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Massive MIMO System for Compressive Sensing Using AMP

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Abstract- Multiple Input-Multiple Output (MIMO) systems have turn out to be necessity of wireless communication systems to conquer bandwidth restrictions. Massive-MIMO systems are capable of improving the channel capability of the system. This paper presents design, architecture, challenges, limitations and the possible improvements in a Massive-MIMO system. In this dissertation proposed improved compressive sensing is simulated using MATLAB. The results of proposed mechanism are in the form of the Receiver Operating Curves (ROC plots), which are used to evaluate the performance of any binary hypothesis. Since compressive sensing is best modeled as a diagnosis that is carried out to MIMO detection, ROC plots are the best way of analyzing the detection process and done channel estimation.

Consider an uplink multiuser MIMO system with $n = 16$ independent users each UE equipped with a single antenna, and the receiver equipped with $m = 64$ and $m = 128$ receiving antennas. Used QPSK and 16QAM as modulation schemes. Generate a random channel matrix H and a random transmit vector x. Assume the channel model is a flat fading channel and the symbols in the random vector are uncorrelated. At the receiver the signal undergoes additive white Gaussian noise. We use the AMP algorithm for detection.

Keywords: MIMO, Compressive Sensing, ROC, AMP, QPSK, 16QAM.

I. INTRODUCTION

Over the last few years, massive multiple-input multiple-output (MIMO) has shown up as an emerging technology for wireless communication systems. Featuring up to thousands of transmit/receive antennas, the possibility of creating extremely narrow beams for many users is gaining the attention of industry and academia. Researchers are focusing their efforts on the promised benefits of this technology to create the next generation of communication systems. The underlying idea is to scale up the number of antennas at the base station (BS) by at least two orders of magnitude. The end effects of indefinitely increasing the number of antennas are small fading effects and additive noise. In a multiuser MIMO scenario, Massive MIMO opens the possibility to steer many spatial streams to dozens of pieces of user equipment (UE) in the same cell, at the same frequency, and at the same time. Mobile networks are currently facing rapid traffic growth from both smartphones and tablets. Sequential improvements of service quality set the new challenge of increasing wireless network capacity about a thousand times within the next decade, but no current wireless access technique can provide a significant improvement in capacity. A possible solution to cope with such a capacity demand is through network densification by adding small cells (SCs) (pico-cells and femtocells) that operate at high frequencies (e.g. 60 GHz) within the macro cell area.

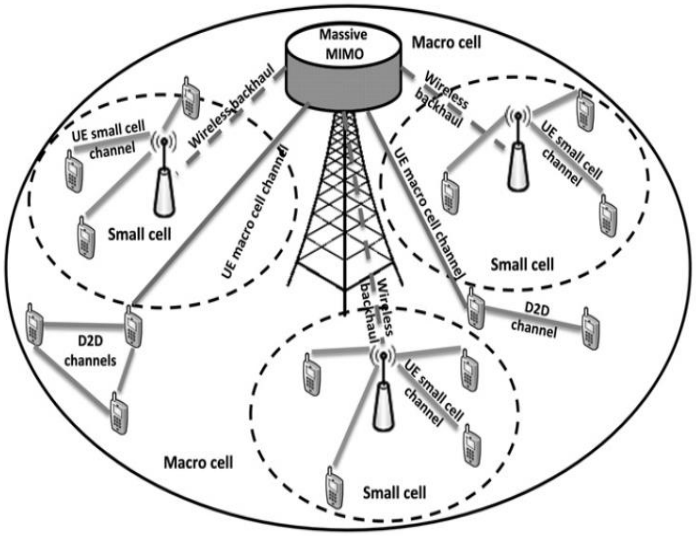

Figure 1 Architecture of HET-NET

SCs that utilize the same band spectrum can increase the capacity of a mobile network from 10 to 100 times, depending on the number of SCs and frequency reuse method. The energy efficiency of massive MIMO and SC has been studied. The authors proved that massive MIMO has better energy efficiency when the number of SCs is low, while SC offers better performance when the number of SCs is high.

However, a globally optimal trade-off between massive MIMO and SC efficiency is hard to achieve due to dynamic network behavior. A viable solution could be found by converging massive MIMO, SCs, and device-to-device (D2D) communications into a single cloud-controlled heterogeneous network (Het-Net), as shown in figure 1.

In this paper we discussed introductory part in section 1 and related work discuss in section 2. System model and results discussion and conclusion describe the section 3, 4 and 5 respectively.

II. RELATED WORK

In this section we describe the literature of different methodologies related to massive MIMO, MIMO detection and MIMO-OFDM.

Di Zhang et al. [1]: proposed that the non-regenerative massive multi-input-multioutput (MIMO) non-orthogonal multiple access (NOMA) relay systems are introduced by this study. The simulation results also illustrate that: i) the transmitter antenna, averaged power value and user number display the positive correlations on the capacity and sum rate performances, whereas the relay number displays a negative correlation on the performance; ii) the combined massive-MIMO-NOMA scheme is capable of achieving higher capacity performance compared to the conventional MIMONOMA, relay assisted NOMA and massive-MIMO orthogonal multiple access (OMA) scheme.

K N R Surya Vara Prasad et al. [2]: Make progress toward the 5G of wireless networks, the bit-per-joule energy efficiency (EE) becomes an important design criterion for sustainable evolution. In this regard, one of the key enablers for 5G is massive multiple-input multiple-output (MIMO) technology, where the BSs are equipped with an excess of antennas to achieve multiple orders of spectral and energy efficiency gains over current LTE networks.

Qurrat-Ul-Ain et al. [3]: Presented that the full-dimension multiple-input multiple-output (FD-MIMO) technology, which is currently an active area of research and standardization in wireless communications for evolution towards Fifth Generation (5G) cellular systems. FD-MIMO utilizes an active antenna system (AAS) with a two-dimensional (2D) planar array structure that not only allows a large number of antenna elements to be packed within feasible base station form factors but also provides the ability of adaptive electronic beamforming in the three dimensional (3D) space. Exploiting the quasi-static channel covariance matrices of users, the problem of determining the optimal down tilt weight vector for antenna ports, which maximizes the minimum signal to-interference ratio of a multi-user multiple-input-single-output system, is formulated as a fractional optimization problem. A quasi-optimal solution is obtained through the application of semi-definite relaxation and Dinkelbach's method. Finally, the user-group specific elevation beamforming scenario is devised, which offers significant performance gains as confirmed through simulations. These results have direct application in the analysis of 5G FD-MIMO systems.

Xin Liu et al. [4]: Presented that the Non-orthogonal multiple access (NOMA) has been considered as a highly efficient communication technology in the fifth generation (5G) networks by serving multiple users concurrently through non-orthogonal sharing communication resources. To reduce the relaying complexity in CNAR system, a simplified-CNAR (S-CNAR) system is proposed as an alternative NOMA enabled relaying strategy. Numerical results show that our antenna selection and user scheduling algorithms achieve similar performance to existing methods with reduced complexity. Under high target rate, CNAR obtains better performance over other transmission strategies and S-CNAR reaches similar performance by simplified relaying scheme.

David M. Gutierrez Estevez et al. [5]: In this paper, a practical novel TDD design principle is proposed for massive multiple-input multiple-output (MIMO) heterogeneous networks (Het-Nets) that leverages the inherent features of a flexible TDD design to mitigate both the beam formed interference caused by the pilot contamination effect and B2B interference. The design is based on the key observation that the transmission path chosen for training by the non-massive MIMO base stations plays an important role in the interference behavior of the network, and the data slots need to be configured accordingly. We propose TDFLEX, a low-complexity heuristic solution that follows these design guidelines. Performance evaluation results show significant gains when our design is compared to the standard TD-LTE.

Manish Madloi et al. [6]: presented study, the authors propose an improved multiple feedback successive interference cancellation (IMF-SIC) algorithm and an ordered IMF-SIC (OIMF- SIC) algorithm for near-optimal multiple-input multiple-output (MIMO) detection. To improve the accuracy of a decision, the authors propose an improved MF strategy where the shadow region condition is checked recursively. Further, the authors also propose an OIMF-SIC algorithm where the log likelihood ratio based dynamic ordering is utilized for ordering the detection sequence. Simulation results validate superiority of the proposed algorithms over the other SIC based detection techniques. In addition, to validate robustness of the proposed algorithms, BER performance is computed and compared under channel state information mismatch.

Guangyi Liu and Xueying Hou et al. [7]: The design has been implemented for 2.6 GHz TDD band, and field trials have been conducted for performance validation with practical inter-cell interference in commercial network. The trial results show that this 3D-MIMO design can meet the spectral efficiency requirement of 5G e-MBB services. The performance gain of 3D-MIMO varies with the traffic load. When the traffic load is heavy, 3D-MIMO can enhance the cell throughput by 4~6.7 times. When the traffic load is low, the performance gain of this 3D-MIMO design decreases. The results from field trial also show that the performance of 3D-MIMO degrades in mobility scenarios, where further enhancement on acquiring instant channel status information are necessary to improve the robustness of 3D-MIMO to mobility.

Sarun Duangsuwan and Punyawi Jamjareegulgarn et al. [8]: The massive MIMO technique has played the most important role in 5G wireless communication. It is anticipated that the new techniques employed in massive MIMO will not only improve peak service data rates significantly, but also enhance capacity, coverage, low-latency, efficiency flexibility, compatibility and convergence, thus meeting the focusing demands imposed by optimal detection. This paper presents the optimal detection of data symbol in massive MIMO for 5G wireless communication. Based on the frequency non-selective fading MIMO channel, we consider three difference detectors for recovering the transmitted data symbols and evaluate their performance for Rayleigh fading and additive white Gaussian noise (AWGN). At the results, we show that the probability of error rate (PER) performance of the detectors are significantly discussed.

Zujun Liu and Weimin Du et al. [9]: This correspondence investigates the fundamental tradeoff between the spectral efficiency (SE) and energy efficiency (EE) for the massive MIMO systems with linear precoding and transmit antenna selection, where both the circuit power consumption and the large-scale fading are considered. The EE and SE are optimized with respect to the number of transmit antennas and transmit power, and consequently we formulate the EE-SE tradeoff as a mixed-integer-continuous-variable multi objective optimization (MOO) problem. Using the derived EESE relations, the properties of the Pareto front for the EE-SE tradeoff are analyzed. To solve the complicated MOO problem, we develop two algorithms: the weighted-sum particle swarm optimization (WS-PSO) algorithm and the normal-boundary intersection particle swarm optimization (NBI-PSO) algorithm. Simulation results show that the two algorithms can achieve the Pareto optimal EE-SE tradeoff, and NBI-PSO provides more evenly distributed solutions than WS-PSO.

Hengzhi Wang and Wei Wang et al. [10]: In this paper, propose a hybrid limited feedback with selective eigenvalue information (HLFSEI), which adopts the individual quantized feedback and the codebook-based feedback jointly. In HLFSEI, we feedback only selective eigenvalue elements for power allocation by individual quantized feedback and the precoding matrix by codebook-based feedback. Furthermore, we study the optimal feedback bit allocation of the aforementioned two feedback methods to minimize the throughput loss with the feedback-link capacity constraint. Specifically, the feedback bits are allocated according to the properties of the throughput loss in high- and low-signal-to-noise regimes. Both the BS–RS communications and the BS/RS–user-equipment communications in cellular systems are taken into consideration. Finally, we evaluate the performance of the proposed HLFSEI strategy by simulation and show its performance gain compared with conventional feedback strategies.

III. SYSTEM MODEL

MIMO systems are not sufficiently capable to cater the need of growing data rate necessities of next generation wireless communications. Also due to technical and design constraints user equipment’s cannot have much more antenna elements. To overcome this problem Massive-MIMO can be used as leading technique in which huge antenna arrays are used at base station with maximum possible separation among antenna elements. It consists of all the advantages of MIMO systems with many fold increased data throughput. It is a low cost and low power communication system.

Multiple antenna systems combined with multi-carrier systems gives tremendous performance for a wireless communication system. MIMO-OFDM using different kind of FFT algorithms is practically very much useful in 4G communication systems. With improved features of conventional OFDM systems integrated with large scale MIMO named as Massive-MIMO-OFDM is one of the most capable techniques for wireless communication systems of future generation (like 5G).

MIMO-OFDM Model: The combination of MIMO with OFDM results in increased throughput due to MIMO systems and flat fading is achieved due to OFDM. Frequency selective MIMO channel can be expressed mathematically as,

$$\begin{aligned}\bar{\boldsymbol{Z}}(\boldsymbol{t}) = \boldsymbol{H}(\boldsymbol{0})\bar{\boldsymbol{S}}(\boldsymbol{t}) + \boldsymbol{H}(\boldsymbol{1})\bar{\boldsymbol{S}}(\boldsymbol{t}-\boldsymbol{1}) + \boldsymbol{H}(\boldsymbol{2})\bar{\boldsymbol{S}}(\boldsymbol{t}-\boldsymbol{2}) \\ + \cdots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \\ + \boldsymbol{H}(\boldsymbol{L}-\boldsymbol{1})\bar{\boldsymbol{S}}(\boldsymbol{t}-\boldsymbol{L}+\boldsymbol{1}) \\ + \bar{\boldsymbol{n}}(\boldsymbol{t})\end{aligned}$$

Where,

$$\bar{\boldsymbol{S}}(\boldsymbol{t}) = \boldsymbol{T_x\ vector\ at\ time\ (t)}$$

$$\bar{\boldsymbol{S}}(\boldsymbol{t}-\boldsymbol{1}) = \boldsymbol{T_x\ vector\ at\ time\ (t-1)}$$

$$\boldsymbol{H}(\boldsymbol{L}) = \boldsymbol{Channel\ matrix\ correshponding\ to\ tap\ L.\ (N \times M\ Matrix);\ and\ \bar{n}(t) = noise.}$$

In a MIMO channel, Inter Symbol Interference (ISI) occurs between current and previous transmitted symbol vectors. To overcome this problem, IFFT operation is performed for each transmit antenna in a MIMO-OFDM system. MIMO-OFDM system converts a MIMO frequency selective channel into a set of multiple parallel flat fading MIMO channels. The N-parallel flat fading MIMO channels can be expressed mathematically as;

$$\bar{\boldsymbol{Z}}(\boldsymbol{0}) = \bar{\boldsymbol{H}}(\boldsymbol{0})\,\bar{\boldsymbol{S}}(\boldsymbol{0})$$

$$\bar{\boldsymbol{Z}}(\boldsymbol{1}) = \bar{\boldsymbol{H}}(\boldsymbol{1})\,\bar{\boldsymbol{S}}(\boldsymbol{1})$$

$$\bar{\boldsymbol{Z}}(\boldsymbol{N}-\boldsymbol{1}) = \bar{\boldsymbol{H}}(\boldsymbol{M}-\boldsymbol{1})\,\bar{\boldsymbol{S}}(\boldsymbol{M}-\boldsymbol{1})$$

In general,

$$\bar{\boldsymbol{Z}}(\boldsymbol{k}) = \bar{\boldsymbol{H}}(\boldsymbol{k})\,\bar{\boldsymbol{S}}(\boldsymbol{k})$$

Where,

$$\bar{\boldsymbol{Z}}(\boldsymbol{k}) = \boldsymbol{Rx1\ receive\ vector\ corresponding\ to\ subcarrier\ (k)}$$

$$\bar{\boldsymbol{H}}(\boldsymbol{k}) = \boldsymbol{flat\ fading\ channel\ matrix\ corresponding\ to\ subcarrier}\ (\boldsymbol{k})$$

$$\bar{\boldsymbol{S}}(\boldsymbol{k}) = \boldsymbol{Tx1\ transmit\ vector\ corresponding\ to\ subcarrier}\ (\boldsymbol{k})$$

Each of $\bar{\boldsymbol{Z}}(\boldsymbol{k})$ can be processed by a simple MIMO-ZF receiver or a MIMO-MMSE receiver for detection of vector $\bar{\boldsymbol{S}}(\boldsymbol{k})$.

AMP for Massive MIMO Detection: The Massive MIMO architecture is to serve tens of users by employing hundreds of antennas,

$$\boldsymbol{y} = \boldsymbol{Hx} + \boldsymbol{w}$$

Where the channel $\boldsymbol{H} \in \mathbb{C}^{m\times n}$ has its element sample from $\boldsymbol{N_C}\left(\boldsymbol{0}, \frac{1}{m}\right), \boldsymbol{m} \gg \boldsymbol{n}$,

- **$\boldsymbol{y} \in \mathbb{C}^{m}$ is the received signal,**
- **AWGN noise components $\boldsymbol{\omega_i}$ are i.i.d with $\boldsymbol{N_C}(\boldsymbol{0}, \boldsymbol{\sigma^2})$;**
- **Regarding the transmitted x, We only assume that it is zero mean and finite variance $\boldsymbol{\sigma_s^2}$.**

Before incorporating the AMP algorithm, we should be well aware of two facts:

1) Directly using maximum a priori (MAP) $\mathbf{arg\,max}\,\boldsymbol{p}(\boldsymbol{x}|\boldsymbol{y})$ or MMSE estimation $\boldsymbol{E_{p(x|y)}}(\boldsymbol{X})$ to work with the exact prior degrade the necessity of employing AMP, because achieving a full diversity requires an extremely large set of constellation points, in which AMP works slowly while doing the moment matching process, not to mention problems about its inability to converge to the lowest fixed point.
2) In the CDMA multiuser detection theory [Verdu98, etc.], their “MMSE” detector does not mean the one working with exact prior , but rather the one assuming a Gaussian prior.

So we use a proxy prior for detecting x, i.e. assuming that $\boldsymbol{x_i} \sim \boldsymbol{N_C}(\boldsymbol{0}, \boldsymbol{\sigma_s^2})$, even though it may be inexact. In this occurrence, we have the signal power $\boldsymbol{\sigma_s^2 = 2}$ **in QPSK,** $\boldsymbol{\sigma_s^2 = 10}$ **in 16QAM,** etc. So the target function becomes**:**

$$\boldsymbol{min}\ ||\boldsymbol{y} - \boldsymbol{Hx}||^2, \boldsymbol{s.t.}\, \boldsymbol{x_i} \sim \boldsymbol{N_C}(\boldsymbol{0}, \boldsymbol{\sigma_s^2})$$

The AMP algorithm to solve the above problem only require three line as depicted below;

$$\boldsymbol{r^t} = \boldsymbol{y} - \boldsymbol{HX^{t-1}} + \frac{\boldsymbol{n}}{\boldsymbol{m}} \frac{\boldsymbol{\sigma_s^2}}{\boldsymbol{\sigma_s^2} + \boldsymbol{\alpha^{t-1}}} \boldsymbol{r^{t-1}}$$

$$\boldsymbol{\alpha^t} = \boldsymbol{\sigma^2} + \frac{\boldsymbol{n}}{\boldsymbol{m}} \frac{\boldsymbol{\alpha^{t-1}\sigma_s^2}}{\boldsymbol{\sigma_s^2} + \boldsymbol{\alpha^{t-1}}}$$

$$\boldsymbol{X^t} = \frac{\boldsymbol{\sigma_s^2}}{\boldsymbol{\sigma_s^2} + \boldsymbol{\alpha^t}} (\boldsymbol{H^* r^t} + \boldsymbol{X^{t-1}})$$

- Where the initialization is to let $\boldsymbol{r^0 = 0, x^0 = 0, \alpha^0 = \sigma_s^2}$.
- In terms of complexity, it only costs $\boldsymbol{2mn} \times (\boldsymbol{\#Iteration})$.
- Also according to the second equation of the algorithm, it is converging extremely fast.
- On the contrary, MMSE has complexity $0(mn^2)$.
- It is noteworthy that known approximation methods to MMSE, such as Richardson’s method or Newman series approximation, both fall behind the complexity performance trade-off of AMP according to our simulation.

IV. SIMULATION RESULTS

Flow Chart for Simulation of the Proposed Optimization: Simulation refers to the imitation of the operation of a real-world process or system. Simulation involves the development of a model using efficient software that closely represents the physical world system/ process under study. This illustrates the simulation of the compressive sensing scheme using MATLAB platform.

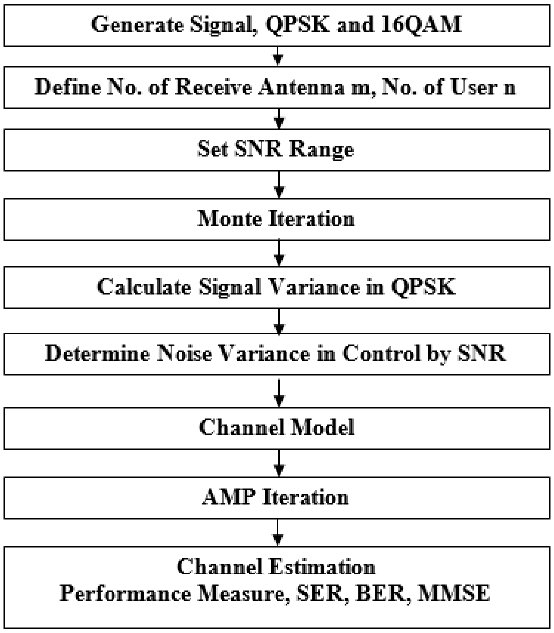

Figure 2: Flow Chart for Simulation of the Proposed Optimization

Steps involve in this proposed optimization for simulation as follows:

1) Generate the signal for transmission, signal noise and receive signal at different node.

2) Define the number of receive antenna and number of user.
3) Set SNR range and iteration done by monte iteration method and calculate the signal variance and noise variance of the transmission signal.
4) Apply approximate message passing for massive MIMO channel model.
5) Iteration done by the AMP iteration method.
6) Estimate the channel performance matrices i.e. SER, BER, MMSE.

We consider an uplink multiuser MIMO system with n = 16 independent users each UE equipped with a single antenna, and the receiver equipped with m = 64 receiving antennas. We use QPSK and 16QAM as modulation schemes. We generate a random channel matrix H and a random transmit vector x. We assume the channel model is a flat fading channel and the symbols in the random vector are uncorrelated. At the receiver the signal undergoes additive white Gaussian noise. We use the AMP algorithm for detection.

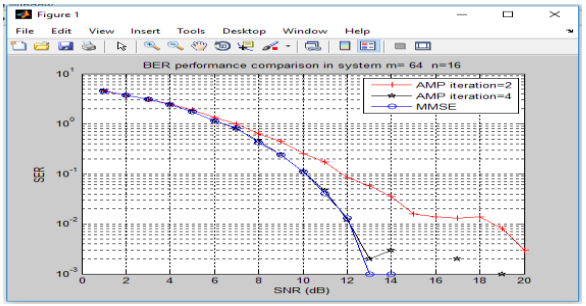

Figure 3: Shows the BER performance comparison in system m=64, n=16

We consider an uplink multiuser MIMO system with n = 16 independent users each UE equipped with a single antenna, and the receiver equipped with m = 128 receiving antennas. We use QPSK and 16QAM as modulation schemes. We generate a random channel matrix H and a random transmit vector x. We assume the channel model is a flat fading channel and the symbols in the random vector are uncorrelated. At the receiver the signal undergoes additive white Gaussian noise. We use the AMP algorithm for detection.

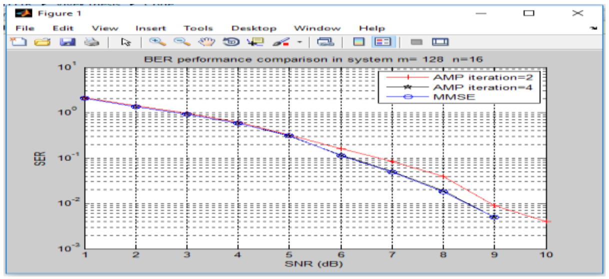

Figure 4: Shows the BER performance comparison in system m=128, n=16

Above these figure 3 and figure 4 depicted that the BER performance comparison between AMP iteration = 2, AMP iteration = 4, and MMSE. We run the simulation at the maximum number of iterations of the AMP algorithm, 20 iterations per trial, 1000 trials per given SNR value. The maximum SNR is 20 dB for (QPSK m=64, n=16), and 10 dB for (QPSK m=128, n=16).

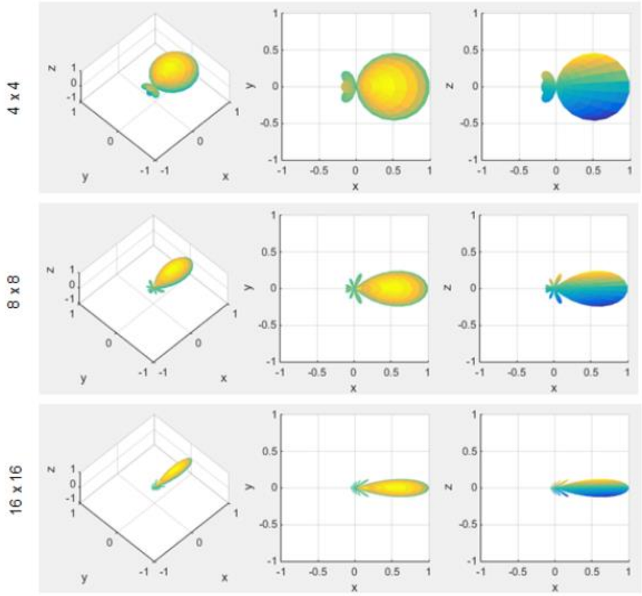

Figure 5: Comparison of beam of different array antenna

Above depicted figure 5 shows the comparison of beam of different array antenna, concluded that narrower the beam width become as the number of antenna in the array get larger.

V. CONCLUSION

We consider an uplink multiuser MIMO system with n = 16 independent users each UE equipped with a single antenna, and the receiver equipped with m = 64 and m = 128 receiving antennas. We use QPSK and 16QAM as modulation schemes. We generate a random channel matrix H and a random transmit vector x. We assume the channel model is a flat fading channel and the symbols in the random vector are uncorrelated. At the receiver the signal undergoes additive white Gaussian noise. We use the AMP algorithm for detection.

In addition to increasing the received power, Massive MIMO provides several other advantages as well. According to "Massive MIMO for Next Generation Wireless Systems", the potential (advantage) of Massive MIMO is described as follows;

- ➢ Massive MIMO can increase the capacity 10 times or more and simultaneously, improve the radiated energy efficiency in the order of 100 times.

- Massive MIMO can be built with inexpensive, low power consumption.
- Massive MIMO enables a significant reduction of latency on the air interface (due to robustness against fading) Massive MIMO simplifies the multiple access layer Massive MIMO increases the robustness both to unintended manmade interference and to intentional jamming.

It is the fact that most of energy transmitted from the antenna array focus on very narrow area. It means the beam width get narrower as you use more antenna. Following plot would give you an example for the effect of bandwidth narrowing with the increased number of antenna. Advantage would be that there will be less interference between beams for different users since each of the beam would be focused in very small area and the disadvantage would be that you have to implement very sophisticated algorithm to find exact location of the user and directing the beam to the user with high accuracy.

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