ACTA SCIENTIFIC COMPUTER SCIENCES

Volume 4 Issue 3 March 2022

Research Article

Network Densification and Massive Mimo: The Road to 5G

Pratibha Singh, Manish Kumar Dixit, Arun Kumar Singh and Saurabh Dixit*

Department of Electronics and Communications Engineering, Dr. A P J Abdul Kalam Technical University, India

***Corresponding Author:** Saurabh Dixit, Department of Electronics and Communications Engineering, Dr. A P J Abdul Kalam Technical University, India.

Received: December 07, 2021

Published: February 22, 2022

Abstract

The road to Fifth Generation (5G) mobile communication standard runs through the Fourth Generation (4G) wireless infrastructure. 5G promises not only a 100x times increase in the peak data rates but also an ultra-reliable low latency (URLL) connections like autonomous cars, remote surgery and Internet of Things (IoT). These remarkable capabilities have been envisaged because of landmark improvements in enabling technologies like carrier aggregation (CA), small cell, massive multiple-input-multiple-output (MIMO), beamforming, carrier network, active antenna system (AAS), full dimension MIMO (FD-MIMO). MIMO technology employs multiple antennas at both the transmit and receive end to boost capacity and augment network efficiency. It has been demonstrated that multi-user MIMO (MU-MIMO) improves Energy Efficiency (EE). Massive MIMO adds a new paradigm to the MIMO communication. The flexibility and scalability of massive MIMO vastly improves the capacity and reliability of the network. The cell size of the network also needs to scalable to blend with the scalability of massive MIMO. To augur well with the scalability of densification of cell size, the role of machine learning algorithms is paramount, as conventional cell size is unable to optimize the efficiency of the network. In this article, the key aspects of massive MIMO are analysed and a model is presented. The dynamics of wireless communications require a scalable and adaptive system. Hence, we have proposed machine learning algorithms which render the network a fair degree of flexibility and scalability.

Keywords: 5G; Energy Efficiency; Machine Learning; Massive MIMO; Network Densification

Introduction

International Telecommunications Union (ITU), an organization set up by the United Nations to coordinate uniform standards in telecommunications worldwide, has laid the vision of the year 2020 [1]. International Mobile Telephony (IMT) Advanced envisions and leverages cutting-edge technologies to meet and surpass its ambitious goals. Figure 1 categorically specifies the goals of IMT-2020 regarding as 10x energy efficiency, 1000x capacity, 10x lower latency, 10-100x peak data rates. These goals significantly surpass IMT-Advanced standards. The ambitious goals of IMT 2020 seek to achieve peak data rates of 20 Gbps; user experienced data rates of 100 Mbps, Spectrum Efficiency of 3x than IMT Advanced. The low latency of 1 ms is targeted in IMT 2020, whereas mobility support of 500 km/h is sought. Energy Efficiency is essential to combat the deleterious effect of carbon emissions of millions of devices, hence 100x more energy efficient networks are envisaged. Additionally, an enhanced connection density of $10^6/\text{km}^2$ is targeted. To meet the rigorous challenges of IMT-2020, the technology solutions competing for consideration are Full Dimensional (FD) and massive MIMO [2,3], mm-wave communication, Heterogeneous Networks (HetNets) and programmable Cloud Networking, along with adaptive antenna technology such as Beamforming. Figure 2 succinctly surmises the objectives of IMT-2020, also known as fifth generation (5G) standard. It encompasses enhanced mobile broadband, the massive machine type communication (MTC), and critical and ultra-reliable communication. Enhanced mobile broadband envisions servicing subscribers and businesses where high data-rate and low latency communications are needed. 5G promises to go far beyond fourth generation (4G) to provide more uniform connectivity and bandwidth over a wide area. Massive machine type communication, also known as the Massive Internet of Things (IoT), requires ubiquitous connectivity for hundreds of thousands of low software and hardware complexity devices. This applies to building automation, smart agriculture and fleet management. Critical MTC and ultra-reliable low latency communications (URLLC) entails the requirement for low latency monitoring and control in real time. This perceives situations such as control systems in a factory environment.

Multiple-input-multiple-output (MIMO) is a key technology for augmenting capacity and data rates. MIMO exploits space diversity to improve link reliability as well as boost capacity. In conventional point-to-point MIMO, each user communicates on multiple channels. However, as compared to point-to-point MIMO, multi-user (MU) MIMO has been proven to provide multiplexing gain [4]. MU-MIMO exploits space division multiple access (SDMA) and user diversity amongst multiple users. However, in MU-MIMO, a major challenge is to combat the co-channel interference of other users. Block diagonalization and successive approximation are the two techniques employed to negate the effect of user interference. FD MIMO and massive MIMO are the cutting-edge technology, which is being leveraged for sub-6 GHz physical layer [5]. The basic premise is to use large antenna arrays at base stations to simultaneously serve many autonomous terminals. Massive MIMO exploits rich scattering environment to achieve high capacity and negate the effects of user interference. Massive MIMO blends the merits of MU-MIMO by enhancing spatial multiplexing, and that of adaptive antenna beam-forming by improving Energy Efficiency (EE) [6-8]. In sharp contrast to MU-MIMO which offers a sublime trade-off between Spectral and Energy Efficiency, massive MIMO [9-11].

System model

Combines the advantages of spectral and energy efficiency. The mathematical model presented in the next section validates the contention that massive MIMO behaves like a flat fading single input single output (SISO) channel, after being subjected to efficient digital processing.

In an MU-MIMO system model, user diversity is exploited to make use of SDMA. Hence capacity is boosted as compared to

Figure 1: Challenges and goals in IMT-2020 5G.

Figure 2: Three Pillars of 5G.

Figure 3: System Model with t transmit antennas and k users.

point-to-point conventional MIMO. For each user, specific information is directed. Figure 3 represents an MU-MIMO system model with t number of users at the transmit end. At the receiver, there are k number of users. To garner the advantage of MU-MIMO, multiuser interference (MUI) must be nullified. This can be achieved by using a precoder matrix at the transmit end to combat MUI. The following mathematical model demonstrates the effect of precoding the transmit vectors to nullify the effect of MUI.

The mathematical model

The Wireless Channel is characterized by the following equations:

$$y = hx + n \qquad (1)$$

$$h = x + jy = ae^{j\emptyset} \qquad (2)$$

$$E\{|h|^2\} = E\{x^2 + y^2\} = 1 \qquad (3)$$

In (1), y is the receive vector, h is the fading coefficient, x is the transmit vector, n is Additive white Gaussian noise (AWGN), where white implies that auto-correlation is an impulse. The fading coefficient h, is characterized by (2), with separate real and imaginary parts. Here x and y are independent and identically distributed (iid) with zero mean complex symmetric complex Gaussian (ZMCSCG). (3) represents the power of the channel where E(.) is the expectation operator. The power of the channel is unity for iid and ZMCSCG channel.

$$\bar{y} = \bar{\bar{H}}\bar{x} + \bar{n} \qquad (4)$$

Here $\bar{y}$ is r ×1 receive vector, is the r × t channel matrix, is the t × 1 transmit vector, is the r × 1 noise vector. In the above model, the system of equations exist which do not have a unique solution. Hence an approximation error with any possible solution needs to be estimated. It is accomplished as:

$$e = y - Hx \qquad (5)$$

$$\min\|e\|^2 = \min\|y - Hx\|^2$$

The estimate which minimizes the error is known as Least Squares solution. This is given as

$$\hat{x} = (H^T)^{-1}H^T y \qquad (6)$$

(6) is known as the Zero Forcing (ZF) Receiver. However, in a ZF receiver, there is a precondition that the inverse of the channel must exist. There is ambiguity if the inverse of the channel does not exist. To obliterate this effect, Linear Minimum Mean Squared Error (LMMSE) receiver is designed. It multiplies the ZF receiver by the transpose of the channel matrix and receive vector , hence the estimate is given as:

$$\hat{x} = R_{xx}R_{yy}^{-1}y \qquad (7)$$

In (7), there can be a special case of signal-to-noise-ratio (SNR) being too high and too low. is the noise power, I is the identity matrix, P_d is the SNR. If SNR is too high (SNR>>1), then LMMSE behaves as a ZF receiver. If SNR is too low(SNR<<1), then LMMSE behaves as matched filter. This property is used in conjugate beamforming in massive MIMO. Table 1 summarizes the key features of ZF, Maximal Ratio Combining (MRC) and matched filter receiver. As implied, the matched filter has very low complexity and operates at very low SNR, hence a massive MIMO model can be operated at a very low SNR to obtain the features of matched filter.

ZF	MRC	Matched Filter
Forces the error to be zero	Maximizes the SNR at the receiver	At low SNR, provides an accurate error estimate
Involves inverse of the matrix, computationally intensive	Involves conjugate of the matrix	Has very low complexity

Table 1: Comparison of three receivers.

Multi-user MIMO Model exploits SDMA in the downlink, a challenge is to combat the co-channel interference of other users. The model is represented as:

$$\begin{bmatrix} y_1 \\ \vdots \\ y_k \end{bmatrix} = \begin{pmatrix} h_{11} & \cdots & h_{1t} \\ \vdots & \ddots & \vdots \\ h_{k1} & \cdots & h_{kt} \end{pmatrix} \begin{bmatrix} x_1 \\ \vdots \\ x_t \end{bmatrix} + \begin{bmatrix} n_1 \\ \vdots \\ n_k \end{bmatrix} \qquad (8)$$

Let t be the transmit antennas and k be the number of users. A precoder matrix is introduced by signal processing

$$P[\bar{y}] = \bar{\bar{H}}\overline{x_k} + \overline{n_k} \qquad (9)$$

Here P is a precoding matrix, An assumption is made as:

$$\bar{x} = P\bar{V} \qquad (10)$$

Here

$$\begin{bmatrix} x_1 \\ \vdots \\ x_t \end{bmatrix} = \begin{pmatrix} p_{11} & \cdots & p_{1k} \\ \vdots & \ddots & \vdots \\ p_{k1} & \cdots & p_{kt} \end{pmatrix} \begin{bmatrix} v_1 \\ \vdots \\ v_k \end{bmatrix}$$

By solving the above system of equations, the following expressions are obtained:

$$\begin{aligned} x_1 &= p_{11}v_1 + p_{12}v_2 + \cdots p_{1k}v_k \\ &\vdots \\ x_t &= p_{t1}v_1 + p_{t2}v_2 + \cdots p_{tk}v_k \end{aligned}$$

By observing the above expressions, all the terms excluding the first terms are contributing to interference. Precoding or preprocessing can accomplish an interference-free MU-MIMO system Using (10) in (9), the result obtained is

$$\begin{aligned} \bar{y} &= HP\bar{v} + \bar{n} \\ &= HP(\bar{v}) + \bar{n} \end{aligned} \qquad (11)$$

In (11), if $HP = I$ where I is an identity matrix, then the MU-MIMO model will reduce to

$$\bar{y} = \bar{v} + \bar{n} \qquad (12)$$

Here (12) represents a flat fading SISO channel. The precoder matrix is given as:

$$P = H^H (HH^H)^{-1} \qquad (13)$$

In (13) P is the right inverse of H, and is known as Zero forcing precoder. For the case of MMSE,

$$P = H^H \left(HH^H + \frac{I}{SNR}\right)^{-1} \qquad (14)$$

Here $SNR = \frac{P_d}{\sigma^2}$ P is known as the MMSE precoder, For the case of low SNR, it will represent a matched filter.

$$P = H^H \bar{v} \qquad (15)$$

(15) is known as the conjugate beamforming used for massive MIMO. Fig. 4 illustrates the sum rate performance of ZF and MRC receiver in a massive MIMO environment. The number of users are assumed to be 10, while the number of base stations vary from 20 to 400. It is observed that the inter cell inference is reduced in ZF receiver as compared to MRC receiver.

Figure 4

Conclusion

The inability of conventional technology to deliver the spectral efficiencies that 5G applications demand, has been the pivotal cause of invention of new technologies. With the blend of massive MIMO with low-complexity RF and baseband circuits, foundation of the new technology is firmly laid down. are calling for. In this article, the authors have proposed a mathematical model which is computationally inexpensive precoding algorithms, taking the form of conjugate beamforming or matched filter. It considerably reduces the complexity of the channel estimation. Further, massive MIMO gels well with single-carrier transmission and OFDM.

Bibliography

1. www.itu.int

2. Prabhu H., *et al*. "A 60 pJ/b 300 Mb/s 128× 8 Massive MIMO Precoder-Detector in 28 nm FD-SOI". International Solid-State Circuits Conference (ISSCC), San Francisco (CA) USA, February (2017).

3. Massive MIMO: News - commentary - mythbusting, www.massive-mimo.net 5. A. Nordrum. “5G researchers set new world record for spectrum efficiency”. IEEE Spectr (2016).
4. Chaiman Lim., *et al*. Qualcomm Incorporated Bruno Clerckx, Imperial College, London Byungju Lee and Byonghyo Shim, Korea University. “Recent Trend of Multiuser MIMO in LTE-Advanced”. *IEEE Communications Magazine* (2013).
5. Kim., *et al*. “Full Dimension MIMO(FD-MIMO): The next evolution of MIMO in LTE Systems”. *IEEE Wireless Communications* (2014).
6. Larsson E G., *et al*. “Massive MIMO for next generation wireless systems”. *IEEE Communications Magazine* 52.2(2014): 186-195.
7. Björnson Emil., *et al*. “Massive MIMO: Ten myths and one critical question”. *IEEE Communications Magazine* 54.2 (2016): 114-123.
8. T Marzetta., *et al*. “Fundamentals of Massive MIMO”. Cambridge University Press (2016).
9. Buzzi S and D’Andrea C. “Are mm Wave Low-Complexity Beamforming Structures Energy-Efficient? Analysis of the Downlink MU-MIMO”. IEEE Globecom workshops 2016, Washington D.C. USA, December (2016).
10. Wu., *et al*. “Recent Advances in Energy advances in Energy-Efficient networks and their application in 5G systems”. *IEEE Wireless Communications* (2015): 145-151.
11. Ning Liang., *et al*. “An Uplink Interference Analysis for Massive MIMO Systems with MRC and ZF Receivers” (2015).