International Journal For Advanced Research In Science & Technology
A peer reviewed international journal www.ijarst.in
ISSN: 2457-0362

Massive MIMO for next generation wireless systems

[1]Dr.Maniganda P, [2]Dr Muralibabu K, [3]Dr. Venkateshwarra Rao
[1,2,3]Professor
Balaji Institute of Technology & Science

ABSTRACT Multi-user MIMO offers big advantages over conventional point-to-point MIMO: it works with cheap single-antenna terminals, a rich scattering environment is not required, and resource allocation is simplified because every active terminal utilizes all of the time-frequency bins. However, multi-user MIMO, as originally envisioned, with roughly equal numbers of service antennas and terminals and frequency-division duplex operation, is not a scalable technology. Massive MIMO (also known as large-scale antenna systems, very large MIMO, hyper MIMO, full-dimension MIMO, and ARGOS) makes a clean break with current practice through the use of a large excess of service antennas over active terminals and time-division duplex operation. Extra antennas help by focusing energy into ever smaller regions of space to bring huge improvements in throughput and radiated energy efficiency. Other benefits of massive MIMO include extensive use of inexpensive low-power components, reduced latency, simplification of the MAC layer, and robustness against intentional jamming. The anticipated throughput depends on the propagation environment providing asymptotically orthogonal channels to the terminals, but so far experiments have not disclosed any limitations in this regard. While massive MIMO renders many traditional research problems irrelevant, it uncovers entirely new problems that urgently need attention: the challenge of making many low-cost low-precision components that work effectively together, acquisition and synchronization for newly joined terminals, the exploitation of extra degrees of freedom provided by the excess of service antennas, reducing internal power consumption to achieve total energy efficiency reductions, and finding new deployment scenarios. This article presents an overview of the massive MIMO concept and contemporary research on the topic.

GOING LARGE: MASSIVE MIMO

Massive multiple-input multiple-output (MIMO) is an emerging technology that scales up MIMO by possibly orders of magnitude compared to the current state of the art. In this article, we follow up on our earlier exposition [1], with a focus on the developments in the last three years; most particularly, energy efficiency, exploitation of excess degrees of freedom, time-division duplex (TDD) calibration, techniques to combat pilot contamination, and entirely new channel measurements. With massive MIMO, we think of systems that use antenna arrays with a few hundred antennas simultaneously serving many tens of terminals in the same time-frequency resource. The basic premise behind massive MIMO is to reap all the benefits of conventional MIMO, but on a much greater scale. Overall, massive MIMO is an enabler for the development of future broadband (fixed and mobile) networks, which will be energy-efficient, secure, and robust, and will use the spectrum efficiently. As such, it is an enabler for the future digital society infrastructure that will connect the Internet of people and Internet of Things with clouds and other network infrastructure. Many different configurations and deployment scenarios for the actual antenna arrays used by a massive MIMO system can be envisioned (Fig. 1). Each antenna unit would be small and active, preferably fed via an optical or electric digital bus.

the number of channel responses each terminal must estimate is also proportional to the number of base station antennas. Hence, the uplink resources needed to inform the base station of the channel responses would be up to 100 times larger than in conventional systems. Generally, the solution is to operate in TDD mode, and rely on reciprocity between the uplink and downlink channels, although frequency-division duplext (FDD) operation may be possible in certain cases [2]. While the concepts of massive MIMO have been mostly theoretical so far, stimulating much research particularly in random matrix theory and related mathematics, basic testbeds are becoming available [3], and initial channel measurements have been performed [4, 5].

THE POTENTIAL OF MASSIVE MIMO

Massive MIMO technology relies on phasecoherent but computationally very simple processing of signals from all the antennas at the base station. Some specific benefits of a massive MU-MIMO system are: •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 increase results from the aggressive spatial multiplexing used in massive MIMO. The fundamental principle that makes the dramatic increase in energy efficiency possible is that with a large number of antennas, energy can be focused with extreme sharpness into small regions in space (Fig. 2). The underlying physics is coherent superposition of wavefronts. By appropriately shaping the signals sent out by the antennas, the base station can make sure that all wavefronts collectively emitted by all antennas add up constructively at the locations of the intended terminals, but destructively (randomly) almost everywhere else. Interference between terminals can be suppressed even further by using, for example, zero-forcing (ZF). This, however, may come at the cost of more transmitted power, as illustrated in Fig. 2

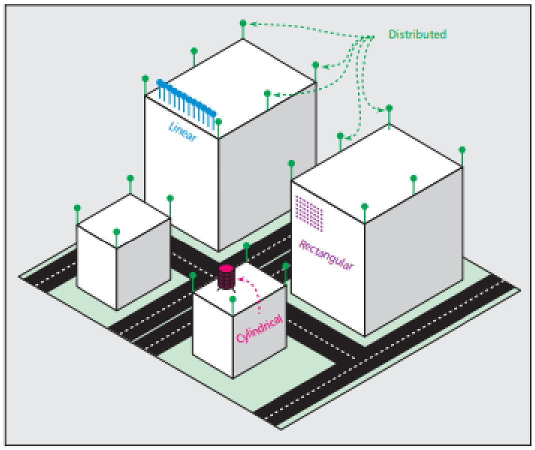

Figure 1. *Some possible antenna configurations and deployment scenarios for a massive MIMO base station.*

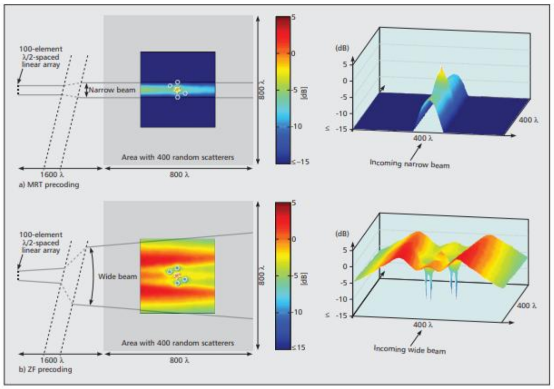

Figure 2. *Relative field strength around a target terminal in a scattering environment of size 800 λ × 800 λ when the base station is placed 1600 λ to the left. Average field strengths are calculated over 10,000 random placements of 400 scatterers when two different linear precoders are used: a) MRT precoders; b) ZF precoders. Left: pseudo-color plots of average field strengths, with target user positions at the center (★) and four other users nearby (○). Right: average field strengths as surface plots, allowing an alternate view of the spatial focusing.*

Massive MIMO reduces the constraints on accuracy and linearity of each individual amplifier and RF chain. All that matters is their combined action. In a way, massive MIMO relies on the law of large numbers to make sure that noise, fading, and hardware imperfections average out when signals from a large number of antennas are combined in the air. The same property that makes massive MIMO resilient against fading also makes the technology extremely robust to failure of one or a few of the antenna unit(s). A massive MIMO system has a large surplus of degrees of freedom. For example, with 200 antennas serving 20 terminals, 180 degrees of freedom are unused. These degrees of freedom can be used for hardware-friendly signal shaping. In particular, each antenna can transmit signals with very small peak-to-average ratio [9] or even constant envelope [10] at a very modest penalty in terms of increased total radiated power. Such (near-constant) envelope signaling facilitates the use of extremely cheap and powerefficient RF amplifiers. The techniques in [9, 10] must not be confused with conventional beamforming techniques or equal-magnitudeweight beamforming techniques. This distinction is explained in Fig. 4. With (near) constantenvelope multiuser precoding, no beams are formed, and the signals emitted by each antenna are not formed by weighing a symbol. Rather, a wavefield is created such that when this wavefield is sampled at the spots where the terminals are located, the terminals see precisely the signals we want them to see. The fundamental property of the massive MIMO channel that makes this possible is that the channel has a large nullspace: almost anything can be put into this nullspace without affecting what the terminals see. In particular, components can be put into this nullspace that make the transmitted waveforms satisfy the desired envelope constraints. Notwithstanding, the effective channels between the base station and each of the terminals can take any signal constellation as input and do not require the use of phase shift keying (PSK) modulation

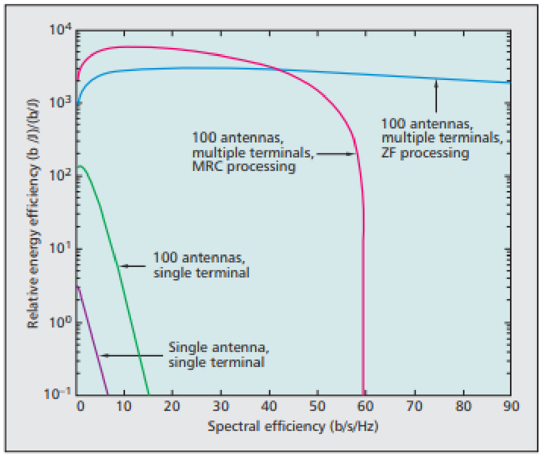

Figure 3. *Half the power — twice the force (from [6]): Improving uplink spectral efficiency 10 times and simultaneously increasing the radiated power efficiency 100 times with massive MIMO technology, using extremely simple signal processing, taking into account the energy and bandwidth costs of obtaining channel state information.*

International Journal For Advanced Research In Science & Technology
A peer reviewed international journal
www.ijarst.in
ISSN: 2457-0362

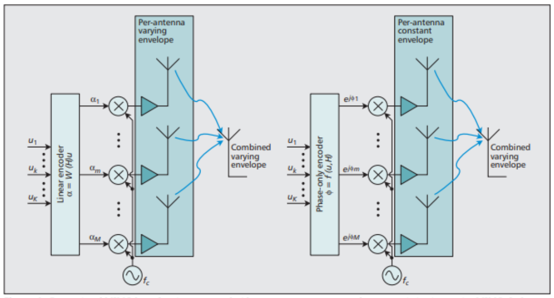

Figure 4. *Conventional MIMO beamforming contrasted with per-antenna constant envelope transmission in massive MIMO. Left: conventional beamforming, where the signal emitted by each antenna has a large dynamic range. Right: per-antenna constant envelope transmission, where each antenna sends out a signal with a constant envelope.*

Numerous recent incidents, especially in public safety applications, illustrate the magnitude of the problem. During the EU summit in Gothenburg, Sweden, in 2001, demonstrators used a jammer located in a nearby apartment, and during critical phases of riots, the chief commander could not reach any of the 700 police officers engaged [11]. Due to the scarcity of bandwidth, spreading information over frequency just is not feasible, so the only way of improving robustness of wireless communications is to use multiple antennas. Massive MIMO offers many excess degrees of freedom that can be used to cancel signals from intentional jammers. If massive MIMO is implemented using uplink pilots for channel estimation, smart jammers could cause harmful interference with modest transmission power. However, more clever implementations using joint channel estimation and decoding should be able to substantially diminish that problem.

LIMITING FACTORS OF MASSIVE MIMO

CHANNEL RECIPROCITY

Time-division duplexing operation relies on channel reciprocity. There appears to be a reasonable consensus that the propagation channel itself is essentially reciprocal unless the propagation is affected by materials with strange magnetic properties. However, the hardware chains in the base station and terminal transceivers may not be reciprocal between the uplink and the downlink. Calibration of the hardware chains does not seem to constitute a serious problem, and there are calibration-based solutions that have already been tested to some extent in practice [3, 12]. Specifically, [3] treats reciprocity calibration for a 64-antenna system in some detail and claims a successful experimental implementation. Note that calibration of the terminal uplink and downlink chains is not required in order to obtain the full beamforming gains of massive MIMO: if the base station equipment is properly calibrated, the array will indeed transmit a coherent beam to the terminal. (There will still be some mismatch within the receiver chain of the terminal, but this can be handled by transmitting pilots through the beam to the terminal; the overhead for these supplementary pilots is very small.) Absolute calibration within the array is not required. Instead, as proposed in [3], one of the antennas can be treated as a reference, and signals can be traded between the reference antenna and each of the other antennas to derive a compensation factor for that antenna. It may be possible to entirely forgo reciprocity calibration within the array; for example if the maximum phase difference between the uplink and downlink chains were less than 60°, coherent beamforming would still occur (at least with MRT beamforming), albeit with a possible 3 dB reduction in gain.

One way of quantifying how different the channel responses to different terminals are is to look at the spread between the smallest and largest singular values of the matrix that contains the channel responses. Figure 6 illustrates this for a case with 4 user terminals and a base station having 4, 32, and 128 antenna ports, respectively, configured as either a physically large single-polarized linear array or a compact dualpolarized circular array. More specifically, the figure shows the cumulative density function (CDF) of the difference between the smallest and largest singular values for the different measured (narrowband) frequency points in the different cases. As a reference, we also show simulated results for ideal independent identically distributed (i.i.d.) channel matrices, often used in theoretical studies. The measurements were performed outdoors in the Lund University campus area. The center frequency was 2.6 GHz and the measurement bandwidth 50 MHz. When using the cylindrical array, the RUSK Lund channel sounder was employed, while a network analyzer was used for the synthetic linear array measurements. The first results from the campaign were presented in [4].

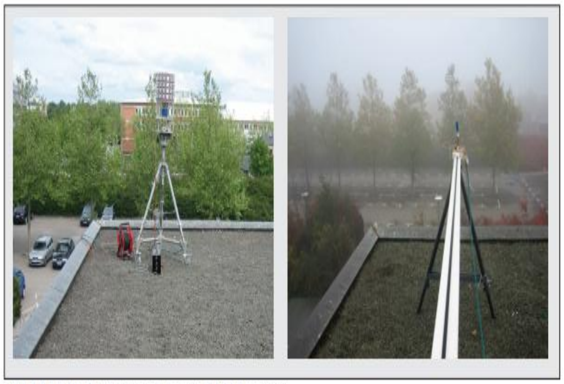

Figure 5. *Massive MIMO antenna arrays used for the measurements.*

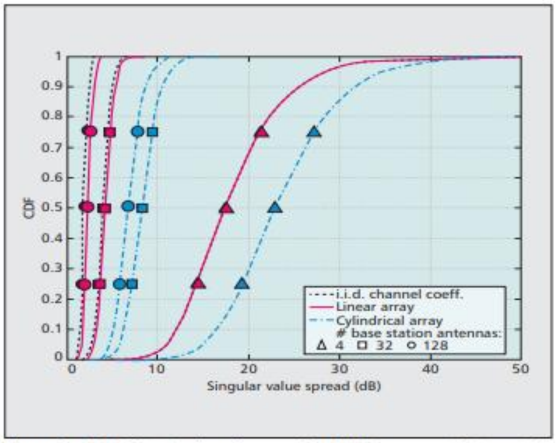

Figure 6. *CDF of the singular value spread for MIMO systems with 4 terminals and three different numbers of base station antennas: 4, 32, and 128. The theoretical i.i.d. channel is shown as a reference, while the other two cases are measured channels with linear and cylindrical array structures at the base station. Note that the curve for the linear array coincides with that of the i.i.d. channel for four base stations.*

Overall, there is compelling evidence that the assumptions on favorable propagation underpinning massive MIMO are substantially valid in practice. Depending on the exact configuration of the large array and the precoding algorithms used, the convergence toward the ideal performance may be faster or slower as the number of antennas is increased. However, with about 10 times more base station antennas than the number of users, it seems that it is possible to get stable performance not far from the theoretically ideal performance also under what are normally considered very difficult propagation conditions.

MASSIVE MIMO: A GOLD MINE OF RESEARCH PROBLEMS

While massive MIMO renders many traditional problems in communication theory less relevant, it uncovers entirely new problems that need research. Fast and distributed coherent signal processing: Massive MIMO arrays generate vast amounts of baseband data that must be processed in real time. This processing will have to be simple, and simple means linear or nearly linear. Fundamentally, this is good in many cases (Fig. 3). Much research needs be invested in the design of optimized algorithms and their implementation. On the downlink, there is enormous potential for ingenious precoding schemes. Some examples of recent work in this direction include [19]. The challenge of low-cost hardware: Building hundreds of RF chains, up/down converters, analog-to-digital (A/D)-digital-to-analog (D/A) converters, and so forth, will require economy of scale in manufacturing comparable to what we have seen for mobile handsets. Hardware impairments: Massive MIMO relies on the law of large numbers to average out noise, fading and to some extent, interference. In reality, massive MIMO must be built with low-cost components. This is likely to mean that hardware imperfections are larger: in particular, phase noise and I/Q imbalance. Low-cost and power-efficient A/D converters yield higher levels of quantization noise. Power amplifiers with very relaxed linearity requirements will necessitate the use of per-antenna low peak-to-average signaling, which, as already noted, is feasible with a large excess of transmitter antennas. With low-cost phase locked loops or even free-running oscillators at each antenna, phase noise may become a limiting factor. However, what ultimately matters is how much the phase will drift between the point in time when a pilot symbol is received and the point in time when a data symbol is received at each antenna. There is great potential to get around the phase noise problem by design of smart transmission physical layer schemes and receiver algorithms.

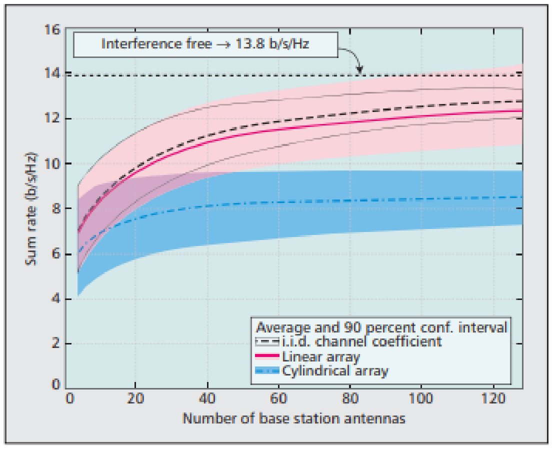

Figure 7. *Achieved downlink sum rates using MRT precoding, with 4 single-antenna terminals and between 4 and 128 base station antennas.*

CONCLUSIONS AND OUTLOOK

In this article we have highlighted the large potential of massive MIMO systems as a key enabling technology for future beyond fourth generation (4G) cellular systems. The technology offers huge advantages in terms of energy efficiency, spectral efficiency, robustness, and reliability. It allows for the use of low-cost hardware at both the base station and the mobile unit side. At the base station the use of expensive and powerful, but power-inefficient, hardware is replaced by massive use of parallel low-cost lowpower units that operate coherently together. There are still challenges ahead to realize the full potential of the technology, for example, computational complexity, realization of distributed processing algorithms, and synchronization of the antenna units. This gives researchers in both academia and industry a gold mine of entirely new research problems to tackle.

REFERENCES

[1] F. Rusek et al., “Scaling Up MIMO: Opportunities and Challenges with Very

Large Arrays," IEEE Sig. Proc. Mag., vol. 30, Jan. 2013, pp. 40–60.

[2] J. Nam et al., "Joint Spatial Division and Multiplexing: Realizing Massive MIMO Gains with Limited Channel State Information," 46th Annual Conf. Information Sciences and Systems, 2012.

[3] C. Shepard et al., "Argos: Practical Many-Antenna Base Stations," ACM Int'l. Conf. Mobile Computing and Networking, Istanbul, Turkey, Aug. 2012.

[4] X. Gao et al., "Measured Propagation Characteristics for Very-Large MIMO at 2.6 GHz," Proc. 46th Annual Asilomar Conf. Signals, Systems, and Computers, Pacific Grove, CA, Nov. 2012.

[5] J. Hoydis et al., "Channel Measurements for Large Antenna Arrays," IEEE Int'l. Symp. Wireless Commun. Systems, Paris, France, Aug. 2012.

[6] H. Q. Ngo, E. G. Larsson, and T. L. Marzetta, "Energy and Spectral Efficiency of Very Large Multiuser MIMO Systems," IEEE Trans. Commun., vol. 61, Apr. 2013, pp. 1436–49.

[7] A. Pitarokoilis, S. K. Mohammed, and E. G. Larsson, "On the Optimality of Single-Carrier Transmission in LargeScale Antenna Systems," IEEE Wireless Commun. Lett., vol. 1, no. 4, Aug. 2012, pp. 276–79.

[8] H. Yang and T. L. Marzetta, "Performance of Conjugate and Zero-Forcing Beamforming in Large-Scale Antenna Systems," IEEE JSAC, vol. 31, no. 2, Feb. 2013, pp. 172–79. [9] C. Studer and E. G. Larsson, "PAR-Aware Large-Scale Multi-User MIMO-OFDM Downlink," IEEE JSAC, vol. 31, Feb. 2013, pp. 303–13.

[10] S. K. Mohammed and E. G. Larsson, "Per-Antenna Constant Envelope Precoding for Large Multi-User MIMO Systems," IEEE Trans. Commun., vol. 61, Mar. 2013, pp. 1059–71.

[11] P. Stenumgaard et al., "An Early-Warning Service for Emerging Communication Problems in Security and Safety Applications," IEEE Commun. Mag., vol. 51, no. 5, Mar. 2013, pp. 186–92.

[12] F. Kaltenberger et al., "Relative Channel Reciprocity Calibration in MIMO/TDD Systems," Proc. Future Network and Mobile Summit, 2010, 2010.

[13] T. L. Marzetta, "Noncooperative Cellular Wireless with Unlimited Numbers of Base Station Antennas," IEEE Trans. Wireless Commun., vol. 9, no. 11, Nov. 2010, pp. 3590–600.

[14] J. Hoydis, S. ten Brink, and M. Debbah, "Massive MIMO in the UL/DL of Cellular Networks: How Many Antennas Do We Need?," IEEE JSAC, vol. 31, no. 2, Feb. 2013, pp. 160–71.

[15] R. Müller, M. Vehkaperä, and L. Cottatellucci, "Blind Pilot Decontamination," Proc. ITG Wksp. Smart Antennas, Stuttgart, Mar. 2013.

[16] H. Yin et al., "A Coordinated Approach to Channel Estimation in Large-Scale Multiple-Antenna Systems," IEEE JSAC, vol. 31, no. 2, Feb. 2013, pp. 264–73.

[17] H. Q. Ngo and E. G. Larsson, "EVD-Based Channel Estimations for Multicell Multiuser MIMO with Very Large Antenna Arrays," Proc. IEEE Int'l. Conf. Acoustics, Speed and Sig. Proc., Mar. 2012.

[18] A. Ashikhmin and T. L. Marzetta, "Pilot Contamination Precoding in Multi-Cell Large Scale Antenna Systems," IEEE

Int'l. Symp. Information Theory, Cambridge, MA, July 2012.

[19] J. Zhang, X. Yuan, and L. Ping, "Hermitian Precoding for Distributed MIMO Systems with Individual Channel State Information," IEEE JSAC, vol. 31, no. 2, Feb. 2013, pp. 241–50.

[20] A. Lozano, R.W. Heath Jr, and J. G. Andrews, "Fundamental Limits of Cooperation," IEEE Trans. Info. Theory, vol. 59, Sept. 2013, pp. 5213–26.

[21] H. Suzuki et al., "Highly Spectrally Efficient Ngara Rural Wireless Broadband ACCESS Demonstrator," Proc. IEEE Int'l. Symp. Commun. and Information Technologies, Oct. 2012.