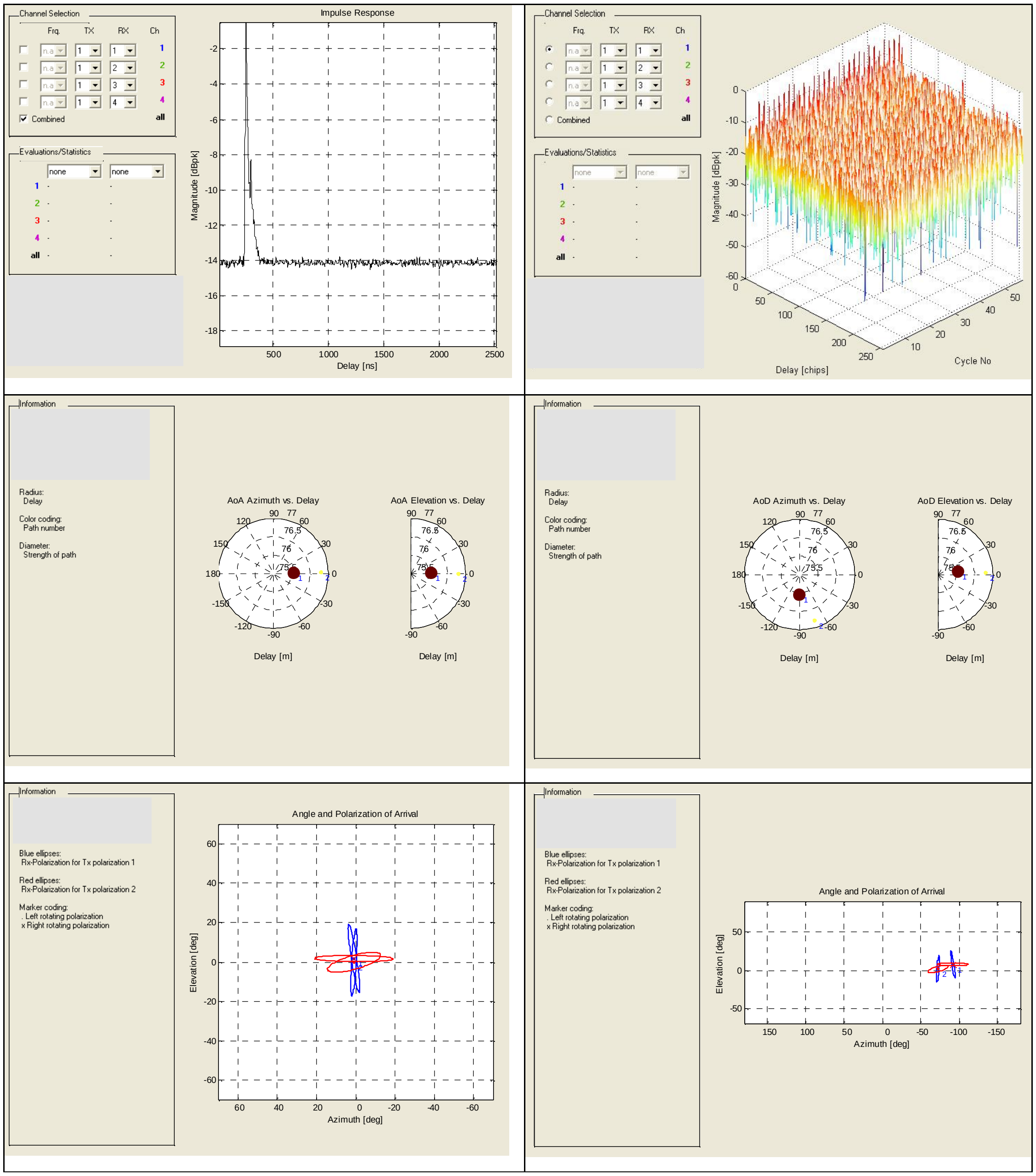

Figure 7. Impulse response measured in position 3 (NLOS case, top left), waterfall representation of it (top right), angles of arrival in polar display (middle left), angle of departure (middle right), polarization (and angle) of arrival (bottom left), and polarization (and angle) of departure (bottom right).

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