Das Gupta, Jishu and Ziri-Castro, Karla I. (2009) ***Body-shadowing effects in indoor MIMO-OFDM channel capacity.*** In: Proceedings of Australasian Telecommunications Networks and Applications Conference, 9-11 November 2009, National Convention Centre, Canberra.

Body-shadowing Effects in Indoor MIMO-OFDM Channel Capacity

Jishu Das Gupta and Karla Ziri-Castro

School of Engineering Systems, Queensland University of Technology, Australia
GPO Box 2434, Brisbane QLD 4001 Australia
j.dasgupta@qut.edu.au, karla.ziricastro@qut.edu.au

***Abstract*—We investigate Multiple-Input and Multiple-Output Orthogonal Frequency Division Multiplexing (MIMO-OFDM) systems behavior in indoor populated environments that have line-of-site (LoS) between transmitter and receiver arrays. The in-house built MIMO-OFDM packet transmission demonstrator, equipped with four transmitters and four receivers, has been utilized to perform channel measurements at 5.2 GHz. Measurements have been performed using 0 to 3 pedestrians with different antenna arrays (2×2, 3×3 and 4×4). The maximum average capacity for the 2x2 deterministic Fixed SNR scenario is 8.5 dB compared to the 4x4 deterministic scenario that has a maximum average capacity of 16.2 dB, thus an increment of 8 dB in average capacity has been measured when the array size increases from 2x2 to 4x4. In addition a regular variation has been observed for Random scenarios compared to the deterministic scenarios. An incremental trend in average channel capacity for both deterministic and random pedestrian movements has been observed with increasing number of pedestrian and antennas. In deterministic scenarios, the variations in average channel capacity are more noticeable than for the random scenarios due to a more prolonged and controlled body-shadowing effect. Moreover due to the frequent Los blocking and fixed transmission power a slight decrement have been observed in the spread between the maximum and minimum capacity with random fixed Tx power scenario.**

***Index Terms*—MIMO-OFDM, dynamic range, channel capacity.**

I. INTRODUCTION

Many researchers have investigated the Multiple-Input Multiple-Output orthogonal frequency division multiplexing (MIMO-OFDM) channel characteristics and contributed to the ultimate advancement of MIMO-OFDM systems [1, 2]. With continuing improvement MIMO-OFDM is currently being considered as a strong candidate for the physical layer transmission scheme of next generation broadband wireless communication systems [3, 4].

Movement of human bodies in indoor environments can create a significant variation in the MIMO-OFDM channel [5, 6]. Other research work has also reported that, sufficiently rich multipath signal propagation has been found in MIMO channels operating within indoor environments [2, 7]. Notwithstanding previous studies, a systematic measurement campaign to characterize pedestrian movement effects in MIMO-OFDM channels has not yet being fully investigated. Measuring channel variations caused by the relative positioning of pedestrians is essential in the study of indoor MIMO broadband wireless networks. In [8–10] we have reported the measured correlation, capacity and dynamic range of time-varying indoor MIMO-OFDM channels. In this paper we have investigated the effect of random human body movement on MIMO-OFDM channels using both simulations and measurements within an indoor environment. Channel measurements were conducted using a 4×4 MIMO-OFDM packet transmission demonstrator in the presence of different number of pedestrians moving randomly in an indoor environment. The remaining of this paper is organized as follows: the criteria used to calculate the MIMO-OFDM channel capacity is in Section II. Section III provides details on the measurements. Section IV presents the time varying results and analysis comparing 2×2, 3×3 and 4×4 , followed by the conclusions in Section V.

II. MIMO-OFDM CHANNEL CAPACITY

The MIMO-OFDM channel is characterized by its coefficient, $g(i, j, k, l)$ where, g is the MIMO-OFDM channel coefficient of ith receiving antenna,jth transmitting antenna,kth OFDM sub-carrier and$l$th receiving antenna array location. The number of transmitting antennas, receiving antennas, OFDM sub-carriers, and the receiving antenna array locations is n_t,n_r,n_f and n_x respectively. To obtain the Shannon capacity of the MIMO channel as a function of average signal to noise ration (SNR) per receiving antenna, it will be convenient to work on the normalized channel coefficient $g(i, j, k, l)$ [2] As follows:

$$h(i,j,k,l) = \frac{g(i,j,k,l)}{\sqrt{\frac{1}{n_r n_t n_f}\sum_{i=1}^{n_r}\sum_{j=1}^{n_t}\sum_{k=1}^{n_f}|g(i,j,k,l)|^2}} \quad (1)$$

The MIMO-OFDM channel capacity without the knowledge of the channel at the transmitter is given by [2]

$$\bar{C} = \frac{1}{n_f}\sum_{k=1}^{n_f}\sum_{j=1}^{n_t}\log_2(1+\frac{\rho\gamma_j(f_k)}{n_t}), \quad (2)$$

where $\bar{C}$ is the normalized capacity in bits/sec/Hz, n_f is the number of OFDM sub-carriers, n_t is the number of Tx antennas, ρ is the average signal to noise ratio (SNR) and γ_j is the eigenvalue of $\mathbf{H}(f_k)\mathbf{H}(f_k)^H$. $\mathbf{H}(f_k)$ is the normalized channel coefficient matrix at sub-carrier f_k and $(.)^H$ denotes

Hermitian transpose. The normalization is performed such that [11]:

$$\mathrm{E}\left(||\mathbf{H}||_F^2\right) = n_t n_r, \tag{3}$$

where $\mathrm{E}(\cdot)$ denotes the expected value, $||\cdot||_F$ denotes the Frobenius norm, and n_r is the number of Rx antennas.

Two different criteria are employed to evaluate the MIMO-OFDM channel capacity. The first assumes an interference-limited system where transmitting power can be adjusted without a limit to provide a fixed average SNR at the receivers. The averaging of SNR and normalization of channel coefficient matrix is performed over all MIMO sub-channels and over all OFDM sub-carriers. This criterion is called fixed SNR capacity. It corresponds to the system where co-channel interference is the limiting factor for the system capacity, and enough Tx power is reserved to cater for every location within the coverage area. SNR=15 dB is used in the following analysis.

The second criterion assumes a power-limited system where the transmitting power is fixed. In this case the averaging of SNR and normalization of channel coefficient matrix is performed over all possible scenarios, MIMO sub-channels, OFDM sub-carriers, measurement samples, and different number of pedestrian. This is called fixed Tx power capacity. It incorporates the effects of the reduction of power due to body shadowing by the pedestrian. This criterion is more suitable for the analysis of WLAN system where the transmitting power is typically fixed.

III. Description of Measurements

Measurement were performed using MIMO-OFDM packet transmission demonstrator developed by CSIRO ICT Centre [12]. MIMO-OFDM packet demonstrator uses a 4×4 array of identical off-the-shelf omnidirectional loop antennas (SkyCross SMA-5250-UA), each with +2.2 dBi gain. The four antenna elements are arranged to form a uniform square array on the horizontal plane. According to [2] when the antenna spacing is considered to be large the exact value of the antenna spacing does not affect the MIMO-OFDM channel capacity. The spacing of the antenna elements is set to 3 wavelengths at Tx and 2 wavelengths at Rx. The MIMO-OFDM demonstrator has a dynamic range of approximately 40 dB and operates at a carrier frequency of 5.24 GHz. The OFDM sub-carrier spacing and operational bandwidth closely follow those of the IEEE 802.11n draft standard [13]. The demonstrator is shown in Fig. 1. Further technical specifications for the demonstrator can be found in [12, 14].

Measurements were performed on the furniture free two different ground floor rooms in the CSIRO ICT Centre, Marsfield, Sydney as shown in Fig. 2(a) and 2(b). In Fig. 2(a) room we have conducted our deterministic experiments and in Fig. 2(b) room we have conducted our random experiments. For deterministic experiments both Tx and Rx , seperated by 10m, are located in 60m^2 room. The room was completely furniture free. Complex channel coefficients for each of 16 MIMO sub-channels and 114 OFDM sub-carriers were collected as pedestrians walked within the given 6m trajectory

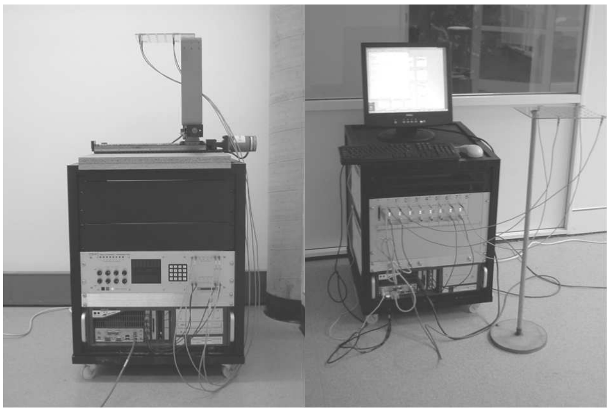
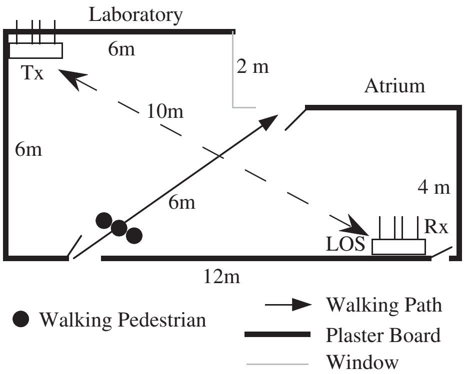
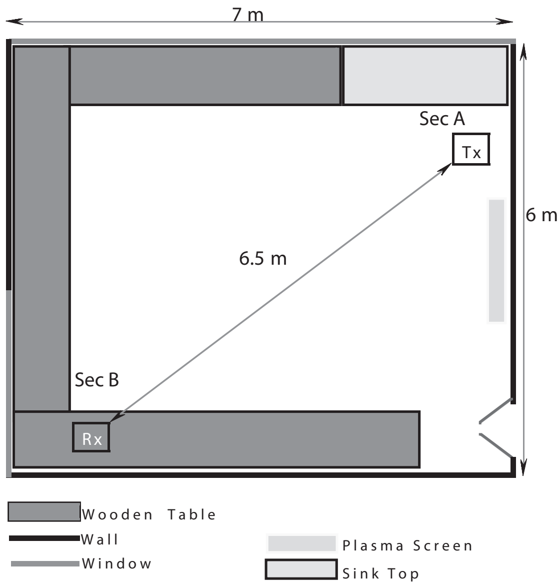


Fig. 1. MIMO-OFDM demonstrator from CSIRO ICT Center (left: Tx, right Rx).



(a) Deterministic Experiment Floor Plan



(b) Random Experiment Floor Plan

Fig. 2. Experimental Floor Plans

crossing the direct line of sight of Tx and Rx within the room. For random experiments both Tx and Rx, separated by 6.5 m, are located inside the same 42m^2 room. All the wooden tables line up with the inside walls surrounding the room. Complex channel coefficients for each of 16 MIMO sub-channels and 114 OFDM sub-carriers were collected at approximately 2 samples per second as pedestrians walked randomly within the room. We note that the Average Channel Capacity does not depend on the speed of the pedestrian or on the sampling rate as long as enough measurement points are collected. The measurements were performed during the day at normal office hours.

IV. Results

Fig. 3 to Fig. 6 show the variation in average channel capacity as a function of the number people (0-3) walking in a pre-determined trajectory and randomly within the room using different antenna arrays (2×2, 3×3 and 4×4). Out of the presented figure cluster Fig. 3 and Fig. 5 show the deterministic Fixed SNR as well as Fixed Tx scenarios, while Fig. 4 and Fig. 6 show the random Fixed SNR as well as Fixed Tx scenarios.

In general, we observe for both deterministic and random Fixed SNR scenarios the average channel capacity is increasing with number of antennas and number of pedestrian. Similar trends have been observed for the deterministic Fixed Tx scenarios. We also note that the average channel capacity is decreasing with number of antenna in Random Fixed Tx scenarios due to fixed transmission power and frequent blocking of line of sight as pedestrian moving randomly in the indoor environment. A higher average channel capacity for the fixed Tx scenarios than for the fixed SNR scenarios have been found. The increase in capacity due to the de-correlation of the channel caused by the obstruction of the direct LoS path for the fixed Tx power criteria causes higher variations in the capacity dynamic range than the expected reduction in channel capacity due to human-body shadowing effects.

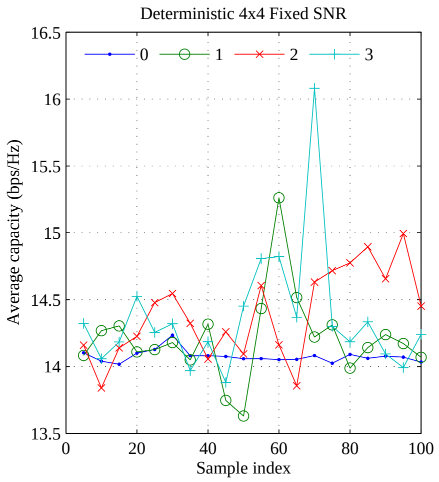
We also note that a deviation of the measurement results fixed Tx power criterion. This is considered to be due to the complexity of the of moving human-bodies and of the environment employed in the process. Additionally, the spread between the highest and lowest value of the the average channel capacity is larger for fixed Tx, measured 3.1 $bits/s/Hz$, in comparison with fixed SNR criteria, measured 2.5 $bits/s/Hz$. This has been confirmed by measurements ranging from 0 to 3 pedestrians. The raise in multipath conditions caused by higher number of pedestrians originate a general increase in average channel capacity for all the array sizes, 2×2, 3×3 and 4×4. The highest measured average capacity for deterministic scenarios, 16.10 $bits/s/Hz$, corresponds to the 4x4 array with 4 pedestrians for fixed SNR and 15.4 $bits/s/Hz$, corresponds to the 4x4 array with 4 pedestrians for fixed Tx moving randomly. Additionally, the highest measured average capacity for random scenarios, 23.6 $bits/s/Hz$, corresponds to the 2x2 array with 4 pedestrians for fixed Tx and 13.75 $bits/s/Hz$, corresponds to the 4x4 array with 4 pedestrians moving randomly. In all the given scenarios, due to the increase of transmission power during the Fixed SNR analysis both the deterministic and random average capacity increases with the number of pedestrian and antenna combination. Similar trend can be seen for the deterministic fixed tx power scenarios as human body was blocking the Los for a certain duration. But during the random Fixed Tx power scenario due to the regular blocking of LoS path and fixed Tx power results a decremented trend in average capacity with the increasing number of pedestrian and antenna combinations.

V. Conclusion

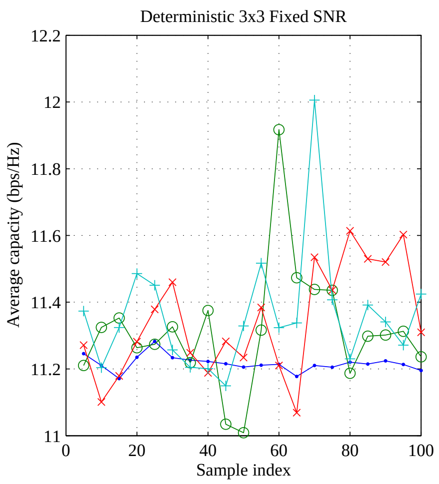
We have conducted systematic measurements for an indoor MIMO-OFDM channel at 5.2 GHz in presence of up to 3 pedestrians walking both randomly and along a predetermined trajectory. MIMO-OFDM channel capacity was evaluated using four different criteria, deterministic, random, fixed transmitted power and fixed Signal-to-Noise-Ratio. Results show higher MIMO-OFDM average channel capacity with increasing number of pedestrians (0-3), as well as with increasing number of antennas (2×2, 3×3 and 4×4) in most of the scenarios. The raise in multipath conditions caused by higher number of pedestrians originate a general increase in average channel capacity for all the array sizes. Future effort should be directed to the measurement as well as analysis of different types of environments such as, meeting rooms and cafeterias where MIMO-OFDM based wireless communication systems are increasingly being used.

Acknowledgment

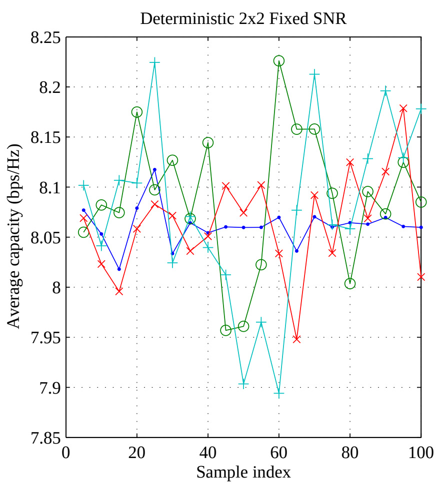
The authors would like to acknowledge the CSIRO ICT Centre personnel at Marshfield, Sydney, for providing the MIMO-OFDM packet transmission demonstrator and measurement sites.



(a) Deterministic 4x4 Fixed SNR

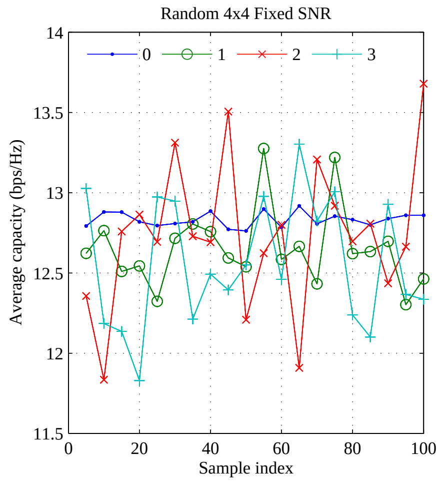


(b) Deterministic 3x3 Fixed SNR

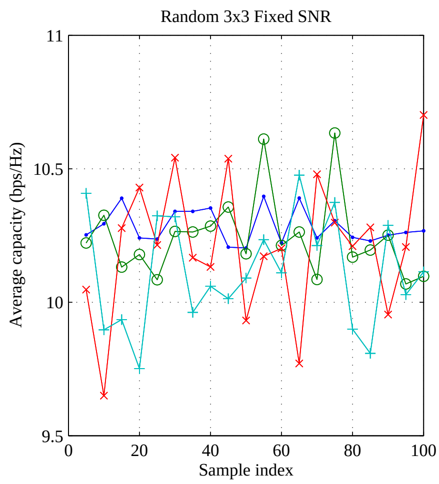


(c) Deterministic 2x2 Fixed SNR

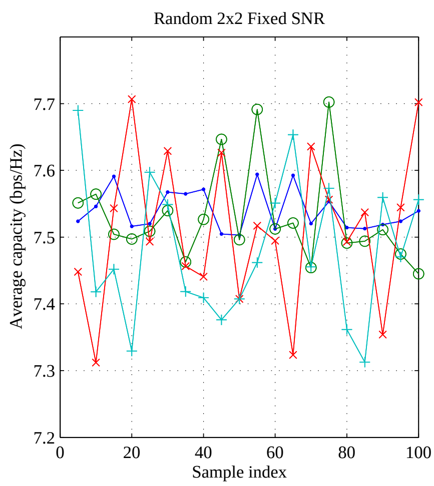
Fig. 3. Deterministic Fixed SNR Average Channel Capacity



(a) Random 4x4 Fixed SNR

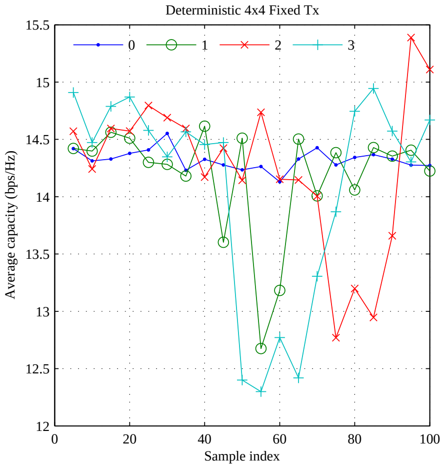


(b) Random 3x3 Fixed SNR

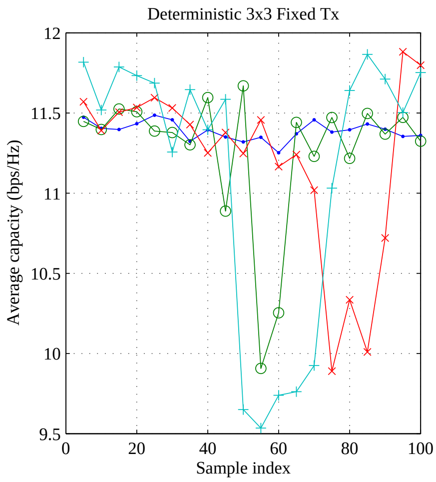


(c) Random 2x2 Fixed SNR

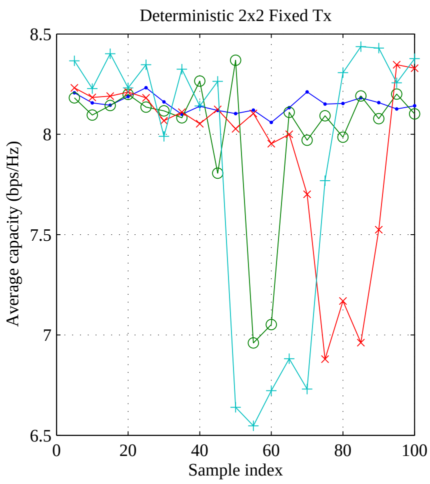
Fig. 4. Random Fixed SNR Average Channel Capacity



(a) Deterministic 4x4 Fixed Tx

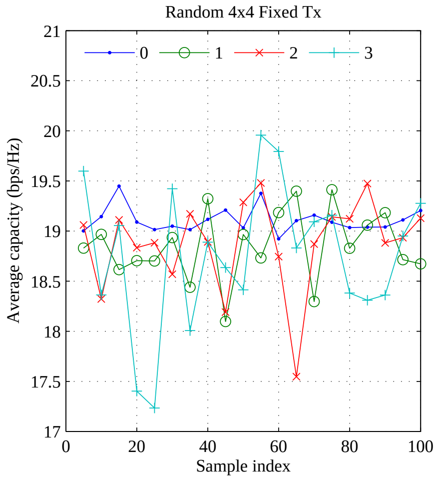


(b) Deterministic 3x3 Fixed Tx

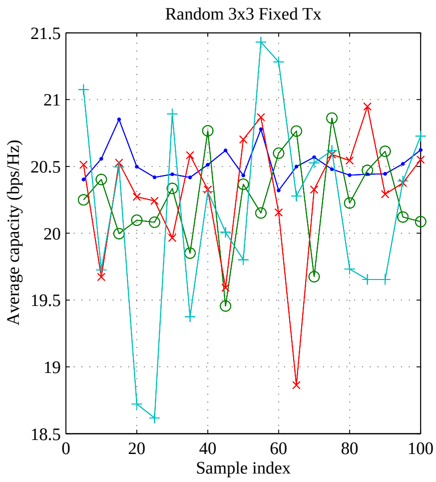


(c) Deterministic 2x2 Fixed Tx

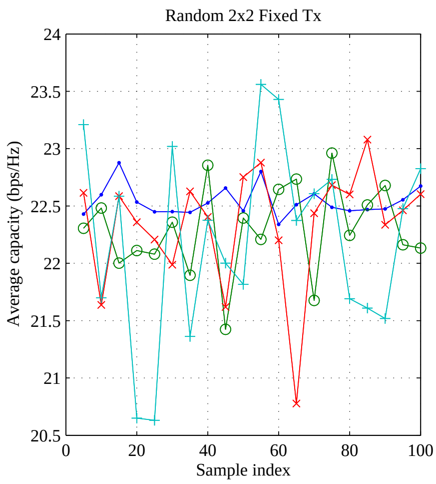
Fig. 5. Deterministic Fixed Tx Power Average Channel Capacity



(a) Random 4x4 Fixed Tx



(b) Random 3x3 Fixed Tx



(c) Random 2x2 Fixed Tx

Fig. 6. Random Fixed Tx Power Average Channel Capcity

REFERENCES

[1] A. van Zelst and T. C. W. Schenk, "Implementation of a MIMO-OFDM-based wireless LAN system," *IEEE Transactions on Signal Processing*, vol. 52, no. 2, pp. 483–494, February 2004.

[2] H. Suzuki, T. V. A. Tran, and I. B. Collings, "Characteristics of MIMO-OFDM channels in indoor environments," *EURASIP Journal on Wireless Communications and Networking*, vol. 2007, no. 19728, January 2007.

[3] C. Dubuc, D. Starks, T. Creasy, and Y. Hou, "A MIMO-OFDM prototype for next-generation wireless WANs," *IEEE Communications Magazine*, vol. 42, pp. 82–87, Dec 2004.

[4] W. Zhang, X. Xiang-Gen, and K. B. Letaief, "Space-time-frequency coding for MIMO-OFDM in next generation broadband wireless systems," *IEEE Wireless Communications*, vol. 14, no. 3, pp. 32–43, June 2007.

[5] K. Ziri-Castro, W. G. Scalon, and N. E. Evans, "Prediction of variation in MIMO channel capacity for the populated indoor environemnt using a radar cross-section-based pedestrian model," *IEEE Transection on Wireless Communications*, vol. 4, no. 3, pp. 1186–1194, May 2005.

[6] K. Ziri-Castro, W. G. Scalon, and N. E. Evans, "Measured pedestrian movement and bodyworn terminal effect for the indoor chanel at 5.2 GHz," *European Trransection on Telecommunications*, Nov/Dec 2003.

[7] A. L. Swindlehurst B. D. Jeffs J. W. Wallace, M. A. Jensen, "Experimental characterization of the MIMO wireless channel: data acquisition and analysis," *IEEE Transactions On Wireless Communications*, vol. 2, no. 2, pp. 335–343, March 2003.

[8] J. D. Gupta, K. Ziri-Castro, and H. Suzuki, "Correlation analysis on MIMO-OFDM channels in populated time varying indoor environment," *10th Australian Symposium on Antennas*, Feb 2007.

[9] J. D. Gupta, K. Ziri-Castro, and H. Suzuki, "Capacity analysis of MIMO-OFDM broadband channels in populated indoor environments," *7th International Symposium on Communications and Information Technologies*, pp. 273–278, Oct 2007.

[10] J. D. Gupta, K. Ziri-Castro, and H. Suzuki, "Dynamic range analysis on MIMO-OFDM broadband channels in a populated time-varying indoor environment," *2007 Australian Telecommunication Networks and Applications Conference*, Dec 2007.

[11] K. Yu, M. Bengtsson, B. Ottersten, D. McNamara, P. Karlsson, and M. Beach, "Modeling of wide-band MIMO radio channels based on NLoS indoor measurements," *IEEE Transactions on Vehicular Technology*, vol. 53, no. 3, pp. 655–665, May 2004.

[12] H. Suzuki, T. V. A. Tran, I. B. Collings, G. Daniels, and M. Hedley, "Transmitter noise effect on the performance of a MIMO-OFDM hardware implementation achieving improved coverage," *IEEE Journal on Selected Areas in Communications*, vol. 26, no. 6, pp. 867–876, August 2008.

[13] 802.11 Working Group of the 802 Committee, "Draft Standard for Information Technology- Telecommunications and information exchange between systems- Local and metropolitan area networks- Specific requirements- Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Amendment 4: Enhancements for Higher Throughput," September 2007.

[14] H. Suzuki, B. Murray, A. Grancea, R. Shaw J. Pathikulangara, and I. B. Collings, "Real-time wideband MIMO demonstrator," *In Proceedings of the 7th International Symposium on Communications and Information Technologies*, pp. 284–289, October 2007.