ISSN : 2231-0711

IJCSET | June 2011 | Vol 1, Issue 5,244-248

Spatial Multiplexing for Millimeter Waves using TSV Model

Savitha Manojna.D, Kirthiga.S, Jayakumar.M

Communications Engineering Research Group, Amrita Vishwa Vidyapeetham, Coimbatore, India

Abstract— **Millimeter waves have the potential of providing multi-gigabit per second wireless networks. Multi Input Multi Output (MIMO) is emerging to be a key technology for enabling wireless technology whose features will improve by increasing the spectral efficiency of the systems at lower cost per bit. Spatial Multiplexing MIMO is found to suffice this requirement which has the principal use of increasing the spectral efficiency. The performance of Spatial Multiplexed system for the Triple Saleh Valenzuela (TSV) Channel model is simulated by assuming a simple indoor LOS environment model. The TSV model takes in to account both the Time of arrival of the rays and Angle of Arrival information of the antenna. Assuming a perfect channel for Estimation, the Bit Error performance of the system is investigated for Zero Forcing, Minimum Mean Square and Maximum Likelihood receivers for 2x2 and 4x4 and 8x8 Spatial Multiplexed systems for BPSK modulation schemes.**

Keywords— **Millimetre Waves, Spatial Multiplexing, Triple Saleh Valenzuela model, Zero Forcing, Minimum Mean Square Error, Maximum Likelihood Equalizer.**

I. INTRODUCTION

Millimeter waves can be classified as Electromagnetic Spectrum that spans between 30 GHz to 300GHz that corresponds to wavelengths from 10mm to 1 mm. Millimeter Wave frequency bands offer an abundance of unlicensed bandwidth of 7GHz spanning 57-64 GHz .The Friis equation given by $\frac{4\pi d^{n}}{\lambda^{2}}$ indicates that path loss of a radio signal is proportional to square of carrier frequency. Then, for equal gain, 60 GHz has additional 21 dB path loss when compared to 5 GHz [3].

Modeling indoor propagation environment is complicated by large variability in building layout and construction materials. Environment can change radically by movement of people, blockage by walls and furniture. Another important element of indoor wireless operation that should be taken in to account is interference. Indoor path loss can change dramatically with either time or position, because of multipath present [6]. The main component of complexity in an indoor propagation is contributed by the multipath. This increases the indoor path loss. The wideband of waves used in indoor applications increase the sensitivity to delay spread [7]. Site-specific and Site-general modeling are the two general types of propagation modeling present. Site-Specific modeling requires information on building layout, furniture, walls, floors etc. This modeling is generally performed using ray-tracing methods. Site-general models give statistical predictions of the path loss for a link design. This model tends to be the more widely used model. Millimeter Waves are mostly affected by small-scale fading that encompasses the fading that occurs with very small changes in the relative position of the transmitter and receiver and reflectors in the environment [8]. This is attributed to the summation of multiple reflected signals arising with different phases and amplitudes. As there is a presence of single- dominant component such as line-of-sight path, this channel model has taken Rician Probability density function in consideration [19], [21]. As the path loss combines with other channel impairments like delay spread, there arises a necessity to use directional antennas to obtain reliable communications. To obtain better Signal to Noise Ratio (SNR) in Millimeter wave band and in order to effectively use frequency with Space Division method, the effect of antenna directivity has to be considered [2].

The channel model that is employed in this paper for the Millimeter wave propagation in the indoor environment is the Triple Saleh Valenzuela (TSV) model which is a Site-general model. This model is contributed by NICT Japan to the 802.15.3c Channel model subgroup. This model is a merger of the two-path model and Saleh-Valenzuela (S-V) model. The Impulse Response of the S-V model takes in to account only the complex amplitude of each ray and the Time-of-arrival information of each ray in a cluster. In order to include the effect of antenna, the angle-of-arrival information was also used in the calculation of the Complex Impulse Response (CIR), thus the directivity of antenna is convoluted to the S-V component that makes the model a modified form of S-V model[1]. The Power Delay Profiles obtained from the simulations from the model describe different parameters like cluster arrival rate, ray arrival rate, cluster decay rate and ray decay rate and gives a clear picture of the LOS component and the NLOS components present in the environment.

The use of MIMO technology in wireless environments is an emerging cost-effective technology that helps in making Gigabit/s links a reality. MIMO channels offer a linear (in min (M_T, M_R)) increase in capacity for no additional power or Bandwidth [11]. This Spatial Multiplexing gain can be achieved by transmitting independent data signals from individual antennas[12]. Under rich scattering environments, the receiver can separate the different streams resulting in a linear increase in capacity.

The LOS channel is modeled here using the TSV model. This model assumed here was found to be much suitable for the indoor environment because of its capability to describe both the LOS and NLOS components and the Bit Error Rate performance of such a Spatial Multiplexed system in an indoor environment is compared for different receivers is compared. As the number antennas are increased from 2x2 to 4x4, the system showed an improved Bit Error Rate performance for SNR of 8dB. Maximum Likelihood equalization technique was found to outperform ZF and MMSE for both the cases.

The remainder of this paper is organized as follows. In Section II, we describe the indoor environment considered and the TSV channel model used. Section III describes the Spatial

Multiplexing in MIMO links for LOS environment and the different Equalization techniques considered. Section IV deals with the performance evaluation of the 2x2 and 4x4 Spatial Multiplexed BPSK systems with ZF, MMSE, ML equalization techniques.

II. TSV MODEL FOR INDOOR ENVIRONMENT

To consider the influence of antenna, the angle-of-arrival information was included in the Impulse Response of modified S-V model [1];

The Complex Impulse Response (CIR) of the TSV model is given by [1] as

$$h(t) = \beta\,\delta(t) + \sum_{l=0}^{\infty}\sum_{m=0}^{\infty} \alpha_{l,m}\,\delta(t - T_l - \tau_{l,m})\,\delta(\varphi - \psi_l - \psi_{l,m}) \quad (1)$$

Where, β is the direct wave component that holds the information about the heights of the transmitter and receiver antenna, distance between the antenna, Reflection Co-efficient and the wavelength of the center frequency.

$\alpha_{l,m}$ is the complex amplitude of each ray.

t is the time, T_l is the delay time of the *l*-th cluster,

$\tau_{l,m}$ is the delay time of the *m*-th ray in *l*-th cluster.

ψ_l is the angle of arrival of the *l*-th cluster,

$\psi_{l,m}$ is the angle of arrival of *m*-th ray in the *l*-th cluster.

Each ray belongs to the cluster. Probability of ray and cluster generation is done by Poisson process and the distribution of the angle is done by Laplacian distribution. The positional parameters are treated as statistical and are estimated by using Uniform distribution [1].

The direct wave component is expressed by the two-path statistical model that helps to take in to consideration the uncertainties associated with the fading caused by slightest movement of the device. The impulse response can be pictorially explained as follows:

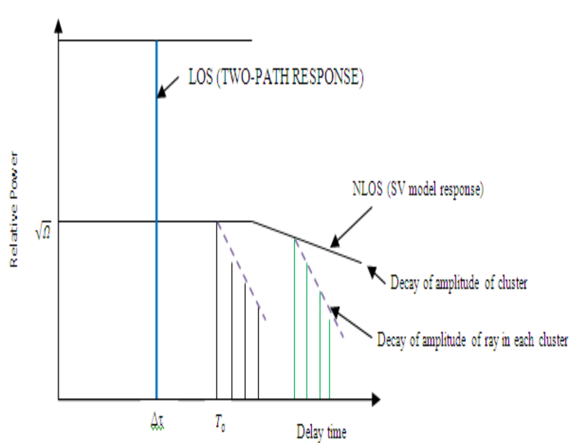

Fig 1: Impulse Response of the TSV model

TABLE I
LAYOUT GEOMETRY AS ASSUMED IN THE MODEL IS AS FOLLOWS [4] AS GIVEN BY TSV MODEL CONTRIBUTED BY NICT:

Ceiling Height	2.47 m
Window Height	2.11m
Transmitter and Receiver Height	1.1m
Polarization	Vertical
Transmitter antenna	Always Fixed
Receiver antenna	Rotated from 0^0 to 360^0 in 5^0 steps.
Assumed Distance	1m
Environment Considered	Desktop environment

III. SPATIAL MULTIPLEXING IN LOS AND NLOS

At Millimeter wave frequencies, Spatial Multiplexing for MIMO links is found to be available with moderate antenna spacing without rich scattering environment. The objective of the Spatial Multiplexed systems as opposed to Space-Time diversity coding is to maximize the Transmission rate. Accordingly, the M_T independent data symbols are transmitted per symbol period. The time varying Impulse Response between j^{th} (1,2,… M_T) transmitter antennas and i^{th} (1,2,….M_R) receiver antenna is denoted as $h_{i,j}(t,\varphi)$. At high SNR, the channel capacity increases with SNR as min $\{M_T, M_R\}$ log SNR (bps/Hz), in contrast to log SNR for single channels[15],[17]. Thus multiple antenna channels are min $\{ M_T, M_R \}$ parallel spatial channels, hence it is the total number of degrees of Freedom to communicate. The Channel Response is given by M_R x M_T matrix H (t,φ) with [4]

$$H(t,\varphi) = \begin{pmatrix} h_{11}(t,\varphi) & h_{12}(t,\varphi)\ldots & h_{1M_T}(t,\varphi) \\ h_{21}(t,\varphi) & h_{22}(t,\varphi)\ldots & h_{2M_T}(t,\varphi) \\ \vdots & . & \vdots \\ h_{M_R1}(t,\varphi) & h_{M_R2}(t,\varphi) & h_{M_RM_T}(t,\varphi) \end{pmatrix} \quad (2)$$

Given that $x_j(t)$ is launched from j^{th} transmitter antenna, the signal received at i^{th} receiver antenna is

$$y_i(t) = \sum_{t=1}^{M_T} h_{i,j}(t,\varphi) * x_j(t) + n_i(t) \quad (3)$$

Any signal processing technique that is used to mitigate the Inter Symbol Interference (ISI) that is caused by the delay spread is called Equalization. When the signal from the channel passes through the equalizer, it increases the noise power also. Hence, proper techniques should be used to reduce the noise enhancement.

The remainder of this section focuses on receiver structures for spatial multiplexing and the corresponding performance-complexity tradeoff. For the sake of simplicity the number of receiver antennas are considered to greater than or equal to transmitter antennas.

A. Maximum Likelihood Receiver (ML)

The transmitter sends one of M signals $s_i(t)$, for i=1,2,…,M .The M signals forms a constellation in the signaling space. The received signal $x(t) = s_i(t) + n(t)$ is decomposed to its components in the signal space. The ML receiver performs optimum vector decoding and is optimal in the sense of minimizing the error probability [18]. ML receiver is a method that compares the received signals with all possible transmitted signal vector which is modified by channel matrix H and estimates transmit symbol vector x according to the Maximum Likelihood principle given as.,

$$y = \arg_{x_k \in \{y_1, y_2, \dots, y_N\}} \min \| r - H_{y_k} \| \quad (4)$$

where the minimization is performed over all possible transmit estimated vector symbols y and H is the (M_T x M_T) impulse response of the channel which contains the TOA and AOA information. Although ML detection offers optimal error performance, it suffers from complexity issues. The maximum Likelihood receiver picks the signal that is closed to the received signal in the signal space. It has exponential complexity in the sense that the receiver has to consider $|C|^M$ possible symbols for an M transmitter antenna system with C as the modulation constellation.[11]

B. Zero Forcing Receiver (ZF)

Considering the MIMO channel model given in (2), where the *N* data sub streams are mixed by the channel matrix. The ZF equalizer can be applied to decouple the *N* sub streams.

$$W_{ZF} = (H^*H)^{-1} H^* \quad (5)$$

where H is the (M_T x M_T) impulse response of the channel which contains the TOA and AOA information and H^* is the conjugate of H.

Multiplying the received signal vector y on the Left Hand Side by W_{zf} , *N* decoupled sub streams is obtained with output SNRs given as.,

$$\rho_{zf,n} = \frac{snr}{(H^*H)^{-1}_{nn}} \quad , 1 \le n \le N \quad (6)$$

The ZF receiver converts the joint decoding problem into M single stream decoding problems thereby significantly reducing receiver complexity. This leads to the trade-off between complexity reduction and performance degradation.[4]

C. Minimum Mean Square Error (MMSE)

Considering the MIMO channel model given in (2), where the *N* data substreams are mixed by the channel matrix. The MMSE equalizers can be applied to decouple the *N* substreams

$$W_{MMSE} = (H^*H + \frac{1}{snr} I)^{-1} H^* \quad (7)$$

Multiplying the received signal vector y on the Left Hand Side by W_{MMSE}, *N* decoupled substreams is obtained with output SNRs given as.,

$$\rho_{mmse,n} = \frac{snr}{(H^*H + \frac{1}{snr} I)^{-1}_{nn}} \quad , 1 \le n \le N \quad (8)$$

The MMSE receiver suppresses both the interference and noise components, whereas the ZF receiver removes only the interference components. Some of the important characteristics of MMSE detector are simple linear receiver, superior performance to ZF and at Low SNR, MMSE becomes matched filter [20]. The linear ZF and MMSE equalizers are classic functional blocks and are ubiquitous in digital communications [21]. They are also the building blocks of more advanced communication schemes such as the decision feedback equalizer (DFE), or equivalently, the V-BLAST (vertical Bell Labs layered Space-Time) architecture and various other MIMO transceiver designs. It is commonly understood that ZF is a limiting form of MMSE as snr $\to\infty$. But when the ZF and MMSE are applied to the MIMO fading channel one may observe through simulations that the error probabilities of MMSE and ZF do not coincide even as snr $\to\infty$. [16].

IV. RESULTS AND DISCUSSION

TABLE II
SIMULATION RESULTS OF THE TSV MODEL IN DESKTOP ENVIRONMENT

LOS Component Pathloss	-81.9842[dB]
Average RMS delay	1.290 [ns]
Maximum RMS delay	2.657 [ns]
Minimum RMS delay	0.693 [ns]
Average Rician factor	27.023 [dB]
Maximum Rician factor	35.799 [dB]
Minimum Rician factor	14.737 [dB]
Environment	Desktop
Distance assumed between Transmitter and Receiver	5m
Number of clusters	4

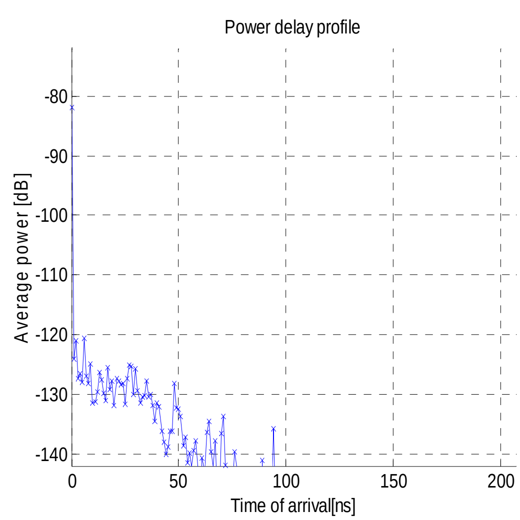

Fig. 2. Power delay Profile Showing LOS and NLOS component

The Power Delay Profile (PDP) in Fig.2shows the presence of direct component having the Average Power of nearly -80 dB. As the number of reflections per ray increases, the corresponding amplitude of the ray decreases, because of both reflection losses and higher free space losses. Hence, the ray amplitude depends on room dimensions and the magnitude of reflection co-efficients.

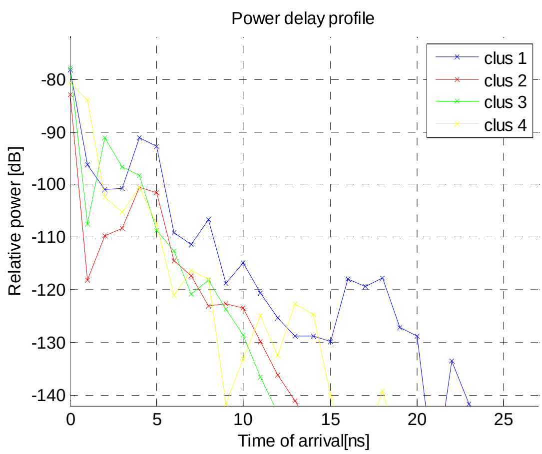

Fig.3. Complex Impulse Response as a function of Relative Power and Time of arrival.

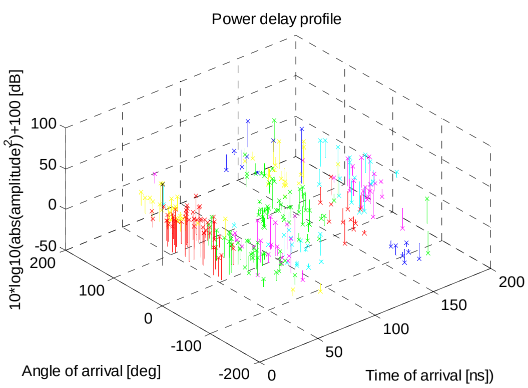

Fig.4. Complex Impulse Response as a function of Time of Arrival and Angle of Arrival information

Power Delay Profile in Figures3 and 4 contains the AOA information which includes the effect of antenna directivity that helps to obtain SNR characteristic of Millimeter Wave band and the effective use of frequency in Space-Division method. In this, we can observe the ray clustering which is evidenced by the peaks in the PDP.

TABLE III
SIMULATION SUMMARY FOR BIT ERROR RATE PERFORMANCE FOR 2X2 SPATIAL MULTIPLEXED SYSTEM.

Modulation Used	BPSK
Number of Bits	10^4
SNR	1:8dB
Channel Model	Triple Saleh Valenzuela
Environment Used	Desktop
Centre Frequency	60GHz
Bit Error Rate	$<10^{-3}$

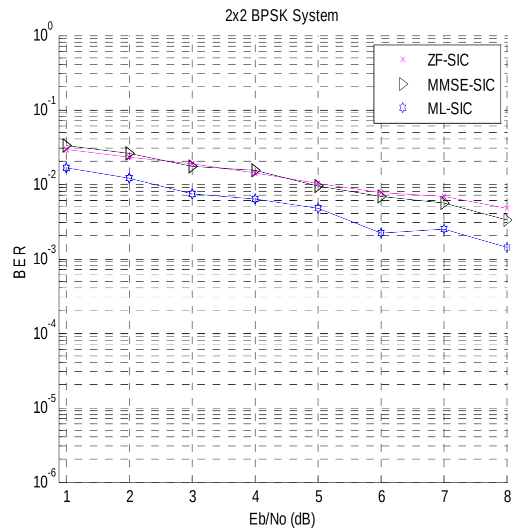

Fig.5.Bit Error Rate performance for a 2x2 Spatial Multiplexed system.

TABLE IV
SIMULATION SUMMARY FOR BIT ERROR RATE PERFORMANCE FOR 4X4 SPATIAL MULTIPLEXED SYSTEM.

Modulation Used	BPSK
Number of Bits	10^4
SNR	1:8dB
Channel Model	Triple Saleh Valenzuela
Environment Used	Desktop
Centre Frequency	60GHz
Bit Error Rate	$>10^{-4}$

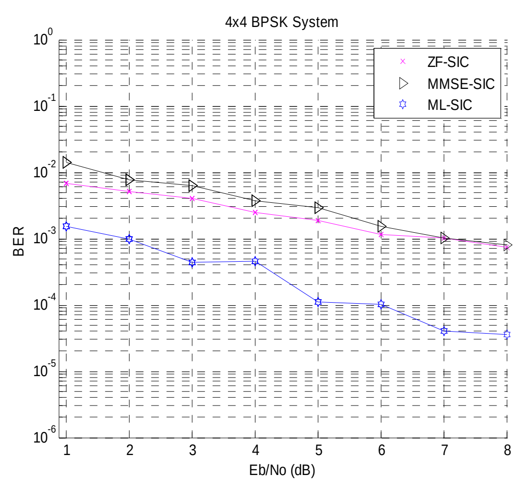

Fig.6. Bit Error Rate performance for a 4x4 Spatial Multiplexed system

TABLE V
SIMULATION SUMMARY FOR BIT ERROR RATE PERFORMANCE FOR 8X8 SPATIAL MULTIPLEXED SYSTEM.

Modulation Used	BPSK
Number of Bits	10^4
SNR	1:8dB
Channel Model	Triple Saleh Valenzuela
Environment Used	Desktop
Centre Frequency	60GHz
Bit Error Rate	$>10^{-4}$ at 5dB

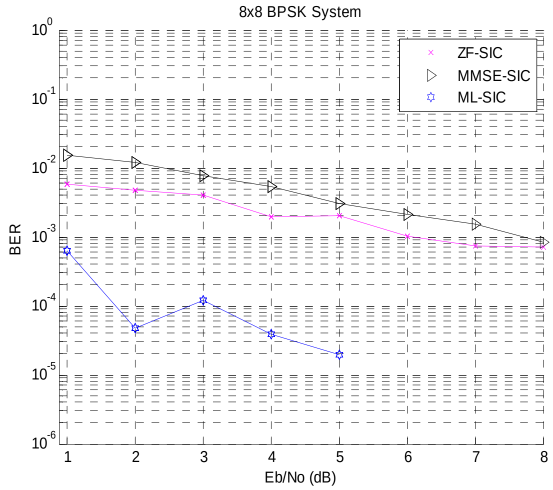

Fig 7: Bit Error Rate performance for a 8x8 Spatial Multiplexed system.

V. CONCLUSION

In this paper, the BER performance of 2x2 , 4x4 and 8x8 Spatial Multiplexed system is studied in indoor environment parameters using a Triple Saleh Valenzuela model and found that with the increase in the number of antennas, there is a decrease in the BER . The parameters considered for the simulation of the Triple Saleh Valenzuela model is as contributed by NICT Japan to the TG3c group. The simulation was performed for an indoor desktop environment having a distance of 1m considering the transmitter antenna beamwidth as 360^0 and receiver antenna beamwidth as 30^0 . Assuming the channel to be time dispersive and having sufficiently large coherence bandwidth , the average delay spread was found to be 1.28 ns.

REFERENCES

[1] Hirokazu Sawada, Yozo Shoji and Chang-Soon Choi, "Proposal of novel statistic channel model for millimeter wave WPAN TSV: Shoji-Sawada-Saleh (Triple S)-Valenzuela model", Proceedings of Asia-Pacific Microwave Conference 2006.

[2] Sylvain Ranvier, Suiyan Geng and Pertti Vainikainen, "Mm-Wave MIMO Systems for High Data-Rate Mobile Communications", Wireless VITAE'09, pp. 142-146, 2009.

[3] "Millimeter Wave Technology in Wireless PAN, LAN, and MAN", Edited by Shao-Qiu Xiao, Ming-Tuo Zhou, Yan Zhang, CRC Press, Auerbach Publications, ISBN-13: 978-0-8493-8227-7,2008

[4] Arogyaswami J. Paulraj, Dhananjay, A. Gore, Rohit U. Nabar, and Helmut Bölcskei, "An Overview of MIMO Communications—A Key to Gigabit Wireless", Proceedings Of The IEEE, Vol. 92, No. 2, pp.198- 218, February 2004.

[5] S. Singh, F. Ziliotto, U. Madhow, E. M. Belding and M. J. W. Rodwell,"Millimeter wave WPAN: cross-layer modeling and multihop architecture,"Proc. IEEE Infocom 2007 Minisymposium, Anchorage, Alaska, May 2007.

[6] John S. Seybold, "Introduction to RF Propagation", Wiley Interscience, ISBN-13 978-0-471-65596-1,2005.

[7] Andr´e Pollok, William G. Cowley, and Ian D. Holland, "Multiple-Input Multiple-Output Options for 60 GHz Line-of-Sight Channels", AusCTW 2008, pp.101-106, 2008.

[8] Eric Torkildson, Colin Sheldon, Upamanyu Madhow, and Mark Rodwell, "Millimeter-Wave Spatial Multiplexing in an Indoor Environment"

[9] C. Liu, E. Skafidas, and R. J. Evans, "Capacity and Data Rate for Millimeter Wavelength Systems in a Short Range Package Radio Transceiver ",IEEE Transactions On Wireless Communications, Vol. 9, No. 3, pp.902- 906, March 2010.

[10] Colin Sheldon, Eric Torkildson, Munkyo Seo, C. Patrick Yue, Mark Rodwell, and Upamanyu Madhow, "Spatial Multiplexing Over a Line-of-Sight Millimeter-Wave MIMO Link: A Two-Channel Hardware Demonstration at 1.2Gbps Over 41m Range",Proceedings of the 1st European Wireless Technology Conference, pp. 198 -221, October 2008

[11] P. Wolniansky, G. Foschini, G. Golden, and R. Valenzuela, "V-BLAST: an architecture for realizing very high data rates over the rich-scattering wireless channel," in Proc. ISSSE'98, 1998, pp. 295-300.

[12] G. J. Foschini and M. Gans, "On the limits of wireless communications in a fading environment when using multiple antennas," Wireless Personal Communications, vol. 6, no. 3, p. 311, Mar. 1998.

[13] P. F. M. Smulders, "Deterministic modelling of indoor radio propagation at 40-60 Ghz," Wireless Personal Communications, vol. 4, no. 2, pp.127–135, June 1994.

[14] C. Sheldon, M. Seo, E. Torkildson, M. Rodwell, and U. Madhow, "Four channel spatial multiplexing over a millimeter-wave line-of-sight link," IEEE - MTTS International Microwave Symposium, June 2009.

[15] F. Bohagen, P. Orten, and G. Oien, "Construction and capacity analysis of high-rank line-of-sight mimo channels," IEEE Wireless Communications and Networking Conference, vol. 1, pp. 432–437,Mar. 2005.

[16] E. Torkildson, B. Ananthasubramaniam, U. Madhow, and M. Rodwell,"Millimeter-wave MIMO: Wireless links at optical speeds," in Proc. of 44th Allerton Conference on Communication, Control and Computing, September 2006.

[17] I. Sarris, A. R. Nix, and A. Doufexi, "High performance wimax architecture using mimo technology in line-of-sight," The Second European Conference on Antennas and Propagation, pp. 1–5, Nov. 2007.

[18] C. Hofmann, A. Knopp, D. Ogermann, R. Schwarz, and B. Lankl, "Deficiencies of common mimo channel models with regard to indoor line-of sight channels," in Personal, Indoor and Mobile Radio Communications,2008. PIMRC 2008. IEEE 19th International Symposium on,pp. 1–6. , Sept. 2008.

[19] A. Poon, R. Brodersen, and D. Tse, "Degrees of freedom in multiple antenna channels: a signal space approach," Information Theory, IEEE Transactions on, vol. 51, no. 2, pp. 523–536, Feb. 2005.

[20] F. Bohagen, P. Orten, and G. Oien, "Design of optimal high-rank line of-sight MIMO channels," Wireless Communications, IEEE Transactionson, vol. 6, no. 4, pp. 1420–1425, April 2007.

[21] S. K. Yong and C. C. Chong, "An overview of multigigabit wireless through millimeter wave technology: potentials and technical challenges," EURASIP Journal on Wireless Communications and Networking, no. 1, pp. 1-10, vol. 2007.

[22] S. Geng, X. Zhao, J. Kivinen, and P. Vainikainen, "Millimeter-wave Propagation Channel Characterization for short-range wireless communications," IEEE Transactions on Vehicular Technology, pp. 3-13, vol. 58, January 2009.

[23] S. Geng, S. Ranvier, X. Zhao, J. Kivinen, and P. Vainikainen, "Multipath Propagation Characterization of Ultra-wide Band Indoor Radio Channels," 2005 IEEE International Conference on Ultra-Wideband (ICU05), Sep. 5-8, 2005, Zurich.

[24] T. Ihara, T. Manabe, M. Fujita, T. Matsui, and Y. Sugimoto, "Research activities on millimeter-wave indoor wireless communications systems at CRL," in Proc. ICUPC'95, Tokyo, Japan, pp. 197–200. , Nov. 1995.

[25] L. Correia and P. Frances, "A propagation model for the estimation of the average received power in an outdoor environment in the millimeter waveband," presented at the IEEE Vehicular Technology Conf. (VTC'94), Stockholm, Sweden, June 7–10,1994.

[26] S. Guerin, "Indoor wideband and narrowband propagation measurements around 60.5 GHz in an empty and furnished room," in Proc. VTC'96, pp. 160–164,Atlanta, GA, 1996.

[27] Suiyan Geng, Jarmo Kivinen, Xiongwen Zhao, and Pertti Vainikainen, "Millimeter-Wave Propagation Channel Characterization for Short-Range Wireless Communications", IEEE Transactions on Vehicular Technology, Vol. 58, No. 1, pp. 3-13, January 2009 .

[28] Savitha Manojna.D, Kirthiga.S. Jayakumar.M, "Study of 2x2 SpatialMultiplexed system for indoor environment".