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A Novel Approximate Message Passing Detection for Massive MIMO 5G System

Nidhi Gour[1], Rajneesh Pareek[1], Karthikeyan Rajagopal[2,3], Himanshu Sharma[1], Mrim M. Alnfiai[4], Mohammed A. AlZain[4], Mehedi Masud[5] and Arun Kumar[6,*]

[1]Department of Computer Science & Engineering, JECRC University, Jaipur, India
[2]Centre for Nonlinear Systems, Chennai Institute of Technology, Chennai, India
[3]Department of Electronics and Communication Engineering and University Centre for Research & Development, Chandigarh University, Mohali, India
[4]Department of Information Technology, College of Computer and Information Technology, Taif University, P.O. Box 11099, Taif, 21994, Saudi Arabia
[5]Department of Computer Science, College of Computers and Information Technology, Taif University, P. O. Box 11099, Taif, Saudi Arabia
[6]Department of Electronics and Communication Engineering, JECRC University, Jaipur, India
*Corresponding Author: Arun Kumar. Email: arun.kumar1986@live.com
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Abstract: Massive-Multiple Inputs and Multiple Outputs (M-MIMO) is considered as one of the standard techniques in improving the performance of Fifth Generation (5G) radio. 5G signal detection with low propagation delay and high throughput with minimum computational intricacy are some of the serious concerns in the deployment of 5G. The evaluation of 5G promises a high quality of service (QoS), a high data rate, low latency, and spectral efficiency, ensuring several applications that will improve the services in every sector. The existing detection techniques cannot be utilised in 5G and beyond 5G due to the high complexity issues in their implementation. In the proposed article, the Approximation Message Passing (AMP) is implemented and compared with the existing Minimum Mean Square Error (MMSE) and Message Passing Detector (MPD) algorithms. The outcomes of the work show that the performance of Bit Error Rate (BER) is improved with minimal complexity.

Keywords: AMP; MMSE; MPD; 5G

1 Introduction

In the present scenario, it is seen that the data traffic is increasing day by day. In the year 2025, it is estimated that data traffic will increase by 30% [1]. The deployment of Fifth Generation (5G) radio is going on all around the world in order to satisfy the demands of the subscribers. Several technologies, including Internet of Things (IOT), Cognitive Radio (CR), M-MIMO, Machine2Machine (M2M), Device2Device (D2D), and Millimeter (mm), may improve data rates and satisfy the demands of various industries [2]. M2M is considered one of the key technologies for 5G and beyond 5G radio frameworks. It allows the integration of several sensors and creates heavy traffic. The regularization of D2D requires high data speed, low latency, high spectral performance, and advanced security [3]. The IoT is regarded as one of the most emerging technologies. It enables several devices to interconnect with each other so that the devices can efficiently communicate with other devices that are close to each other [4]. One of the major issues in the current situation is the Spectrum issue. It is seen that 70% of the spectrum is wasted, causing the scarcity of spectrum. Cr is a clever way of sensing idle spectrum and allocating it from licence users to non-license users without causing any interface. This technique efficiently utilises the spectrum, thus overcoming the spectrum scarcity issue [5]. D2D is one of the most popular techniques in 5G and beyond 5G. It enables the devices to transmit the information without passing it through a channel network [6]. In these techniques, the devices that are close to each other can interconnect and transmit data between them. This technique does not use a base station (BS) for transmitting and receiving the signal [7]. mm wave refers to a frequency range from 30 to 300 GHz. The 5G radio will utilise the spectrum from 24 to 40 GHz. As a result, the mm wave is expected to improve the data rate, capacity, and spectrum performance of the 5G framework [8]. M-MIMO is regarded as one of the key techniques in the uplink (UL) and downlink (DL) of the 5G and beyond 5G radio systems [9]. The Fourth Generation (4G) radio framework utilises a MIMO system, where antennas are used at the BS. M-MIMO will be utilised for 5G radio, where more than eight antennas will be used at the BS. However, it is important to maintain the proper orientation of antennas to avoid interference between the signals transmitted from the antenna [10]. The utilisation of the M-MIMO will enhance the throughput, data-rate, capacity, and spectral efficiency of the advanced radio framework. The use of advanced detection algorithms, effective encoders, and channel estimation methods in M-MIMO can obtain an optimal performance [11]. However, the large numbers of antennas at the BS involve the use of advanced signal processing algorithms. As a result, one of the major concerns in the 4G and 5G frameworks is the detector with a low complexity. Prior and precise channel state information is considered one of the perquisites at the BS. The data is decoded in M-MIMO DL to direct spatial signals at the end user's location [12]. In the UL, an advanced detection framework is required for evaluating the transmitted signals where the main concern is the high detection complexity due to the large number of antennas at the BS.

2 Literature Review

In recent years, several detection algorithms such as Minimum Mean Square Error (MMSE), Zero Forcing Equalizer (ZFE), and Maximum Likelihood (ML) have been proposed. The ML is regarded as one of the most efficient detection methods [13]. However, it increases the complexity due to its comprehensive search characteristics. MMSE is also considered an ideal line detector, but it also enhances the complexity due to the matrix inversion process. It is noted that several experiments have been performed to obtain an acceptable performance with low intricacy. The authors of [14–17] presented extensive research and challenges on the M-MIMO DL. In [18], the authors introduced a hybrid detection algorithm based on the QR Decomposition M Algorithm-Maximum Likelihood (QRM-MLD) methods. It is observed that the proposed algorithm efficiently enhances the throughput and latency performance with minimal computational intricacy as compared with the existing detection algorithms. In [19], several detection algorithms are comprehensively studied for the M-MIMO DL framework. The performance of detectors is estimated for the Rayleigh and Rician channels. It is observed that the conventional MMSE, ZFE, ML, and QRM-MLD upshot the complexity of the structure. However, it is concluded that the conventional detectors require redesigning to achieve optimal performance with low intricacy in the complex environmental scenario. The Approximation Message Passing (AMP) is one of the most popular detection algorithms that can be utilised to obtain optimal performance in 5G and beyond 5G radio. In [20], bi-directional long-term memory (Bi-LSM) is implemented to detect 5G signals. The simulation outcomes reveal that the symbol error rate performance of the presented Bi-LSM is better than the MMSE. The authors in [21] implemented a MMSE algorithm for M.MIMO UL. The outcome of the work reveals that the proposed MMSE outperforms the conventional MMSE method. However, the complexity of the presented model is not estimated. QRM-MLD is designed for Orthogonal Frequency Division Multiplexing (OFDM) structures in [22]. It is noted that the proposed detection QRM-MLD reduces the complexity of the structure by 95% and a gain of 2 dB is obtained as compared with the traditional MLD method [23]. The simulation outcomes obtained optimal performance as compared with the conventional algorithms. The outcomes of the presented article are given as:

- In this work, we studied the performance of the novel AMP algorithm and conventional detection schemes on non-orthogonal multiple access waveforms in the Rician channel.
- The various parameters such as BER and Peak to Average Power Ratio (PAPR) are estimated and compared with the conventional detection algorithms.
- We introduced a novel 5G signal detection algorithm based on the combination of detection schemes. The key objective of the designed algorithm is to reduce the propagation delay and complexity with minimal degradation of the BER performance.
- The conventional PAPR methods have been successfully reducing the PAPR but the complexity is also increasing, which has been significantly achieved in the presented article.

3 System Model

The detection of M-MIMO signals is considered a critical task as it involves the number of signals received at the receiver and the complexity is extensively increased. The throughput of the MIMO is compromised to obtain a low-complexity M-MIMO framework and vice versa. The arrangement of conventional M-MIMO is shown in Fig. 1.

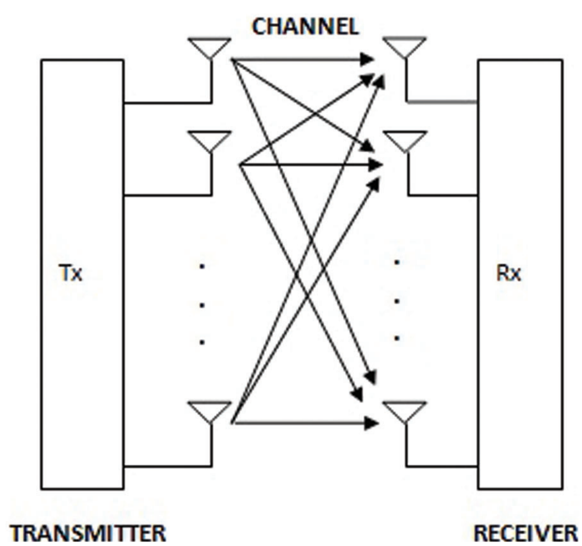

Figure 1: MIMO transmission system

The conventional M-MIMO signai is given by:

$$Y = [Y_0,\ Y_1,\ \ldots, Y_{N-1}]^T \tag{1}$$

At this stage, we are generating a phase factor ($\varnothing^u$) to overcome the amplitude error, given by:

$$\varnothing^u = \left[\varnothing_0^{\mathrm{u}}, \varnothing_1^{\mathrm{u}}, \ldots, \varnothing_{\mathrm{N}}^{\mathrm{u}}\right]^{\mathrm{T}} \tag{2}$$

The phase weighting factor can be expressed as:

$$\varnothing_{-\mathrm{u}}^{\mathrm{v}} = \mathrm{e}^{\mathrm{j}\varnothing_{\mathrm{u}}^{\mathrm{v}}} \tag{3}$$

The modulated signal (Y^{v}) of M-MIMO is given by:

$$\mathrm{Y}^{\mathrm{v}} = \left[\mathrm{Y}_0^{\mathrm{v}}, \mathrm{Y}^{\mathrm{v}}, \ldots, \mathrm{Y}_{\mathrm{N}-1}{}^{\mathrm{v}}\right]^{\mathrm{T}} \tag{4}$$

In order to reduce the amplitude and phase error, the MIMO modulated symbol is weighted by phase factor:

$$Y = \mathrm{Y}^{\mathrm{v}} * \varnothing_{-\mathrm{u}}^{\mathrm{v}^{v}} \tag{5}$$

The Eq. (5) can be written as:

$$Y = \left[\mathrm{Y}_0^{\mathrm{v}}, \mathrm{Y}_1^{\mathrm{v}}, \ldots, \mathrm{Y}_{\mathrm{N}-1}{}^{\mathrm{v}}\right]^{\mathrm{T}} * \mathrm{e}^{\mathrm{j}\varnothing_{\mathrm{u}}^{\mathrm{v}}} \tag{6}$$

An Inverse Fast Fourier Transform (IFFT) is applied to the Eq. (6) to estimate the time domain of the signal given by:

$$y = IFFT(Y) \tag{7}$$

The PAPR of M-MIMO can be estimated as:

$$PAPR = \frac{\mathrm{Max}_{t \in T} \lfloor y(t)^2 \rfloor}{\frac{1}{T}\int_0^T \lfloor y(t)^2 \rfloor \, dt} \tag{8}$$

The received signal (Z) considering the noise (N) and channel response (h) is given by:

$$Z^v = \mathrm{h}\, Y^v + \mathrm{N} \tag{9}$$

In AMP, the messages are linked with the code, which significantly decreases the quantity of messages in a significant manner due to the computational complexity being reduced. The AMP was initially designed to estimate the signal correction and resolve the selection issues in the digital processing framework. The AMP detector has grown in popularity due to its ability to reduce complexity while increasing framework throughput. The AMP gave an efficient performance, and it is easy to design for massive framework dimensions. Hence, AMP is efficiently utilised in linear evaluation of M-MIMO structure, encoding, and multi-signal detection. It is also seen that the concurrency rate of the AMP is extremely good. However, the concurrence rate degrades for highly complex systems. The efficiency of the Message Passing Detector (MPD) is further enhanced by utilising the channel hardening hypothesis, which results in a simple estimation of the Gram Matrix determination. Further, the throughput performance of the MPD is better than the MMSE due to the fact that the matrix inversion is not required in the MPD. However, it is seen that the complexity of the MPD increases due to the large number of exponential calculations [24]. Hence, it is concluded that the MPD is not suitable for the M-MIMO framework. The block diagram of the proposed AMP is given in Fig. 2. In this work, we presented an AMP algorithm to obtain an efficient throughput and low-complex structure.

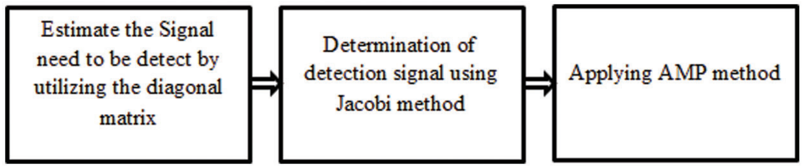

Figure 2: Schematic of detection procedure

In AMP, the error is reduced and efficient signal detection is carried out by utilising the repetitive threshold technique, given as:

$$\mathbf{z}_{n+1} = x - \boldsymbol{H}\widehat{z_n} + \frac{\boldsymbol{h}}{\omega_n}\left[\frac{\omega_n^2}{N^2 + \beta_n}\overline{\mathbf{z}_n}\right] \tag{10}$$

The conventional representation of the transmit (y) and receive signal (z) is given by [25]

$$Z = \boldsymbol{hy} + \boldsymbol{N} \tag{11}$$

The characteristics of the channel can be written as:

$$H = \begin{bmatrix} H_{00} + \cdots + H_{M,0} \\ \vdots \qquad\qquad \vdots\vdots \\ H_{0,N-1} + \cdots + H_{M,N} \end{bmatrix} \begin{bmatrix} Y_1 \\ Y_2 \\ \vdots \\ Y_N \end{bmatrix} \tag{12}$$

The rank (r) of the channel is given by [26]

$$r = \begin{bmatrix} h_1 r(N) & \cdots & h_1 r(1) \\ \vdots & \ddots & \vdots \\ h_N r(N) & \cdots & h_N r(1) \end{bmatrix} \tag{13}$$

The signal at the receiver is given by:

$$\bar{z} = \boldsymbol{h}\,\bar{\boldsymbol{y}} + \boldsymbol{N} \tag{14}$$

The representation of the channel with QRM is estimated as:

$$\boldsymbol{H} = \boldsymbol{M} * \boldsymbol{v} \tag{15}$$

In Eq. (2), M represents the unit matrix and v is known as the braiding matrix. The 5G signal at the receiver is given by:

$$\bar{\mathbf{z}} = \boldsymbol{M} * \boldsymbol{v} * \boldsymbol{y} = \boldsymbol{v}\bar{\boldsymbol{M}} + \boldsymbol{N} \tag{16}$$

The conventional M-MIMO is given by:

$$\begin{bmatrix} \bar{\mathbf{z}}_1 \\ \bar{\mathbf{z}}_2 \\ \vdots \\ \bar{\mathbf{z}}_n \end{bmatrix} = \begin{bmatrix} \boldsymbol{v}_{11} & \ldots \boldsymbol{v}_{1n} \\ \mathbf{0} \ldots & \boldsymbol{v}_{2n} \\ \vdots & \vdots \\ \mathbf{0} \ldots & \boldsymbol{v}_{m\,n} \end{bmatrix} \begin{bmatrix} \bar{\boldsymbol{y}}_1 \\ \bar{\boldsymbol{y}}_2 \\ \vdots \\ \bar{\boldsymbol{y}}_m \end{bmatrix} + \begin{bmatrix} \boldsymbol{n}_1 \\ \boldsymbol{n}_2 \\ \vdots \\ \boldsymbol{n}_m \end{bmatrix} \tag{17}$$

The signal estimated by the proposed algorithm is given by:

$$\bar{\boldsymbol{y}} = \|\bar{\boldsymbol{Z}} - \boldsymbol{v}\bar{\mathbf{z}}\|^2 \tag{18}$$

The detection of the 5G signal by the multiple antennas is given by:

$$\bar{\bar{\mathbf{Z}}} = (|\boldsymbol{H}_1| + |\boldsymbol{H}_2| + \cdots + |\boldsymbol{H}_M|) * \bar{\boldsymbol{X}} + \boldsymbol{N} \tag{19}$$

The estimation of the BER is given below:

$Step\ 1{:}\ \ Estimation\ of\ 5G\ symbol = \bar{y},\ n,\ h,\ \ P)$

$Step\ 2{:}\ \ Received\ 5G\ signal\ is\ given\ by{:}\ \bar{z}$

$Step\ 3{:} Power\ transmission - \sqrt{P},\ \ \sqrt{P}\ is\ the\ power\ given\ to\ the\ signal$

Step 4: $\bar{z} = v\bar{y} + N$

Step 5: The power of the transmitted signal is ($\sqrt{P}$):

$\sqrt{P} = v\bar{y}$

$Step\ 6{:} Determination\ of\ BER{:}\ \bar{y} > 0$

4 Simulation Results

The primary objective of the proposed article is to investigate the performance of AMP for 32×32 MIMO and 64×64 MIMO structures. The 64-QAM transmission scheme and rician channel are selected for our analysis. The FFT size is 64 and number of sub-carriers is selected as 64, over sampling is 4, iteration perform is 50 with coding rate (1/16) and constraint length (8). Matlab-2014 is utilised to simulate the AMP algorithms for M-MIMO structures. The BER of the 32×32 MIMO structure for the AMP algorithm is given in Fig. 3. The BER of 10^{-3} is obtained at the SNR of 6.2, 9.1 and 10.2 dB for AMP, MPD, and MMSE. It is seen that the proposed AMP obtained a gain of 3.2 and 4 dB as compared with the detection method mentioned above. It is also seen that the complexity of the proposed AMP is low due to the non-utilization of matrix inversion. Hence, it is concluded that the proposed AMP outperforms the MPD and MMSE detection algorithms.

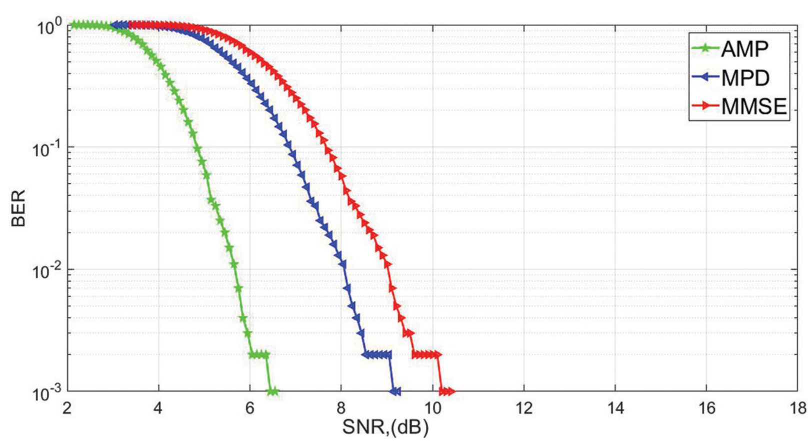

Figure 3: SNR *vs.* BER analysis of 32×32 MIMO structure for the rician channel showing AMP achieving 2.3 dB gain as compared with the MMSE

To further evaluate the performance of the proposed AMP, the 64 × 64 MIMO structure is simulated and the AMP is applied to detect the signal. The BER curve, given in Fig. 4, reveals that the performance of the AMP is better than the conventional detection schemes. Further, it is also noted that the 64 × 64 MIMO obtained a better performance as compared with the 32 × 32 MIMO structure. In 64 × 64, AMP obtained a gain of 0.4 and a 2.1 dB gain as compared with MPD and MMSE. Further, it is observed that the complexity is high for 64 × 64 structures as compared with the 32 × 32 MIMO.

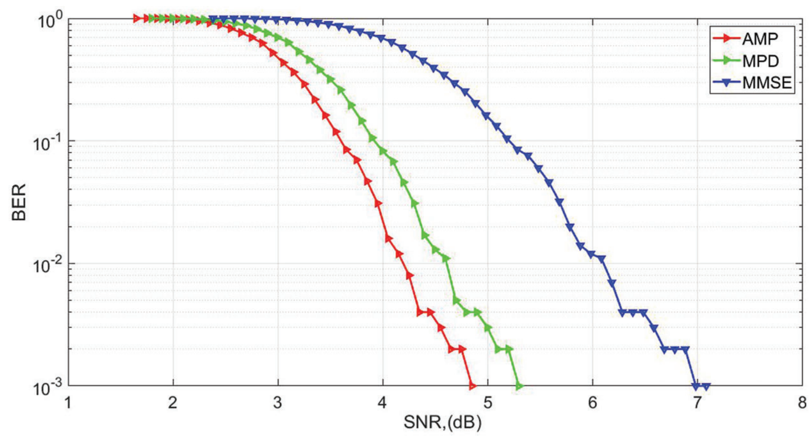

Figure 4: SNR *vs.* BER analysis of 64 × 64 MIMO structure for the rician channel showing AMP achieving 2.4 dB gain as compared with the MMSE

PAPR is considered a significant problem in multicarrier waveforms. In Fig. 5, we estimate the PAPR of M-MIMO without applying the peak power reduction algorithms. At the Complementary Cumulative Distribution Function (CCDF) of 10^{-3}, the PAPR of 32 × 32 and 64 × 64 MIMO is 9 and 5.2 dB. Hence, it is concluded that the throughput of the system is enhanced with an increasing number of antennas, but the complexity of the structure also increases with the size of the MIMO structure.

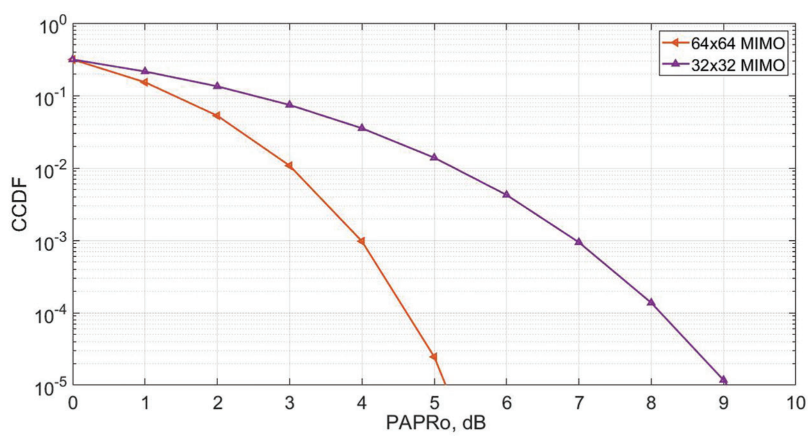

Figure 5: PAPR analysis of M-MIMO structure

In this work, we define number of additions and multiplications as the complexity of the algorithms. Tab. 1, represents the number of additions for MMSE, MPD and proposed AMP algorithms. It is concluded that the AMP additions requirement is 152321, MMSE [27] is 223518, and MPD [28] is 282342.

Table 1: Addition requirements

S. No	Algorithms	Additions
1	MMSE	$2L(M + 2L - 1)$ [29]
2	MPD	$2L(Mn + 2M)$ [29]
3	Proposed work	LM

5 Conclusion

The utilisation of M-MIMO structures efficiently improves the throughput of the 5G and beyond 5G frameworks. However, the detection of the signal is complicated due to the utilisation of the several numbers of antennas at the BS. Advanced detection algorithms in 5G radio will ensure efficient performance and service quality. However, the existing detection schemes are not suitable for the advanced waveforms. In this paper, we present an advanced AMP algorithm for M-MIMO structures. It is seen that the proposed AMP algorithm gives an efficient BER performance and complexity is also reduced as compared with the MMSE and MDP algorithms. However, it is noted that the PAPR is one of the significant advanced waveforms proposed for 5G radio. The simulation results reveal that the PAPR is high in 64×64 MIMO as compared with 32×32. It is also suggested that suitable PAPR algorithms be used at the transmitting portion of the 5G radio to reduce the PAPR, which can further increase the complexity of the schemes.

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Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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