Resource Allocation in 5G and Beyond Networks for Mu-MIMO Systems

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***Abstract*—The resource allocation problem focuses on finding an optimal allocation of a specific number of resources to maintain Quality of Service (QoS). That is where Multiple-Input Multiple-Output (MIMO) come in as a radio antenna technology. In order to optimize data speed, minimize errors and improve the radio transmission capacity, MIMO utilizes multiple antennas at both the transmitter and the receiver. This technology uses a variety of antennas and paths that carry the data. Each antenna uses different paths. Multi-user MIMO (mu-MIMO) stands for a technology that allows routers to communicate simultaneously with multiple endpoint devices and it is the next evolutionary step of single user MIMO. Over the past decade, significant advances have been made to improve the performance of mu-MIMO. Although non-negligible progress has been achieved so far, optimal algorithms for Resource Allocation (RA) will help better the performance of mu-MIMO by increasing the system's performance in terms of throughput, fairness, and QoS. The purpose of this paper is to provide a comparison of different beamforming techniques used for resource allocation and list them in ascending order depending on their efficiency.**

***Index Terms*—5G; MIMO; Mu-MIMO; Bandwidth; Spectral Efficiency; Networks.**

I. INTRODUCTION

Radio Resource Allocation (RRA) uses a frequency reuse planning of first-generation cellular systems aiming to increase spectrum efficiency. The above utilization plays a significant role since the spectrum is a widely shared and scarce resource. Resource Allocation (RA) as a discipline of its own encompasses a variety of techniques such as dynamic channel allocation, frequency hopping, and power control. More advanced multiantenna concepts such as Multiple-Input Multiple-Output (MIMO) solutions and beamforming also integrate RA.

Significant advances and remarkable research activities have occurred over the past decade in Multi-user MIMO (mu-MIMO) systems. MIMO aims to provide practical solutions and techniques to send and receive more than one data signal simultaneously at the same radio. There is a separation or isolation that helps prevent them from interfering with each other. That allows the wireless devices and Access Points (AP) to send and receive multiple streams of data simultaneously. That eventually increases the transmission speed of the connection. The transmitter and the receiver have more than one antenna/radio chain aiming to support MIMO connectivity. Each spatial stream is transmitted at the same frequency for both the transmitter and the receiver, but using a different radio/antenna chain. The receiver reconstructs the original stream as it knows the phase offsets of its antennas. While multiple streams can be transmitted, only one device can be served and all the other streams are wasted. The total number of antennas that are transmitting the data must be equal to the quantity of the receiving ones at any moment. MIMO can multiply the network capacity by using the horizontal and vertical polarity of a radio wave. All of the above make scaling challenging and this is where mu-MIMO provides many benefits.

In [1], the authors show how MIMO can increase the capacity of the communication system while also improving the reliability of the link that uses a variety of schemes beyond the spatial diversity. Applications involving multiple-cell networks with multiple access channels are presented in [2] where possible coordination between base stations has set the foundation for research.

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lowing them to transmit and receive concurrently between multiple subscribers. MIMO refers to a range of technologies used to multiply the capacity of a wireless connection without requiring additional spectrum by using the horizontal and vertical polarities of the radio wave. A system's Spectral Efficiency (SE) is mainly based on Signal-to-Noise Ratio (SNR), channel estimated accuracy [3], spatial correlation modeled by the propagation environment that is considered in [4] and is also limited by the theoretic capacity [5].

Early surveys report that RA enhances when tracing the momentary fluctuations of the channel in scenarios using a single transmitter, as presented in [6]. During the last years, various techniques are developing for many heterogeneous and diverse MIMO scenarios. This paper's purpose is to classify the state-of-the-art of the already existing algorithms used for single and multiple transmitter scenarios in regards to mu-MIMO.

Furthermore, an overview of different methodologies used for RA is presented in mu-MIMO systems. Moreover, we compare them, explaining the way that they are defined. We aim to provide guidelines for efficient design of RA algorithms, point out practical challenges, and comment on and compare the processing techniques of mu-MIMO's state of the art.

The paper is organized as follows. In Section II, we are presenting RA in mu-MIMO analyzing both transmission and precoding techniques. Furthermore, in Section III, we present RA algorithms, compare them and propose changes to the most promising one in order to make it more efficient. Finally, the conclusions and our future work are provided in Section IV.

II. Resource Allocation in Mu-MIMO

During the last years, mu-MIMO systems have been studied from a practical as well as a theoretical point of view. Mu-MIMO systems come without propagation limitations. Channel rank loss or antenna correlation are some of them and make the mu-MIMO system a perfect candidate for the upcoming wireless systems and standards [7]. Massive MIMO or large-scale MIMO employs a few hundred antennas at the Base Station (BS) that are responsible for sending simultaneously data streams to many users. These are evolutions of the mu-MIMO technology. Massive MIMO is an example of a very promising technology, able to get by with the continuous, growing, capacity needs arising with 5G networks. RA management in wireless communications includes various network functions, such as power control, transmission rate control, call admission control, scheduling, handover, transmitter assignment, and bandwidth reservation. Figure 1 illustrates the components mentioned above, the RA policy, and the connection between them. As displayed in Figure 1, each RA technique can either implement in optimal or suboptimal way. A mu-MIMO system uses various RA techniques that are based on user scheduling and signal to process, as mentioned, and presented in Figure 1, and depend on the SNR value, quantity of users, antennas and coordinated transmitters.

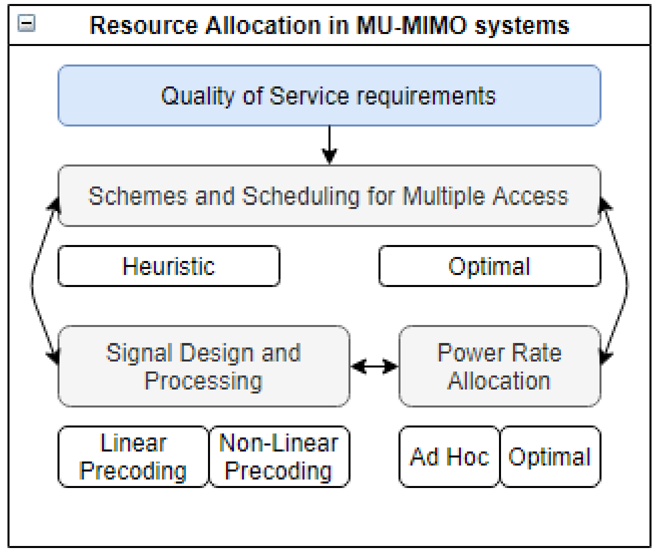

Fig. 1. Coordinated Network in mu-MIMO

In order to maintain the QoS and reduce potential interference that may occur to the users, various components are used. Scheme and Scheduling components as well as a multiple access technique are used to distribute the resources to the users. Mu-MIMO also uses signal design and processing components that are responsible for the transmission of data to the scheduled users simultaneously. Last but not least, a power rate allocation guarantees QoS.

Mu-MIMO allows the same data channels to distribute messages for different users. After the distribution, follows a classification of the individual users that takes place when the data reaches their mobile devices [8]. Serving multiple users with the same transmission ensures increased capacity and better utilization of resources. The latter increases the ability to stream or download with improved user experience even if the area is crowded. Shared data can also provide a faster and more efficient system for all users and can furthermore be switched between one or multiple users.

Each antenna receives both direct and indirect components. The direct ones are intended for this particular antenna and the indirect ones are not. That happens because these two antennas use the same channel. So, it is imperative to divide the transmitted data into multiple independent data streams. The number of streams is always less or equal to the number of antennas and this is further explained in the following section.

The literature on MIMO communications is very rich, and this paper's goal is to provide and compare the different aspects considering RA schemes and mechanisms in Mu-MIMO systems. Users with independent channels can increase the overall performance of a system. However, there are systems that provide orthogonal resource that can be accessed by each user of the cell as stated in [9] and in [10], but the real diversity in MU-MIMO systems comes when many users access the same resource simultaneously.

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A. Transmission

Surveys over the years have pointed out that the increase of RA is possible if the instant channel inconstancies are tracked for scenarios including a single transmitter. RA decisions are affected because users have heterogeneous long-term gains because of the wide coverage of areas in wireless communications. Mu-MIMO transmissions are organized into two types, partial and full bandwidth. The latter mode is when Mu-MIMO streams are transmitted and occupy the entire channel of the system in 802.11ac. On the other hand, partial bandwidth mode is the simultaneous use of Orthogonal Frequency-Division Multiplexing Access (OFDMA) and Mu-MIMO. That means that users multiplex in both time and frequency. In order to transmit independently and separately coded data signals from each of the multiple transmit antennas, MIMO uses multiplexing or spatial streaming. The number of mu-MIMO Space-Time Streams (STS) supported by the Access Point (AP) in the Downlink and Uplink depends on the number of transmitter antennas. In general, an AP with N antennas should be able to support up to N STS in both downlink and uplink. When discussing clients, the maximum number of STS for one user can be up to four despite the amount of antennas. Furthermore, the total number of STS is less than or equal to eight. Mu-MIMO aims to accommodate as many users as possible per resource. That is the reason why RA techniques are thoroughly examined at the basic resource unit, e.g., time-slot, code, frequency-time resource block, or single-carrier. Since the RA strategy applies to overall resources, the global system model (single-carrier, OFDM, or Code-division Multiple Access (CDMA)) is not taken into account.

B. Precoding

The term precoding indicates the rotation and scaling of the set of beams having their spatial properties and power adjusted towards one particular purpose. Multi-antenna transmitters provide spatial dimensions and can create autonomous channelization schemes, allowing the user transmitting to serve multiple ones concurrently using the same frequency band and time slot. The above is also known as Space-Division Multiple Access (SDMA). Taking into account the constraints, different techniques can be considered optimal. Precoding can be either linear or non-linear. The latter techniques can provide better performance while the former is computationally less expensive and requires no prior signaling. In mu-MIMO wireless technology, the term beamforming indicates the signal steering needed to achieve SDMA using beams.

III. Comparison

In [11], the authors propose an optimized algorithm for Zero-Forcing (ZF) precoding for a downlink massive MIMO system. To maximize Energy Efficiency (EE), the authors are proposing an iteration algorithm having a sensible power consumption model. Aiming at optimal EE, this particular algorithm uses the perfect Channel State Information (CSI) scenario and uniform rates for each user. In [12], the authors investigate an efficient algorithm achieving the same goal in a massive MIMO system having imperfect CSI. The proposed RA scheme has low complexity and concurrently optimizes the number of antennas, power allocation, and user selection. The EE optimization problem is intractable to solve since it is a mixed integer and non-convex problem and was therefore divided into two subproblems to be solved efficiently. In [13], the authors compared different schemes based on energy efficiency of RA. In Table I, all those schemes are presented and compared based on their results according to their techniques. The first scheme is based on designing prefilters at the Base Transceiver Station (BTS). The above condition meets the ZF criterion and efficiently removes Multi-User Interference (MUI). Having MUI eliminated throughput multiplication can also be achieved since every subcarrier could be assigned concurrently to all the user ends.

TABLE I
COMPARED ALGORITHMS

Work	Algorithm	Techniques	Results
[11]	ZF	Design prefilters to remove multi-user interference	Good throughput, EE quite low
[12]	EE optimization	Obtain an asymptotic EE expression utilizing smatrix theory	Target QoS
[13]	TSD	Assign each subcarrier to one user.	Best EE Bad throughput
[13]	SM	Spatial Multiplexing	Good throughput EE quite low
[13]	SDMA	Subcarrier assigned to multiple users concurrently	Improved throughput for low power consumption
[14]	Power allocation	Global optimization ranges depending on the user's high or low SINR.	Total EE increases significantly
[14]	MRT	Beamforming	Low Complexity Processing
[15]	Fully-adaptive RA scheme	Joint EE-SE performance	EE performance exceeds semi-adaptive and non-adaptive RA schemes
[16]	MMSE	Combination of ZF and MRT	Good throughput, EE quite low

*EE: Energy Efficiency

The second scheme presented in this paper bases on Transmit Spatial Diversity (TSD). A subcarrier is assigned by the BTS to a user having the maximum vector channel gain.

The third scheme presented in the same paper utilizes the Spatial Multiplexing (SM) technique. This particular technique employs the MIMO system between a specific RT and BTS. Data rate increases since the MIMO system can potentially

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send multiple substreams. Every subcarrier is assigned to a particular user each time for both the TSD and the SM scheme. Lastly in the fourth scheme presented, the subcarrier is designated for every user having spatial signatures. This scheme is also known as SDMA and it manages to increase the throughput. The main disadvantage is that spatial channels are seldom orthogonal in practice.

In [14], the authors investigated a MIMO downlink system. This particular system contains a BS with an immense number of antennas serving many single-antenna users. This kind of system creates a problem that considers the circuit power consumption, CSI, QoS requirements including a minimum required data throughput rate. The power allocation scheme which is proposed is optimized for maximization of the EE of data transmission.

Furthermore, in [14] the authors analyze Maximum Radio Transmission (MRT) and present it as practical precoding that can balance the system's performance and complexity. This algorithm provides excellent performance having low processing complexity in massive MIMO systems. Furthermore, MRT manages to maximize the signal gain of the designated user. MRT appears to be almost optimal at systems where noise is limited and inter-user interference is insignificant compared to the noise.

In [15], a demonstration of a fully adaptive RA scheme is presented. The scheme exceeds the EE performance of semi-adaptive and non-adaptive RA schemes. The authors point out that data streams or Radio Frequency (RF) chains are equivalent to two times the number of receiving antennas. These are adequate for achieving EE in a mmWave massive MIMO network. That concludes in reducing the amount of required RF chains and further decreasing the power consumption needed.

In [16], authors analyze the Minimum Mean Square Error algorithm (MMSE) which employs both the ZF and the MRT algorithms analyzed above and is a linear precoding algorithm. Hence, this creates a balance between them and achieves adequate performance in systems with moderate noise and interference. By utilizing the mean square error, this algorithm manages to minimize the error and filter the already sent symbols transmitted from the BS to the received terminal. MMSE's performance exceeds the one of ZF and MRT.

Having analyzed the algorithms, we will compare them further and place them in descending order proposing the one we think excels.

In our opinion, the best algorithm appears to be the TSD since it has the best EE and high utility, which is the result of low power consumption. This algorithm also has low throughput as it is a single-user RA algorithm. The second best algorithm is the power allocation scheme, implementing a low complexity algorithm that also presents a significant EE increase. The following algorithm is considered to be the EE optimization that achieves target QoS and better performance by having low complexity and good EE. The SDMA scheme presents improved throughput for low power consumption since it is a multi-user protocol. SDMA has increased EE when an antenna array at BTS is employed. The disadvantage of SDMA is that channels are not orthogonal most of the time, and the spatial signatures are designated that way. The SM algorithm is a single-user scheme that presents low EE, but has good throughput. The next scheme is MMSE which is a combination of the ZF and MRT algorithms. Although MMSE achieves adequate throughput, it comprises a matrix inversion throughout the processing, making detection methods computationally ineffective for many antennas. The following algorithm is ZF, and even though it has good throughput, it presents bad EE and utility. That is a result of the significant power consumption needed to separate the transmission of multiple users. The MRT algorithm balances performance and efficiency. Despite that fact, it is almost optimal only when the Inter-User Interference (IUI) is less contrasted to the noise. This comparison lowers the efficiency of the algorithm. Adding to that pilot contamination and the imperfect CSI should be taken into account. The Fully Adaptive RA scheme requires a panoramic view of the traffic demands and the loading of the network for efficient scheduling. Despite that disadvantage, EE increases according to the SE. When EE peaks, it starts degrading even if SE is still increasing.

Since the TSD scheme appears to perform better compared to the other schemes, an analysis of the TSD algorithm explained in [17] is presented. The algorithm consists of the following steps:

1) The first subcarrier is assigned to the channel with maximum gain. That corresponds to the maximum number of bits transmitted among all users and antennas in that subchannel. We set Y as the following: $Y = (a, b)$. The pair $(a*, b*)$ represents the data modulated onto the nth subcarrier. The data is transmitted from the BS to the b*th antenna of the a*th Remote Terminal (RT). Furthermore, we set $m^n_{(a,b)}$ as the maximum number of bits that can potentially be transmitted to ath user using nth subcarrier.
2) Calculate $m^n_{(a,b)}$ and T_{a^*} using the appropriate math equations.
3) Ensure that the user T_{a^*} meets the minimum bit rate constraint stating that the data rate designated for ath user should equal Ra bits per OFDM symbol. If $Ta* < Ra*$, the algorithm has to backtrack and check for the next subcarrier. If $Ta* \geqslant Ra*$, then we temporarily dismiss user a^* and backtrack to the first step distributing the subchannels to those users that fail to meet the above constraint.
4) The algorithm keeps backtracking to step 1 until all the users meet the minimum bit rate constraint and, therefore, all the subcarriers have been allocated to subchannels.

Observing Table I, the TSD algorithm seems to be the best option for resource allocation. It is also visible and noticeable that TSD's disadvantage, bad throughput, it's MMSE's advantage. That means, in an ideal scenario, the combination of both of them will lead up to the most efficient resource allocation

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algorithm.

IV. Conclusion

Considering that the technology is constantly evolving, it is difficult to keep up with, especially when it comes to wireless networks. Thus, already existing algorithms and technologies must be reconsidered. This paper's ultimate goal, as mentioned above, is to compare algorithms and techniques that a mu-MIMO system uses, and provide the reader with useful information about how the resource allocation works in mu-MIMO systems and how that can significantly improve in order to increase the system's performance. The comparison results show that the TSD algorithm is the most efficient, having the best EE, as well as low power consumption among the others. A suggestion for possible future work might be a comparison provided with the simulation of each algorithm based on fixed network topology in order to present the results figuratively.

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