Frequency scaling of spatial correlation from co-located 2.4 and 5.2 GHz wideband indoor MIMO channel measurements

B.T. Maharaj, J.W. Wallace, L.P. Linde and M.A. Jensen

Multiple-input multiple-output (MIMO) spatial correlation functions for co-located measurements at 2.4 and 5.2 GHz using 8-element linear arrays are compared. A single-parameter exponential model for the magnitude correlation coefficient provides a good fit, with an average mean squared error of 0.019. Results demonstrate that a linear model can describe the dependence of decorrelation at the two frequencies.

Introduction: Theoretical [1] and experimental [2, 3] research on MIMO wireless systems has demonstrated the potential performance gains achievable using multi-antenna technology. To date, however, measurement campaigns have focused on channel characteristics at specific centre frequencies and have not carefully examined how these properties change with frequency. To illustrate how frequency can impact channel properties, we present measurements taken simultaneously at 2.4 and 5.2 GHz in an indoor office environment. To simplify the analysis, we reduce the shift-invariant spatial correlation at transmit (TX) and receive (RX) to a single parameter using an exponential decay model. Remarkably, the decay or decorrelation parameter at the two different frequencies exhibits almost linear dependence, suggesting that multipath properties at 2.4 and 5.2 GHz are very similar for this environment.

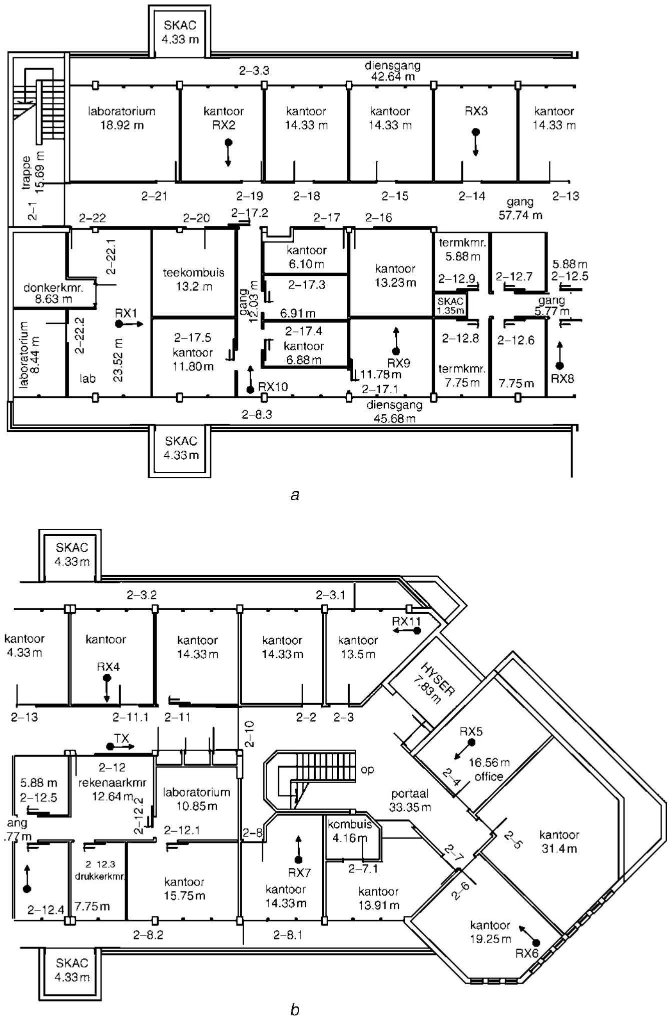

Fig. 1 *Location layout schematics*

a Left section of location layout
b Right section of location layout

Measurement setup: A new experimental 8 × 8 MIMO wideband channel sounder was used in the measurement campaign, and full details of this system will be described in later publications. The system operates in the 2–6 GHz range with an instantaneous excitation bandwidth of 80 MHz. At the TX, a 15 µs multi-tone signal with a given target centre frequency is fed through a single-pole 8-throw (SP8T) microwave switch to each of eight transmit antennas, while at the RX another SP8T switch routes the incoming signal to each of eight receive antennas. A custom synchronisation circuit ensures that all TX/RX pairs are probed. The RX signal is down-converted to an intermediate frequency (IF) of 50 MHz, filtered, sampled, and stored. The wideband MIMO channel response $\mathbf{H}(\omega)$ for the jth TX and ith RX is computed at $K = 80$ discrete frequency bins by dividing the FFT of the captured signal on the jth TX and ith RX timeslot by the FFT of a calibration signal (the RX signal when TX/RX are directly connected) and selecting bins corresponding to the tones.

An 8-element vertically polarised linear monopole array with an element spacing of 0.3λ and 0.5λ at 2.4 and 5.2 GHz, respectively, was employed at both the TX and RX. The RX was placed at 11 different office and laboratory locations as depicted in Figs. 1*a* and *b*, while the TX was set at a single fixed position as shown in Fig. 1*b* in the second floor 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.

Data processing: At each of the 11 locations, 20 unique channel observations (one per 200 ms) were recorded. Because the TX and RX remained stationary, the channel variation was negligible over the 4 s measurement interval.

The shift-invariant correlation coefficient at RX with an element displacement of ℓ is computed according to

$$\rho_\ell = \frac{[\sum_{k=1}^{N_S}\sum_{j=1}^{N_T}\sum_{i=1}^{N_R-\ell} H_{i,j}^{(k)} H_{i+\ell,j}^{(k)*}]}{[(\sum_{k=1}^{N_S}\sum_{j=1}^{N_T}\sum_{i=1}^{N_R-\ell} |H_{i,j}^{(k)}|^2)(\sum_{k=1}^{N_S}\sum_{j=1}^{N_T}\sum_{i=1}^{N_R-\ell} |H_{i+\ell,j}^{(k)}|^2)]^{1/2}} \tag{1}$$

where $N_S = 20 \cdot 80$ is the number of snapshots (observations and frequency bins), $N_T = 8$ and $N_R = 8$ are the number of transmit and receive antennas, respectively, and $H_{i,j}^{(k)}$ is the kth channel snapshot from the jth TX to ith receive antenna. The shift-invariant TX correlation is computed by interchanging the roles of TX and RX in (1). To simplify our analysis of correlation, we model the magnitude of ρ_ℓ with the exponential function $y_\ell = e^{-b\ell\Delta x}$, where Δx is the element separation in wavelengths. The decay or decorrelation parameter b is chosen to minimise the average MSE $\bar{d}$ at {TX, RX}, where

$$\bar{d} = \frac{1}{\{N_T, N_R\}} \sum_{\ell=0}^{\{N_T, N_R\}-1} (|\rho_\ell| - y_\ell)^2 \tag{2}$$

and separate values of b are estimated at TX and RX for each frequency.

Remarkably, scatter plots of the decorrelation at 5.2 GHz against that at 2.4 GHz for both TX and RX exhibit near linear dependence, and the function $b_{5.2} = a_1 + a_2 b_{2.4}$ is therefore used to describe their approximate relationship, where $b_{\{5.2, 2.4\}}$ is the decorrelation at 5.2 and 2.4 GHz, respectively, and a_1 and a_2 are obtained with a minimum MSE fit.

Results: Fig. 2 compares the measured and modelled RX correlation coefficients for location 4, with similar plots occurring for most other locations. Typical MSE values lie in the range $0.002 \le \bar{d} \le 0.032$, with average and worst-case values of 0.019 and 0.058, respectively. The values of b are provided in Table 1 for all locations. To see the effect of frequency scaling on the decorrelation, Fig. 3 plots the RX parameter $b_{5.2}$ against $b_{2.4}$. Very high dependence is present, with the exception of location 9. The lines in Fig. 3 show the linear regression of the data when all data points are included (dashed line) and when location 9 is discarded as an outlier (solid line), resulting in standard deviations of 0.33 and 0.11, respectively. Linear regression for the TX decorrelation (not plotted) in these two cases is 0.37 and 0.20, respectively. This high conformance of the decorrelation at the two frequencies suggests that the scattering mechanisms at 2.4 and 5.2 GHz are very similar, indicating that MIMO channel characteristics at several carrier frequencies can possibly be inferred from a single measurement.

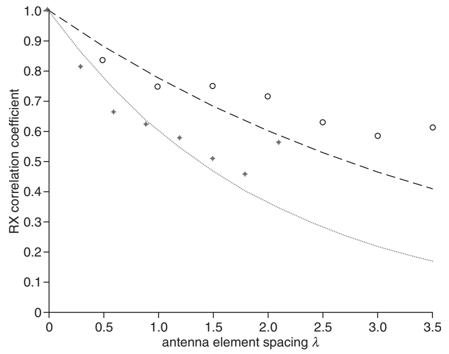

Fig. 2 *Calculated relative correlation coefficients with curve fit for receive location 4*

* LIN 2.4 GHz data set — LIN 2.4 GHz model
○ LIN 5.2 GHz data set -- LIN 5.2 GHz model

Table 1: Decorrelation parameter b for wideband channels at the various locations

Physical location	Decorrelation parameter (b) wrt wavelength (λ)			
	RX		TX	
	5.2 GHz	2.4 GHz	5.2 GHz	2.4 GHz
1	0.870	0.869	0.977	0.951
2	1.279	1.090	1.019	0.885
3	1.559	1.255	1.299	1.067
4	0.255	0.408	0.249	0.427
5	1.054	0.879	0.875	0.833
6	0.343	0.318	0.740	0.683
7	0.907	0.998	1.463	1.268
8	0.488	0.419	0.285	0.430
9	0.344	1.204	0.353	1.670
10	1.040	0.998	1.013	1.421
11	1.972	1.554	0.951	1.046

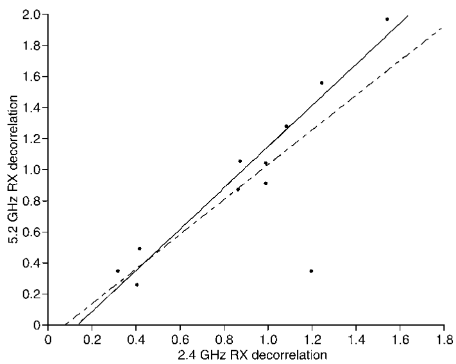

Fig. 3 *Relationship of RX decorrelation with respect to frequency scaling*

• computed data set -- data model fit — model fit without outlier

Conclusion: We have presented an initial study aimed at understanding the effect of frequency scaling on the performance of MIMO wireless systems. We have shown how an exponential correlation model describes measurements collected at both 2.4 and 5.2 GHz, and that a simple linear dependence exists between the decorrelation at the two centre frequencies.

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