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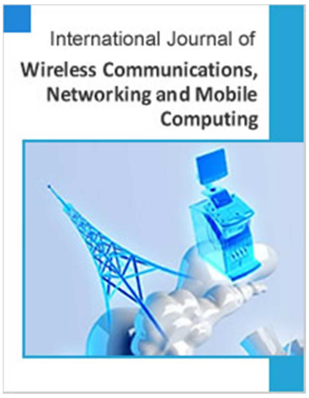

MIMO Cognitive Radio Capacity in Flat Fading Channel

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Abstract

In this paper capacity of a cognitive radio (CR) system enabled with multiple input multiple output (MIMO) technology is derived and simulated under flat fading channel situation. Multiple input multiple output cognitive radio system provides effective spectrum utilization along with increased diversity gain as more number of antennas are used in the transmitting and receiving terminals. Derivation of capacity is done in flat fading channel situation following Rayleigh distribution. From the derived capacity formula, simulation is performed for different transmitting and receiving antennas and it is analyzed for the amount of information bits which a flat fading channel can process. This analysis will contribute for designing and developing MIMO CR systems which can be employed for wireless applications in smart cities.

1. Introduction

As digitization of wireless communication systems is increasing at a faster rate for catering day to day wireless applications, spectrum allocation gains importance. Spectrum allocation is done effectively by cognitive radio (CR) system [1] and [2] which senses the availability of white space or free spectrum holes and transfers digitized information between a transmitter and a receiver [3]. However, to provide further enhancement of CR systems, multiple input multiple output (MIMO) technology can be an optimal solution. MIMO technology provides increased diversity gain, spectral efficiency due to usage of more number of antennas in transmission and reception [4]. Diversity gain provided by MIMO technology is the product of the number of transmit and receive antennas employed in the MIMO system which refers to usage of transmit diversity and receive diversity concepts. Spectral efficiency refers to capacity considered along with frequency in Hertz represented as bits/sec/Hz. Combining MIMO technology for CR systems can result in MIMO CR systems which attain more significance for evolving wireless applications which are digitized and hence, analysis of such systems needs to be done. Analyzing capacity [5] for MIMO CR systems can provide valuable insights for wireless applications development for 4G and 5G systems.

Capacity analysis of MIMO CR systems [6]-[8] gives the possible amount of information bits which can be handled depending on the wireless channels. Basically, capacity of a CR system incorporated with single input single output (SISO) technology refers to instantaneous capacity represented in bits/sec which also represents the maximum data rate. Determination of capacity can be calculated for an Additive White Gaussian Noise (AWGN) channel and fading channels. For AWGN channel the channel capacity is calculated as the logarithm of base 2 for a given bandwidth and signal to noise ratio (SNR). The capacity of an AWGN channel does not involve the fading channel coefficient and it is non fading channel where the best example can be noise due to movement of electrons in the printed circuit board (PCB) of a personal digital assistant (PDA). On the other hand, capacity of a fading channel for a CR system involves incorporation of a fading channel coefficient to give a real impact of the fading channel in line of sight (LOS) or non line of sight (NLOS) scenario. The mathematical representation of capacity of a fading channel for a CR system needs to be obtained either for a flat fading channel or a frequency selective fading channel during data transmission.

Similar to SISO systems, MIMO CR systems [9] are probably subjected to operate in frequency flat fading channels and frequency selective fading channels. Moreover, MIMO CR capacity [10] and [11] analysis can contribute to digital data detection in digital wireless systems and a number of research works have been dealt as given from [6]-[12]. Research papers from [6]-[12] give the research works relating to capacity analysis of MIMO CR and their graphical results. In the work of [6] ergodic capacity and outage capacity of MIMO cognitive radio channel is discussed by considering the interference temperature. Contribution [7] gives MIMO cognitive radio networks capacity balancing in wireless channels. [8] addresses throughput for MIMO systems with maximum and minimum constraints. Maximization of channel capacity for space division access multiple access MIMO cognitive networks is dealt in [9]. In research paper [10] it discusses MIMO along with CR spectrum sharing for the performance enhancement of CR. [11] provides information about cognitive radio sensor networks in large scale multi-cluster MIMO. In [12] multi-user MIMO cognitive radio systems for simultaneous spectrum sensing and data transmission is proposed. Though excellent research works from [6]-[12] are available, this work presents capacity analysis of MIMO CR systems in wireless flat fading channels as an addition to existing research works.

The considered MIMO wireless flat fading channel coefficients in this research paper follow Rayleigh distribution representing a non line of sight (NLOS) scenario. The capacity of wireless channel [15] is derived in perfect channel scenario and imperfect channel scenario where the imperfect channel estimates can be found out using estimation algorithms [16]. The commonly available estimation algorithms are least squares (LS), minimum mean square error (MMSE), maximum likelihood (ML) algorithms [16]. Least squares estimation algorithm produces a least value of the parameter which needs to be estimated which are the MIMO wireless channel coefficients. Least squares algorithm is a simple computational algorithm. Minimum mean square error (MMSE) estimation algorithm produces an estimate of the parameter using probability density function (PDF) for a given condition, probability of the input and output parameters. MMSE algorithm is complex but at the same time produces better performance in terms of mean square error (MSE) for a parameter which needs to be estimated from the actual value of the parameter. Maximum likelihood is also another estimation algorithm which produces an estimation parameter using PDF by maximizing the value. Among LS, MMSE and ML estimation algorithms, ML produces a superlative approach in comparison to MMSE and LS approach in terms of mean square error (MSE). MMSE estimation algorithm too performs well under conditions given the PDF. The task of this paper is to use a simple algorithm such as LS and obtain capacity of MIMO CR wireless channel. Also, simulations results are done to support the derivations of capacity of MIMO CR system.

Outline of this paper is that section 1 gives the introduction about MIMO cognitive radio and capacity. Section 2 presents system model for MIMO cognitive radio system in flat fading and frequency selective fading channels. Section 3 derives capacity of a MIMO cognitive radio in a wireless flat fading channel. Section 4 presents MIMO capacity of CR system with imperfect channel estimates. Section 5 presents simulation results for capacity analysis of MIMO cognitive radio. Conclusion of the paper is given in section 6. Representation $\mathbf{I}$ refers to an identity matrix used in the context of this paper.

2. Mimo Cognitive Radio System Model

MIMO cognitive radio system model considered in this paper has a primary transmitter with $\mathbf{P}_t$ transmitting antennas and a primary receiver with $\mathbf{P}_r$ receiving antennas which is licensed spectrum. Also, a cognitive transmitter (secondary transmitter) has $\mathbf{S}_t$ transmitting antennas and a cognitive receiver (secondary receiver) has $\mathbf{S}_r$ receiving antennas. In a situation, where a cognitive transmitter having $\mathbf{S}_t$ antennas intends to access a receiver with $\mathbf{P}_r$ receiver antennas through $\mathbf{P}_r \times \mathbf{S}_t$ MIMO channel matrix $\mathbf{H}_{cog}$ it represents a cognitive radio communication scenario.

A cognitive transmitter after acquiring the frequency spectrum of primary users through sensing [13], if it intends to transmit a $\mathbf{S}_t \times \mathbf{S}_t$ data matrix $\mathbf{D}$ undergoing binary phase shift keying (BPSK) [14] modulation scheme, the $\mathbf{P}_r \times \mathbf{S}_t$ received signal matrix $\mathbf{R}_{cog}$ at the primary receiver takes the representation

$$\mathbf{R}_{cog} = \mathbf{H}_{cog}\mathbf{D} + \mathbf{N}_{cog} \tag{1}$$

where $\mathbf{H}_{cog}$ is the $\mathbf{P}_r \times \mathbf{S}_t$ MIMO wireless channel matrix with flat fading having Rayleigh distribution. $\mathbf{N}_{cog}$ is the $\mathbf{P}_r \times \mathbf{S}_t$ noise matrix at the primary receiver and it is a complex Gaussian noise matrix. Similarly a CR system in MIMO frequency selective fading channel is represented as

$$\mathbf{R}_{cog}[N] = \mathbf{H}_{cog}(t;\tau)\mathbf{D}[N] + \mathbf{N}_{cog}[N] \tag{2}$$

where $\mathbf{H}_{cog}(t;\tau)$ represents the MIMO channel with time delay represented by using a multipath power delay profile. A multipath power delay profile (PDP) is a plot of time delay in μs and corresponding power value in decibel.

3. Derivation of Mimo Cognitive Radio Capacity

To derive the capacity of MIMO cognitive radio system, capacity is considered as maximization of mutual information [14] and [15]. It is represented as

$$C = \max_{f_{\mathbf{D}}(\mathbf{D})} \left| I(\mathbf{D};\mathbf{R}_{cog}) \right| \tag{3}$$

where $I(\mathbf{D};\mathbf{R}_{cog})$ is mutual information and it is given as

$$I(\mathbf{D};\mathbf{R}_{cog}) = \mathbf{H}(\mathbf{R}_{cog}) - \mathbf{H}(\mathbf{R}_{cog} / \mathbf{D}) \tag{4}$$

where $\mathbf{H}(\mathbf{R}_{cog})$ is differential entropy of the received signal matrix, $\mathbf{H}(\mathbf{R}_{cog} / \mathbf{D})$ is conditional entropy. The differential entropy is given as

$$\mathbf{H}(\mathbf{R}_{cog}) = \frac{1}{2}\log_2 2\Pi e\sigma^2_{\mathbf{R}_{cog}} \tag{5}$$

$\sigma_{\mathbf{R}_{cog}}{}^2$ is variance of received signal matrix given by; $\sigma^2_{\mathbf{R}_{cog}} = E[\mathbf{R}_{cog}\mathbf{R}^H_{cog}]$; where H is Hermitian and also known as complex conjugate and it is $\sigma^2_{\mathbf{R}_{cog}} = E[(\mathbf{H}_{cog}\mathbf{D}+\mathbf{N}_{cog})(\mathbf{H}_{cog}\mathbf{D}+\mathbf{N}_{cog})^H]$. Further it is rewritten as

$$\sigma^2_{\mathbf{R}_{cog}} = E[(\mathbf{H}_{cog}\mathbf{D}+\mathbf{N}_{cog})(\mathbf{D}^H\mathbf{H}_{cog}+\mathbf{N}^H_{cog})] \tag{6}$$

$$\sigma^2_{\mathbf{R}cog} = E[\mathbf{H}_{cog}\mathbf{D}\mathbf{D}^H\mathbf{H}^H_{cog} + \mathbf{H}_{cog}\mathbf{D}\mathbf{N}^H_{cog} + \mathbf{N}_{cog}\mathbf{D}^H\mathbf{N}^H_{cog} + \mathbf{N}_{cog}\mathbf{N}^H_{cog}] \tag{7}$$

$$\sigma^2_{\mathbf{R}cog} = E[\mathbf{H}_{cog}\mathbf{D}\mathbf{D}^H\mathbf{H}^H_{cog}] + E[\mathbf{H}_{cog}\mathbf{D}\mathbf{N}^H_{cog}] + E[\mathbf{N}_{cog}\mathbf{D}^H\mathbf{N}^H_{cog}] + E[\mathbf{N}_{cog}\mathbf{N}^H_{cog}] \tag{8}$$

Second and third terms in (8) are independent of each other and it is zero. Considering first and fourth terms it is

$$\sigma^2_{\mathbf{R}_{cog}} = \mathbf{D}E[\mathbf{H}_{cog}\mathbf{H}^H_{cog}]\mathbf{D}^H + E[\mathbf{N}_{cog}\mathbf{N}^H_{cog}] \tag{9}$$

where D is data matrix, $\mathbf{H}_{cog}$ is MIMO channel matrix which is flat fading channel, $\mathbf{R}_{\mathbf{H}_{cog}} = E[\mathbf{H}_{cog}\mathbf{H}^H_{cog}]$ is the $\mathbf{P}_r \times \mathbf{P}_r$ channel correlation matrix and $\mathbf{R}_{\mathbf{N}_{cog}}$ is $\mathbf{P}_r \times \mathbf{P}_r$ noise correlation matrix, which is random and follows Gaussian distribution

$$\mathbf{H}(\mathbf{R}_{cog}) = \frac{1}{2}\log_2 2\Pi e[\mathbf{D}\mathbf{R}_{\mathbf{H}_{cog}}\mathbf{D}^H + \mathbf{R}_{\mathbf{N}_{cog}}] \tag{10}$$

Further, conditional entropy is

$$H(\mathbf{R}_{cog} / \mathbf{D}) = \mathbf{H}(\mathbf{N}_{cog}) = \frac{1}{2}\log_2 2\Pi e[\mathbf{R}_{\mathbf{N}_{cog}}] \tag{11}$$

Also, mutual information is written by substituting (10) and (11) in (4)

$$I(\mathbf{D}:\mathbf{R}_{cog}) = \frac{1}{2}\log_2 2\Pi e\left[\mathbf{D}\mathbf{R}_{\mathbf{H}_{cog}}\mathbf{D}^H + \mathbf{R}_{\mathbf{N}_{cog}}\right] - \frac{1}{2}\log_2 2\Pi e\left[\mathbf{R}_{\mathbf{N}_{cog}}\right] \tag{12}$$

On further simplification it is

$$I(\mathbf{D};\mathbf{R}_{cog}) = \frac{1}{2}\log_2 \frac{2\pi e}{2\pi e}\left(\frac{\mathbf{D}\mathbf{R}_{\mathbf{H}_{cog}}\mathbf{D}^H + \mathbf{R}_{\mathbf{N}_{cog}}}{\mathbf{R}_{\mathbf{N}_{cog}}}\right) \tag{13}$$

$$I(\mathbf{D};\mathbf{R}_{cog}) = \frac{1}{2}\log_2 \frac{2\pi e}{2\pi e}\left(\frac{\mathbf{D}\mathbf{R}_{\mathbf{H}_{cog}}\mathbf{D}^H}{\mathbf{R}_{\mathbf{N}_{cog}}} + \frac{\mathbf{R}_{\mathbf{N}_{cog}}}{\mathbf{R}_{\mathbf{N}_{cog}}}\right) \tag{14}$$

Mutual information on simplification of (14) is

$$I(\mathbf{D};\mathbf{R}_{cog}) = \frac{1}{2}\log_2(\mathbf{D}\mathbf{R}_{\mathbf{H}_{cog}}\mathbf{D}^H\mathbf{R}_{\mathbf{N}_{cog}}{}^{-1} + 1) \tag{15}$$

Capacity of MIMO cognitive radio system in flat fading channel is obtained by substitution of (15) in (3) and it is given as

$$C = \max_{f_{\mathbf{D}}(\mathbf{D})} \left| \frac{1}{2}\log_2(\mathbf{I} + \mathbf{D}\mathbf{R}_{\mathbf{H}_{cog}}\mathbf{D}^H\mathbf{R}_{\mathbf{N}_{cog}}{}^{-1}) \right| \tag{16}$$

4. Mimo Cognitive Radio Capacity with Imperfect Channel Estimates

The $\mathbf{P}_r \times \mathbf{S}_t$ received signal matrix $\mathbf{R}_{impcog}$ at the primary receiver with least squares (LS) [16] imperfect channel estimates is formulated as

$$\mathbf{R}_{impcog} = \mathbf{D}\,(\hat{\mathbf{H}}_{cogLS} + \mathbf{E}_{\mathbf{R}cog}) + \mathbf{N}_{cog} \tag{17}$$

where $\hat{\mathbf{H}}_{cogLS}$ represents $\mathbf{P}_r \times \mathbf{S}_t$ MIMO wireless channel matrix obtained by LS channel estimation algorithm [16], $\mathbf{E}_{\mathbf{R}cog}$ is the $\mathbf{P}_r \times \mathbf{S}_t$ error vector matrix which is

$$\mathbf{E}_{\mathbf{R}cog} = \mathbf{H}_{cog} - \hat{\mathbf{H}}_{cogLS} \tag{18}$$

where values of error matrix are complex Gaussian having zero mean and variance $\sigma^2_{\mathbf{E}_{\mathbf{R}cog}}$. The capacity of MIMO CR system with imperfect channel estimates using LS is

$$C_{impcog} = \max_{f_{\mathbf{D}}(\mathbf{D})}[I(\mathbf{D};\mathbf{R}_{impcog})] \tag{19}$$

where $I(\mathbf{D};\mathbf{R}_{impcog})$ is the average mutual information between D and $\mathbf{R}_{impcog}$. The mutual information of MIMO CR system with imperfect channel estimates using LS is defined as

$$I(\mathbf{D};\mathbf{R}_{impcog}) = \mathbf{H}(\mathbf{R}_{impcog}) - \mathbf{H}\left(\mathbf{R}_{impcog}/\mathbf{D}\right) \tag{20}$$

where $\mathbf{H}(\mathbf{R}_{impcog})$ is differential entropy of the $\mathbf{P}_r \times \mathbf{S}_t$ MIMO received signal matrix with imperfect channel estimates and $\mathbf{H}\left(\mathbf{R}_{impcog}/\mathbf{D}\right)$ is conditional differential entropy with imperfect channel estimates. Differential entropy $\mathbf{H}(\mathbf{R}_{impcog})$ is

$$\mathbf{H}(\mathbf{R}_{impcog}) = \frac{1}{2}\log_2 2\pi e\left|\sigma^2_{\mathbf{R}_{impcog}}\right| \tag{21}$$

where $\sigma^2_{\mathbf{R}_{impcog}}$ is the variance of $\mathbf{P}_r \times \mathbf{S}_t$ MIMO correlation matrix of the received signal matrix with LS channel estimates at the primary receiver with representation

$$\sigma^2_{\mathbf{R}_{impcog}} = E[\mathbf{R}_{impcog}\mathbf{R}^H_{impcog}] \tag{22}$$

Substituting (17), (22) takes the form

$$E[\mathbf{R}_{impcog}\mathbf{R}_{impcog}{}^H] = E[(\mathbf{D}(\hat{\mathbf{H}}_{cogLS} + \mathbf{E}_{\mathbf{R}cog}) + \mathbf{N}_{cog})\,(\mathbf{D}(\hat{\mathbf{H}}_{cogLS} + \mathbf{E}_{\mathbf{R}cog}) + \mathbf{N}_{cog})^H] \tag{23}$$

As signal and noise are independent, considering mathematical constraints (23) is simplified as

$$E[\mathbf{R}_{impcog}\mathbf{R}_{impcog}{}^H] = \mathbf{D}\mathbf{R}_{\hat{\mathbf{H}}_{cogLS}}\mathbf{D}^H + \mathbf{D}\mathbf{R}_{\mathbf{E}_{\mathbf{R}cog}}\mathbf{D}^H + \mathbf{R}_{\mathbf{N}cog} \tag{24}$$

where $\mathbf{R}_{\hat{\mathbf{H}}_{cogLS}} = E[\hat{\mathbf{H}}_{\mathbf{cog}LS}\hat{\mathbf{H}}^H_{\mathbf{cog}LS}]$ is the $\mathbf{P}_r \times \mathbf{P}_r$ channel correlation matrix with imperfect channel estimates, $\mathbf{R}_{\mathbf{E}_{RcogLS}}$ is the $\mathbf{P}_r \times \mathbf{P}_r$ error correlation matrix and $\sigma^2_{\mathbf{R}_{impcog}} = \mathbf{R}_{\mathbf{N}_{cog}} = E[\mathbf{N}_{cog}\mathbf{N}^H_{cog}]$ is $\mathbf{P}_r \times \mathbf{P}_r$ correlation matrix of the noise. Further, substituting (24) in (21) the differential entropy of the $\mathbf{P}_r \times \mathbf{S}_t$ MIMO received signal matrix is

$$\mathbf{H}\left(\mathbf{R}_{impcog}\right) = \frac{1}{2}\log_2 2\pi e\left|\mathbf{D}\mathbf{R}_{\hat{H}cogLS}\mathbf{D}^H + \mathbf{D}\mathbf{R}_{\mathbf{E}cogLS}\mathbf{D}^H + \mathbf{R}_{\mathbf{N}cog}\right| \tag{25}$$

Conditional differential entropy $\mathbf{H}\left(\mathbf{R}_{impcog}/\mathbf{D}\right)$ is $\mathbf{H}(\mathbf{N}_{cog})$. Due to $\mathbf{N}_{cog}$ following Gaussian distribution, noise entropy $\mathbf{H}\left(\mathbf{R}_{impcog}/\mathbf{D}\right)$ is

$$\mathbf{H}\left(\mathbf{R}_{impcog}/\mathbf{D}\right) = \mathbf{H}(\mathbf{N}_{cog}) = \frac{1}{2}\log_2 2\pi e\left|\mathbf{D}\mathbf{R}_{\mathbf{E}cogLS}\mathbf{D}^H + \mathbf{R}_{\mathbf{N}_{cog}}\right| \tag{26}$$

Also, mutual information is

$$I(\mathbf{D}:\mathbf{R}_{impcog}) = \frac{1}{2}\log_2 2\Pi e\left[\mathbf{D}\mathbf{R}_{\hat{\mathbf{H}}cogLS}\mathbf{D}^H + \mathbf{D}\mathbf{R}_{\mathbf{E}cogLS}\mathbf{D}^H + \mathbf{R}_{\mathbf{N}cog}\right] - \frac{1}{2}\log_2 2\Pi e\left[\mathbf{D}\mathbf{R}_{\mathbf{E}cogLS}\mathbf{D}^H + \mathbf{R}_{\mathbf{N}_{cog}}\right] \tag{27}$$

Further, on solving (27)

$$I(\mathbf{D};\mathbf{R}_{cog})=\frac{1}{2}\log_2\frac{2\pi e}{2\pi e}\left(\frac{\mathbf{DR}_{\hat{\mathbf{H}}cogLS}\mathbf{D}^H+\mathbf{DR}_{\mathbf{E}cogLS}\mathbf{D}^H+\mathbf{R}_{\mathbf{N}cog}}{\mathbf{DR}_{\mathbf{E}cogLS}\mathbf{D}^H+\mathbf{R}_{\mathbf{N}_{cog}}}+\frac{\mathbf{DR}_{\mathbf{E}cogLS}\mathbf{D}^H+\mathbf{R}_{\mathbf{N}_{cog}}}{\mathbf{DR}_{\mathbf{E}cogLS}\mathbf{D}^H+\mathbf{R}_{\mathbf{N}_{cog}}}\right) \tag{28}$$

The mutual information on simplification of (28) is

$$I(\mathbf{D}:\mathbf{R}_{impcog})=\frac{1}{2}\log_2((\mathbf{DR}_{\hat{\mathbf{H}}cogLS}\mathbf{D}^H+\mathbf{DR}_{\mathbf{E}cogLS}\mathbf{D}^H+\mathbf{R}_{\mathbf{N}cog})\ (\mathbf{DR}_{\mathbf{E}cogLS}\mathbf{D}^H+\mathbf{R}_{\mathbf{N}_{cog}})^{-1}+1) \tag{29}$$

Capacity of MIMO cognitive radio system with least squares imperfect channel estimates is obtained by substituting (29) in (19) and it is

$$C=\max_{f_{\mathbf{D}}(\mathbf{D})}\left|\frac{1}{2}\log_2(\mathbf{I}+(\mathbf{DR}_{\hat{\mathbf{H}}cogLS}\mathbf{D}^H+\mathbf{DR}_{\mathbf{E}cogLS}\mathbf{D}^H+\mathbf{R}_{\mathbf{N}cog})\ (\mathbf{DR}_{\mathbf{E}cogLS}\mathbf{D}^H+\mathbf{R}_{\mathbf{N}_{cog}})^{-1})\right| \tag{30}$$

5. Simulation Results

Simulation results are given for MIMO CR system for Flat fading channel. Capacity in bits/second is observed between secondary transmitter, the cognitive user and primary receiver. The cognitive user is also the secondary transmitter where it represents the unlicensed band of communication and the primary transmitter and primary receiver form the licensed band of communication. Simulation is done by varying the signal power and keeping the noise power as constant and various values of capacity of MIMO CR systems are obtained for different transmitting and receiving antennas.

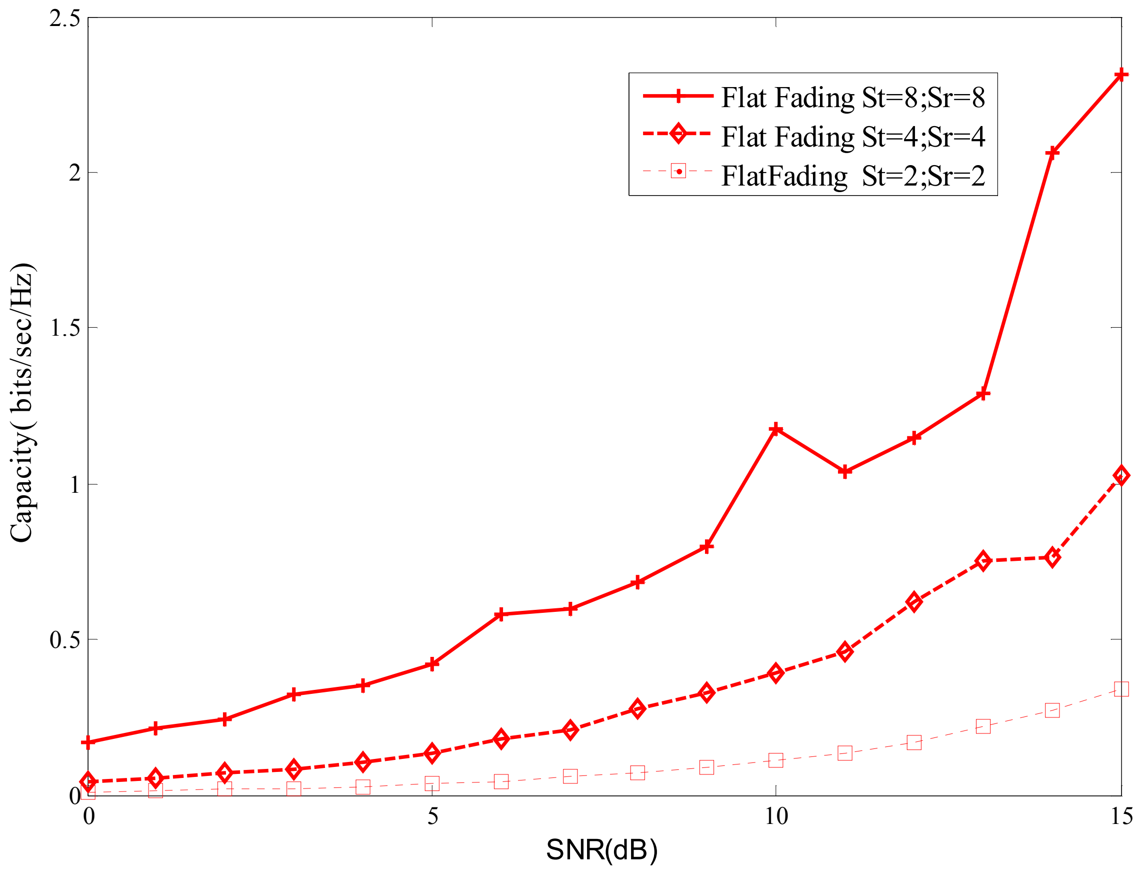

Figure 1. *Capacity vs SNR (dB) in MIMO CR flat fading wireless channel.*

In Figure 1, capacity analysis is done for MIMO CR flat fading wireless channels. A capacity value of 0.05 bits/sec/Hz for signal to noise ratio (SNR) value of 5 dB, a value of 0.15 bits/sec/Hz for SNR value of 10 dB, and a capacity value of 0.37 bits/sec/Hz for SNR value of 15 dB for 2 transmitting and receiving antennas. For 4 transmitting and receiving antennas it has 0.14 bits/sec/Hz as capacity for 5dB, 0.39bits/sec/Hz for 10dB and 1.02bits/sec/Hz capacity for 15dB. Also, for 8 transmitter and receiver antennas it has 0.42bits/sec/Hz for 5dB, 1.18bits/sec/Hz for 10dB and 2.32bits/sec/Hz as capacity for 15dB. Capacity refers to the instantaneous capacity of MIMO cognitive radio system. Capacity increases as the number of transmitting and receiving antennas increases. This is due to the fact transmitting and receiving antennas provide an additional diversity gain. The capacity represented in terms of frequency is also spectral efficiency which is in bits/sec/Hz for a specific frequency.

Table 1. *Capacity vs SNR (dB) in frequency flat fading channels for MIMO Scenario.*

SNR (dB)	Number of Transmitting and Receiving Antennas and Capacity in bits/sec/Hz		
	St=2; Sr=2	St=4; Sr=4	St=8; Sr=8
5 dB	0.05	0.14	0.42
10 dB	0.15	0.39	1.18
15 dB	0.37	1.02	2.32

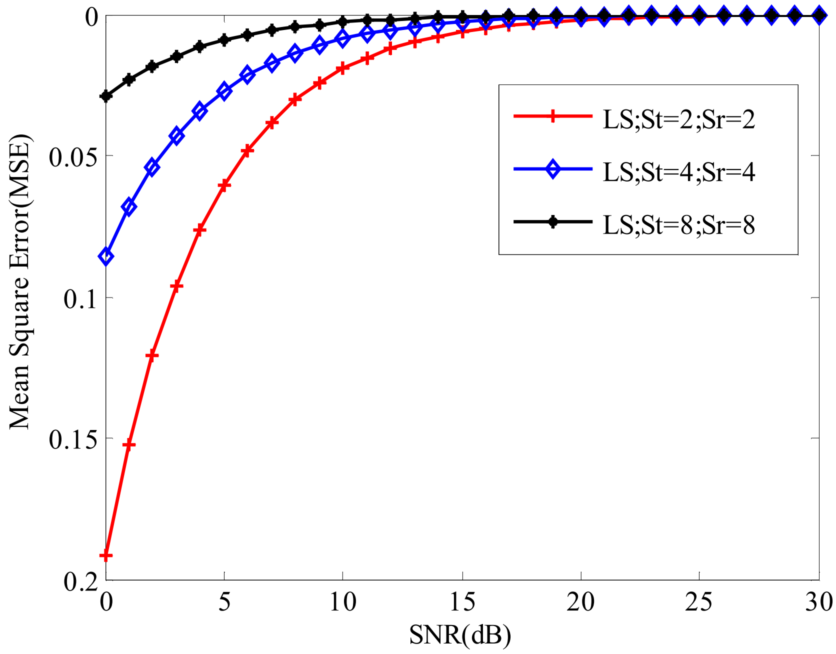

Figure 2. *Mean Square Error vs Signal to Noise Ratio for MIMO CR using LS algorithm.*

Figure 2, shows mean square error (MSE) and signal to noise ratio for transmitting and receiving antennas for known training sequence matrices using least squares (LS) channel estimation algorithm in flat fading channel. When the number of antennas increases for increasing SNR values, mean square error value reduces which signifies the importance of imperfect channel estimate scenario analysis for MIMO CR system. MSE reduces for increasing antennas as antennas contribute diversity gain which governs the importance of MIMO technology with cognitive radio systems.

6. Conclusion

By deriving capacity and performing simulation, capacity of MIMO CR system is analyzed in flat fading channel with Rayleigh distribution. The obtained simulation results for MIMO CR system provide that capacity increases as the number of transmitting and receiving antennas increases. Incorporation of MIMO technology with CR can provide a new path for applications to be developed which require very high data rates to cater day to day requirements. Further, obtained results can used for development of wireless applications relating to CR with MIMO technology and this in turn can contribute for development of digitized wireless products for usage in smart cities.

References

[1] J. Mitola III “Cognitive Radio”, Licentiate Proposal, KTH Stockhom, Sweden 1998.

[2] J. Mitola III and G. Q. Maguire Jr., “Cognitive radio: Making Software Radios more personal”, IEEE Personal Communications, vol. 6. no. 4, pp-13-18, August 1999.

[3] S. Haykin, “Cognitive radio: Brain-empowered wireless communications”, IEEE J. Sel. Areas Commun., vol. 23, no. 2, pp. 201-220, Feb 2005.

[4] S. Alamouti,”A simple transmit diversity technique for wireless communications” IEEE J. Sel. Areas commun., vol. 16, no. 8. pp. 1451-1458, Oct 1998.

[5] C. X. wang, X. Hong, H. H. Chen and J. Thompson, “On capacity of cognitive radio networks with average interference power constraints” IEEE Transactions on Wireless Communications, vol. 8, no. 4, pp. 1620-1625, April 2009.

[6] E. A. Gharavol, Y. C. Liang, K. Mouthaan, “Robust Cooperative Nonlinear Transceiver Design in Multi-Party MIMO Cognitive Radio Networks with Stochastic Channel Uncertainty”, IEEE 72nd Vehicular Technology Conference Fall (VTC 2010-Fall), Sept 2010.

[7] Asaduzzaman H. Y. Kong, “Ergodic and outage capacity of interference temperature-limited cognitive radio multi-input multi-output channel” IET Communications, vol 5, issue: 5, pp. 652-659, March 2011.

[8] Z. Xiong, C. Gong, L. Wu, K. Cumanan; S. Lambotharan,“Capacity Balancing for Multiuser MIMO Cognitive Radio Network”, IEEE Vehicular Technology Conference (VTC Fall), Sept 2011.

[9] J. T. Wang, “Maximum–Minimum Throughput for MIMO Systems in Cognitive Radio Networks”, IEEE Transactions on Vehicular Technology vol. 63, issue: 1, pp. 217-224, Jan. 2014.

[10] M. Hefnawi and A. Abubaker, “Channel capacity maximization in MIMO-SDMA based cognitive networks”, in Proceedings of International Conference on Multimedia Computing and Systems (ICMCS), April 2014.

[11] P. S. Kale and P. Lohiya, “Performance Enhancement of cognitive radio spectrum sharing (CRSS) with MIMO system”, in Proceedings of International Conference on Computer, Communication and Control (IC4), Sept 2015.

[12] M. Hefnawi,“Large-Scale Multi-Cluster MIMO Approach for Cognitive Radio Sensor Networks”, IEEE Sensors Journal vol. 16, issue: 11, pp. 4418-4424, June, 2016.

[13] N. I. Miridakis, T. A. Tsiftsis, G. C. Alexandropoulos, M. Debbah, “Simultaneous Spectrum Sensing and Data Transmission for Multi-User MIMO Cognitive Radio Systems” in Proceedings of IEEE Global Communications Conference (GLOBECOM), Dec 2016.

[14] S. Haykin, “Digital Communication”, John Wiley & Sons, 1998.

[15] D. Tse and P. Viswanath, “Fundamentals of Wireless Communication”, Cambridge University Press, 2005.

[16] S. M. Kay, “Statistical Signal Processing: Vol. 1 Estimation Theory”, Prentice Hall, 1993.