New Radio in the Pretext of Cell-free Massive MIMO

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Abstract. The fifth generation (5G) of mobile communication, technically known as New Radio(NR) is a reality now. This 5G networks are being installed all around the world and the first line of 5G devices are already commercially available. 5G networks provide seamless connectivity and excellent quality of service to cope up with the ever increasing demand of digital real-time data. Massive MIMO(multiple-input-multiple-output) is a key constituent for 5G networks. The principle of the technology is to transmit/receive signals to/from multiple users coherently. The major drawback of such a massive MIMO system is inter-cell interference which affect signals for the users at edges of the cell. To overcome this a revolutionary approach is given in this paper to make every user as the cell-center by increasing the number of array of antennas at base stations(BSs) referred as access points(APs) such that no user experiences a cell edge is called as Cell-free massive MIMO. As a result not even a single user is affected by inter-cell interference.

Keywords: Massive MIMO, New Radio, 5G, Cell-free massive MIMO, Inter-cell interference, Access points, Cell edge, Base stations

1 Introduction

The emergence of cellular mobile technology some thirty years back has come a long way from giving end to end calling facility to providing real time information by interacting with the people all around the world. The evolution from 1G to 5G has created a huge revolutionary impact on the lives of people. Initially, it was only analog voice transmission, but now it is mostly digital data(viz., remote file sharing, video streaming, social networking, etc.). This digital data has surpassed the actual voice transmission in December 2009[1] globally. As the semiconductor technology and computing standards are changing every 180 days the mobile users are craving for more and more digital data which subsequently increased the demand for mobile connectivity.

5G coming to be known as New Radio(NR)[2] meant to be known for very high data speeds of the order of Gbps[3] which is thousand times greater than that of 4G for meeting the requirements of the mobile broadband using population of the world. This is not only the single goal of 5G. 5G focuses on bringing ultra-reliable low-latency communication (URLLC), and massive machine-type communication (mMTC)[4]. URLLC pushes to serve effective time critical applications such as remote medical assistance, industrial automation driver less autonomous cars[5] and tactile Internet[6,7]. mMTC presents with connectivity of sensors and devices on the internet which is called Internet of Things(IoT). In reaching to the above requirements the 5G networks need to be physically designed and sliced into various logic networks for different services. This mechanism is called network slicing[8]. This is accomplished by software-defined networking(SDN) and network function virtualization(NFV)[9].

The enhanced mobile broad band is the need of the hour in the progress of 5G. The question arises how to increase the data rate(i.e, throughput) in 5G networks.

The area throughput given as the amount of information bits that can be successfully transferred to a particular area, per unit time. It is indicated in bit/s/km^2 and given by

$$T_{area} = B \times D \times SE \quad (1)$$

where B is the bandwidth in Hz, D is the cell density in cells/km^2 and SE is spectral efficiency in bit/s/Hz/cell .

Increasing the bandwidth might look like the immediate solution to enhance the throughput but spectrum is a costly affair for a telecommunication company. And so only a less amount of bandwidth is available under 6 GHz, where most wireless technologies operate presently, so now it interests to take up 30-300 GHz band which is called millimeter wave (mmWave) band as the wavelength is in the order of millimeter. But electromagnetic signals experience many propagation issues in this range of frequencies that consists of attenuation over large distances(path loss) and penetration of objects(blocking) that shows mmWave suitable for line-of-sight(LoS) communications only. Raising the cell density diminishes the cells by employing more base stations(BSs). Populating the network with more BSs rises the installation and operationals costs. Further these dense networks have inter-cell interference that degrade throughput[10] significantly. The SE can be increased by incorporating multiple transmitting and receiving antennas at both the BS and user side. This is called as MIMO(multiple-input multiple-output)[11] technology.

2 Emergence of MIMO systems

2.1 MIMO systems

Increasing the number of transmitting and receiving antennas improves the transmission/reception directivity. The properties of transmission and reception are similar. The focus on transmission relates directly to reception and so the viewpoint can be applied to reception as well. By time synchronizing each antenna the signal can be directed to any desired direction.

In doing so the signals of all antennas add up to form a beam and the receiver receives M-times stronger signal. This phenomena is called beamforming[12] and M represents the beamforming gain. The beamforming gain is equal to the number of the transmitting antennas, provided that they are half-wavelength apart. So higher the number of the antennas greater the beamforming gain and the SE.

The utilization of multiple transmitting and receiving antennas does not improve SE. As the signal moves through various independent channels this enhances the spatial diversity gain[13] of the MIMO system.

Even though the MIMO has been existent from few decades, MIMO is first initiated in LTE(Long Term Evolution, also called 4G) in 2010. It uses 8 antenna ports scrolling 120 degrees, totally 24 antennas. The gains mentioned above are noticed in LTE but they come at the cost of complex signal processing techniques and solid estimation of channel resources.

2.2 Massive MIMO environment

Massive MIMO[14] also called as large-scale antenna system is a scaled version of multiuser MIMO[15] technology. In this the BS gets a higher number of antennas, which are far greater than the number of active users for a frequency resource. Thus, in massive MIMOs there is unmatchable beamforming gain and spatial diversity.

As the number of BSs are more than the users the channels become mutually orthogonal that makes inter-user interference disappear gives excellent spatial multiplexing of the users. The massive MIMO gives a benefit of channel hardening[16], a phenomenon where a fading channel behaves as if it was not a non-fading channel.

The time division duplex(TDD) operation is preferred in massive MIMO to use radio resources optimally. The resources given to the channel estimation is independent of antenna number, though it scales with the user number. This lets massive MIMO technology to be called a scalable one. As the scale of number became huge closed form expressions for a possible SE can be deduced to estimate system performance. This simplifies the resource allocation tasks like power control and pilot assignment.

The first commercial 5G NR equipment by Ericcson used 64 transmit antennas and 64 receive antennas and operated in sub 6 GHz band[17]. Then there were other companies such as Huawei, ZTE and Nokia demonstrated with 128 antennas of massive MIMO systems. This is serious blow on the argument of the massive MIMO theory needs infinite number of BS antennas.

3 Cell-free Massive MIMO

Cell-free massive MIMO[18] is a combination of the constituent 5G technologies discussed above. This includes ultra-densification, mmWave and massive MIMO technologies and theoretically provide enormous amount of throughput.

In cell-free massive MIMO, several antennas are geographically distributed rather than co-located in a BS. The antennas, denoted as access points (APs), operate jointly, synchronously and coherently to serve the users in the same time-frequency resources. The APs act as a single massive MIMO BS, coordinated by one or more central processing units (CPUs) through a fronthaul connection as shown in Fig.1

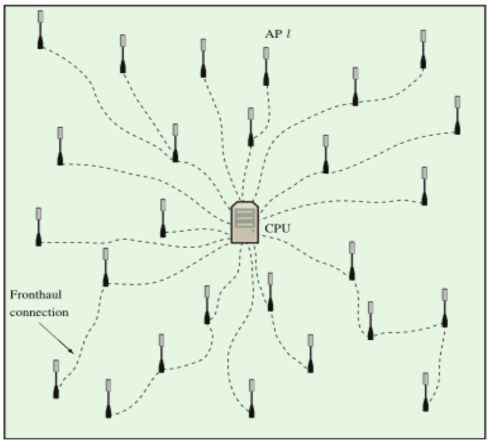

Fig.1 Illustrates the network architecture of Cell-free massive MIMO

The signal processing at distributed APs gives additional benefits other than beamforming gain and spatial diversity shown as follow:

3.1 Macro-diversity gain

Macro diversity occurs when the distance from one transmitter to the other is greater than the wavelength and so geography comes into picture through enhancing the level of spatial diversity. As the APs move closer to the user the path loss and shadowing effects can be decreased drastically. The reliability of the link is also improved as each user is surrounded by serving APs and the probability that each user is obstructed from every direction is quite low. These attributes of cell-free massive MIMO facilitate for mmWave communications. The macro-diversity gain results is higher channel gains as well.

3.2 Inter-cell interference mitigation

This is an immediate consequence of signal co-processing that turns the inter-cell interference into useful signal. The APs serve all the users in the surroundings thus by eliminating cell boundaries in transmitting and receiving data. Therefore the name coined as cell-free. As opposed to small cellular networks cell-free massive MIMO outperform[19] because the cell networks are inter-cell interference limited and do not have macro-diversity.

3.3 Uniform quality of service with peer users:

This is a consequence of the two above points. In cell-free massive MIMO there is no edge of the channel at all and all the users are present at the cell center who will have the same good channel conditions.

The enormous potential of cooperative multi-antenna transmission/reception techniques has been explored since the early 2000s[20], leading the way to a parallel line of research on distributed MIMO[21] networks, also known as network MIMO[22]. There have been different flavors of network MIMO with different names: distributed antenna systems (DAS)[23], cooperative MIMO[24], virtual MIMO[25] and coordinated multipoint (CoMP)[26]. They all shared the same basic concept of mitigating the inter-cell interference by grouping multiple cells in fixed co-operation clusters. However, this just shifts the interference management from the cell level to the cluster level, and the inter-cluster interference constitutes a fundamental limit of cooperation[27]. Indeed, CoMP—included in LTE-Advanced (4.5G)—has not met the initial expectations.

Conversely, there are at least five main reasons why cell-free massive MIMO,unlike CoMP, is deemed to be a beyond-5G key[28] enabling technology : (i)the massive MIMO baseline operation, (ii) the user-centric perspective set up by dynamic cooperation clustering, (iii) predictable performance which gives room to a simplified resource optimization, (iv) the potential marriage with mmWave, and (v) the emerging cost-efficient solutions for the deployments.

On the other side to implement a user-centric cell-free massive MIMO requires a widespread and expensive architecture, synchronized time among the APs and very effective resource allocation scheme to reduce signalling overhead.Importantly, in its canonical form, cell-free massive MIMO is not a scalable system, namely it is not able to handle a growing amount of users and APs in the system. Understanding which network tasks should be implemented either in a distributed manner at each APs or in centralized manner at the CPU is crucial in order to preserve the system scalability and make cell-free massive MIMO practical.

4 Conclusions

Cell-free massive MIMO is potentially an important constituent for beyond 5G technology but can come into evolving 5G technology as well. This is a combination of network MIMO and massive MIMO with the advantages of CoMP.

The industry is ready to take a shift to the cell-free MIMO by installing massive MIMO units as part of their infrastructure to make their networks cell-free. Currently the networks are considered to be cell-centric that is a base station serving all its users in its coverage region called as cell. Only the lucky ones located near to the base station can have excellent quality-of-service.

Cell-free massive MIMO changes this very perception taking that each and every user is important that every one is treated as the center served by many access points at a time. Thus it is a user-centric architecture. The main challenge is to synchronize and coordinate all the access points to implement such a user-centric service. The key for its success is the preservation of scalability of the system to meet the demands of ever increasing users and access points.

Cell-free massive MIMO is a relatively new concept not as developed as co-located massive MIMO and there is a lot to explore out of it. The cell-free systems has just arrived.

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