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Mythri Hunukumbure and Mark Beach

Abstract: This document outlines an outdoor field trial campaign to gather MIMO channel data, using a directional linear array and an omni-directional circular array at the receiver. The analysis into the channel data focuses on the channel de-correlation and the SNR achievable with the two receiver arrays and how these properties are reflected in the MIMO channel capacity.

Introduction: Application of Multiple transmit and receive antennas to practical wireless communications has the potential to increase the spectral efficiency (or Shannon capacity) by several folds [1]. With the huge demand anticipated for high-bit rate services in 3G and 4G, the incorporation of MIMO technology into out-door wireless schemes can yield significant gains. An essential pre-requisite is to obtain a better understanding of the outdoor MIMO channels through practical measurements and analysis.

Measurement campaign: Outdoor MIMO field trials in the 2GHz UMTS band was carried out in Bristol, using the state-of-the-art Medav RUSK BRI channel sounder. In the first set of trials, two dual polarised (±45°) panel antennas located on a roof top with 20λ spacing were used at the transmitter. The receiving array, mounted on top of a car, consisted of four dual polarised (±45°) directional patch antennas with 0.5λ spacing. This configuration resulted in a 4Tx * 8Rx MIMO system with polarisation and spatial diversity. Technical details of the field trials can be found in [2].

A second set of field trials were conducted by replacing the patch array at the receiver with a uniform circular array made up of 8 omni-directional mono-poles with 0.5λ spacing. All other aspects were kept unchanged from the previous trial, and measurements were taken at the same locations.

Narrow band system analysis: During the measurements 129 discrete frequency fingers in the Medav channel sounder were activated spanning across a 20MHz bandwidth. In this analysis each frequency bin is considered as a narrowband channel and the parameters are averaged across the possible 129 channels. Two measurement locations, one at line of sight (LOS) and the other non-light of sight (NLOS) were considered in the analysis. Measurements were taken with both receiver arrays while the vehicle was moving.

The system capacity is given by modifying the Shannon's capacity limit for the MIMO configuration [1].

$$C = \log_2 \left\{ \det \left[\mathrm{I}_n + \frac{\rho}{n_T} \cdot \mathrm{H} \cdot \mathrm{H}^{\mathrm{H}} \right] \right\} \quad (bits/s/Hz) \quad ....(1)$$

Where; H = normalised channel gain matrix $[.]^{H}$ = Hermitian transpose
ρ = signal to noise ratio (SNR) I_n = n*n identity matrix

For the 4Tx * 8Rx MIMO system employed, n_T = 4 and n = min{8,4} = 4.

Equation(1) reveals that the system capacity depends on the level of de-correlation among the constituent MIMO channels and the SNR. The average capacity for the LOS and NLOS measurements with the two receiver arrays are shown in Figure 1. Here the channels are normalised to unity average power and the SNR is increased arbitrarily. The capacity variations are a result of the difference in channel correlation.

In Figure 2, the correlation coefficients among the 32 possible combinations of the 4*8 MIMO channels are plotted in matrix form. In the average values shown, the self correlation terms which are always 1 are excluded. The two NLOS files show lower correlation than LOS files as the NLOS channels are randomised by the extensive multi-path activity. Within the LOS measurements, the average correlations for the two receiver arrays are similar, but for the omni-directional circular array the correlation values are evenly distributed. With the directional patches (having 120° beam width) at the receiver, the MIMO channels from transmitters 1 and 2 (from a single dual polar antenna) show very high correlation, reducing the achievable capacity.

The MIMO capacity can also be expressed with the eigen values (λ_i) of the normalised channel gain matrix. The eigen values represent the equivalent spatial channels available in a MIMO configuration.

$$C = \sum_{i=1}^{n} \log_2 \left(1 + \frac{\rho}{n_T} \cdot \lambda_i \right) \quad (bits/s/Hz) \quad ....(2)$$

Figure 3 shows the variations of the 4 eigen values for the LOS and NLOS channel scenarios. In the highly correlated LOS measurement with the stacked patch array, two prominent spatial channels are evident, contrary to the expectation of finding a single channel. This is a result of having polarisation diversity at the transmitter and receiver ends. With sufficient cross-polar discrimination, two spatial channels can be operated in this manner even in a pure LOS situation [3]. In Figure 4b, the second spatial channel resulting from the secondary multi-paths collected by the circular array, is significantly weaker than the first channel. Within the 2 NLOS measurements the spatial channel magnitudes vary in a narrower range, which explains the larger MIMO capacity.

The variations of the average received signal power for each of the measurements are given in Table 1. The signal received power directly links to the achievable SNR in the system and hence to the MIMO capacity. The 6dB power gain in the LOS measurement with the stacked patch array is resulting from the antenna gains of the directional elements. The higher SNR from this gain can counter balance the effects of higher correlation discussed above. For the NLOS measurements, (where the receiving antennas capture the secondary multi-paths) there is no significant change in the received power.

Conclusions: The performance of a narrow-band, outdoor MIMO system is analysed with the use of real channel data gathered from two different receiver arrays. In LOS measurements the circular array gives better de-correlation, but the antenna gain of the directional patches can achieve better SNR. Also the use of polarisation diversity is shown to provide advantages in LOS situations.

References:

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3. R..U. Nabar et. al., “Performance of multi-antenna signalling techniques in the presence of polarisation diversity”, IEEE transactions on signal processing, Vol. 50, No.10, Oct 2002. Pp 2553-2562

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Figure 1: Capacity curves for LOS and NLOS measurements with the two receiver arrays

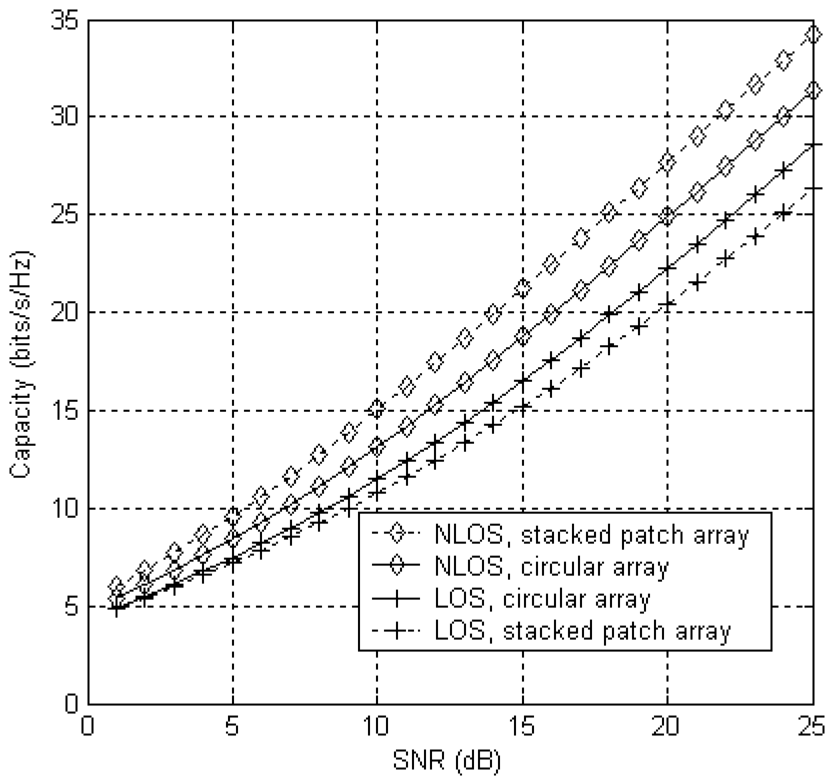
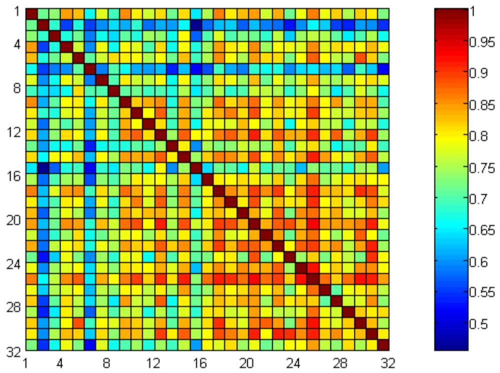


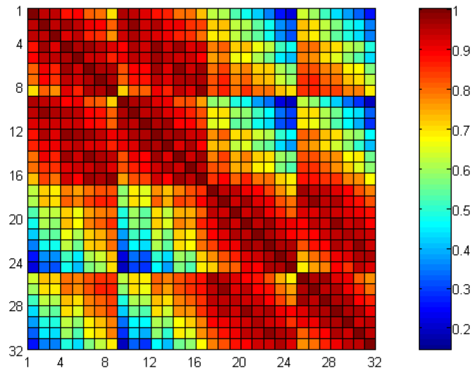
Figure 2: Correlation coefficients in different measurements

a) Circular array – LOS



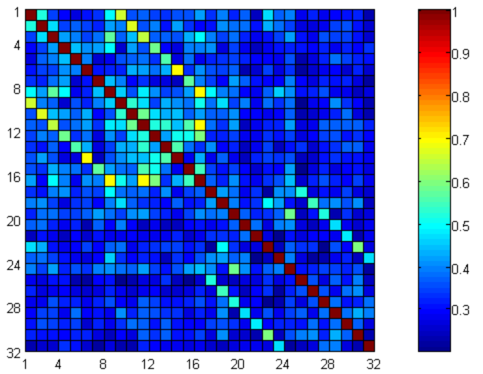
Average = 0.761

b) Stacked patch array - LOS



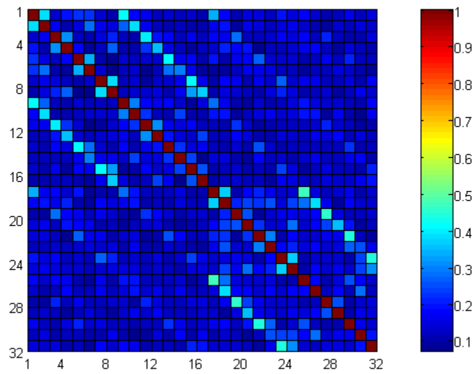
Average = 0.754

c) Circular array – NLOS



Average = 0.344

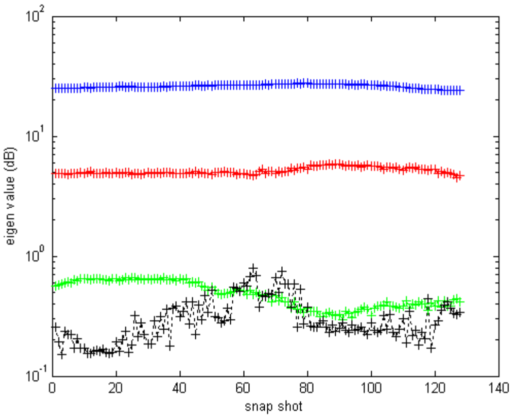
d) Stacked patch array - NLOS



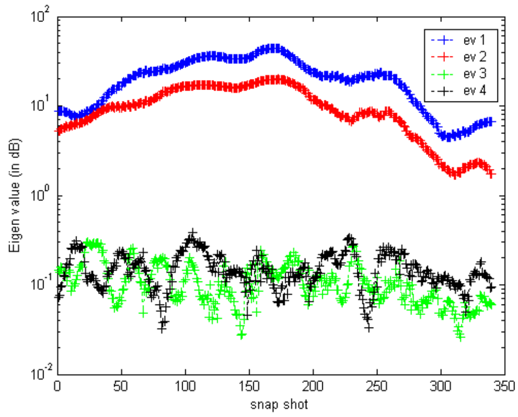
Average = 0.16

Figure 3: Eigen value variations for different measurements

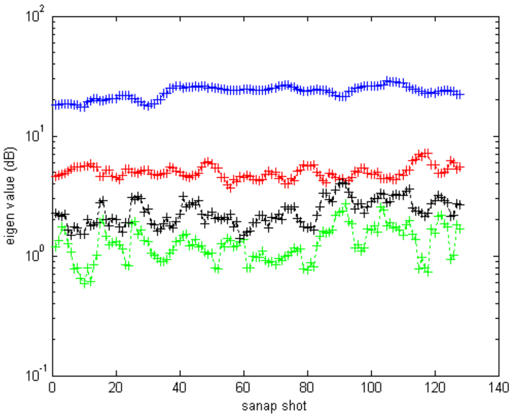
a) Circular array – LOS



b) Stacked patch array - LOS



c) Circular array – NLOS



d) Stacked patch array - NLOS

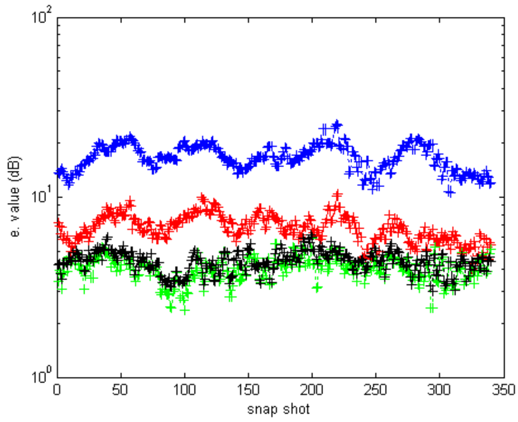


Table 1: Received power variations for different measurements

Measurement Scenario	Receiver Array Type	Average Received Power (dBm)
LOS	Circular mono-pole	-22.7
LOS	Stacked patch	-16.7
NLOS	Circular mono-pole	-30.2
NLOS	Stacked patch	-29.9