Review on Massive MIMO (Multiple Input Multiple Output)

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Abstract- *This paper gives an overview of Massive MIMO (Multiple Input Multiple Output). Massive MIMO (also known as large-scale antenna systems, hyper MIMO, full-dimension MIMO and hybrid MIMO) makes a clean break with current practice through the use of a large number of service antennas over active terminals and provide large network capacities in multi-user scenarios.The large number of antenna arrays can improve the spectral and energy efficiency of system as compared to single antenna system. Additional benefit of massive MIMO is that the cost of components is less as low power components are used. This technology renders different problems but it also solves many problems that are the need of time. This paper reviews about massive MIMO concept, description of system model, challenges and its benefits to wireless communication systems.*

Key Words: **Massive MIMO, very-large MIMO, multi-user MIMO (MU-MIMO), BS- Base Station**

1. INTRODUCTION

Massive multiple-input multiple-output (MIMO) is an emerging technology that scales up MIMO by orders of magnitude compared to the present state of the art. Multiple-input multiple-output (MIMO) technology is a topic of concern from the past twenty years because it is proved to be efficient in terms of reliability and capacity of the wireless systems.In massive MIMO, we take into account multi-user MIMO (MU-MIMO) systems [1] where base stations are equipped with a large number (say, tens to hundreds) of antennas. As a comparison, the LTE standard only allows for up to 8 antennas at the base station [2]. In this way, massive MIMO scales up conventional MIMO by an order or two in magnitude. Typically, a base station with a large number of antennas serves many single-antenna users within the same time-frequency resource.

While initial work on the problem mainly focused on point-to-point MIMO systems where two devices with multiple antennas can communicate with one another, focus has been shifted in recent years to more practical multi-user MIMO (MU-MIMO) systems, where a base station (BS) with multiple antennas at the same time serves a group of single-antenna users and the multiplexing gain will be shared by all users. In this manner, expensive equipment is only needed on the BS side, and the user terminals can be comparatively low cost single-antenna devices. The performance of MU-MIMO systems is usually less sensitive to the propagation environment than in the point-to-point MIMO system because of multiuser diversity. As a result, MU-MIMO has become an integral part of communications standards, like 802.11 (Wi-Fi), 802.16 (WiMAX), LTE, and is progressively being deployed throughout the globe. In the most of MIMO system implementations, the BS generally consists only a few (i.e., fewer than 10) antennas, according to that the improvement in spectral efficiency, while importance is still comparatively modest.

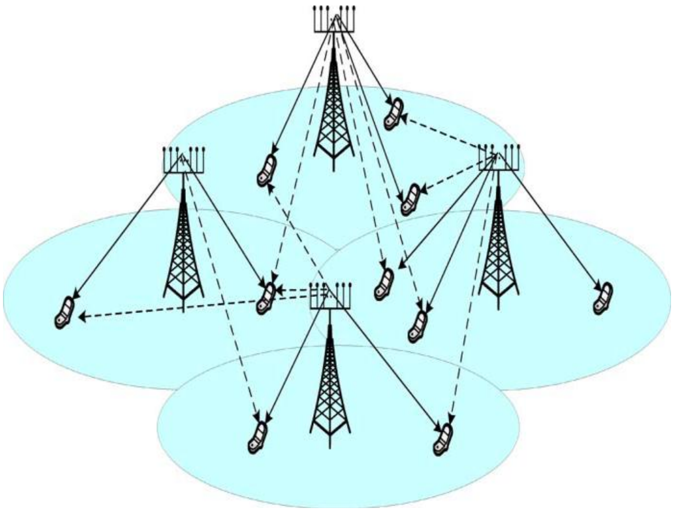

Fig. 1. Illustration of Massive MU-MIMO systems [5]

Massive MIMO systems or large-scale antenna systems (LSAS) have been proposed in [3], [4], where every BS is provided with orders of magnitude more antennas, e.g., a hundred or more to realize additional dramatic gains as well as to simplify the required signal processing with recent efforts. A massive MU-MIMO network is depicted in Fig. 1. Asymptotic arguments supported random matrix theory [4] demonstrate that the result of uncorrelated noise and small-scale attenuation are eliminated, the number of users per cell are not dependent of the dimensions of the cell, and the required transmitted energy per bit vanishes as the number of antennas in a MIMO cell increases to infinity [5].

2. SYSTEM DESCRIPTION

Consider massive MIMO and MU-MIMO technology in cellular systems, where a base station is equipped with tens to hundreds of antennas, and communicates with many users simultaneously through spatial multiplexing. Fig. 2 illustrates the MU-MIMO system model in both downlink and uplink transmissions, for a single cell. MIMO with a large number of antennas, however, should not be limited to multi-user scenarios. It can also be used in single-user scene

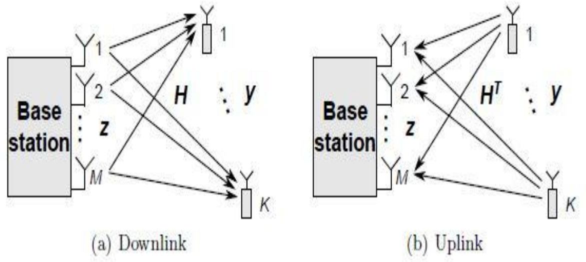

Fig. 2: An MU-MIMO system model, in the (a) downlink and (b) uplink [7]

An M-antenna base station serves K single-antenna users in a spatial-multiplexing manner. Channel reciprocity is assumed, so the relation between the downlink and uplink channel matrices is simply the matrix transpose [7].The downlink signal model for each time-frequency resource is,

$$Y_\ell = \sqrt{\rho_{dl}}\, Hz_\ell + n_\ell \qquad (1)$$

Where H_l is a K*M the propagation channel matrix, z_l is normalized vector across the M antennas Assume that $E\{||zl||^2\} = 1$, y is the receive signal vector at the K users, and n is the white-noise vector with i.i.d. circularly-symmetric complex Gaussian, CN $(0; \sigma_n^2)$, elements, so $\sqrt{\rho_{dl}}$ contains the total transmit power in the downlink. Two power-scaling factor ($\rho_{dl} = \rho K/M$), where ρ is an SNR factor. We scale up to transmit power with the number of users K, and choose to 1) keep it constant or 2) scale it down with the number of antennas M. From the term ρ K /M, we increase the transmit power with the number of users and reduce it as the number of base station antennas grows [7]. As K Increases, we keep the same transmit power per user. With increasing M the array gain increases and we choose to harvest this as reduced transmit power instead of increased receive SNR at the users

Due to reciprocity, the uplink channel matrix is H_l^T, and the signal model becomes

$$Z_\ell = \sqrt{\rho_{ul}}\, H_\ell^T y_\ell + n_\ell \qquad (2)$$

The total transmit power from all users is ρ_{ul} and $\rho_{dl} = (\rho K/M)$ depending on used power-scaling scheme. If we assume independent and identically distributed (i.i.d.) Gaussian transmit signals and that perfect CSI is available at the receiver, the instantaneous achievable rate can be expressed as [6]

$$C = \log_2 (\det (I + \frac{\rho}{Nt} HH^H)) \text{ bps/Hz} \qquad (3)$$

The actual achievable rate depends on the distribution of the singular values of HH^H.

3. THE POTENTIAL OF MASSIVE MIMO

Massive MIMO technology depends computationally very simple processing of signals from all the antennas at the base station. Some potentials of a massive MU-MIMO system are [8]:

- Massive MIMO can increase the capacity 10 times or more and simultaneously improve the radiated energy efficiency on the order of 100 times. The capacity of Massive MIMO increase due to aggressive spatial multiplexing use. The basic principle that creates the dramatic increase in energy efficiency possible is that with a large number of antennas.
- Massive MIMO are often designed with low-cost, low-power components. Massive MIMO is a game changing technology with relation to theory, systems, and implementation. With massive MIMO, expensive ultra-linear 50 W amplifiers used in conventional systems are replaced by hundreds of low-cost amplifiers with output power in the milli-Watt range.
- Massive MIMO increases the robustness against both unintended man-made interference and intentional jamming. Intentional jamming of civilian wireless systems is a growing concern and a serious cybersecurity threat that seems to be little known to the public.
- Massive MIMO allows a major reduction of latency on the air interface. The performance of wireless communications systems is generally restricted by fading. Fading will render the received signal strength terribly small at certain times. This happens when the signal sent from a base station travels through different paths before it reaches to the end of terminal, and the waves resulting from these different paths interfere destructively.
- Massive MIMO simplifies the multiple access layer. Due to the law of large numbers, the channel hardens in order that frequency domain duplexing no longer pays off.

4. OPPORTUNITIES FOR RESEARCH

To create massive MIMO systems a reality, there are still several problems that need to be studied and addressed. Some of these opportunities are discussed below.

- Propagation Models: Most existing work on massive MIMO is predicted on the fact that the individual user channels are spatially uncorrelated and their channel vectors asymptotically become pairwise orthogonal under favorable propagation conditions [5], whenever the number of antennas grows. Theoretical studies of massive MIMO generally assume i.i.d. complex Gaussian (Rayleigh fading) conditions [4], [9], the real antenna correlation coefficients are considerably larger than would be expected under i.i.d. channel assumptions. Moreover, very extremely correlated channel vectors cannot be rendered orthogonal by increasing the number of antennas. This means that user planning should be a major part of massive MIMO systems and is much more important than in regular MIMO implementation where more complicated signal processing will be used to separate spatially correlated users.

- Modulation: To construct a BS with a large number of antennas, cheap power-efficient RF amplifiers are necessary, and problems with high PAPR can impede good performance for OFDM [9]. Single-carrier transmission can achieve near-optimal sum-rate performance at low-transmit-power-to-receiver-noise-power ratios, without requiring equalization at the receiver and multi-user resource allocation. Whether this is possible for more general and complicated scenarios needs further investigation.

- Channel Reciprocity: Time-division duplexing operation depends on channel reciprocity. There seems to be a reasonable consensus that the propagation channel itself is basically reciprocal unless the propagation is suffering from materials with strange magnetic properties. Between the uplink and the downlink there is the hardware chains in the base station and terminal transceivers may not be reciprocal. Calibration of the hardware chains does not appear to constitute a serious problem. If the maximum phase difference between the hardware chains in case of uplink and downlink is less than 60º, then significant reduction in the gain can be observed. If the base station is properly calibrated then it is not necessary to calibrate the uplink and downlink chains, proper gain can be obtained. If the base station is not properly calibrated then effective techniques are needed to be used.

- Low cost hardware: -As in the massive MIMO systems a large number of RF chains, Analog-to-Digital (A/D) converters, Digital-to-Analog (D/A) converters etc. are needed, the economy study of the manufacturing unit should be done.

- Pilot Contamination: In every MIMO system a terminal is assigned with limited amount of orthogonal pilot sequence. The limit depends on the duration of the coherence interval divided by the channel delay spread [13]. In [13] the number of orthogonal pilot sequence is limited to about 200 with coherence interval of 1 msec. If the pilots are reused from one cell to other then its effect can be seen as Pilot Contamination. The effect of pilot contamination is of less importance to classical MIMO but it is more for Massive MIMO.

5. CONCLUSIONS

In this paper, the massive MIMO systems are comprehensively described with uplink and downlink systems. The technology offers huge advantages in terms of energy efficiency, spectral efficiency, robustness, and reliability. Different algorithms which can improve the efficiency of such systems are the need of future. The Massive MIMO technology has proven to be a goldmine for researchers. However to get benefited from the opportunities of MIMO, significant research is needed in hardware design, interference management and channel correlation. It will open many opportunities in the field of wireless communication and antenna wave propagation.

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