# COMPARISON OF DOUBLE-DIRECTIONAL CHANNEL RESPONSE AT 2.4 AND 5.2 GHZ FROM INDOOR CO-LOCATED WIDEBAND MIMO CHANNEL MEASUREMENTS

B. T. Maharaj(1), J. W. Wallace(2), M. A. Jensen(2)

*(1)Department of Electrical, Electronic and Computer Engineering, University of Pretoria, Lynnwood Road 0002, Pretoria, South Africa, e-mail: sunil.maharaj@up.ac.za*

*(2)Department of Electrical and Computer Engineering, Brigham Young University, 459 CB, Provo, UT, USA, e-mail: wall@ieee.org, jensen@ee.byu.edu*

## I. INTRODUCTION

Since initial research in multiple-input multiple-output (MIMO) wireless systems [1], the opportunities and demands of higher spectral efficiency, quality of service and data rates in wireless systems have stimulated ongoing research in this area. MIMO architectures are potentially good candidates for future wireless systems, since they employ multiple antennas at both the transmitter (TX) and the receiver (RX) to significantly increase channel capacity in a multi-path environment, without increasing the system bandwidth or transmit power.

Accurate characterization of the propagation channel is essential in order to assess the potential benefit of employing sophisticated coding, modulation, and antenna arrays in MIMO systems. This is accomplished either by statistical or geometrical modeling, advanced modeling strategies (such as ray tracing) and direct measurement [2]. Modeling approaches have the advantage of inexpensive implementation on a computer, but may lack sufficient accuracy in representing real-world channels. Direct channel measurement provides accurate characterization, but can be time-consuming and expensive, allowing only a small set of communications channels to be investigated. With the advent of technologies such as ultra-wideband (UWB) communications, and the allocation of new RF spectra, channel characterization becomes necessary not only for several different scenarios, but also for many different communication bands.

This paper explores the effect of center frequency on the MIMO channel response in an indoor environment, showing that in certain cases the double-directional response of the channel at 2.4 GHz is remarkably similar to that at 5.2 GHz, indicating that propagation mechanisms at the two frequencies may also be very similar. Employing measurements at one frequency to predict channel behavior at a different frequency is referred to herein as *frequency scaling*. In theory, this technique can drastically reduce the cost of MIMO channel measurement campaigns, decrease development time of MIMO systems and network planning, etc.

This paper is structured as follows: Section II briefly describes the measurement system and the environment. Section III outlines the data processing aspects and the use of joint TX/RX beamformers to obtain double-directional channel responses, referred to as spatial spectra. Section IV analyzes the potential for frequency scaling at 2.4 and 5.2 GHz by comparing representative measured channels. Finally, Section V concludes the paper.

## II. MEASUREMENT SYSTEM

The experimental $8\times8$ MIMO wideband channel sounder used in the measurement campaign is described in detail in [3], and a simplified block diagram is given in Fig. 1. At the TX, a waveform generator creates a windowed baseband multi-tone signal consisting of 80 tones separated by 1 MHz (80 MHz instantaneous bandwidth), which is mixed with an RF carrier in the range of 2-6 GHz, amplified, and fed into a single-pole 8-throw (SP8T) microwave switch. Through control of the SP8T by a custom designed synchronization (SYNC) unit, the wideband RF signal is routed into each of the antenna array elements, thus exciting each TX antenna for 20 $\mu$s.

At the RX, another matched SP8T switch, controlled by a SYNC unit synchronized to the one at the TX, routes the incoming RF signal from each of the RX antenna elements to a common RF receiver. Each RX antenna is connected via the switch for a complete scan of all 8 TX antennas, or a total of 160 $\mu$s. Thus, a complete scan of the MIMO channel

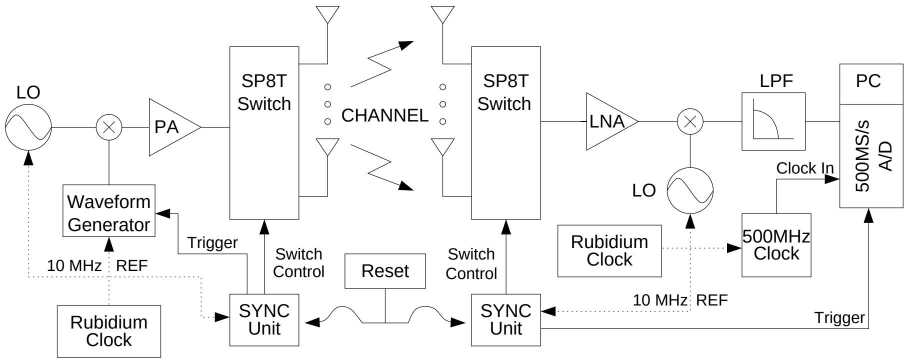



Fig. 1. Simplified block diagram of the 8×8 wideband MIMO channel sounder

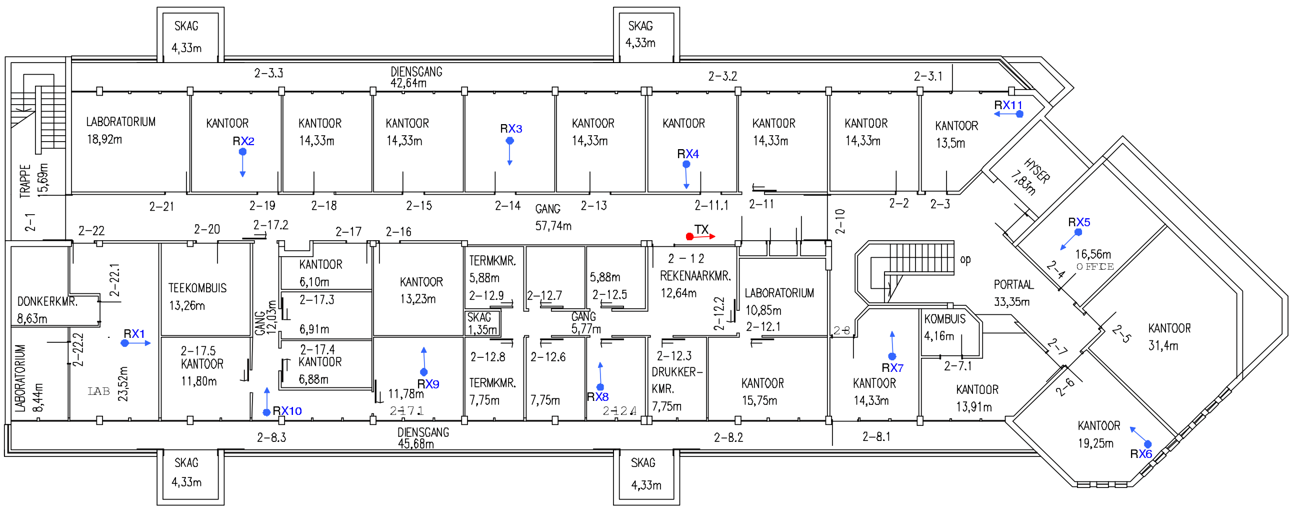



Fig. 2. Measurement campaign locations in CEFIM, University of Pretoria

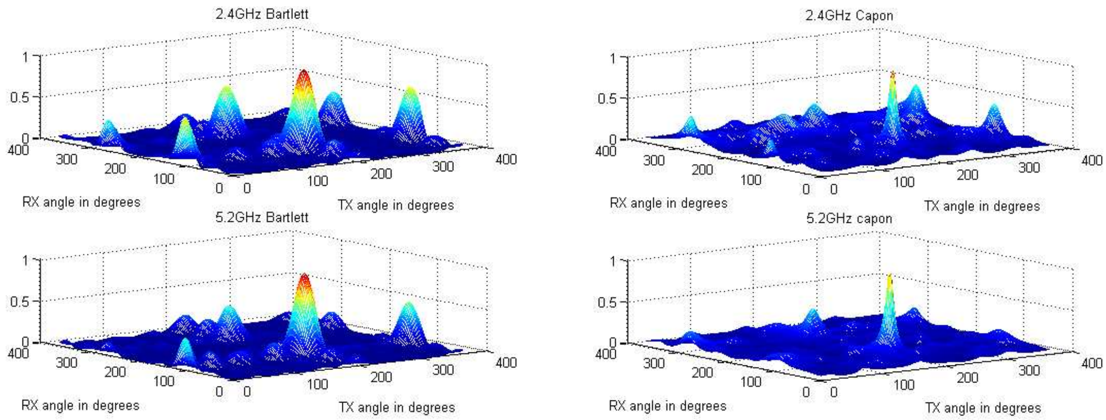
takes 1.28 ms. The RX signal is first amplified by a gain of 40 dB through a low noise amplifier, down-converted to an intermediate frequency (IF) of 50 MHz, low-pass filtered, sampled at 500 Msamples/s though a high speed data acquisition card, and stored on a PC. System synchronization is achieved with highly stable 10 MHz rubidium oscillators at the TX and RX.

The antenna arrays employed in this measurement were uniform circular arrays (UCAs) with $0.5\lambda$ spacing at both 2.4 and 5.2 GHz, where $\lambda$ is the free-space wavelength. As depicted in Fig. 2, the RX was placed at 11 different office and laboratory locations, while the TX 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.

## III. DATA PROCESSING

At each location, 20 channel snapshots were recorded with 200 ms between snapshots. 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 $i$ and $j$ are the receive and transmit antenna indices, respectively. To remove the effect of path loss in our computations, channel matrices were normalized to have average unit SISO gain, as indicated in [3].

Previous channel modeling 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 very difficult. We therefore have chosen to define the double-directional response in terms of spatial power spectra, obtained with either joint TX/RX Bartlett or Capon beamformers. The joint Capon




(a) Bartlett (b) Capon

Fig. 3. Measured spatial spectra for Location 4

beamformer [5] is given by

$$P_{\mathrm{CAP}}(\nu_T, \nu_R) = \frac{1}{\mathbf{a}(\nu_T, \nu_R)^H \hat{\mathbf{R}}^{-1} \mathbf{a}(\nu_T, \nu_R)}, \tag{1}$$

where $\{\cdot\}^H$ is complex conjugate transpose, $\nu_T$ and $\nu_R$ are azimuth angles at the TX and RX, and $\hat{\mathbf{R}}$ is the sample covariance matrix. The joint steering vector $\mathbf{a}(\nu_T, \nu_R)$ is defined as

$$\mathbf{a}(\nu_T, \nu_R) = \mathbf{a}_T(\nu_T) \otimes \mathbf{a}_R(\nu_R), \tag{2}$$

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

$$\hat{\mathbf{R}} = \frac{1}{K} \sum_k \mathbf{h}^{(k)} \mathbf{h}^{(k)H}, \tag{3}$$

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

$$P_{\mathrm{BF}}(\nu_T, \nu_R) = \frac{\mathbf{a}(\nu_T, \nu_R)^H \hat{\mathbf{R}} \mathbf{a}(\nu_T, \nu_R)}{\mathbf{a}(\nu_T, \nu_R)^H \mathbf{a}(\nu_T, \nu_R)}. \tag{4}$$

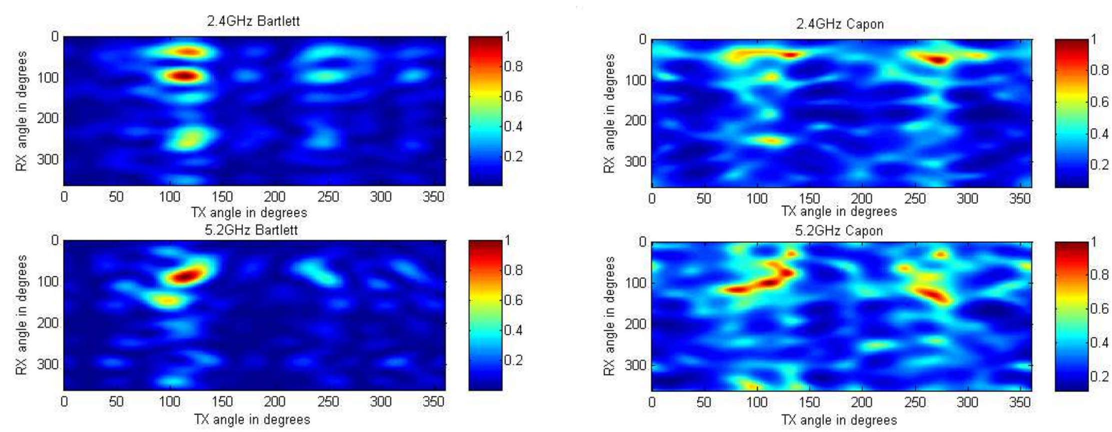
The similarity of the spectra at 2.4 and 5.2 GHz is evaluated by computing the correlation coefficient on the double-directional spectra at the two different frequencies using either the Capon or Bartlett beamformer. The correlation coefficient is computed as

$$\rho = \frac{\sum_{j=0}^{N} \sum_{i=0}^{N} (P_{2.4,ij} - \overline{P}_{2.4})(P_{5.2,ij} - \overline{P}_{5.2})}{\sqrt{\left[\sum_{i=0}^{N} \sum_{j=0}^{N} (P_{2.4,ij} - \overline{P}_{2.4})^2\right] \left[\sum_{i=0}^{N} \sum_{j=0}^{N} (P_{5.2,ij} - \overline{P}_{5.2})^2\right]}}, \tag{5}$$

where $N$ is the number of discretization points, $P_{f,ij} = P_{\{CAP,BF\}}(\nu_{T,i}, \nu_{R,j})$, $f$ is the center frequency in GHz, $\nu_{T,i} = \nu_{R,i} = 2\pi i/N$, and $\overline{P}_f = (1/N^2) \sum_i \sum_j P_{f,ij}$.

## IV. RESULTS

Fig. 3 shows joint spectra at Location 4 for the Bartlett and Capon beamformers. 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 0.56 (Bartlett) and 0.94 (Capon) shown in Table I. As depicted in Fig. 4, Location 11 has more scattering but still exhibits a high degree of correlation in the spectra for either beamforming technique.




(a) Bartlett

(b) Capon

Fig. 4. Measured spatial spectra for Location 11

TABLE I

CORRELATION COEFFICIENT OF 2.4 AND 5.2 GHZ 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 | 0.35 | 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 |

Table I indicates that the Capon beamformer usually produces a higher correlation coefficient than the Bartlett beamformer, with the exception of Locations 6 and 10. 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 sensitive metric for comparison, the Capon beamformer will focus on comparing the principal directions of arrival and departure.

## V. CONCLUSION

This paper has proposed the idea of frequency scaling, or using measured channel characteristics at one center frequency to predict behavior at another frequency, potentially saving the time and cost of channel characterization and network planning. The ability to perform frequency scaling was investigated by comparing the double-directional spectra of measured indoor channels at 2.4 and 5.2 GHz. Comparison of the spatial spectra at the two center frequencies showed a high degree of similarity, suggesting that the multi-path propagation at the two frequencies is mainly due to specular reflections. This basic result is promising, since it suggests that models may be developed that predict channel behavior at many different bands given measurements at only a single center frequency.

## REFERENCES


[1] I. E. Telatar, "Capacity of multi-antenna gaussian channels," AT&T Bell Laboratories, Tech. Rep. Technical Report #BL0112170-950615-07TM, 1995.

[2] J. W. Jensen, M. A.and Wallace, "A review of antennas and propagation for MIMO wireless communications," *IEEE Trans. Antennas Propag.*, vol. 52, pp. 2810–2824, Nov. 2004.

[3] B. T. Maharaj, L. P. Linde, J. W. Wallace, and M. A. Jensen, "A cost-effective wideband MIMO channel sounder and initial co-located 2.4GHz and 5.2GHz measurements," in *Proc. 2005 IEEE Intl. Conf. Acoustics, Speech, and Signal Processing*, vol. 3, Philadelphia, PA, Mar. 18-23 2005, pp. 981–984.

[4] M. Steinbauer, A. F. Molisch, and E. Bonek, "The double-directional radio channel," *IEEE Antennas and Propag. Mag.*, vol. 43, pp. 51–63, Aug. 2001.

[5] H. Krim and M. Viberg, "Two decades of array signal processing research: The parametric approach," *IEEE Signal Processing Magazine*, vol. 13, pp. 67–94, Jul. 1996.