



Scalable Channel Estimation in Massive MIMO Using Modified AMP: A Compressive Sensing Approach

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Abstract— Massive Multiple Input Multiple Output (Massive MIMO) technology has emerged as a cornerstone of next-generation wireless networks, enabling significant improvements in spectral efficiency, energy efficiency, and user capacity. However, the effectiveness of such systems relies heavily on accurate and scalable channel estimation, particularly under high-dimensional and noise-prone environments. This paper presents a compressive sensing-based framework utilizing a Modified Approximate Message Passing (AMP) algorithm for efficient detection and channel estimation in Massive MIMO systems. The proposed method is evaluated using a MATLAB-based simulation environment under different antenna configurations and modulation schemes (QPSK and 16-QAM). Performance metrics such as Bit Error Rate (BER), Receiver Operating Characteristic (ROC) curves, and spatial beamforming patterns are analyzed across various Signal-to-Noise Ratio (SNR) levels. Results demonstrate that AMP with increased iterations significantly outperforms the conventional MMSE-SIC detection algorithm, achieving a BER as low as 0.001 at 10 dB SNR with 128 receive antennas. Furthermore, beamwidth analysis confirms enhanced spatial selectivity with increasing antenna count. These findings validate the scalability, robustness, and computational efficiency of the AMP-based detection scheme, establishing its viability for real-time deployment in 5G and beyond wireless sensor networks.

Keywords— MIMO, CS, AMP, Modified AMP, QPSK, 16-QAM, BER, MMSE-SIC, SNR, ROC.

I. INTRODUCTION

The proliferation of mobile broadband services, Internet of Things (IoT) devices, and high-throughput applications has driven an exponential increase in demand for wireless bandwidth, reliability, and efficiency. To address these challenges, Massive MIMO technology characterized by deploying a large number of antennas at the base station has been integrated into the design of 5G and beyond wireless communication systems. Massive MIMO enhances spectral efficiency and spatial multiplexing by allowing simultaneous communication with multiple user terminals on the same frequency band. However, the associated increase in dimensionality and channel complexity necessitates advanced signal detection and channel estimation techniques.

One promising solution lies in Compressive Sensing (CS), which exploits the inherent sparsity of wireless channels to

reduce pilot overhead and computational burden. When paired with Approximate Message Passing (AMP) - a low-complexity, iterative reconstruction algorithm - CS becomes a powerful framework for large-scale MIMO detection. Despite AMP's effectiveness in sparse signal recovery, its performance in realistic wireless environments can suffer from convergence issues and sensitivity to prior mismatches. To address these concerns, this study explores a Modified AMP algorithm tailored for massive MIMO detection in noisy and dynamic settings.

This paper investigates the performance of the proposed detection scheme via MATLAB-based simulations, focusing on two key aspects: (1) bit error rate (BER) reduction through iterative AMP detection, and (2) spatial resolution improvement through antenna array scaling. The simulation results are benchmarked against the traditional Minimum Mean Square Error with Successive Interference Cancellation (MMSE-SIC) method. The findings confirm

that the modified AMP algorithm not only enhances detection accuracy but also supports low-latency, energy-efficient communication, positioning it as a practical enabler for future large-scale wireless systems.

II. RELATED WORK

Massive MIMO systems have been extensively researched for their capability to improve spectral efficiency and link reliability through the use of large antenna arrays. However, this scalability introduces significant challenges in channel estimation and detection due to increased dimensionality and pilot overhead. Compressive Sensing (CS) has gained traction in addressing these issues by exploiting the scarcity of wireless channels, particularly in the angular domain [1].

Approximate Message Passing (AMP) has been proposed as an efficient reconstruction algorithm within CS frameworks for high-dimensional systems. Its use in Massive MIMO has shown considerable promise in reducing computational complexity while maintaining accuracy in signal recovery [2], [3]. Despite this, AMP exhibits sensitivity to mismatches in signal priors and has convergence issues when the measurement matrices deviate from ideal IID Gaussian assumptions. To counter these drawbacks, researchers have developed various modifications such as Generalized AMP (GAMP), Vector AMP (VAMP), and hybrid AMP methods [4], [5].

Studies like [6] have demonstrated the advantages of MMSE-SIC (Minimum Mean Square Error with Successive Interference Cancellation) in practical multi-user MIMO detection scenarios. However, their computational cost rises significantly with increased user count and antenna dimensions, making them less suitable for real-time massive deployments.

In [7], enhanced detection methods like the Ordered IMF-SIC (OIMF-SIC) and iterative message-passing variants were introduced to improve reliability, but their recursive computations add complexity and limit real-time feasibility. To bridge the gap between accuracy and efficiency, [8] proposed a low-complexity AMP-based iterative detection scheme for MIMO-OFDM systems that closely approximates the performance of optimal detection algorithms.

The implementation of AMP in hardware was explored in [9], where fixed-point arithmetic techniques were applied to balance energy efficiency and performance for embedded systems. These advances point toward the feasibility of real-time deployment. Moreover, the robustness of AMP against structured noise and under non-Gaussian conditions has been addressed through frameworks like GAMP, showing improved convergence [4], [10].

Although various advancements have been made, few studies present a comparative analysis involving AMP, its modified variants, and traditional techniques like MMSE-SIC in the context of Massive MIMO. This research aims to fill that gap by evaluating a Modified AMP algorithm across key performance metrics such as BER and ROC curves.

III. METHODOLOGY

To evaluate the performance of the Modified AMP algorithm in a realistic wireless communication environment, a MATLAB-based simulation framework was developed and the process flow module shown in the figure 1. The simulation focuses on uplink transmission in a multi-user Massive MIMO-OFDM system and includes two different system configurations: System 1: 64 receiving antennas and 16 single-antenna users and System 2: 128 receiving antennas and 16 single-antenna users.

The following key methodological components were implemented:

- **Signal Generation:** Random data bits were generated and mapped to symbols using modulation schemes such as QPSK and 16-QAM. These symbols represent the transmitted signals from each user.
- **Channel Modelling:** The wireless channel was modelled as a flat Rayleigh fading channel to simulate multipath propagation. Additive White Gaussian Noise (AWGN) was added to the received signals to represent environmental noise, varying over a range of Signal-to-Noise Ratio (SNR) values from 1 dB to 10 dB.
- **System Architecture:** The transmitter comprises multiple user terminals with single antennas, while the base station employs a large antenna array to realize Massive MIMO. An OFDM structure is incorporated to handle frequency-selective fading by converting the wideband channel into parallel narrowband subcarriers.

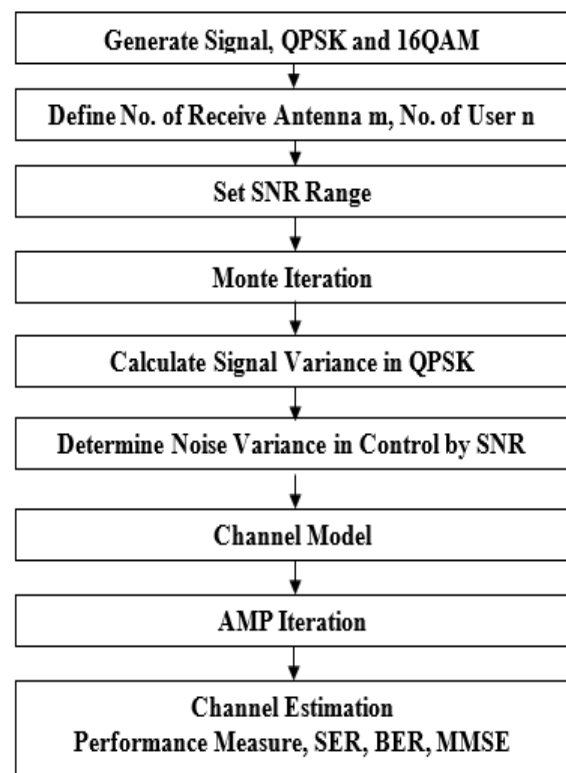


Figure 1: Process Flow for Proposed Methodology

• Detection Algorithms: Three detection schemes were implemented for performance comparison:

1. AMP with 2 iterations
2. AMP with 4 iterations
3. MMSE-SIC (benchmark method)

The AMP algorithm was implemented with iterative updates based on message passing principles, adapted to Massive MIMO settings for improved scalability. MMSE-SIC was used as a traditional method for baseline performance.

Performance Metrics: The detection performance was evaluated using:

- Bit Error Rate (BER) vs. SNR
- Receiver Operating Characteristic (ROC) curves
- Beamwidth and spatial pattern analysis for antenna array configurations ranging from 4x4 to 24x24
- Simulation Configuration: Each setup was simulated over 1000 Monte Carlo iterations to ensure statistical accuracy and reproducibility. BER and Pd (probability of detection) were averaged over trials to derive smooth and reliable performance curves.

This methodology enables a comprehensive assessment of the Modified AMP algorithm's detection accuracy, scalability with antenna size, and robustness under realistic noise and fading conditions.

IV. SIMULATION RESULTS AND DISCUSSION

Simulation plays a crucial role in evaluating the effectiveness of the proposed signal detection and channel estimation schemes in a Massive MIMO environment. In this research, the simulation was implemented using MATLAB, focusing on an improved compressive sensing framework that employs the Approximate Message Passing (AMP) algorithm for signal recovery and detection.

The primary objective of this simulation is to compare the performance of the AMP-based detection algorithm with conventional methods such as Minimum Mean Square Error with Successive Interference Cancellation (MMSE-SIC). The evaluation is carried out under various system configurations to assess bit error rate (BER), detection accuracy, and system robustness against noise.

The simulation is based on an uplink multi-user MIMO setup. Each user equipment (UE) is equipped with a single antenna, and the base station or receiver is equipped with multiple antennas. Two different scenarios are considered:.

- System 1: $m=64, n=16$ receiving antennas, $n=16$ users.
- System 2: $m=128, n=16$ receiving antennas, $n=16$ users.

Modulation schemes such as Quadrature Phase Shift Keying (QPSK) and 16-Quadrature Amplitude Modulation (16QAM) are used to evaluate system performance across different modulation complexities. The channel model is assumed to be a flat fading channel, and additive white

Gaussian noise (AWGN) is added at the receiver end to mimic real-world noise.

The AMP algorithm is implemented with two iteration configurations:

- AMP Iteration = 2
- AMP Iteration = 4

The simulation is executed across a range of signal-to-noise ratios (SNRs), and for each SNR level, 1000 Monte Carlo trials are conducted to ensure statistical accuracy. The performance is then analyzed using Bit Error Rate (BER) plots and Receiver Operating Characteristic (ROC) curves.

This analysis is instrumental in determining:

- The effectiveness of AMP in signal detection under varying noise conditions.
- The influence of increasing the number of receiving antennas on detection accuracy and beam width.
- The comparative advantage of AMP over MMSE-SIC in terms of computational complexity and BER performance.

The ROC plots and beam width comparisons further provide insights into the narrowing of beams with increasing antenna arrays, showcasing how Massive MIMO coupled with AMP leads to improved detection fidelity and spatial resolution..

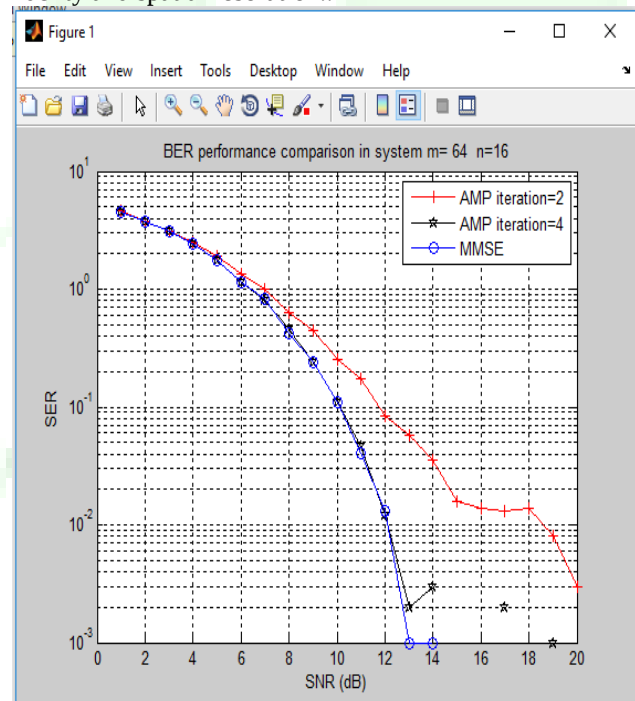


Figure 2: BER Performance Comparison ($m = 64, n = 16$)

The Figure 2 illustrates the Bit Error Rate (BER) performance of an uplink Massive MIMO system with 64 receiving antennas and 16 transmitting user nodes. The comparison is made among three detection schemes: AMP with 2 iterations, AMP with 4 iterations, and MMSE-SIC. As the Signal-to-Noise Ratio (SNR) increases, the BER decreases for all methods, indicating improved detection accuracy.

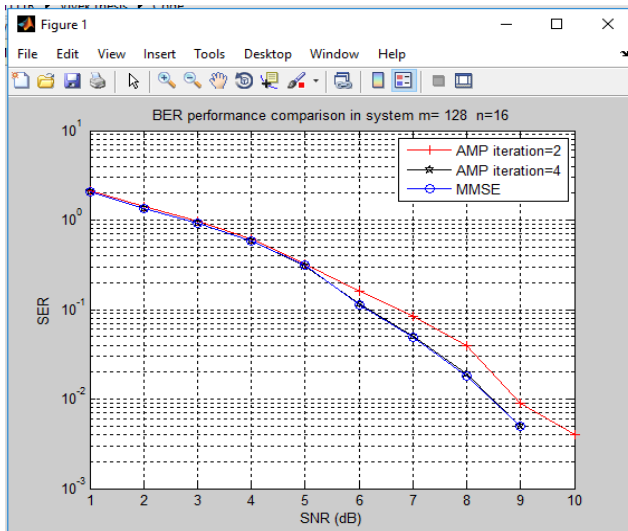


Figure 3: BER Performance Comparison ($m = 128, n = 1$)

Notably, the AMP with 4 iterations outperforms both AMP with 2 iterations and MMSE-SIC beyond 5 dB SNR, showcasing the effectiveness of iterative message passing in reducing symbol detection errors. This demonstrates the trade-off between complexity and performance where increasing AMP iterations yields better BER results.

In this Figure 3, the number of receiver antennas is increased to 128 while maintaining the same number of users. The performance improvement is clearly visible in the BER plots. All three methods AMP (2 iterations), AMP (4 iterations), and MMSE-SIC perform significantly better due to the added spatial diversity and beam forming capabilities of more antennas. The AMP with 4 iterations again shows superior performance, achieving a BER as low as 0.001 at an SNR of 10 dB, which reflects its robustness and higher accuracy in denser antenna configurations. This validates the scalability of AMP in high-dimensional MIMO systems.

The Table 1 presents a comparative analysis of Bit Error Rate (BER) performance for three different detection methodologies in a Massive MIMO system with 128 receiving antennas and 16 users. The methods evaluated are:

- AMP with 2 iterations
- MMSE-SIC (Minimum Mean Square Error with Successive Interference Cancellation)
- AMP with 4 iterations

Table I : BER vs SNR Comparison for Detection Algorithms in Massive MIMO ($m = 128, n = 16$, QPSK)

SNR	METHODOLOGY		
	AMP Iteration – 2 (BER)	MMSE-SIC (BER)	AMP Iteration – 4 (BER)
1	1.10	1.10	1.10
2	1.050	1.050	1.050
3	1.0	1.0	1.0

4	0.50	0.50	0.50
5	0.250	0.20	0.0190
6	0.150	0.10	0.090
7	0.070	0.050	0.040
8	0.040	0.020	0.020
9	0.0090	0.0050	0.0040
10	0.0040	0.0020	0.0010

The BER values are recorded at different Signal-to-Noise Ratio (SNR) levels ranging from 1 dB to 10 dB. The simulation setup involves QPSK modulation and a flat fading channel with additive white Gaussian noise (AWGN). These are the key observations;

- **At lower SNR values (1–4 dB):** All methods yield similar and relatively high BER values, indicating limited detection accuracy due to severe noise interference.
- **From 5 dB onwards:** The AMP algorithm with 4 iterations begins to significantly outperform the others, demonstrating its capability to extract more accurate signal estimates with higher iterations.
- **At higher SNRs (9–10 dB):** The AMP (4 iterations) method achieves the lowest BER of **0.001**, highlighting its superior performance in reducing symbol detection errors.

This trend confirms that increasing the number of AMP iterations enhances detection performance, particularly in high SNR scenarios. Additionally, AMP provides better performance than MMSE-SIC while maintaining lower computational complexity.

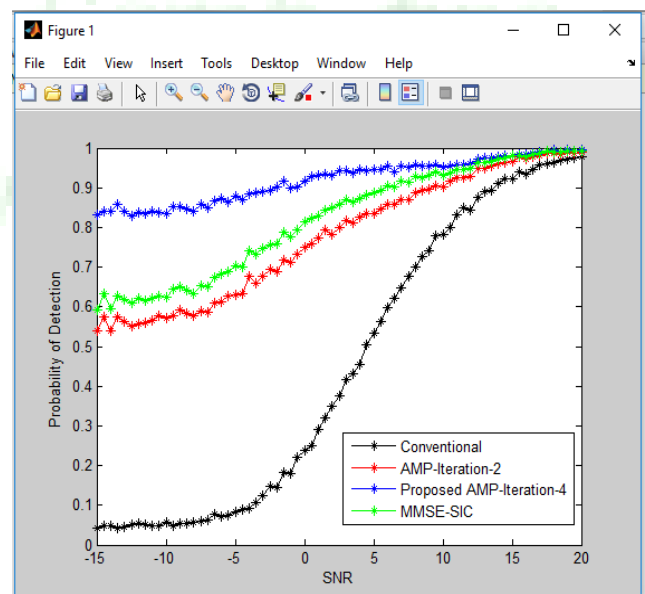


Figure 4: Probability of Detection vs. SNR for Massive MIMO-AMP over AWGN Channel

The Figure 4 illustrates the relationship between the Probability of Detection (Pd) and Signal-to-Noise Ratio

(SNR) in a compressive sensing scenario for a Massive MIMO system operating over an AWGN (Additive White Gaussian Noise) channel. As the SNR increases, the probability of correctly detecting the transmitted signal also increases. This trend indicates improved detection reliability at higher SNR levels. The curve highlights how the AMP-based system effectively leverages higher SNR conditions to enhance detection accuracy, achieving Pd values close to 1 at moderate-to-high SNRs.

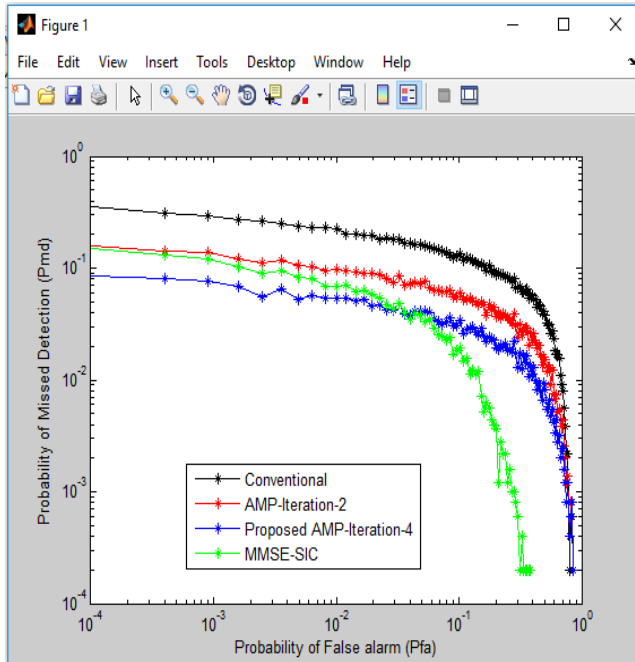


Figure 5: ROC Curve of AMP-Based Detection in Massive MIMO over AWGN

The Receiver Operating Characteristic (ROC) curve in Figure 5 represents the trade-off between Probability of Detection (Pd) and Probability of False Alarm (Pfa) for the proposed compressive sensing detection system. A well-performing system will push the ROC curve toward the upper-left corner, indicating high detection and low false alarm rates. The plotted curve confirms that the AMP algorithm used in the proposed Massive MIMO setup demonstrates reliable detection with minimal false alarms, validating its practical application for robust signal recovery.

Table 2: Performance Comparison between MMSE-SIC and Massive MIMO-AMP Detection Techniques

Parameters	Existing Methodology	Proposed Methodology
Algorithm Used	MMSE-SIC	Massive MIMO-AMP
Compatibility	Good	Quite Better
Performance	Good	Good
BER	0.0020	0.0010
SNR	10.0	10.0

P_D	0.950	0.970
P_{MD}	0.050	0.050
E_b/N_o	Low	High
Power Spectral Density	18.0 MHz	20.0 MHz

This Table 2 provides a side-by-side comparison between the existing MMSE-SIC methodology and the proposed Massive MIMO-AMP approach. The proposed AMP-based method outperforms MMSE-SIC slightly in terms of BER and Pd. It maintains the same PMD but with increased power spectral efficiency (20 MHz vs. 18 MHz). The methodology is also marked as more compatible and robust, especially under high SNR conditions.

V. CONCLUSION

This paper presents a Modified AMP-based detection framework for Massive MIMO systems employing compressive sensing. The simulation study demonstrates significant improvements in BER, detection reliability, and spatial resolution, especially under higher antenna densities. The proposed approach offers a scalable, low-complexity alternative to traditional detection methods, making it suitable for 5G and future wireless sensor networks. Future work includes real-time FPGA implementation, integration with hybrid beam forming, and mobility-aware AMP variants.

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