Linear dependence of double-directional spatial power spectra at 2.4 and 5.2 GHz from indoor MIMO channel measurements

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Multiple-input multiple-output (MIMO) double-directional spatial channel responses for co-located indoor measurements at 2.4 and 5.2 GHz using eight element uniform circular arrays are compared. Correlation coefficients of the power spectra demonstrate a linear dependence, indicating similarity in propagation mechanisms at the two frequencies.

Introduction: Initial research in MIMO wireless systems [1] demonstrates opportunities for higher spectral efficiency, quality of service, and data rates in wireless systems. Characterisation of MIMO propagation channels has thus far been accomplished by statistical or geometrical modelling, advanced modelling strategies (such as ray tracing), and direct measurement [2]. To date, however, measurement campaigns have focused mainly on channel characteristics at specific frequencies and not carefully examined how these properties change with centre frequency. This Letter explores the effect of centre frequency on the MIMO channel response in an indoor environment, showing in most cases that the double-directional response of the channel at 2.4 GHz is very similar to that at 5.2 GHz, indicating that propagation mechanisms at the two frequencies may also be very similar.

Measurement setup: The experimental 8×8 MIMO wideband channel sounder that we employed is described in detail in [3], and a simplified block diagram is given in Fig. 1. At the transmitter (TX), a windowed base-band multi-tone signal consisting of 80 tones separated by 1 MHz (80 MHz instantaneous bandwidth), is mixed with an RF carrier in the range of 2 to 6 GHz, amplified, and fed into a single-pole eight-throw (SP8T) microwave switch. Through control of the SP8T by a custom designed synchronisation (SYNC) unit, the wideband RF signal is routed into each of the antenna array elements, thus exciting each TX antenna for 20 μs.

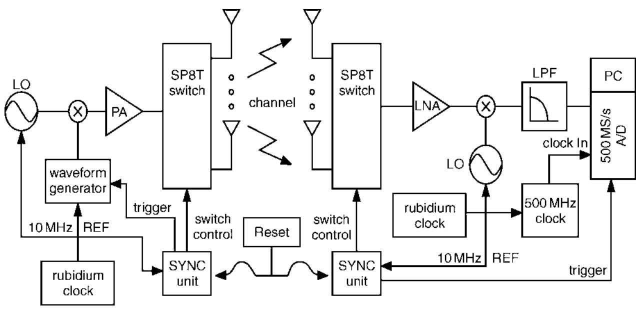

Fig. 1 *Block diagram of implemented 8 × 8 wideband MIMO channel sounder*

Shown in Fig. 1, another matched SP8T switch, controlled by a SYNC unit synchronised to the one at the TX, routes the incoming RF signal from each of the RX antenna elements to a common RF receiver. A complete scan of all eight TX antennas for each RX antenna takes 160 μs. Thus a complete scan of the MIMO channel takes 1.28 ms. The RX signal is first amplified by a gain of 40 dB through a low-noise amplifier (LNA), downconverted to an intermediate frequency (IF) of 50 MHz, lowpass filtered, sampled at 500 Msamples/s through a high-speed data acquisition card, and stored. System synchronisation is achieved with highly stable 10 MHz rubidium oscillators at the TX and RX.

The antenna arrays employed in this measurement were uniform circular arrays (UCAs) of omnidirectional monopole elements with 0.5λ spacing at both 2.4 and 5.2 GHz, where λ is the free-space wavelength. As depicted in Fig. 2, the RX was placed at 11 different office and laboratory locations, while the TX as shown in Fig. 2 was placed at a single fixed position in the corridor of the Carl and Emily Fuchs Institute of Microelectronics (CEFIM) at the University of Pretoria, South Africa. The RX was set at exactly the same position, height, configuration, and direction for both the 2.4 and 5.2 GHz measurements.

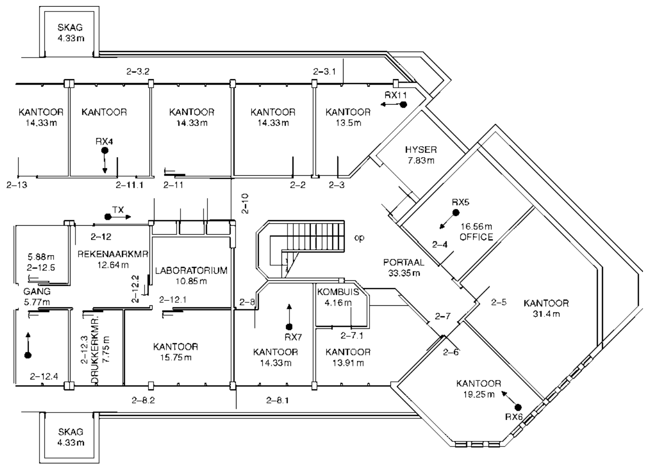

Fig. 2 *Location layout schematics*

Right section of location layout

Data processing: At each of the 11 locations, 20 channel snapshots with 200 ms temporal separation were recorded. Since negligible channel variation was observed for each stationary measurement, only a single snapshot from each location was considered. Here, a channel snapshot is defined as $H_{ij}^{(k)}$, where k is a frequency bin index, and i,j are the receiver and transmit antenna indices, respectively. To remove the effect of path loss in our computations, channel matrices were normalised to have average unit single-input single-output (SISO) gain, as indicated in [3].

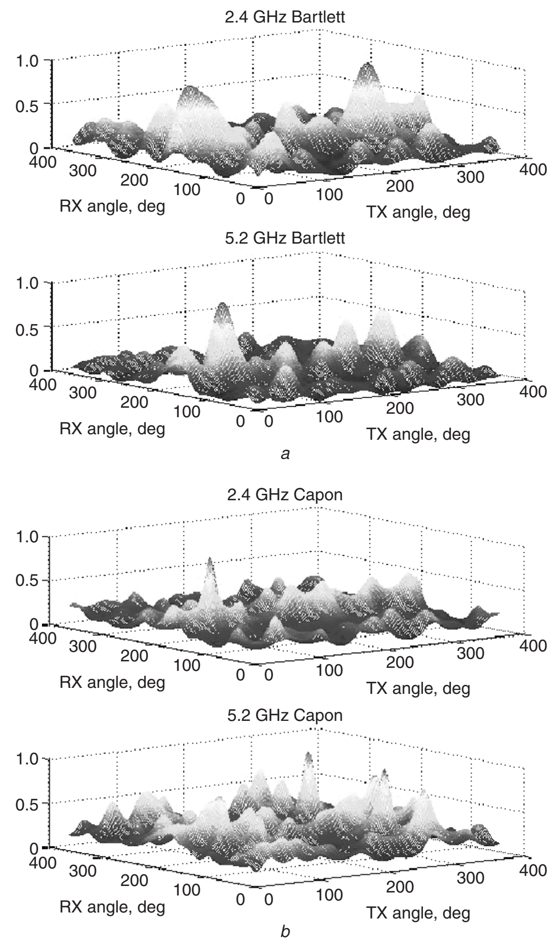

Fig. 3 *Measured spatial spectra for location 7*

a Bartlett *b* Capon

Previous channel modelling efforts have defined the double-directional channel [4] in terms of paired discrete plane-wave departures and arrivals at the TX and RX. In indoor environments, where multipath scattering is severe, extracting individual plane-wave arrivals can be extremely difficult. We therefore have chosen to characterise the double-directional response in terms of spatial power spectra, obtained with either joint TX/RX Capon or Bartlett beamformers [5], given by $P_{CAP}(\nu_T, \nu_R) = 1/\mathbf{a}(\nu_T, \nu_R)^H \hat{\mathbf{R}}^{-1} \mathbf{a}(\nu_T, \nu_R)$ and $P_{BAR}(\nu_T, \nu_R) = \mathbf{a}(\nu_T, \nu_R)^H \hat{\mathbf{R}} \mathbf{a}(\nu_T, \nu_R) / \mathbf{a}(\nu_T, \nu_R)^H \mathbf{a}(\nu_T, \nu_R)$, respectively, where $\{\cdot\}^H$ denotes the complex conjugate transpose, ν_T and ν_R are azimuth angles at the TX and RX, and $\hat{\mathbf{R}}$ is the sample covariance matrix. The joint steering vector $a(\nu_T, \nu_R)$ is defined as

$$\mathbf{a}(\nu_T, \nu_R) = \mathbf{a}_T(\nu_T) \otimes \mathbf{a}_R(\nu_R) \tag{1}$$

where $a_{\{T,R\}}$, are the separate array steering vectors for the TX and RX, and $\otimes$ is the Kronecker product. The sample covariance matrix is computed as

$$\hat{\mathbf{R}} = \frac{1}{K} \sum_k \mathbf{h}^{(k)} \mathbf{h}^{(k)H} \tag{2}$$

where K is the total number of frequency bins, $\mathbf{h}^{(k)} = \mathrm{Vec}\{\mathbf{H}^{(k)}\}$, and the vector operation Vec $\{\cdot\}$ stacks a matrix into a vector.

The similarity of the spectra at 2.4 and 5.2 GHz is evaluated by computing the correlation coefficient of the double-directional spectra at the two different frequencies using either the Capon or Bartlett beamformer. The correlation coefficient is computed as

$$\rho = \frac{\sum_{i=1}^{N} \sum_{j=1}^{N} (P_{2.4,ij} - \bar{P}_{2.4})(P_{5.2,ij} - \bar{P}_{5.2})}{\sqrt{\left[\sum_{i=1}^{N} \sum_{j=1}^{N} (P_{2.4,ij} - \bar{P}_{2.4})^2\right]\left[\sum_{i=1}^{N} \sum_{j=1}^{N} (P_{5.2,ij} - \bar{P}_{5.2})^2\right]}} \tag{3}$$

where N is the number of discretisation points, $P_{f,ij} = P_{\{\mathrm{CAP,\,BAR}\}}(\nu_{T,i}, \nu_{R,j})$, f is the centre frequency in GHz, $\nu_{T,i} = \nu_{R,i} = 2\pi(i-1)/N$, and $\bar{P}_f = 1/N^2 \Sigma_i \Sigma_j P_{f,ij}$.

Results: One observes that there is similarity in the spatial structure of the electromagnetic waves for either beamforming technique. This is verified by the respective correlation coefficient of 0.36 (Bartlett) and 0.50 (Capon) shown in Table 1.

Table 1 indicates that the Capon beamformer generally produces a higher correlation coefficient than the Bartlett beamformer, with the exception of location 10 and marginally at location 6. This result might be expected, since the Bartlett beamformer tends to produce complicated interference patterns between major scattering directions, but the Capon beamformer often suppresses this effect. Thus, although the Bartlett beamformer may be a more senstitive metric for comparison, the Capon beamformer will focus on comparing the principal directions of arrival and departure.

Table 1: Correlation coefficient of 2.4 and 5.2 GHz power spectra

Location	1	2	3	4	5	6	7	8	9	10	11
Bartlett beamformer	0.37	0.56	0.43	0.56	0.62	0.59	0.36	0.51	0.33	0.25	0.41
Capon beamformer	0.73	0.77	0.72	0.94	0.59	0.46	0.56	0.76	0.56	0.16	0.63

Conclusion: By comparing the double-directional spectra of measured indoor channels at 2.4 and 5.2 GHz, we have shown that a strong linear dependence exists. Comparison of the spatial spectra at the two centre frequencies indicates similarity in the dominant propagation mechanisms. This result is promising, since it suggests that models may be developed that predict channel behaviour at many different bands given measurements at only one single centre frequency.

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