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Development of a Channel Measurement System for Multiple-Input Multiple-Output (MIMO) Applications

M.A. Beach, D.P. McNamara & P. Karlsson

Centre for Communications Research, University of Bristol
Merchant Venturers Building, Woodland Road, Clifton, Bristol, BS8 1UB, UK.
E-Mail: M.A.Beach@bristol.ac.uk

Abstract: *Recent investigations of Multiple-Input Multiple-Output (MIMO) architectures for wireless communication have aroused much interest in their potential to achieve high spectral efficiencies. This increase in capacity is dependent upon the propagation environment exhibiting sufficient scattering. The characterisation of MIMO channels is therefore required in order to analyse the performance of such architectures in real environments. This paper describes the development of a measurement system for this application, capable of completing measurements within the coherence time of the channel. Initial results are presented which illustrate both temporal and spatial channel variations.*

1. Introduction

In order to meet the anticipated demand for high bit-rate, real-time multimedia and e-commerce services, much interest is being shown in the combination of antenna arrays with novel space-time processing techniques. These, so-called, *Smart Antennas* have already been shown to offer wireless communication systems many advantages such as capacity enhancement, range extension or interference reduction [1].

As recently reported in the literature [2], the smart antenna concept can be extended by employing multi-element arrays at both ends of the communication link in order to create a multiple-input multiple-output (MIMO) channel. When deployed in a suitably rich scattering environment, multiple paths, or spatial channels, are excited between each of the transmitting elements and each element within the receiving array. It has been shown [3] that this architecture can be exploited to gain a significant enhancement in spectral efficiency over that of the single array topology.

The partners within the IST SATURN project [4] are addressing the application of smart antennas to enhancing the availability of high bit-rate wireless services to a larger number of users. A key aspect of this work is the appraisal of MIMO architectures in order to meet this goal by means of channel characterisation, system modelling and hardware validation.

This paper describes the Medav RUSK BRI vector channel sounder and it’s customisation for the measurement of MIMO channels at 5.2GHz. Initial results are presented from system verification trials that illustrate typical MIMO channel responses and verify the ability to measure the channel within its coherence time.

2. MIMO Communication

Assuming a minimum of n elements at both a transmitter and receiver, it has been shown that in a suitably rich scattering environment n parallel channels will effectively be created between the arrays. The potential spectral efficiency of this MIMO system will therefore be n times greater than that of a single-input single-output (SISO) system [3]. Alternatively, the presence of these parallel channels could be utilised to obtain a vastly increased diversity order [5].

The number and capacity of each of these parallel channels will depend on the multipath scattering excited by the propagation environment. Increased scattering results in increased decorrelation between the signals received by each antenna element, hence generating greater capacities.

Measurements of MIMO channels taken within the coherence time of the channel are therefore necessary in order to ensure that decorrelation between the signals received at each element is due only to multipath fading and not temporal channel variation.

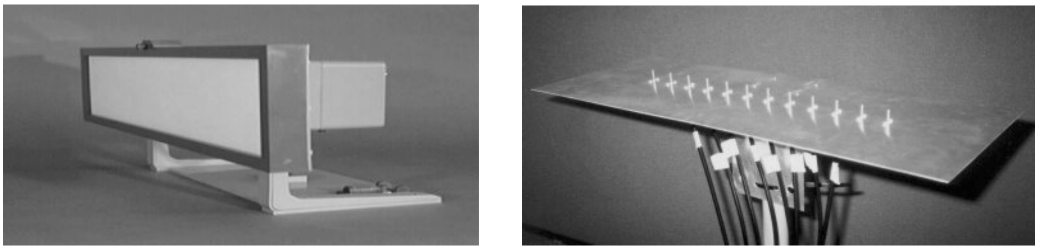
3. Measurement Platform

A. Medav RUSK BRI

The measurement platform used for these measurements is based on a Medav RUSK BRI vector channel sounder [6]. This employs a periodic multi-tone signal with a maximum bandwidth of 120MHz, centred at 5.2GHz, and with the measurement period being variable between 0.8 and 25.6μs.

In its standard configuration the RUSK BRI transmits up to +27dBm from an omni-directional antenna to an eight element uniform linear array at the receiver. This array (Figure 1a) is composed of 14 dipole like elements, 8 active and 6 passive, giving an overall beamwidth of 120°. A fast multiplexing system is used to switch the receiver between each of the active elements in turn in order to take a full 'vector snapshot' of the channel. The receiver downconverts the resultant RF signal to an 80MHz IF which is sampled at 320MHz. This data is then converted to the frequency domain before being stored to DAT or hard disk for subsequent post-processing.

Measurement time accuracy is assured through the use of Rubidium referenced clocks at both transmitter and receiver, with an optical fibre connection providing synchronisation and absolute phase stability. The start of each measurement campaign is also preceded by a back-to-back system calibration that accounts for any amplitude and phase distortions in the hardware. Further calibration is also conducted on the receive array to compensate for mutual coupling.



(a) RX Array

(b) TX Array

Figure 1: Antenna arrays employed for MIMO channel sounding (5.2GHz deployment)

B. Customisations for MIMO channel sounding

MIMO channel sounding is achieved through the replacement of the single omni-directional antenna at the transmitter with a uniform linear array and associated switching control and synchronisation circuitry. At present this array is composed of eight active elements with two dummy elements at either end (Figure 1b). The element type was chosen to be a simple monopole so as to retain an omni-directional radiation pattern and therefore excite as much scattering as possible within the indoor environments to be measured. It is also likely that this type of element could be employed at the mobile terminal within HiperLAN/2 and other wireless LAN standards.

For each transmit element in turn, a vector snapshot of the channel is taken at the receiver. In this way eight consecutive vector snapshots will contain the channel responses of all 64 combinations of the eight transmit and receive elements (Figure 2). Operating the channel sounder at its fastest repetition rate (0.8μs) allows a full 'MIMO snapshot' of the channel to be recorded in 102.4μs - well within the coherence time of an indoor channel (see section 4). Furthermore, the fast-access memory incorporated in the RUSK BRI can store 32 consecutive MIMO snapshots, enabling their measurement back-to-back without delay and permitting the calculation of both angular and correlation properties within the channel coherence time and the HiperLAN/2 frame period [7][8].

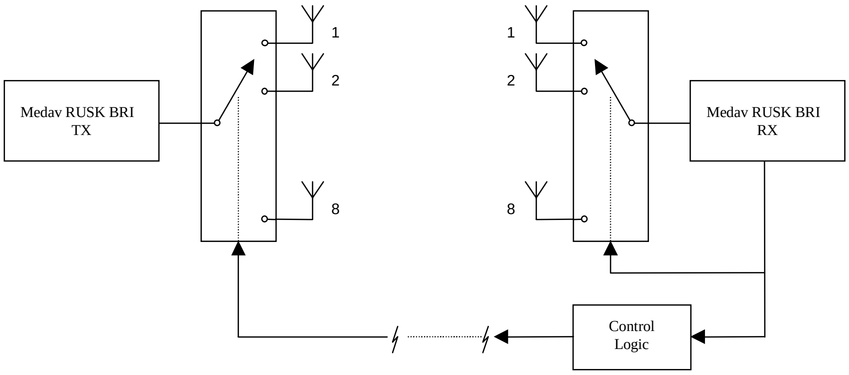
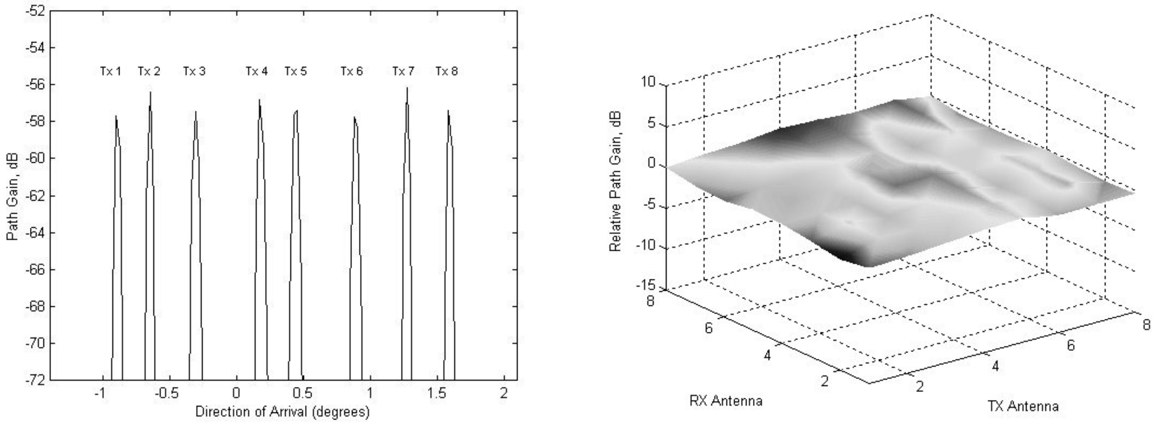


Figure 2: System configuration for MIMO channel sounding

4. System Verification & Initial Results

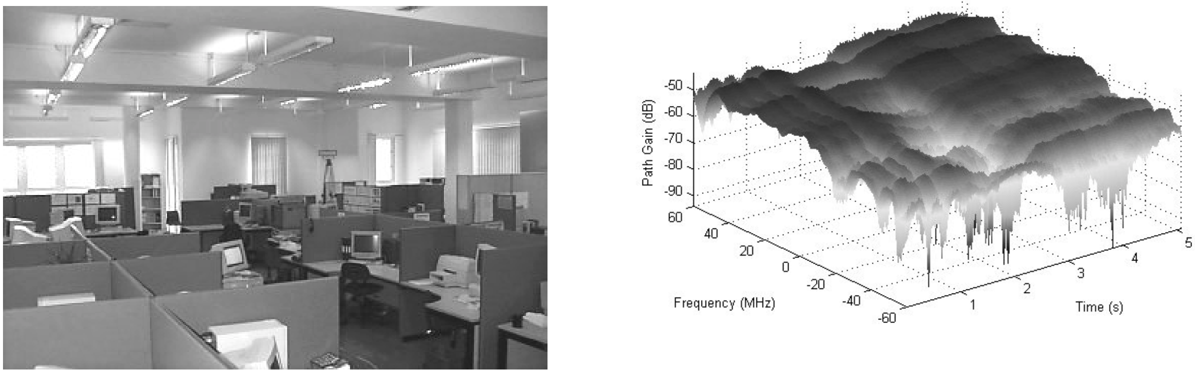
With both the transmit and receive arrays arranged facing each other in an anechoic chamber and separated by 4.4m, the directions of arrival of the signals from each transmit element (spaced $\lambda/2$ apart) can be seen in Figure 3a to vary as expected. This not only demonstrates the angular resolution of the post processing software (Medav MATSYS using the ESPRIT algorithm [6]), but also that the critical timing synchronisation between transmitter and receiver units is operating correctly. For this same arrangement in the anechoic chamber, Figure 3b shows the relative narrowband path loss between all combinations of transmit and receive elements. It can be seen that although the chamber is not perfectly anechoic, a very flat and hence highly correlated channel response is achieved.



(a) (b)

Figure 3: Anechoic chamber responses: (a) Directions of arrival for each TX element
(b) MIMO channel response

Initial MIMO channel characterisation has been conducted in the office environment shown in Figure 4a, prior to the full MIMO measurement campaign within the SATURN project. The coherence time of this environment has been analysed here by considering the channel variation seen by one pair of transmit and receive elements. Figure 4b shows this temporal variation against frequency for a fixed location with a non line-of-sight propagation path. During the measurement period the room was occupied and people were free to move about normally.

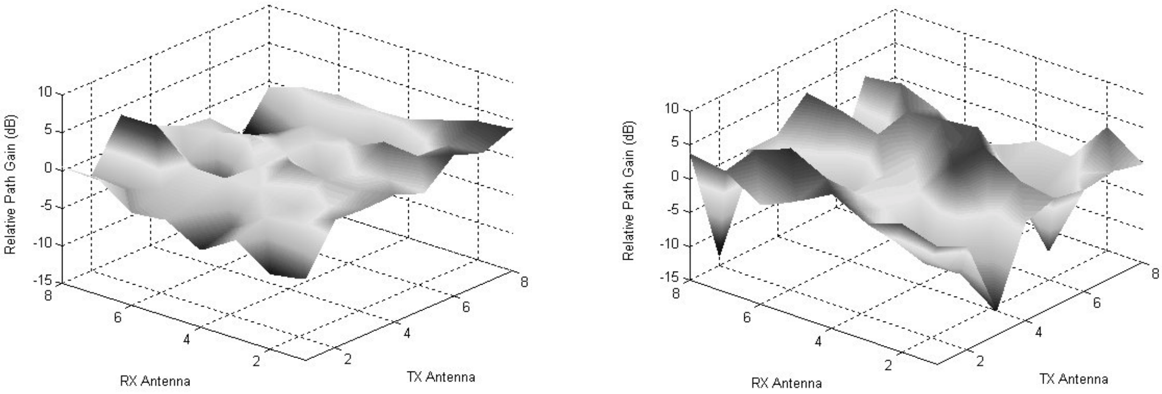


(a) (b)

Figure 4: (a) Office measurement environment (b) Channel variation with time

Since we are concerned with ensuring that our MIMO measurements are completed whilst the channel response is stationary, we are interested in the minimum coherence time. For the indoor environment described above, this minimum coherence time was found to be in the order of 100ms – several orders of magnitude larger than our measurement period. This was calculated from the worst case narrow-band fading channel observed during these trials and assuming a 0.9 correlation coefficient.

Figure 5 shows the relative path loss variation between all transmitter and receiver combinations for both a line-of-sight (LOS) and non line-of-sight (NLOS) location respectively in the indoor environment shown in Figure 4a. When compared with the response obtained from the anechoic chamber (Figure 3b), it can be seen that even the LOS location displays significant multipath activity. The peak to minimum gain variations recorded over all 64 element combinations were 10.12dB and 19.57dB respectively for LOS and NLOS conditions. This demonstrates the noticeable effect of the more deterministic propagation in LOS conditions, but also that significant multipath scattering is still present. Reference [9] shows that this is still sufficient to generate a significant channel capacity and also presents some initial analysis of the measured data.



(a) LOS (b) NLOS

Figure 5: Normalised narrowband MIMO channel responses for an office environment

5. Conclusions

In this paper we have presented a measurement system for determining the channel response of indoor MIMO channels at 5.2GHz within the coherence time of the channel. We have also shown results indicating the validity of our approach alongside initial channel data obtained from an office environment. Within the SATURN project, the University of Bristol will embark on an indoor MIMO channel characterisation campaign, whereas CNET will perform a complementary outdoor study. Data sets gathered for both environments will be analysed by KTH in order to obtain channel models and a capacity benefit analysis based on real channel data.

6. Acknowledgements

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