MIMO CHANNEL OPTIMIZATION IN INDOOR LINE-OF-SIGHT (LOS) ENVIRONMENT

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Abstract- This paper optimizes the narrowband MIMO channel gain by considering the channel parameters of the Line-of-Sight (LOS) rays arriving at the receiving point. LOS MIMO is one possible technology for increasing the channel capacity of wireless communication. The performance of this channel gain is evaluated by calculating the channel capacity and compared with other channel capacity values. The theoretically achievable Shannon capacity is a function of the channel between transmitters and receivers. One of the mathematical methods from linear algebra, namely Singular Value Decomposition (SVD) is used for diagonalizing the channel matrix and finding the eigenvalues. All the experiments are conducted at the main building portico of Mandalay Technological University, the Republic of the Union of Myanmar in LOS environment at a carrier frequency of 2.4 GHz. The performance comparison of channel capacity with respect to the experimental data is implemented with the help of MATLAB programming language.

Index Terms- MIMO, channel capacity, indoor, channel gain, Line-of-Sight (LOS).

I. INTRODUCTION

It is well known that communication systems that make use of multi-element antenna arrays at both ends of the link can, in principle, offer an increase in spectral efficiency. This increase is proportional to the minimum number of transmit and receive elements for fixed power and bandwidth [1]. While it is possible for the channel to be so nonstationary that it cannot be estimated in any useful sense [2], in this paper a quasistationary channel assumption will be employed. MIMO systems provide a greater capacity in comparison with the systems based on Single-Input Single-Output (SISO) communications. MIMO system mitigates deep fades on any of the channel by the spatial diversity provided by multiple spatial paths. Each pair of transmit-receive antennas provides a signal path from transmitter to receiver. By sending the same information through different paths, multiple independently-faded replicas of the data symbol can be obtained at the receiver end and hence, more reliable reception is achieved. Capacity increases linearly with Signal-to-Noise Ratio (SNR) at low SNR, but increases logarithmically with SNR at high SNR. A given total transmitted power can be divided among multiple spatial paths (or modes), driving the capacity closer to the linear regime for each mode, thus increasing the aggregate spectral efficiency. Finally, because MIMO systems use antenna arrays, interference can be naturally mitigated [3]. In general, most of the propagation models assumed that the MIMO channel coefficients are Rayleigh distributed, which is reasonable in Non-LOS (NLOS) scenarios as long as there are no dominant paths. However, many scenarios can be described as LOS, when the direct path between the receiver and transmitter dominates the channel. In such cases, the channel is Ricean distributed rather than Rayleigh distributed [4]. The objective of this paper is to optimize the channel gain for a narrowband system at a frequency range of 2.4 GHz in indoor LOS environment.

II. WIRELESS COMMUNICATION SYSTEM

A. Narrowband MIMO

The narrowband MIMO transmission system with N antennas that transmits independent data streams which
are received byM antennas is represented as [5],

$$r = Hs + n \quad (1)$$

Where r is the M×1 received complex-valued signal vector, s is the N×1 transmitted complex-valued signal vector, H is the M×N complex-valued channel transfer matrix, and n is the M×1 complex-valued Additive White Gaussian Noise (AWGN) vector. The additive noise vector contains independent and identically distributed (i.i.d) circularly symmetric complex Gaussian elements with zero mean and variance σ2n, denoted by CN (0, σ2n). The block diagram of a MIMO system is shown in Fig. 1.

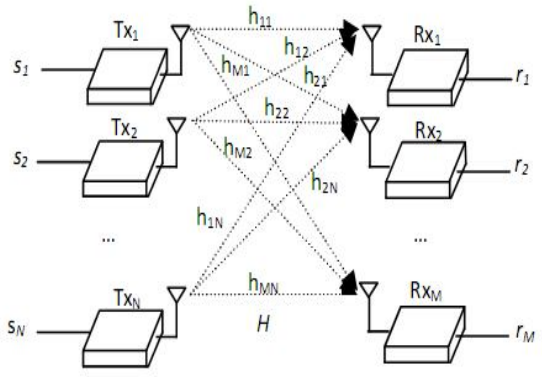


Fig. 1: The diagram of a MIMO system

B. Capacity of Additive White Gaussian Noise (AWGN) Channel with Fixed Channel Coefficients

The most general formula for calculating channel capacity in the case where channel coefficients are either known or unknown at the transmitter is the Shannon capacity formula [6]:

$$C = \sum_{i=1}^{m} \log_2[1 + \frac{P_{ri}}{\sigma_n^2}] bps / Hz \quad (2)$$

Where m = min (N, M), Pri is the received power at each Rx antenna from the ith sub-channel, for i = 1,…,m during the considered symbol time slot and σ2n is the noise variance (power) of the receiving system. Assuming that there is no channel state information at the transmitter and the total transmitted power is equally allocated to all N antennas, the channel capacity for such a scenario is

$$C = \log_2 \det[I_M + \frac{P_t}{N\sigma_n^2} HH^H] bps / Hz \quad (3)$$

Where IM is the M×M identity matrix, det denotes the determinant, Pt is the total average transmitted power from all Tx antennas and HH is the Hermitian transpose operation of H, i.e. the conjugate transpose of complex matrix H. In the following, it is also assumed that the average total power Pr received by each Rx antenna (regardless of noises) is equal to the average total transmitted power Pt from all Tx antennas, the SNR at each Rx antenna is then

$$\rho = \frac{P_r}{\sigma_n^2} \quad (4)$$

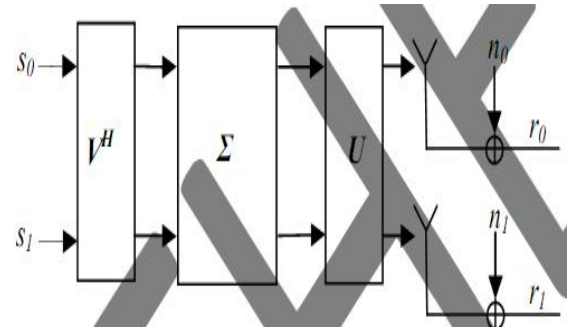


Fig. 2: Singular Value Decomposition (SVD) of a 2×2 MIMO transmission channel

As shown in Fig. 2, by applying a singular value decomposition to H [7],

$$H = U \Sigma V^H \quad (5)$$

Where, the columns in matrix U and V are defined by the eigenvectors of H·HH and HH·H, respectively, i.e. they can be calculated purely from the channel matrix. Matrix Σ contains only the singular values from channel matrix H on the principle diagonal and is otherwise 0. After that,equation (3) can be written as

$$C = \sum_{i=1}^{m} \log_2(1 + \frac{\rho}{N}\lambda_i) bps / Hz \quad (6)$$

Where, λi is the ith eigenvalue of HHH and this equation shows that a MIMO system can be viewed as consisting of m parallel Single-Input Single-Output (SISO) channels, where each channel has gain λi, and an average SNR downscaled with the number of transmitters compared to a SISO system with the same total transmitted power.

III. CHANNEL GAINOPTIMIZATION

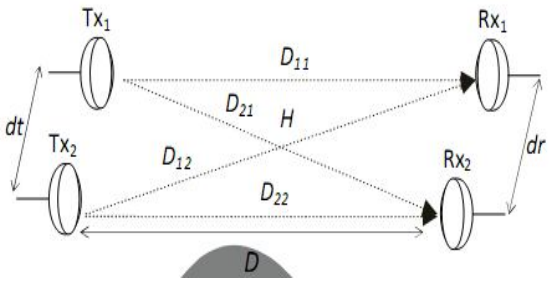


Fig. 3: Line-of-Sight (LOS) channel between Tx and Rx antenna arrays

A MIMO channel with direct line-of-sight paths between the antennas is assumed and both transmitted, Tx and received, Rx antennas are in linear arrays as shown in Fig. 3. The antenna separation is denoted by dt and dr for both Tx and Rx antennas respectively and the distance between Tx and Rx by Dji (j=1,…,M, i=1,…,N). H is the channel transfer function between each Tx and Rx antenna and each of its entries (hji) is a distortion coefficient acting on the transmitted signal amplitude and phase in frequency domain. The term hji, the channel gain, can be a gain or a loss, it can be phase shift or it can be time delay, or can be all of these together. The quantity hji can be considered an enhancing or distorting agent for the signal SNR [8]. In free space, the channel gain, hji (channel impulse response) for a narrowband system between jth received antenna and ith transmitted antenna is given only by phase shift of carrier frequency [9] as:

$$h_{ji(Ps)} = \exp(\frac{-j2\pi D_{ji}}{\lambda}) \quad (7)$$

and the channel matrix can be expressed as:

$$H_{Ps} = \begin{bmatrix} h_{11(Ps)} & h_{12(Ps)} \\ h_{21(Ps)} & h_{22(Ps)} \end{bmatrix} \quad (8)$$

However, the channel gain is extended in [10] by considering phase shift, path delay, τji (τji= Dji /c, c is the speed of light) with carrier frequency, f0 and the received signal strength, Prji together as

$$h_{ji(PsPd)} = \sqrt{P_{rji}} \exp(\frac{-j2\pi D_{ji}}{\lambda}) \exp(-j2\pi f_o \tau_{ji}) \quad (9)$$

The channel matrix with this channel gain can be described as follows:

$$H_{PsPd} = \begin{bmatrix} h_{11(PsPd)} & h_{12(PsPd)} \\ h_{21(PsPd)} & h_{22(PsPd)} \end{bmatrix} \quad (10)$$

The distance of D12 and D21 are evaluated by using Pythgoras' Theorem. In a purely LOS channel, each Rx antenna will receive all direct LOS rays from each Tx antenna and the complex channel gain should also consider

phase shift of path differences together and the channel gain with this phase shift is:

$$h_{ji(Pdiff)} = \exp(\frac{-j2\pi\Delta D_{ji}}{\lambda}) \quad (11)$$

and the channel matrix with this channel gain is

$$H_{Pdiff} = \begin{bmatrix} h_{11(Pdiff)} & h_{12(Pdiff)} \\ h_{21(Pdiff)} & h_{22(Pdiff)} \end{bmatrix} \quad (12)$$

Where, ΔDji is the difference between longer distance and shorter distance from each transmitter to receiver. In a 2×2 LOS MIMO, the phase shift of distances D11 and D12 arriving at the received antenna 1, Rx1 is the same phase shift of path differences D12−D11. Also, the phase shift of distances D22 and D21 arriving at the received antenna 2, Rx2 is the same phase shift of path differences D21−D22. The channel gain and channel matrix with this phase shift
of path differences are as follows:

$$h_{ji(PsPd+Pdiff)} = h_{ji(PsPd)} + h_{ji(Pdiff)} \quad (13)$$

$$H_{PsPd+Pdiff} = H_{PsPd} + H_{Pdiff} \quad (14)$$

IV. EXPERIMENTAL PARAMETERS AND RESEARCH PROCEDURES

The system parameters used in the experiments are described in Table I and the research procedures for this proposed system are shown with system block diagram in Fig. 4.

TABLE I: Experimental Parameters

Parameter Name	Parameter Value
Transmitter	TL-WR1043N
Receiver	TL-WN722N 150 Mbps wireless adapter
Tx Power	20 dBm
Carrier Frequency	2.4 GHz
Bandwidth	0.0835 GHz
Distance	1 – 24 *m*
Antenna Spacing Distance	0.1524 *m*, 0.5 *m*
Antenna	8dBi Omnidirectional Antenna
Number of Antenna (Tx × Rx)	2×2
Analyzer Software	InSSIDer in Window 7 OS

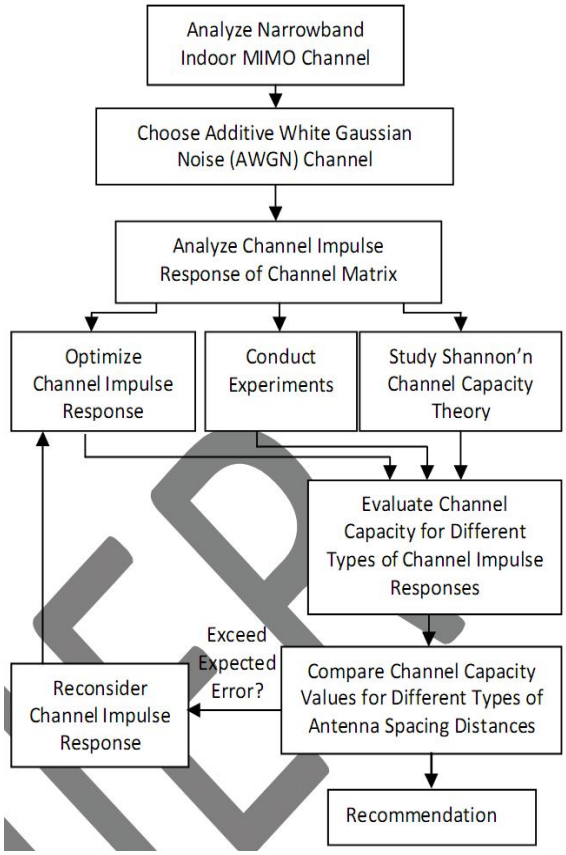


Fig. 4: Block diagram of proposed System

All the experiments were conducted at the portico (Fig.5) of the three floors of Mandalay Technological University (MTU), the Republic of the Union of Myanmar. There is no movement of Tx and Rx antennas during measurements
and all experimental points were marked at the center of the portico as one meter from one end of the portico to the other end before measuring the experiments. To estimate the channel attenuation and variations, the experiments were made by moving the receiver at every one meter while the placement of transmitter was stable. The heights of transmitter and receiver were constant at the centre of this portico as shown in experimental record photos of Fig.6.

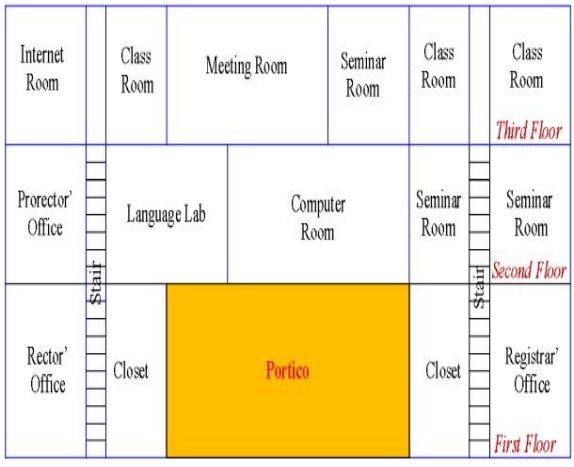


Fig. 5: Front view of the portico



Fig. 6: Placement of transmitter and receiver in the portico

V. SIMULATION RESULTS

The simulation results for channel capacity using different types of channel gains with phase shift, hji(Ps) only, phase shift and path delay, hji(PsPd) and phase shift caused by path difference with all of these together, hji(PsPd+Pdiff) are described. The antenna spacing distances for both Tx and Rx antennas (dt, dr) are equally allocated. Fig. 7 shows the channel capacity versus SNR for dt = dr = 0.1524 m and Fig. 8 shows these comparison results for dt = dr = 0.5 m. In this simulation, the value of SNR (dB) is assumed to be 1 dB at D = 1 m and so on.

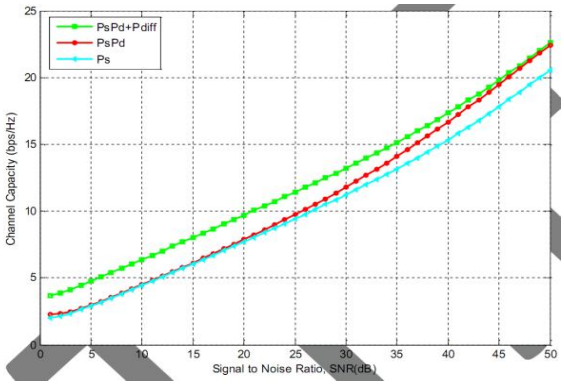


Fig. 7: Comparison of channel capacity versus SNR for dt = dr = 0.1524 m using simulated results

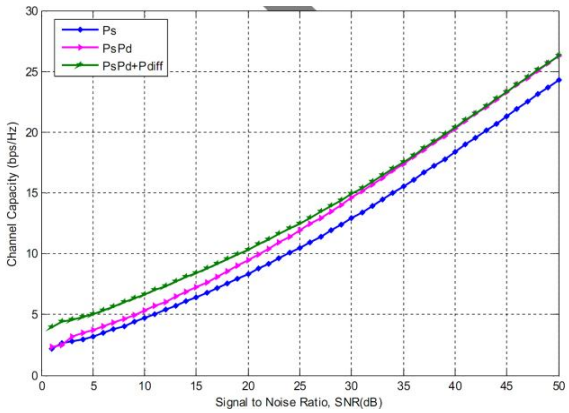


Fig. 8: Comparison of channel capacity versus SNR for dt = dr = 0.5 m using simulated results

It can be seen that the channel capacity for channel gain, hji(PsPd+Pdiff) increases as SNR values becomes higher than any other channel capacity values in both antenna spacing distances. However, channel capacity improvements at higher SNR values are almost identical for both antennas spacing distances. The comparison of channel capacity using optimized channel gain, hji(PsPd+Pdiff) with SNR for different types of mobile phone carrier frequencies are also described in Fig. 9. By optimizing the channel gain to the channel capacity, it is clear that the more carrier frequency increases the more channel capacity develops.

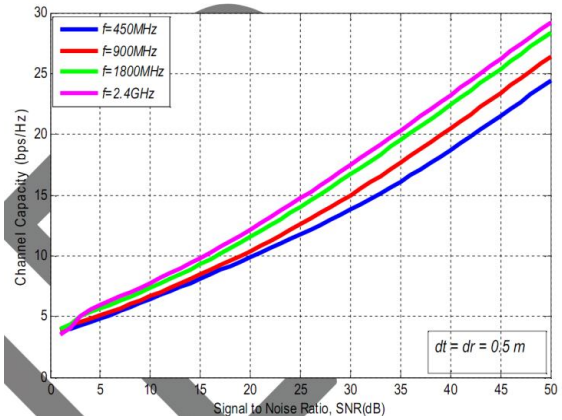


Fig. 9: Channel capacity versus SNR for different types of carrier frequencies

VI. EXPERIMENTAL ANALYSIS

The channel gain with the phase shift caused by path differences is considered to optimize the channel gain for 2 × 2 LOS MIMO in the portico of Mandalay Technological University, the Republic of the Union of Myanmar. The distance between Tx and Rx antennas, (D) ranges from 1 m to 24 m in the portico and SNR (dB) values are from 34 to 46 which are calculated using the experimental received signal strength (Prji). The comparison of channel capacity values using different types of channel gains for antenna spacing distances of dt = dr = 0.1524 m and dt = dr = 0.5 m are shown in Fig. 10 and Fig. 11 respectively.

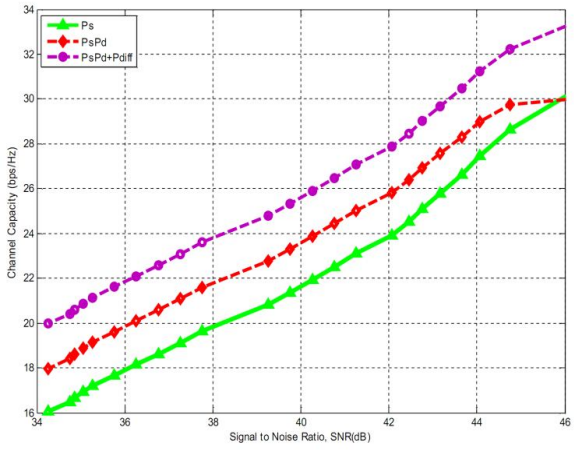


Fig. 10: Comparison of channel capacity versus SNR for dt =dr = 0.5 m using experimental results

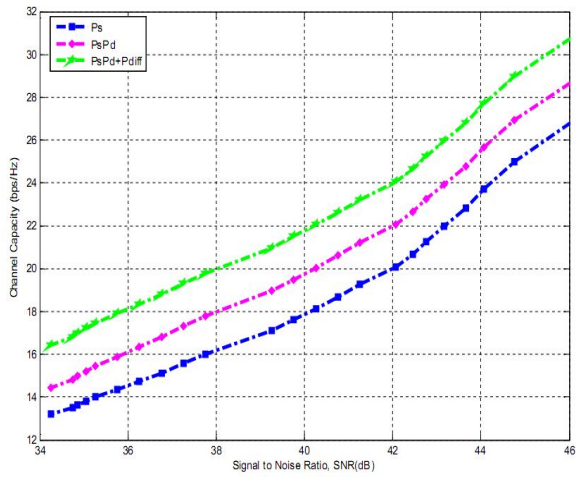


Fig. 11: Comparison of channel capacity versus SNR for dt =dr = 0.1524 m using experimental results

In the experimental point of view, it is also clear that the capacity grows when the value of SNR becomes higher with different types of channel gains. The channel capacity for dt = dr = 0.5 m is 3 bps/Hz higher for every channel gain than the channel capacity for dt = dr = 0.1524 m. This increase is because of the more antenna spacing distance and therefore, when evaluating the MIMO channel capacity, not only the distance between Tx and Rx (D) but also antenna spacing distances (dt, dr) should be taken into consideration in conducting experiments. In addition, the channel capacity value with hji(PsPd) is likely stable after the SNR value of 44.4 dB due to the affect of antenna spacing distance (dt, dr) and the ratio of distance between Tx and Rx antennas to the speed of light (Dji /c) fluctuation. That is why this paper takes into consideration of the proposed optimization technique in evaluating channel capacity.

CONCLUSION

In this paper, the channel gain is optimized by considering different channel parameters, including phase shift caused by path differences, ΔDji in indoor LOS narrowband communication system. The channel capacity values for three types of channel gains are evaluated and compared in both simulation and experimental point of views. In both studies, the proposed optimization on channel gain can get higher channel capacity value for both antenna spacing distances. However, the channel capacity value will fluctuate at higher SNR value when antenna spacing distance is more than 0.5 m. In addition, only 2 x 2 matrix antennas radiation type can be used in all experiments because of the lack of experimental facilities and antenna configurations. This comparison will be useful in estimating the channel capacity anywhere in the building and in estimating the indoor wireless communication coverage.

FURTHER EXTENSION

As the further extension, the experiments in different indoor environments with different frequency ranges at Mandalay Technological University will be conducted.

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