BER Comparison of Linear and Non linear MIMO Detectors in AWGN, Rician Fading and Rayleigh Fading channel

Rutika J. Upadhyay, Ashish B. Makwana and Aslam Durvesh

Abstract—**With the integration of Internet and multimedia applications in next generation wireless communications, the demand for wide-band high data rate communication services is growing. As the available radio spectrum is limited, higher data rates can be achieved only by designing more efficient signaling techniques. Multiple Input Multiple Output (MIMO) technology is one of the most promising wireless technologies that can efficiently boost the data transmission rate, improve system coverage, and enhance link reliability. By employing multiple antennas at transmitter and receiver sides, MIMO techniques enable a new dimension– the spatial dimension – that can be utilized in different ways to combat the impairments of wireless channels. While using MIMO techniques, there is intersymbol interference present between the symbols. Detection is a well known technique for combating intersymbol interference. This paper will focus on linear and Non linear Detection techniques in the AWGN (Additive White Gaussian Noise) channel, Rician Fading channel and the Rayleigh fading channel. This paper discusses different types of Detectors like Zero Forcing (ZF), Minimum Mean Square Error (MMSE), Maximum likelihood (ML) and Successive interference cancellation (SIC) and concludes that ML has better performance over other all. A simulation results shows in which fading channel getting better performance in terms of BER v/s SNR.**

Keywords— **AWGN channel, Rayleigh fading channel , BER, SNR, Intersymbol Interference (ISI), Multiple Input Multiple Output (MIMO), Minimum Mean Square Error (MMSE) and Zero Forcing (ZF).**

I) INTRODUCTION

In broad sense, the term communications refers to the sending, receiving and processing of information by electronic means. It is the technique of transmitting a message, from one point to another, knowing how much information, if any, is likely to be lost in the process [1-2]. Hence, the term "communication" is covered all forms of distance communications including radio, telegraphy, television, telephony, data communication and computer networking. Communications started with wire telegraphy in the eighteen forties, developing with telephony some decades later and radio at the beginning of this century. More recently, the use of satellites and fiber optics has made communications even more widespread, with an increasing emphasis on computer and other data communications [1],[3]. A modern communications system is first concerned with the sorting, processing and sometimes storing of information before its transmission. The actual transmission then follows, with further processing and filtering of noise. Finally it come reception, which may include processing steps such as decoding, storage and interpretation [4]. Demands for capacity in wireless Communications, driven by Cellular mobile, Internet and Multimedia services have been rapidly increasing worldwide. On the other hand available radio spectrum is limited and the Communication capacity needs cannot be met without a significant increase in communication spectral efficiency. Advances in coding, such as Turbo codes, Low density parity check codes and Space time codes [1],[5] made it feasible to approach the Shannon capacity limit in system with a single antenna link. Significant further advances in spectral efficiency are available though increasing the number of antennas at both transmitter and the receiver which is as MIMO technology. It is one of several forms of smart antenna technology. In fact, the MIMO concept is much more general and embraces many other scenarios such as wire line digital subscriber line (DSL) systems [6] and single-antenna frequency-selective channels [2-3]. MIMO technology has attracted attention in wireless communications, because it offers significant increases in data throughput and link range without additional bandwidth or transmit power. It is achieved by higher spectral efficiency (more bits per second per hertz of bandwidth) and link reliability or diversity (reduced fading). Because of these properties, MIMO is an important part of modern wireless communication standards such as IEEE 802.11n (Wifi), 4G, 3GPP Long Term Evolution, WiMAX and HSPA+.

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II) THE MIMO SYSTEM MODEL

Spatial Multiplexing (SM) has been utilized in MIMO systems to provide higher transmission rate without allocating additional bandwidth or increasing the transmit power [7]. The VBLAST was the practical implementation approach of spatial multiplexing technique. Spatial multiplexing involves deploying multiple antennas at both transmitter and receiver ends as shown in Figure 1. Input data streams can be divided into different independent sub streams and then transmitted simultaneously via sufficientlyseparated antennas (λ / 2 or more, to obtain highly uncorrelated and independent signal). It has been shown in [8] that utilizing spatial multiplexing schemes under certain conditions and assumptions, can linearly increases capacity with relation to the minimum of the number of transmit antennas and the number of receive antennas.

In this system received signal is given by

$$y = Hx + n \tag{1}$$

Where, $H = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix}$

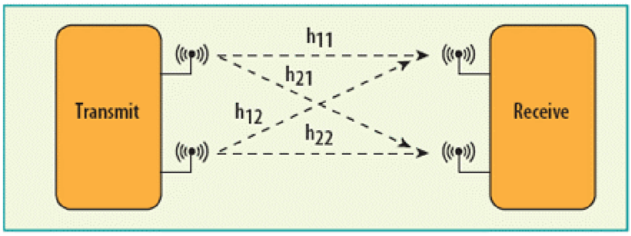

Figure 1 2x2 MIMO Channel

III. MIMO CHANNEL MODEL

A. AWGN Channel

For an AWGN (Additive White Gaussian Noise) channel, 'θ' is a constant and is equivalent to the AoA of the LoS propagation path. In this case, we use the so-called narrowband data model to model the received signal at the antenna arrays. The narrowband data model assumes that the envelope of the signal wave front propagating across the antenna array essentially remains constant. This model is valid when the signals or the antennas have a bandwidth that is much smaller than the carrier frequency fc. Under the above assumptions, the vector from of the baseband complex equivalent received signal can be written as,

$$Y(n) = V(\theta)s(n) + G(n)$$

Where, $V(\theta)$ is the array manifold vector and G(n) is AWGN with zero mean and two-sided power spectral density given by No/2. This is simply a plane-wave model.

B. Rayleigh Fading Channel

In wireless telecommunications, multipath is the propagation phenomenon that results in radio signals reaching the receiving antenna by two or more paths. Causes of multipath include atmospheric ducting, ionosphere reflection and refraction, and reflection from water bodies and terrestrial objects such as mountains and buildings.

The effects of multipath include constructive and destructive interference, and phase shifting of the signal. This causes Rayleigh fading. The standard statistical model of this gives a distribution known as the Rayleigh distribution. Rayleigh fading is a term used when there is no direct component, and all signals reaching the receiver are reflected. Mathematically, the multipath Rayleigh fading wireless channels modeled by the channel impulse response (CIR)

$$h(t) = \sum_{l=0}^{Lp-1} \propto_l \partial(t - \tau_l)$$

Where, Lp is the number of channel paths, $\propto_l$ and τ_l are the complex value and delay of path *l*, respectively. The paths are assumed to be statistically independent, with normalized average power.

C. Rician Channel

A Rician model is obtained in a system with LOS propagation and scattering. The model is characterized by the Rician factor, denoted by K and defined as the ratio of the line of sight and the scatter power components. The pdf for a Rician random variable x is given by

$$p(x) = 2x(1 + k)e^{-k(1+k)x^2} I_0(2x\sqrt{k(k + 1)}), x \geq 0$$

Where

$$K = \frac{D^2}{2\sigma_r^2}$$

And D^2 and $2\sigma_r^2$ are the powers of the LoS and scattered components, respectively. The powers are normalized such that $D^2 + 2\sigma_r^2 = 1$

The channel matrix for a Rician MIMO model can be decomposed as,

$$H = DH_{LOS} + \sqrt{2}\sigma_r H_{RAYL}$$

Where, HLOS is the channel matrix for the LoS propagation with no scattering and H_{RAYL} is the channel matrix for the case with scattering only.

III) MIMO DETECTORS

A. Zero Forcing(ZF)

A zero-forcing equalizer uses an inverse filter to compensate for the channel response function. In other words, at the output of the equalizer, it has an overall response function equal to one for the symbol that is being detected and an overall zero response for other symbols. If possible, this results in the removal of the interference from all other symbols in the absence of the noise. Zero forcing is a linear equalization method that does not consider the effects of noise. In fact, the noise may be enhanced in the process of eliminating the interference[9].

To solve for x in equation (1), we know that we need to find a matrix WZF which satisfies WZF H =1. The Zero forcing linear detectors for meeting this constraint is given by:

$$W_{ZF} = (H^H H)^{-1} H^H$$

In other words, it inverts the effect of channel as

$$\tilde{X}_{ZF} = W_{ZF} + y$$
$$= x + (H^H H)^{-1} n$$

B. *MINIMUM MEAN SQUARE ERROR (MMSE)*

If the mean square error between the transmitted symbols and the outputs of the detected symbols, or equivalently, the received SNR is taken as the performance criteria, the MMSE detector is the optimal detection that seeks to balance between cancelation of the interference and reduction of noise enhancement.

The W_{MMSE} that maximizes the SNR and minimizes the mean square error which is given by:

$$E[(x - W_{MMSE}y)^T (x - W_{MMSE}y)]$$

To solve for x in equation (1), we know that we need to find a matrix W_{MMSE}. The MMSE linear detector for meeting this constraint is given by:

$$W_{MMSE} = (H^H H + \sigma_n^2 I)^{-1} H^H$$

When comparing to the equation in Zero Forcing equalizer, apart from the σ^2_n term both the equations are comparable. In fact, when the noise term is zero, the MMSE equalizer reduces to Zero Forcing equalizer at high SNR [9].

C. Successive Interference Cancelation(SIC)

When signals are detected successively, the outputs of previous detectors can be used to aid the operations of next ones which leads to the decision directed detection algorithms including SIC, Parallel Interference cancelation (PIC), and multistage detection. ZF SIC with optimal ordering, and MMSE-SIC with equal power allocation approaches the capacity of the i.i.d. Rayleigh fading channel [10]. After the first bit is detected by the decorrelator the result is used to cancel the interference from the received signal vector assuming the decision of the first stream is correct [11]. For the ZF-SIC, since the interference is already nulled, the significance of SIC is to reduce the noise amplification by the nulling vector. The nulling vector w_1 filters the received vector y as:

$$\hat{x}_k = sgn[w_1^T y]$$

Assuming $\hat{x}_k = x_1$, by substituting x_1 from the received vector y , we obtain a modified received vector y_1 given by:

$$y_1 = y - \widehat{x_k}(H)_1$$

Where $(H)_1$ denotes the first column of H. We then repeat this operation until all M_T bits are detected. Once the first stream is detected, the first row of H is useless and will be eliminated. Therefore after the first cancelation the nulling vector for the second stream need only M_r -1 dimensions. For the MMSE detector the significance of SIC is not only to minimize the amplification of noise but also the cancelation of the interference from other antennas. In addition, there is another opportunity to improve the performance by optimal ordering the SIC process. The ordering is based on the norm of the nulling vector. At each stage of cancelation, instead of randomly selecting the stream to detect, we choose the nulling vector that has the smallest norm to detect the corresponding data stream. This scheme is proved to be the globally optimum ordering more complex.

D. Maximum Likelihood (ML)

The Linear detection method and SIC detection methods require much lower complexity than the optimal ML detection, but their performance is significantly inferior to the ML detection [24]. Maximum likelihood detection calculates the Euclidean distance between received signal vector and the product of all possible transmitted signal vectors with the given channel H, and finds the one with minimum distance. Let C and N_T denote a set of signal constellation symbol points and a number of transmit antennas, respectively. Then, ML detection determines the estimate transmitted signal vector x as:

$$\widehat{x_{ML}} = arg \min_{x \in C^{N_T}} \|y - Hx\|^2$$

Where: $\|y - Hx\|^2$ corresponds to the ML metric. The ML method achieves the optimal performance as the maximum a posterior detection when all the transmitted vectors are likely. However, its complexity increases exponentially as modulation order N and/or the number of transmit antennas increases [4], the requires number of ML matrix calculation is $|C|_T^N$, that is the complexity of metric calculation exponentially increases with the number of antennas. The ML receiver performs optimum vector decoding and is optimal in the sense of minimizing the error probability. ML receiver is a method that compares the received signals with all possible transmitted signal vectors which is modified by channel matrix H and estimates transmit symbol vector $\hat{c}$ according to the Maximum Likelihood principle, which is shown as:

$$\hat{c} = \min_{\hat{c}} \arg [\![y - \grave{c}H]\!]_F^2$$

where $_F$ is the Frobenius norm. Expanding the cost function using Frobenius norm given by

$$\hat{c} = \min_{\hat{c}} \arg \left[Tr[(y - \grave{c}H)^H * (y - \grave{c}H)] \right]$$

$$\hat{c} = \min_{\hat{c}} \arg \left[Tr \left[y^H.y + H^H.c'^H.c'.H - H^H.c'^H.y - y^H.c'.H \right] \right]$$

Considering $r^H.r$ is independent of the transmitted codeword so can be rewritten as

$$\hat{c} = \min_{\hat{c}} \arg [Tr[(y - \grave{c}H)^H * (y - \grave{c}H)] - 2.Real(Tr[H^H.\grave{c}^H.y])]$$

where $.^H$ is a Hermition operator. Although ML detection offers optimal error performance, it suffers from complexity issues.

IV) SIMULATION RESULTS

A. Simulation Setup

TABLE I
SIMULATION PARAMETERS

NTx	2
NRx	2
Symbols	1000000(10^6)
Noise	Gaussian noise
Channel	AWGN channel, Rician fading channel and Rayleigh flat fading channel

SNR	0 to 25
Modulation	BPSK
Detector	ZF, MMSE, ZF-SIC, MMSE-SIC, ZF-OSIC, MMSE-OSIC,ML

B. RESULTS

For ZF detection technique, In Figure.3 BER of 10^{-2} is achieved for the SNR value of 11 dB at AWGN channel, whereas the same BER is achieved for the SNR value of 14 dB at Rayleigh channel in Figure.2.

For MMSE detection technique, In Figure.3 BER of 10^{-2} is achieved for the SNR value of 8.5 dB at AWGN channel, whereas the same BER is achieved for the SNR value of 11 dB at Rayleigh channel in Figure.2.

For ZF-SIC detection technique, In Figure.3 BER of 10^{-2} is achieved for the SNR value of 9 dB at AWGN channel, whereas the same BER is achieved for the SNR value of 11.5 dB at Rayleigh channel in Figure.2.

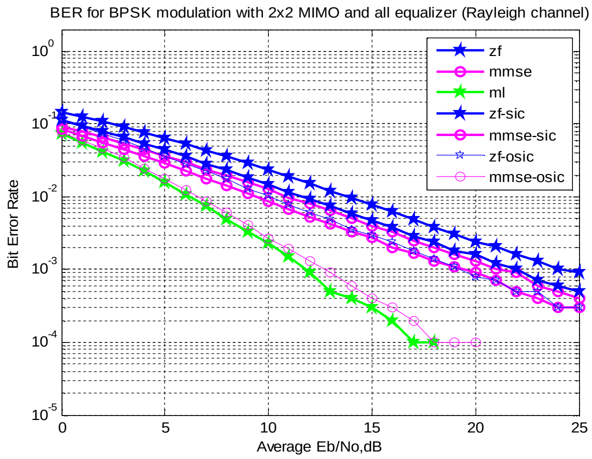

Figure 2 MIMO All EQUALIZERS IN RAYLEIGH CHANNEL

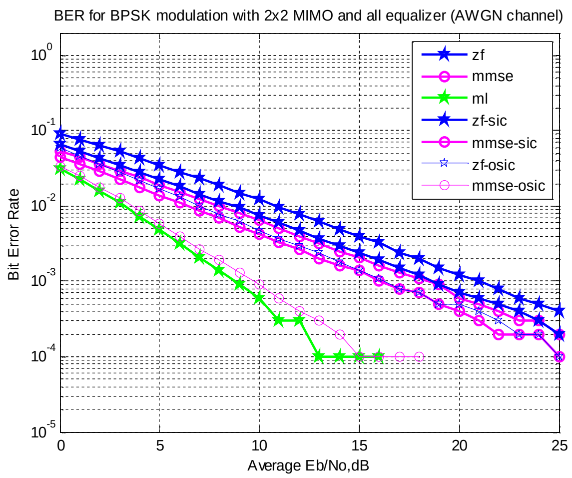

Figure 3 MIMO All EQUALIZERS IN AWGN Channel

For ZF-OSIC detection technique, In Figure.3 BER of 10^{-2} is achieved for the SNR value of 7 dB at AWGN channel, whereas the same BER is achieved for the SNR value of 10 dB at Rayleigh channel in Figure.2.

For MMSE-OSIC detection technique, In Figure.3 BER of 10^{-2} is achieved for the SNR value of 4 dB at AWGN channel, whereas the same BER is achieved for the SNR value of 6.5 dB at Rayleigh channel in Figure.2.

For ML detection technique, In Figure.3 BER of 10^{-2} is achieved for the SNR value of 3.6 dB at AWGN channel, whereas the same BER is achieved for the SNR value of 6 dB at Rayleigh channel in Figure.2.

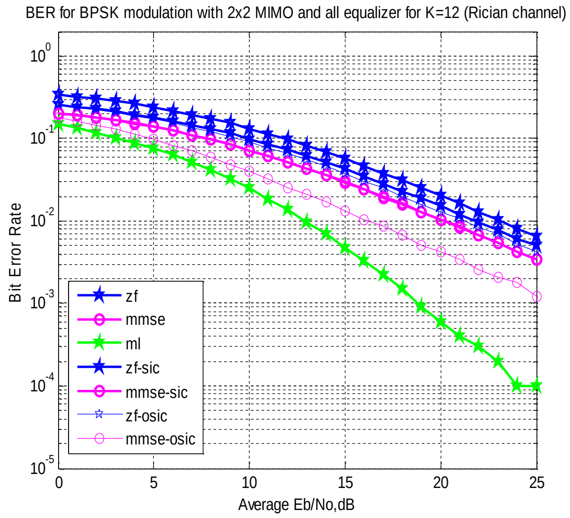

Figure 4 MIMO All EQUALIZERS IN Rician fading Channel (K=12db)

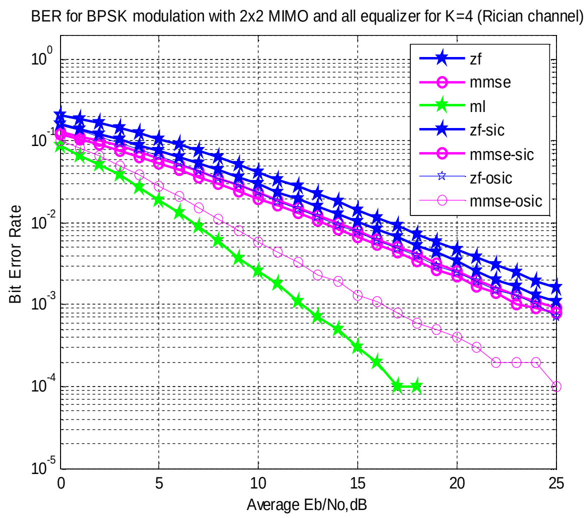

Figure 5 MIMO All EQUALIZERS IN Rician fading Channel (K=4db)

For RICIAN FADING channel at ZF detection technique, In Figure.4 BER of 10^{-2} is achieved for the SNR value of 23 dB at K=12, whereas the same BER is achieved for the SNR value of 16.5 dB at K=4 in Figure.5.and BER is achieved for the SNR value of 20 dB at K=8 in Figure.6.

For MMSE detection technique, In Figure.4 BER of 10^{-2} is achieved for the SNR value of 20 dB at K=12, whereas the same BER is achieved for the SNR value of 14.2 dB at K=4 in Figure.5.and BER is achieved for the SNR value of 16.2 dB at K=8 in Figure.6.

For ZF-SIC detection technique, In Figure.4 BER of 10^{-2} is achieved for the SNR value of 22 dB at K=12, whereas the same BER is achieved for the SNR value of 15 dB at K=4 in Figure.5.and BER is achieved for the SNR value of 19 dB at K=8 in Figure.6.

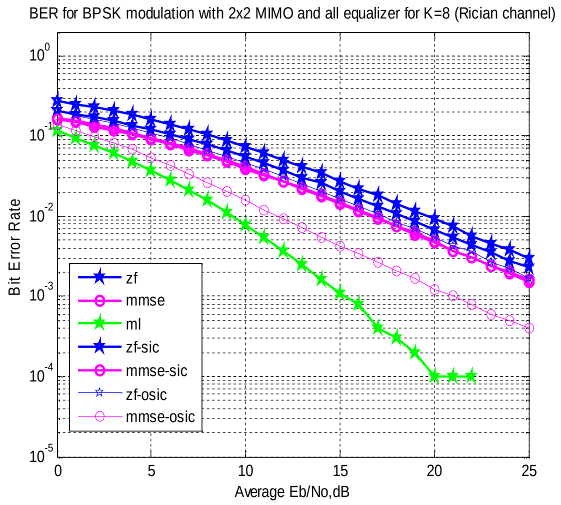

Figure 6 MIMO All EQUALIZERS IN Rician fading Channel (K=8db)

For MMSE-SIC detection technique, In Figure.4 BER of 10^{-2} is achieved for the SNR value of 19 dB at K=12, whereas the same BER is achieved for the SNR value of 14 dB at K=4 in Figure.5.and BER is achieved for the SNR value of 16 dB at K=8 in Figure.6.

For ZF-OSIC detection technique, In Figure.4 BER of 10^{-2} is achieved for the SNR value of 21 dB at K=12, whereas the same BER is achieved for the SNR value of 13.5 dB at K=4 in Figure.5.and BER is achieved for the SNR value of 18.5 dB at K=8 in Figure.6.

For MMSE-OSIC detection technique, In Figure.4 BER of 10^{-2} is achieved for the SNR value of 16 dB at K=12, whereas the same BER is achieved for the SNR value of 8.5 dB at K=4 in Figure.5.and BER is achieved for the SNR value of 11.2 dB at K=8 in Figure.6.

For ML detection technique, In Figure.4 BER of 10^{-2} is achieved for the SNR value of 12 dB at K=12, whereas the same BER is achieved for the SNR value of 7 dB at K=4 in Figure.5.and BER is achieved for the SNR value of 9 dB at K=8 in Figure.6.

From the simulation results it is observed that the performances of the all receivers in AWGN channel are all most 3dB improved over Rayleigh fading channel. Compared to Rician fading channel for all fading factor of K, all receivers in AWGN channel are better. When comparing all receivers performance at each channel the performance of ML detector is best than all other detector and comparing this detectors performance in ascending order it's goes from most efficient ML detector to some what moderated MMSE-OSIC than ZF-OSIC, MMSE-SIC, ZF-SIC, MMSE and ZF detector. ML uses the Euclidean distance method to detect the received signal where as MMSE detector removes effect of channel and noise by minimizing mean square error between transmitted and received symbols whereas ZF detectors removes only effect of channel.

Performance of all detect is better in AWGN channel due to AWGN is a channel model in which the only impairment to communication is a linear addition of wideband or white noise with a constant spectral density (expressed as watts per hertz of bandwidth) and a Gaussian distribution of amplitude. The model does not account for fading, frequency selectivity, interference, nonlinearity or dispersion. However, it produces simple and tractable mathematical models which are useful for gaining insight into the underlying behaviour of a system before these other phenomena are considered. In Rayleigh channel, performance of MIMO with linear and non linear detectors degrades as compared to AWGN channel. Rayleigh fading is the specialised model for stochastic fading when there is no line of sight signal, and is sometimes considered as a special case of the more generalised concept of Rician fading. Rician fading is a stochastic model for radio propagation anomaly caused by partial cancellation of a radio signal by itself — the signal arrives at the receiver by several different paths (hence exhibiting multipath interference), and at least one of the paths is changing (lengthening or shortening). Rician fading occurs when one of the paths, typically a line of sight signal, is much stronger than the others. In Rician fading, by increasing value of K from 4 to 12 dB performance of MIMO system degrades, where K is the ratio between the power in the direct path and the power in the other, scattered paths.

V) CONCLUSION

In this paper, MIMO system analysed with linear and non linear detection schemes under AWGN, Flat Fading Rayleigh channel and Rician fading channel. Further this system is compared with different channel models and system gets better result in AWGN channel and worst result in Rician channel. Performance of MIMO system is better in AWGN because AWGN does not account for fading, frequency selectivity, interference, nonlinearity or dispersion. Performance of MIMO system is degraded in Rayleigh channel due to consideration of multipath. In Rician channel by increasing value of K performance of MIMO system degrades. This paper also investigated example of different types of receivers utilized within a wireless communication system. From the simulation it is clear that ML detector out performed than other detectors and MMSE,MMSE-SIC,MMSE-OSIC detectors are better than ZF,Zf-SIC,ZF-OSIC detectors because of MMSE detectors removes effect of channel and noise whereas ZF detectors removes only effect of channel.

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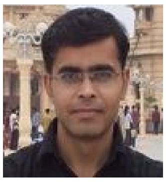

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