

A Review: Hybrid Beamforming for Massive MIMO

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Abstract

The goal of 5G and beyond 5G wireless networks is to provide users with faster data transfer rates and reduced latency. The rapid evolution of communication has stimulated the study of Multiple Input Multiple Output (MIMO) systems in response to the resulting data load. Both the sender and the receiver use a wide range of antenna types. To achieve fast and reliable communication, it is necessary to improve present technology. To improve the system's spectral efficiency, this study proposes using antenna-based hybrid beamforming in a large MIMO model. As a result, we use channel constraints with limited RF channels. Chebyshev tapering has been used to dampen the signals from the side lobes so that the major curve may have a strong signal. The suggested Hybrid Beamforming for Massive Output MIMO therefore achieves both lower complexity and greater spectrum efficiency. Both Hybrid and completely digital beamforming have been suggested in this study, with varying numbers of radio frequency (RF) chains for varying numbers of antennas on the transmitter and reception sides, respectively. Results from the simulation show that the proposed antenna-based Hybrid beamforming in a massive MIMO system can reduce computational complexity by as much as 98% compared to conventional fully digital beamforming while still achieving the same or better spectral efficiencies, making it a promising model for 5G wireless networks.

Keywords: 5G wireless networks, Massive MIMO, Hybrid beamforming, spectral efficiency

Introduction

When compared to their less-advanced predecessors, such as the 3G and 4G mobile communication systems, the 5G mobile communication systems will be like a super-'techy' high-way, thanks to recent developments in the mobile communication sector. The advent of 5G new radio (NR) will open up boundless opportunities in every facet of human existence. 5G will have a significant influence on many future technologies, including but not limited to smart industries, smart cities, driverless vehicles, and augmented reality. However, 5G NR isn't currently

widely available since it's still being studied to see whether improvements can be made. The International Telecommunication Union-Radio Communication Sector (ITU-R) ratified the international mobile tele-communication-2020 (IMT-2020) specifications in 2015 [1], which detail the main features and importance of the 5G NR system. When considering a wide range of use cases, it becomes apparent that 5G will address many connectivity-related problems and boost system performance. In order to surpass the performance of the current long-term evolution

(LTE) system, implementers and researchers of 5G system devices have been working tirelessly over the last several years to raise the overall performance standard. Specifications released by the 3G partnership project (3GPP) in release-15 [2] suggest that by 2020, 5G will operate primarily utilizing LTE as a non-stand-alone (NSA) topology. Millimeter wave (mmWave) technology used in 5G NR is notoriously vulnerable to route losses in a multi-propagation environment. Some of the design goals of 5G are to decrease device power consumption, path loss, coverage area, data speeds, spectrum efficiency, and interference suppressing. Beamforming is one of several techniques and approaches that have been developed or are now under study to accommodate such system needs. While beam-forming itself isn't new, its implementation in 5G with huge MIMO has made it a crucial part of the 5G NR infrastructure. In this paper, we attempt to show the breadth of the connection between 5G and beamforming. Beamforming is used to send and receive signals in a targeted manner and to adjust the transmitted strength accordingly. The inclusion of amplitude and phase variation in the beamforming system has made this a reality. For this, we use arrays of antennas that can switch between amplitude and phase [3].

The primary objective of beam shaping is to focus energy or data in one direction while blocking out noise from other sources. By creating a phased array with three antenna components in 1905, German scientist and inventor Karl F. Braun proved the concept [4]. This idea is generally recognized in the domains of sonar, radar, acoustics, seismology, the biological sciences, and wireless communication. Beamforming, however, has quickly emerged as a crucial component of modern mobile communication infrastructure. Beamforming's effects on the transmitter-receiver link have shown to be more positive than negative. However, several obstacles must be overcome before this technological revolution can take place. However, technological advancements in areas such as circuit design and antenna modeling will also be essential for developing future

communication systems. Plus, a deeper knowledge of electromagnetics at mmWave frequencies

Literature review

A large-scale antenna system that uses radio antennas is an example of massive MIMO. Compared to conventional MIMO, this greatly increased the number of antennas used in both the receivers and the transmitters, hence increasing the array gain [5]. Massive MIMO expanded upon the capabilities of multiuser MIMO (MU-MIMO) by adding more users. When channel state information (CSI) is available, it may be utilized in conjunction with beamforming methods. Data from the signal's transmission (from sender to receiver) was CSI [6].

The huge MIMO throughput and radiated energy efficiency may be greatly improved by using the additional antennas even in relatively small spaces. An important MIMO technique, beam-forming directed signals from an array of antennas in a predetermined direction. The various channel parameters were extracted using the perturbation-aided opportunistic approach.

This was utilized to generate pre-coders for the short correlated millimeter wave MIMO systems [7]. To improve the Signal-to-Noise Ratio, the received signals were combined in a coherent fashion using a diverging scale factor. The mixed analog/digital signal components at each antenna in mmWave massive MIMO may be mitigated by designing different hybrid beamforming topologies [8], reducing costs and power consumptions. When compared to analog/digital beamforming methods, the number of RF components needed by the hybrid beamforming architecture is lower.

Due of this, base-band (multistream) digital processing has emerged. After that, RF and Baseband analog processing were performed. [9]. Millimeter wave multiple-input multiple-output (MU-MIMO) systems may benefit from an HB mechanism based on a partly connected structure (PCS). [10].

Beam patterns and information about azimuth and elevation angles were combined to generate the PCS's revealed mechanism. Millimeter wave

communication has been discussed as a possible solution to the bandwidth scarcity issue in the future generation of wireless communication [11, 12].

The mmWave technology used a maximum bandwidth of 252GHz, a frequency range of 30GHz to 300GHz, and a wavelength of 1mm to 10mm. The path loss and absorption at mmWave frequencies are greater than at lower frequencies, yet several antennas may be stacked in a limited space. Which has increased the adoption of transceiver-based large-scale antenna array devices to deal with channel propagation problems [13]

The evolution of UDN has been characterized by the dense proliferation of small cell base stations (SBS) within the framework of macro-cell base stations (MBSs). In terms of increasing the networks' capacity, EE, throughput, SE, and coherent coverage, UDN has shown to be an effective strategy.

HetNets architecture was developed by a concerted effort to merge millimeter Wave Technology, UDN, and massive MIMO. Key elements of coupled mmWave massive MIMO technology, including millimeter wave BW characteristics and massive MIMO antenna array improvements, have been accomplished. This is now an essential part of 5G and other next-generation cellular networks [14].

The vast number of antennas available in MIMO may be combined and pre-coded to maximize their array gain [15]. Power requirements and expenses, particularly for mmWave technology, might increase due to the necessity for individual RF chain hardware components for each antenna. Consequently, it was crucial to create novel antenna system designs that could take use of the potential benefit from stack of low-cost antennas using less costly radio-frequency systems. [16]

An Overview of the Concepts Fundamentals of Beamforming Beamforming is often used to receive and transmit signals in a targeted manner while yet permitting flexible power levels. The

beamforming system's ability to adjust both amplitude and phase enables this. Antenna arrays with amplitude/phase switching are used to achieve this [17]. Here are some examples of beamforming techniques:

There are three types of beamforming technology: digital, analog, and hybrid.

Before we go into hybrid beamforming, let's go through the fundamentals of digital and analog beamforming.

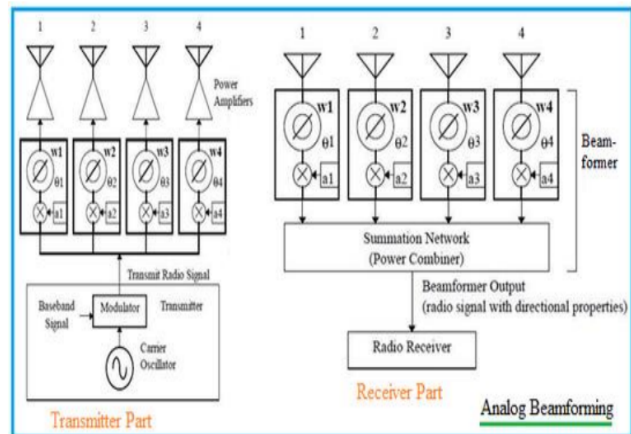


Fig. 1. The receiver and transmitter components used in analog beam-forming are shown in [16]

At the transmission end, an analog signal is modulated in amplitude and phase. Analog beamforming combines incoming signals from several antennas into a single signal before passing it via an ADC converter.

C- Digital beamforming architecture

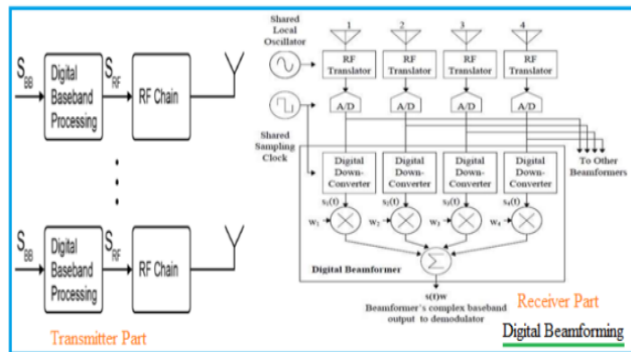


Fig.2 Components of a receiver and transmitter used in digital beamforming.[16]

In digital beamforming, the digital signal has already been converted from ADC to DDC at the transmitter's end and then subjected to amplitude/phase (W_k) fluctuation. Signals picked up by antennas are converted using an analog-to-digital converter (ADC) and a digital-to-analog converter (DDC) before being added together.

In many circumstances, the signal of interest only occupies a tiny percentage of the available bandwidth, despite the fact that digital radio receivers often have fast ADC converters transmitting enormous volumes of data. With the help of a DDC, unnecessary information may be thrown out and focused processing can be applied to the signal of interest.

In order to transform the digital IF into the baseband I/Q components or combined $(I+j*Q)$ signal, the DDC uses $\cos(2*F_c*t)$ and $\sin(2*F_c*t)$ and low pass filtering. In the following equation, the combined signal is denoted by the symbol $s(t)$, and the receiver and transmitter components used in digital beamforming are shown in Figure 2.

D-Beamforming Hybrid

To increase data transmission in a dispersed setting, cutting-edge wireless communication systems use spatial multiplexing. In order to transmit many streams of data over a single channel, we have compiled a set of precoding and combining weight values based on the channel matrix. Each data stream might then be restored separately after that. These weights, which consist of magnitude and phase components, are often used in the digital realm. Antenna arrays, which are used to increase the SNR and capacity of wireless communication, are one way to model such a setup in a simulation. All of the antennas in the system below are connected to their own individual send and get (TR) module. [18]



Fig. 3 hybrid beamforming system diagram [17]

On the transmit side, the figure shows that the number of TR switches, N_{TRF} , is smaller than the number of antenna elements, N_T . For maximum adaptability, each antenna element may be linked to a different TR module. Between each TR module and antenna, analog phase shifters might be installed to provide some degree of steerability.

The setup on the receiving end is quite identical, as shown in the figure. The maximum number of data streams that the system may handle is N_s , which is the smaller of N_{RRF} and N_{TRF} . There is no way to give each antenna element its own digital weight in this configuration. On the other hand, digital weights may only be used across all RF channels. Analog phase shifters, which only modify the signal's phase, are used to make adjustments at the component level. This necessitates a two-step process of precoding or merging. Beamforming is performed in both the analog and digital domains, which is why this approach is known as hybrid beamforming.

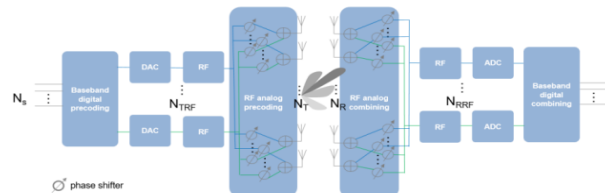


Figure 4: Setup of a Hybrid Beamforming System [17]

E Hybrid Beamforming: Disadvantages and Advantages of Different Designs

Hybrid beamforming comes in two varieties, which are as follows: Full HB, HB with some connections broken. This architecture style makes use of a separate antenna array ("sub-array") for the RF beam-former in each Analog Front End and Radio Frequency (AFE/RF) chain. In the receive chain of an AFE, you'll find an RF LNA and downconverter, while in the transmit chain, you'll find an RF power amplifier and an upconverter. The RF antenna and the DAC/ADC were connected to the AFE. Low or no IF is produced by AFE. Algorithms executed by an FPGA or DSP process the baseband data. Due to its structural makeup, this category is also known

as sub-array HB. In Fig.5, we saw an HB type that was just loosely joined.

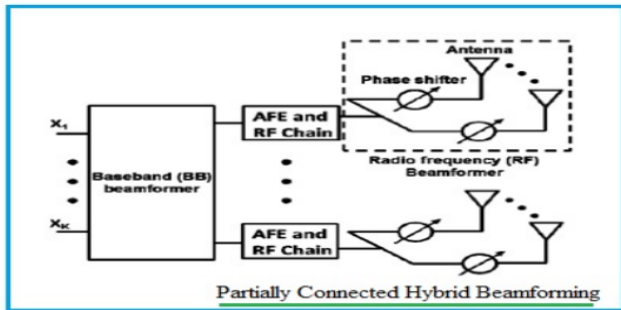


Figure 5: A kind of partly linked HB

All of the antennas are used by the RF beamformers in each AFE/RF chain. Signals from many AFE/RF chains are combined before being transmitted via an antenna. This is done for every antenna in the setup. Due to its design, this kind of technology has also been called full-array hybrid beamforming. Signal attenuation and power loss will occur in a fully linked architecture due to the increased usage of components for mixing RF signals [19].

This is a major challenge for the millimeter wave radio system. The AFE/RF chain may also access fewer antennas in a partly connected topology. The interference from other chains is high, the beamwidth is large, and the directivity is poor. Despite these limitations, interference in partly connected hybrid beamforming may be mitigated with the use of modern MIMO techniques.

In addition, partly linked architecture facilitates simpler circuit design with reduced losses in comparison to fully linked architecture. The complexity of the applications, the software, and the hardware, as well as the available technologies, all have a role in determining the optimal design. Reconfigurable HB is also developing for usage in single-user MIMO-based systems.

Proposed Model for the System

This section models a 64x16 MIMO HB system, simulating a 64-element square array with four RF chains at the transmitter and a 16-element square array with four RF chains at the receiver.

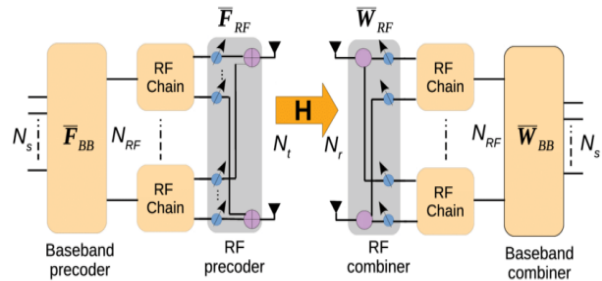


Fig.7 Diagram of massive MIMO with HB

The proposed research system is shown in Figure 7. We factored in the enormous MIMO system. It's a multi-user (MU) system that uses both downlink (3D N_t antenna arrays) and uplink (3D N_r antenna arrays) RF (radio frequency) chains of varying strengths. The value of N_r represents the total number of streams that have been received by all of the receivers. x N_t RF N_t and N_r RF N_r were the configurations used for the proposed hybrid MIMO model. A transmitter may be sectored to reduce interference and increase beamforming gain.

Beam-forming and massive antenna arrays immediately bring to mind the extraordinary adaptability with which a beam may be steered in a multi-user environment. In terms of beam steering flexibility, the fully digital MIMO beamforming technique offers the most for an extremely high price [20].

Combining beamforming techniques from the analog, digital, and RF domains may provide the greatest results, but at the expense of the flexibility of a completely digital MIMO system. In conventional (entirely digital) MIMO systems, the number of RF chains, the number of transmitter-side antennas used for precoding, and the number of receiver-side antennas used for combination are all the same. Hybrid MIMO systems, which use hybrid precoding and combining, are evaluated against conventional fully digital MIMO systems.

Hybrid MIMO's reduced loss is especially apparent when compared to digital-only implementations. The usual completely digital beam-forming method will be highly costly and complex since it will need a separate RF chain for each of the antennas. On the other hand, as can be shown in Fig. 7, hybrid

beamforming systems promise to reduce hardware complexity and cost by using a reduced number of RF chains. Their contributions are discussed and analyzed. To simplify the hardware, researchers considered a hybrid MIMO setup that combines digital and analog precoding architecture.

Conclusions This illustration uses the orthogonal matching pursuit technique to show how to split pre-coding and combine weight values, thereby clarifying the fundamental idea behind hybrid beamforming. Because beamforming allows for the use of a greater number of the antennas in a smaller array, it suggests that HB might equal the performance of optimal digital weights very soon.

This high density of antenna components improves the beam pattern's directivity, which may be put to use in 5G millimeter-wave systems to make up for severe route loss. In addition to increasing adaptability, this method guarantees the highest possible throughput and spectrum efficiency by permitting the creation of a narrower beam from the base station to the user.

Beam-forming, in combination with other mimo techniques, has been shown to provide spatial variety and mitigate fading due to multi-path propagation. In terms of diversity gain and array gain, beamforming has the potential to increase SNR at the receiver and decrease BER as a function of SNR. Different beamformers were able to effectively reduce interference by directing nulls in the appropriate direction.

Beamforming helps save energy not just during active modes but also during sleep modes, making it preferable to alternative methods. In this case, the orthogonal matching pursuit technique was used to demonstrate how to partition the precoding and combining weights. It demonstrates that hybrid beamforming may get results that are very near to those achieved with ideal digital weights.

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