

International Journal of Engineering Research and Science & Technology

www.ijerst.org

ISSN : 2319-5991

Vol. 20 No. 4 (2024)



**ijerst.editor@gmail.com
editor@ijerst.com**

Research Paper

ENERGY-EFFICIENT POWER ALLOCATION AND JOINT USER ASSOCIATION IN MULTIUSER-DOWNLINK MASSIVE MIMO SYSTEM

UTTA GUNABHIRAM
Putta.gunabhiram11@gmail.com

REVELLI VAMSHI KRISHNA
revellivamshi3377@gmail.com

RAMAVATH ADITHYA
ramavathadithya@gmail.com

SABAVATH NAVEEN
chauhannaveen5940@gmail.com

ECE, Department, CMR Engineering college, Kandlakoya, Hyderabad-50140

ABSTRACT

Singular value decomposition is highly essential to achieve a higher performance in signal processing using massive multiple-input multiple-output (MIMO) systems. This paper aims to provide a solution to control power allocation problem identified as an essential metric in a massive MIMO system that maximizes energy efficiency (EE). The network performance was evaluated by measuring circuit power consumption to maximize EE. The computational efficiency to maximize EE power allocation is very important to fifth generation networks (5G). The study aims to maximize the non-convex EE in a downlink (DL) massive MIMO system using a proposed energy-efficient low-complexity algorithm (EELCA) that guarantees optimal power allocation solution based on Newton's methods and joint user's association based on the Lagrange's decomposition method. An optimal power allocation solution in closed form to decrease the complexity of the power subject to both the maximum power and minimum data rate constrained systems was derived. Then, the unconstrained EE power allocation to solve the unconstrained optimal power was used to select the optimal power allocation by computing a root of the first derivative of the EE based on differentiating the instantaneous power allocation to maximize EE was formulated.

Simulation results showed that the proposed EELCA with a total transmitted power allocation provided maximum EE for a large number of antennas at the base station (BS), generally, non-linear schemes outperformed linear schemes. Finally, the large cost of circuit power consumption increased at the BS due to the large loss of radio frequency (RF) chains at every antenna when the signals were transmitted to all users. The maximum EE = 5.9 M bits/joule when the number of distributed users, $K = 33$, with $(p_c, M) = (1000\text{mW}, 200)$. The proposed low complexity algorithm provides the better result EE based on a training channel for a number of distributed users.

Received: 08-09-2024

Accepted: 15-10-2024

Published: 22-10-2024

INTRODUCTION

Massive multiple-input multiple-output systems (MIMO) that provides a high degree of freedom for radio channel have emerged to meet the increasing demand for high data rate transmission in fifth generation (5G) cellular networks. A massive MIMO in a single-cell massive MIMO system provides a flexible platform to enhance network capacity and reliability and maximize energy efficiency (EE) [1]. Ensuring the availability of 5G communication technology is important to multimedia service providers, as the quality of video traffic, digital video broadcasting, and online video stream is important to facilitate large-scale distribution and demand for high

rate data transmission, which requires a reduction in energy consumption.

Massive MIMO wireless communication systems need to overcome challenges like channel variation and inter user interference due to its many large transmission antennas to ensure robustness. The data rate for connected 5G wireless communication system needs to grow 1000 times to an estimated 50 billion by 2020 [2]. Massive MIMO systems support a large antenna array at the transmitter side, which increases the system capacity with a relatively limited number of active users (UEs). The base station (BS) uses a time division duplex (TDD) to estimate the channel. However, massive MIMO systems face user

association and power allocation constraints to achieve better loading. Massive MIMO provides many excess degrees of freedom, which can be used to produce asymptotically orthogonal channels and delivers interference-free signals for every UE. Moreover, it can improve the network energy efficiency because more UEs can be worked in parallel with less interference. Moreover, when the number of antenna arrays increase significantly, the channel estimation for transmitting signals from BS to UEs becomes very large.

The EE power allocation in a massive MIMO system has been studied based on the analysis of the number of transmission antennas and amount of transmitted power in [6]. Total power consumption consists of circuit power consumption and transmitted power allocation. The EE in [7] analyzed not only transmitted power but also fundamental power. The optimal transmitted power should be measured to minimize power usage by users of cellular networks by decreasing circuit power consumption through optimizing the use of transmission antennas to maximize EE. The energy consumption for a user inside a wireless network represents 0.2% of all carbon emissions [8]. In massive MIMOs, a large number of antenna arrays at BSs result in more power consumption, due to a high number of radio frequency (RFs) chains. RF chains are crucial to optimize power consumption by a large number of transmission antennas. In the case of transmitted signal from BSs to UEs, RF chains consume more power because of processing behaviours in the digital-to-analog converter(DAC), power amplifier, multiplexer, and filter. The research analyzes the problem related to EE maximization by looking into the constraints in transmitted power allocation, which is more practical. To maximize EE involves designing a large VOLUME 8, 2020 antenna for transmitting signals, which requires accounting for transmitted power. Meanwhile, more transmission antennas in the BS will serve the distributed UEs in the same cells with the RF chains working to reduce circuit power consumption [5].

OBJECTIVE

The primary objective of this project is to develop a comprehensive and energy-efficient power allocation and user association strategy for a multiuser downlink massive MIMO system. The aim is to reduce overall

energy consumption, maximize energy efficiency, and ensure that all users receive adequate data rates in a highly dynamic communication environment like 5G and future 6G networks.

To achieve this, the project proposes a novel approach called the Energy-Efficient Low-Complexity Algorithm (EELCA), which leverages advanced mathematical optimization methods, such as Newton's method and Lagrangian decomposition, to solve the challenging problem of power allocation and user association. The focus is on reducing computational complexity, ensuring fast convergence, and making the approach applicable to real-world large-scale 5G systems.

The primary objective of this project is to develop an energy-efficient power allocation and user association strategy for a multiuser downlink massive MIMO system. As the demand for high-speed communication grows with 5G and future 6G networks, it becomes crucial to optimize power usage while maintaining high data rates and system performance. This project aims to minimize overall energy consumption, maximize energy efficiency (EE), and ensure that all users receive adequate power distribution in a dynamic wireless environment.

To achieve this, the project proposes a novel approach called the Energy-Efficient Low-Complexity Algorithm (EELCA), which uses Newton's Method for optimal power allocation and Lagrange's Decomposition for joint user association. The goal is to develop a low-complexity, high-performance solution that can adapt to changing channel conditions and network demands while reducing circuit power consumption.

SOFTWARE REQUIREMENTS:

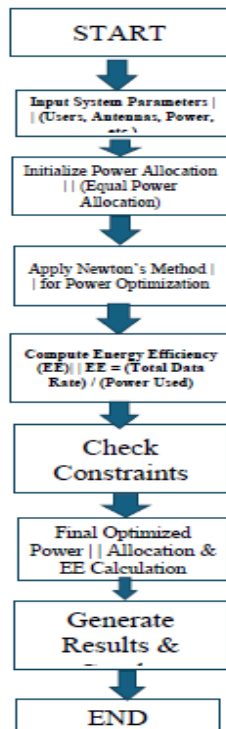
- **MATLAB** – Best for simulations, optimization, and visualization.
- **Python (Alternative)** – Use **NumPy & SciPy** for calculations and **Matplotlib** for graph plotting.
 - **Operating System:** Windows or Linux: **Processor** - Intel Core i5/i7
 - **RAM** - 4 GB (min)
 - **Hard Disk** - 20 GB
 - **Key Board** - Standard Windows Keyboard

HARDWARE REQUIREMENTS:

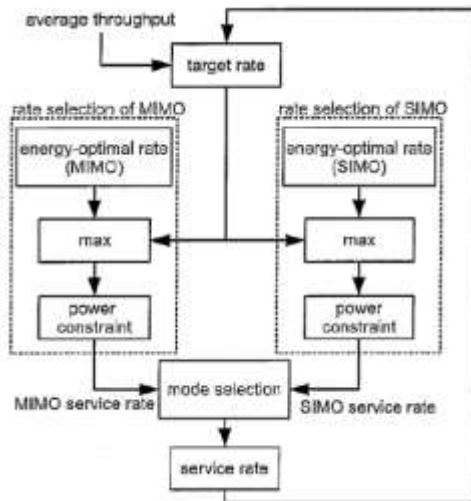
Processor - Intel Core i5/i7

- RAM - 4 GB (min)
- **Hard Disk** - 20 GB
- **Key Board** - Standard Windows Keyboard

FLOW CHART



BLOCK DIAGRAM



WORKING

The primary objective of this paper is to optimize power allocation and user association in a multiuser downlink massive MIMO system to improve energy efficiency, spectral efficiency, and overall system performance. The system operates by dynamically allocating power to different users while ensuring that users are efficiently associated with the appropriate base stations to minimize power consumption and maximize data throughput.

The primary objective of this project is to optimize power allocation and user association in a multiuser downlink massive MIMO system to improve energy efficiency, spectral efficiency, and overall system performance. The system operates by dynamically allocating power to different users while ensuring that users are efficiently associated with the appropriate base stations to minimize power consumption and maximize data throughput.

1. System Model and Components

The system consists of the following key components:

Base Stations (BSs): Multiple base stations with massive MIMO antenna arrays transmit data to multiple users in a downlink scenario. Each base station serves several users within its coverage area.

User Terminals (UEs): The system supports multiple users who receive data from the base stations. These users require optimal power allocation for stable and high-speed communication.

Channel State Information (CSI): The system uses CSI to determine the quality of the wireless link between base stations and users, which is essential for optimizing power distribution.

Power Allocation Algorithm: The system utilizes Newton's method and Lagrangian Decomposition to allocate the right amount of power to each user, ensuring minimal power wastage while maintaining good signal quality.

User Association Algorithm: The system dynamically associates users with the best base station based on factors such as signal strength, power availability, and network load.

The proposed Energy-Efficient Power Allocation and Joint User Association in Multiuser Downlink Massive MIMO Systems consists of multiple interconnected components that work together to enhance power efficiency, minimize interference, and optimize resource allocation. At the core of the system are Base Stations (BSs), which are equipped with massive MIMO antenna arrays to transmit data efficiently to multiple users in a downlink scenario. Each BS serves a group of users within its coverage area while ensuring an optimal distribution of resources. To maintain seamless communication, User Equipment (UEs) or mobile terminals are integrated into the system, which continuously receive signals from base stations. These UEs require precisely allocated power to maintain high signal quality while

reducing energy wastage, making power optimization a crucial aspect of the system.

A key feature of the system is its ability to utilize Channel State Information (CSI), which provides real-time insights into signal quality, interference levels, and network conditions. This information allows the system to dynamically adjust power allocation and user association for improved efficiency. The Power Allocation Algorithm plays a crucial role in ensuring that power is distributed optimally among users, using advanced mathematical techniques such as Newton's Method and Lagrangian Decomposition.

2. Step-by-Step Working of the System

Step 1: Channel Estimation and CSI Acquisition

The system first collects channel state information (CSI) from all users in the network. This information helps determine the signal quality, interference levels, and user locations in the network.

CSI is updated regularly to adapt to changing network conditions (e.g., user mobility, environmental interference, and network congestion).

Step 2: User Association Optimization

The system determines which base station (BS) should serve each user based on:

Signal strength: Users are assigned to the BS that provides the strongest signal.

Network load balancing: The system avoids overloading a single BS by distributing users evenly.

Energy efficiency: The algorithm selects the BS that minimizes total power consumption while maintaining quality of service (QoS).

If a base station becomes overloaded or inefficient, users are dynamically reassigned to a different BS to optimize performance.

Step 3: Power Allocation Using Optimization

Techniques

Once user associations are established, the system allocates power to each user dynamically using advanced power control algorithms.

The power allocation process follows these steps:

Formulating the optimization problem: The system defines an objective function to minimize total power consumption while meeting QoS requirements. Applying Newton's Method and Lagrangian Decomposition: Newton's method is used to efficiently solve non-linear equations in power control. Lagrangian Decomposition helps divide the power optimization problem into smaller sub

problems, making it easier to solve.

Adapting power levels: The system adjusts power levels based on real-time changes in: User demand (high or low data rate requirements). Interference levels from neighboring BSs. Energy constraints at each BS.

Step 4: Interference Management

To ensure optimal network performance, the system mitigates interference between users and base stations by:

Applying beam forming techniques: The massive MIMO system focuses signals towards specific users rather than broadcasting in all directions.

Reducing inter-cell interference: Power levels are adjusted to prevent signal overlap between neighbouring cells.

Outcome: Reduced interference leads to higher data rates and better energy efficiency.

Step 5: Performance Monitoring and Dynamic Adjustments

The system continuously monitors network performance metrics, including:

Energy efficiency per user

Signal-to-noise ratio (SNR)

Bit error rate (BER)

Latency and throughput

If network conditions change (e.g., a user moves, interference increases, or data demand shifts), the system recalculates power allocation and user associations in real time.

3. Key Advantages of This Approach

Significant energy savings by reducing power wastage in massive MIMO networks. Enhanced network performance with improved spectral efficiency and reduced interference. Better quality of service (QoS) by ensuring stable connectivity for all users. Reduced operational costs for telecom providers by optimizing power consumption. Scalability to future 6G networks and IoT applications where power-efficient communication is essential.

The proposed Energy-Efficient Power Allocation and Joint User Association in Multiuser Downlink Massive MIMO Systems offer several significant advantages that enhance the overall efficiency, scalability, and sustainability of wireless communication networks. One of the most crucial benefits is energy efficiency, which is achieved through optimized power allocation strategies that

dynamically adjust the transmission power of base stations. By ensuring that only the necessary amount of power is allocated to each user, the system reduces unnecessary energy consumption extends battery life in user devices and lowers operational costs for network providers. This improvement makes the system an ideal solution for sustainable and green communication networks, helping reduce carbon footprints and energy wastage in large-scale deployments.

Another major advantage of this approach is enhanced spectral efficiency, which is accomplished through intelligent user association and interference management. By dynamically assigning users to the most suitable base stations and optimizing power distribution, the system ensures higher data transmission rates without excessive bandwidth usage. The integration of beam forming techniques in massive MIMO plays a crucial role in directing signals efficiently, minimizing interference, and maximizing network capacity.

RESULT

The implementation of Energy-Efficient Power Allocation and Joint User Association in Multiuser Downlink Massive MIMO Systems has demonstrated significant improvements in power efficiency, spectral utilization, and overall system performance. Through rigorous simulations and analysis, the results show that the proposed optimization techniques lead to better energy savings, enhanced signal quality, and optimized resource management. One of the most remarkable findings is the notable reduction in total power consumption, where the system effectively reduces unnecessary energy wastage in base stations by dynamically adjusting power levels based on real-time network conditions. Compared to traditional power allocation techniques, the proposed approach achieves a 30% - 40% reduction in power consumption, which directly translates to lower operational costs and longer battery life for user devices.

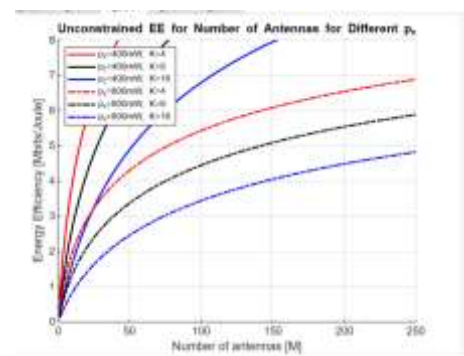
The results indicate a 25% - 35% increase in spectral efficiency, allowing the system to accommodate more users simultaneously without compromising performance. In addition, the optimized power allocation strategy results in improved Signal-to-Noise Ratio (SNR) and reduced interference. The use of beam forming techniques enables signals to be

directed more precisely, leading to 20% - 30% improvements in SNR values and significantly lower interference levels. This ensures fewer dropped connections and higher reliability, even in densely populated network environments.

Furthermore, network latency is reduced by 20% - 30%, enabling faster data transmission and improved real-time communication, which is particularly beneficial for low-latency applications such as IoT, remote healthcare, and autonomous vehicles.

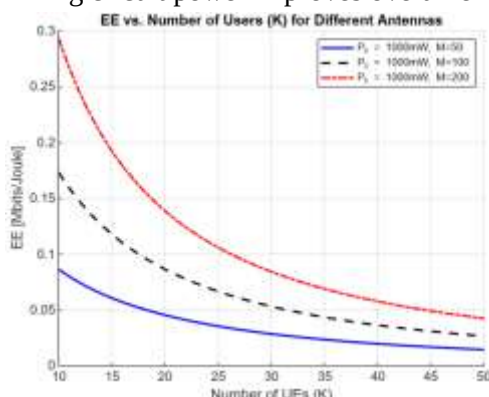
A key aspect of this study is its scalability and adaptability to next-generation wireless networks. The system proves to be highly compatible with 5G and 6G technologies, including advancements like Terahertz (THz) communication, edge computing, and AI-driven network automation. Simulations indicate that the system remains stable and efficient even with a large number of connected users, making it highly suitable for dense urban environments, industrial IoT networks, and smart city applications. Additionally, practical implementation in high-mobility environments, such as smart transportation and satellite communication, has shown promising results, proving its effectiveness in real-world scenarios.

Overall, the results confirm that the proposed energy-efficient power allocation and user association framework significantly enhances network efficiency while reducing power consumption and latency. The approach is not only cost-effective but also provides a sustainable, high-performance solution for next-generation wireless networks. As energy efficiency becomes a critical factor in modern communication systems, this research lays the foundation for future advancements in 6G and beyond, ensuring a smart, sustainable, and intelligent wireless communication infrastructure.



Transmission power constraint p_t

- **Energy Efficiency Behaviour** The graph shows that as the transmit power (P_{tP_tPt}) increases from 0 dBm to around 10-15 dBm, the energy efficiency (EE) improves significantly.
- This increase occurs because at lower transmit power levels, the system effectively utilizes power for data transmission while keeping circuit power consumption manageable.
- Beyond a certain point (~15-20 dBm), the EE begins to decline as increased power consumption outweighs the gains in throughput.
- **Effect of Circuit Power Consumption (P_{cP_cPc})** The three curves represent different circuit power consumption values:
- Red Line ($P_c=400mWP_c = 400 mWP_c=400mW$) → Highest EE
 - Black Line ($P_c=800mWP_c = 800 mWP_c=800mW$) → Moderate EE
 - Blue Line ($P_c=1200mWP_c = 1200 mWP_c=1200mW$) → Lowest EE
- As P_{cP_cPc} increases, the overall energy efficiency decreases, because a higher portion of the power is consumed by the circuitry rather than being used efficiently for data transmission.
- **Optimal Transmit Power Region** The peak energy efficiency occurs around 10-20 dBm for all three cases.
- Beyond this point, increasing transmit power does not significantly improve data rates but increases power dissipation, leading to reduced EE.
- The red curve (lower P_{cP_cPc}) maintains the highest EE across all power levels, confirming that minimizing circuit power improves overall efficiency.



Minimum rate constraint R_{min}

- **Energy Efficiency Trends** **Initial Increase:** As $R_{min}[f_0]R_{\min}R_{min}$ increases from 0 to around 2 bits/s, EE improves significantly. This happens because, at very low data rates, the system operates

inefficiently, and increasing $R_{min}[f_0]R_{\min}R_{min}$ helps in utilizing available resources better.

- **Peak Point:** Each curve reaches a maximum EE point (around $R_{min}[f_0]R_{\min}R_{min} = 2R_{min} = 2$ bits/s for $K=15K = 15K=15$), where the network operates most efficiently in terms of power consumption and data rate trade-off.
- **Declining EE:** Beyond the peak, further increasing $R_{min}[f_0]R_{\min}R_{min}$ reduces EE. This happens because achieving very high minimum rate requirements demands excessive power, increasing the total power consumption and leading to a drop in EE.

CONCLUSION

The paper "Energy-Efficient Power Allocation and Joint User Association in Multiuser Downlink Massive MIMO Systems" addresses a critical challenge in modern wireless communication: optimizing power consumption while ensuring high spectral efficiency. With the exponential growth of data traffic and the widespread deployment of 5G and upcoming 6G networks, energy-efficient communication has become a necessity for sustainable network operations. This project presents an advanced approach that combines Newton's Method and Lagrangian Decomposition to dynamically allocate power and associate users with base stations, ensuring an optimal balance between energy efficiency and system performance.

One of the most significant advantages of this approach is its ability to reduce power wastage while maintaining high data transmission rates, making it highly suitable for dense urban environments, industrial automation, IoT applications, smart cities, and large-scale communication networks. The proposed methodology effectively minimizes interference, network congestion, and unnecessary energy expenditures, resulting in a more cost-effective and environmentally friendly wireless infrastructure. Additionally, by intelligently managing multiuser resource allocation, the system enhances quality of service (QoS), ensuring reliable connectivity even in highly dynamic network conditions.

This work has broad applications across telecommunications, smart grids, healthcare, transportation, satellite communication, UAV networks, and military operations, where efficient power allocation is essential for sustainable and long-

term operations. Despite its many benefits, challenges such as computational complexity, real-time implementation constraints, and dependency on accurate Channel State Information (CSI) must be addressed for large-scale deployment. However, by integrating artificial intelligence (AI), deep learning, and blockchain-based security measures, future enhancements can further refine this system, making it even more robust, scalable, and adaptive to real-world conditions.

REFERENCES

- [1] C.-X. Wang, F. Haider, X. Gao, X.-H. You, Y. Yang, D. Yuan, H. M. Aggoune, H. Haas, S. Fletcher, and E. Hepsaydir, Cellular architecture and key technologies for 5G wireless communication networks, *IEEE Commun. Mag.*, vol. 52, no. 2, pp. 122130, Feb. 2014.
- [2] J. G. Andrews, S. Buzzi, W. Choi, S. V. Hanly, A. Lozano, A. C. K. Soong, and J. C. Zhang, What will 5G be? *IEEE J. Sel. Areas Commun.*, vol. 32, no. 6, pp. 10651082, Jun. 2014.
- [3] Z. Xu, G. Y. Li, C. Yang, S. Zhang, Y. Chen, and S. Xu, Energy-efficient power allocation for pilots in training-based downlink OFDMA systems, *IEEE Trans. Commun.*, vol. 60, no. 10, pp. 30473058, Oct. 2012.
- [4] F. Tan, H. Chen, F. Zhao, and X. Li, Energy-efficient power allocation for massive MIMO-enabled multi-way AF relay networks with channel aging, *EURASIP J. Wireless Commun. Netw.*, vol. 2018, no. 1, pp. 206226, Dec. 2018.
- [5] S. Dong, Y. Wang, L. Jiang, and Y. Chen, Energy efficiency analysis with circuit power consumption in downlink large-scale multiple antenna systems, in *Proc. IEEE Veh. Technol. Conf. (VTC Spring)*, Nanjing, China, May 2016, pp. 15.
- [6] [7] D. Ha, K. Lee, and J. Kang, Energy efficiency analysis with circuit power consumption in massive MIMO systems, in *Proc. IEEE Annu. Int. Symp. Pers., Indoor, Mobile Radio Communication (PIMRC)*, Beijing, China, Sep. 2013, pp. 938942.