Editorial

ICSES Transactions on Computer Hardware and Electrical Engineering (ITCHEE)

Journal Homepage: www.i-cses.com/itchee

Massive MIMO: A Survey of Benefits and Challenges

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Abstract—Massive multiple-input multiple-output (MIMO) has been regarded as a promising technique for the next generations of wireless communication networks. Massive MIMO refers the idea equipping cellular base-station (BS) with a very large number of antennas that it mainly can improve either the spectrum efficiency or energy efficiency. The network capacity is also improve to satisfy the increasing requirements of high rate of wireless communication networks in which different kinds of smart elements are integrated. This paper review main advantageous points of massive MIMO and also show the existing challenges that need to be solved for the better performance. The capacity, the energy efficiency the spectral efficiency are briefly analyzed together with other advantages. The massive MIMO antenna configurations, the pilot contamination, the channel models and the signal processing complexity are also mentioned as challenges. Explanations are also provided accordingly to each problems. Some opening topics are addressed to be focused in order to improve the network with massive MIMO.

Keywords—Massive MIMO; spectral efficiency; energy efficiency; pilot contamination; capacity; channel models.

I. INTRODUCTION

MASSIVE multiple-input multiple-output (MIMO) provides promising points for the next wireless communication system generations. The start of traditional MIMO supports many wireless communication standards to significantly improve capacity and reliability of wireless systems [1-4]. The first systems often have point-to point MIMO links where multiple antennas are used to communicate between two devices [5-7]. Multi-user MIMO is developed with a base-station (BS) utilizing multiple antennas that serve simultaneously many single-antenna devices [8, 9]. The most benefit of using multiple antenna is the system capacity is increased proportionally to the number of antennas [5, 7, 10]. The fact that not many antennas are deployed in the systems that need to be improved with many requirements of high capacity, spectrum efficiency, energy efficient power consumptions, etc.

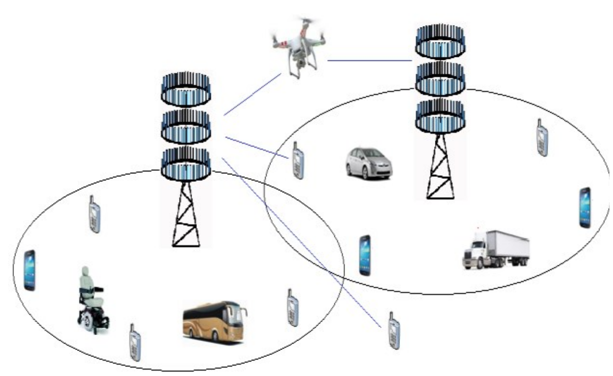

Figure 1. A massive MIMO system with cylindrical antenna array in wireless communication networks. The networks support many applications with different objects.

 — ISSN: 2467-294X
Website: www.i-cses.com — E-mail: info@i-cses.com

MIMO combining with orthogonal frequency division multiplexing (OFDM) is considered as key techniques in the third generation (3G) and the fourth generation (4G) of the communication networks [11-13]. The fifth generation (5G) considerers massive MIMO as the key roles to improve the previous networks quickly [14, 15]. In MIMO, there are two concepts based on how base-station (BS) antennas are used to serve users of the cellular network. The concepts are classified as single user MIMO and multi-user MIMO. In single user MIMO, all the streams from BS antennas are focused to one single user. In multi-user MIMO, different streams produced using combination of different antennas are focused to different users or subscribers. Moreover one stream can serve more than one users or subscribers. Massive MIMO uses multi user MIMO concept. Massive MIMO has many benefits over conventional MIMO system.

The recent requirements for high rate of wireless communication networks grow quickly corresponding to the growth of smart applications. Massive MIMO is developed with the use of hundreds antennas simultaneously serving many users in the same time-frequency resource. Linear antenna array, rectangular antenna array, spherical antenna array, cylindrical antenna array are some of several different antenna configurations for massive MIMO systems. The linear array is an example of one-dimension (1D) antenna array, which generally propagates signals on the two-dimension (2D). The spherical, the cylindrical and the rectangular antenna array are some kinds of 2D antenna array, which can radiate the signals into any directions in the 3D space. These kind of array are more likely to be used in practical systems.

Massive MIMO provides many edges over the previous versions, especially spectral efficiency and energy efficiency. This paper addresses briefly the benefits and the challenges of massive MIMO, respectively.

II. BENEFITS

Massive MIMO has been shown to potentially allow for orders of magnitude improvement in spectral and energy efficiency using linearly processing from all the antennas the base-station. Some benefits of massive MIMO can be discussed as follows.

Massive MIMO can increase the capacity more than ten times and simultaneously improve the radiated energy efficiency on the order of hundred times. The capacity results from the aggressive spatial multiplexing. The capacity in wireless cellular networks can be improved by the unprecedented array gain and spatial multiplexing offered by massive MIMO. Since its inception in the systems, the coherent interference caused by pilot contamination has been believed to create a finite capacity limit, as the number of antennas goes to infinity. So, the capacity is claimed to be unlimited as well as the number of antennas [16, 17].

Massive MIMO techniques can be built into low-power consumption and inexpensive devices [18]. Different from the conventional MIMO, ultra-linear amplifiers, a massive MIMO system has hundreds of small low cost amplifiers in milliwatt range. This also eliminates high power amplifiers and other bulky elements in the systems. They also reduce the constraints on accuracy and linearity of each individual amplifier and RF chain. The properties of the large number of antennas support massive MIMO resilient against fading and also make the technology extremely robust to failure of one or a few of the antennas.

With the large number of antennas, the energy efficiency is increased and focused into small specific regions. When the number of relay antennas go to infinity, the asymptotic spectral efficiencies together with energy efficiencies are achieved [19, 20] as shown in Figure 2. The underlying physics is coherent superposition of wave-fronts. The BS sends out the shaped signals through the antennas and makes sure that all wave-fronts emitted by all the antennas add up constructively at the location of the intended terminals, but randomly almost everywhere else.

Massive MIMO reduces the latency [21] on the air interface. It also simplifies the multiple access layer [18] and increase the robustness against both unintended man-made interference and intentional jamming [22]. In addition, there are still many other advantages of massive MIMO that support wireless communication systems in general, especially in 5G.

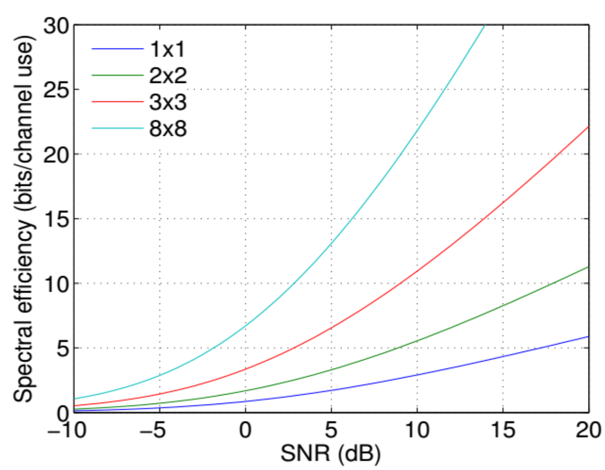

Figure 2. Spectrum efficiency via signal to noise ratio in a massive MIMO system with different antenna models. The greater the number of antennas, the more gain the system can achieve.

III. CHALLENGES

In massive MIMO systems, numerous antennas with different configurations are deployed to be able to gain advantages. Active antenna array can be used in which both radiofrequency circuits and the antenna elements are integrated into one circuit board. This is an important milestone for the development of the antenna array [23]. Since the space of adjacent antennas is half a wavelength, the designs of antenna array configurations should be considered to reduce the affects to propagation channels.

Pilot contamination that is a basic phenomenon significantly affects massive MIMO more than conventional MIMO. The upper bounded number of orthogonal pilots as of bounded coherent interval and bandwidth limits the system performance [24]. Pilot contamination precoding that requires only the corresponding slow-fading coefficients still needs to be improved [25]. The allocation of pilot waveforms also could be optimized for the better performance.

As mentioned, the systems include many antennas with different configurations, spherical, rectangular and cylindrical antenna array. Different channel measurements should be considered to be adapted to corresponding configurations. The propagation channels response from the base station to either different user terminals or different environments are also different. This is also a practical challenge for the systems [16, 18].

The systems currently have high signal processing complexity based on the large number of antennas and the channel multiplexing [26]. This generate a challenge for finding fast and distributed coherent signal processing algorithms since massive MIMO arrays radiate vast amounts of baseband data being processed in real time. There are many algorithms needed to propose to simplify and to optimize the issues.

There are many other challenges for massive MIMO systems to be able to become the leading technologies for the next wireless communication systems. The challenge of low cost hardware for either base-station or user terminals in building hundreds of antenna, converters, power amplifiers, etc. requires a lot of efforts. Even massive MIMO already offers energy efficiency, the total power consumption for such systems still need to be considered seriously. This is a promising point since the total power consumption is accumulated from many elements that could be improved separately. The properties of massive MIMO channels should be modeled correspondingly to specific behaviors in practice to facilitate the network performance. The heterogeneous network architectures are resulted from the combinations of different technologies, different kinds of data or applications, etc. This is also a big challenge to be considered soon.

IV. CONCLUSIONS AND FUTURE WORK

This paper points out the highlighted benefits and challenges of massive MIMO for the next generation wireless communication networks. The technology offers many advantages in terms of spectral efficiency, energy efficiency, robustness and reliability. There are still many concerns about massive MIMO relating to the system complexity, channel models, antenna design, low-cost devices that actually provide challenges or opening topics for researchers in the related fields to exploit and to improve the systems.

With Regards
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November 26, 2018

Minh T. Nguyen received his B.S., M.S. and PhD degrees in Electrical Engineering from Hanoi University of Communication and Transport, Hanoi, Vietnam in 2001, Military Technical Academy, Hanoi, Vietnam in 2007, Oklahoma State University, Stillwater, OK, USA, in 2015, respectively. Dr. Minh Nguyen is currently the director of International training and Cooperation center at Thai Nguyen University of Technology, Vietnam, and also the director of Advanced Wireless Communication Networks (AWCN) Lab. He has interest and expertise in a variety of research topics in the communications, networking, and signal processing areas, especially compressive sensing, and wireless/mobile sensor networks. He serves as technical reviewers for several prestigious journals and international conferences. He also serves as Editors for Wireless Communication and Mobile Computing journal and Associated Editor for ICSES Transactions on Computer Networks and Communications.

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