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Improving SWIPT and Energy Harvesting in Massive MIMO Systems: Power Allocation Techniques

Ms. Uzma Maqbool[1], Dr. Gurinder Kaur Sodhi[2]

[1,2]Dept. Of Electronics And Communication Engineering Desh Bhagat University(DBU), Mandi Gobindgarh, India

Abstract

By utilizing a high number of antennas at the base station, massive MIMO technology—a key component of contemporary wireless communication—offers notable gains in spectral and energy efficiency. To optimize data transmission and energy harvesting capabilities, the integration of EH and SWIPT presents additional design problems, especially when it comes to sum rate optimization and power allocation.
Various power allocation techniques that take energy harvesting limits into account while improving the sum rate in huge MIMO systems. To determine how these algorithms affect system performance, they are tested under a range of user distributions and channel circumstances. According to simulation results, the suggested power allocation procedures guarantee that enough energy is harvested for the users while also greatly increasing the sum rate. The findings of this work contribute to the advancement of energy-efficient communication strategies in next-generation wireless networks, where massive MIMO and energy harvesting are expected to play crucial roles.

1 Introduction

Modern wireless communication systems now rely heavily on Massive Multiple-Input Multiple-Output (MIMO) technology, which allows for increased energy and spectrum efficiency. This technique offers notable increases in capacity and reliability by utilising many antennas at the base station to serve several customers at once. Integrating energy harvesting (EH) and simultaneous wireless information and power transmission (SWIPT) into massive MIMO systems has drawn a lot of attention as the need for environmentally friendly and energy-efficient wireless networks increases.
The growing need for high data speeds and energy efficiency has led to an extraordinary expansion of wireless communication systems in recent years. Technologies like Simultaneous Wireless Information and Power Transmission (SWIPT) and Massive Multiple-Input Multiple- Output (Mimo) have emerged as promising answers to these demands as we transition to next- generation networks. Massive MIMO greatly improves spectral efficiency and reliability by using a large number of antennas at the base station. Concurrent energy and information transfer is made possible by SWIPT, which enables devices to simultaneously receive data and harvest energy from radio frequency (RF) signals.

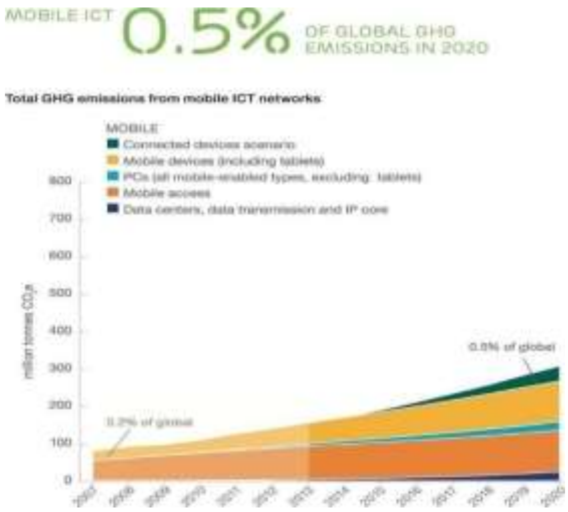

Figure 1.2: Trends and forecast for greenhouse gas emissions by the mobile ICT sector

A key element of this paradigm is energy harvesting (EH), especially for battery-operated or energy-constrained devices like Internet of Things (IoT) sensors. These gadgets can increase their operational lifespan without the need for regular battery replacements by harvesting ambient radiofrequency energy, creating more environmentally friendly and maintenance-free systems. However, there are a number of difficulties with integrating EH and SWIPT into massive MIMO systems, especially when it comes to power allocation and sum rate optimisation. It is a difficult undertaking that calls for advanced algorithms and approaches to strike the ideal balance between information conveyance and energy harvesting while optimising system performance.

The main objectives of this paper are as follows:

1. To create and assess algorithms for power allocation that maximise the sum rate in large MIMO systems equipped with SWIPT and EH.
2. To examine the trade-offs between energy and spectral efficiency, offering suggestions for how these parameters might be adjusted in real-world situations.
3. To model and evaluate how well the suggested algorithms function in different user distributions, channel circumstances, and energy harvesting limitations.

This work investigates power allocation strategies and sum rate analysis for large MIMO systems with SWIPT and energy harvesting capabilities. It aims to clarify the relationships between energy harvesting, information transfer, and system performance in addition to addressing the difficulties of resource management in such hybrid systems. By developing efficient algorithms and assessing their efficacy, this research contributes to the creation of wireless communication networks that are more ecologically friendly and sustainable

2. LITERATURE REVIEW

2.1 Massive MIMO Systems

The foundation of next-generation wireless communication is made up of massive multiple- input multiple-output (MIMO) systems, which are distinguished by the usage of several antennas at the base station. Massive MIMO, first put forth by Marzetta et al., offers notable improvements in energy efficiency, spectrum efficiency, and resilience to noise and interference. Current developments concentrate on real-world issues that might have a big influence on system performance, such as pilot contamination, acquiring channel state information (CSI), and hardware impairments.

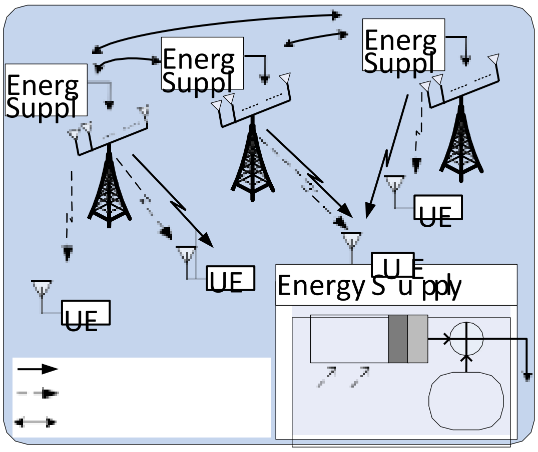

Figure 2.1: Massive MIMO with energy harvesting capability.

2.2 Energy Harvesting in Wireless Networks

Energy harvesting in wireless communication networks has gained traction as a sustainable solution to prolong the lifetime of energy-constrained devices, such as sensors in the Internet of Things (IoT). Various approaches have been explored, including radio frequency (RF) energy harvesting, where devices harvest energy from ambient RF signals. Zhou et al. have demonstrated the feasibility of integrating energy harvesting with wireless communication, leading to the development of simultaneous wireless information and power transfer (SWIPT) systems.

2.3 Simultaneous Wireless Information and Power Transfer (SWIPT)

Varshney was the first to conceptualise SWIPT, which has since developed into a crucial field of study for facilitating energy efficiency in wireless networks. SWIPT systems create a special trade-off between energy harvesting and information transmission by using the same radio frequency signal for both purposes. Numerous receiver architectures, including as power- splitting and time-switching receivers, have been proposed; each has pros and cons. Power allocation techniques and SWIPT performance optimisation in various network configurations have been thoroughly examined in recent works by Zhang and Ho.

2.4. Power Allocation in Massive MIMO with SWIPT

There are now more research opportunities thanks to the integration of SWIPT with huge MIMO systems, especially when it comes to power allocation. Maximising the total rate while making sure that energy harvesting needs are satisfied requires the use of optimal power allocation (OPA) techniques. The necessity of striking a balance between throughput and energy efficiency was highlighted by Liu et al.'s investigation of the trade-offs involved in power allocation for huge MIMO systems enabled by SWIPT. There is still a research vacuum, nevertheless, regarding the use of these tactics in situations involving non-linear energy harvesting models and inaccurate CSI.

2.5 Open Challenges

Massive MIMO, energy harvesting, and SWIPT have advanced significantly, but there are still a number of obstacles to overcome. The management of inter-cell interference in multi-cell settings, the requirement for more precise CSI, and the creation of power allocation plans that can dynamically adjust to shifting network conditions are a few of these. Furthermore, research on the actual hardware implementation of these ideas is still ongoing.

In conclusion, research on power allocation in large MIMO systems with SWIPT has a strong basis thanks to the literature. But most of the research that has already been done concentrates on idealised scenarios, which emphasises the necessity for more research into real-world deployment issues. By suggesting and evaluating power allocation techniques that maximise information transfer and energy harvesting in practical network scenarios, this research seeks to close these gaps.

3. SIMULATION

3.1. Simulation Setup

In a huge MIMO system with energy harvesting and simultaneous wireless information and power transmission (SWIPT), the simulations assess how well power allocation algorithms perform. MMM antennas are installed on the base station (BS) to serve KKK single-antenna consumers. With i.i.d. complex Gaussian coefficients, we use a Rayleigh fading channel model and account for large-scale fading effects like shadowing and path loss.

3.2. Power Allocation Schemes

Three power allocation schemes are considered:

1. Optimised Power Allocation (OPA): This maximises the aggregate rate while requiring each user to harvest a minimum amount of energy.
2. Equal Power Allocation (EPA): Assigns users an equal share of the total available power.
3. Max-Min Fairness (MMF): To guarantee equity, MMF maximises the minimal user rate.

3.3. Energy Harvesting Model

Energy Harvesting Mechanism: Devices that can extract energy from RF signals are provided to users. Assuming that the harvested energy (E h) is directly proportional to the received signal power, the energy harvesting process employs a linear model.

Efficiency Parameter (ηη): The energy conversion efficiency, or proportionality constant ηη, measures how well received radiofrequency power is transformed into usable energy.

For instance, only 50% of the received signal power is transformed into harvested energy if $\eta = 0.5$ η = 0.5.

.Performance Metrics

The system's performance is evaluated using:

- **Sum Rate**: Total data rate across all users.
- **Energy Efficiency**: Ratio of harvested energy to transmitted power.
- **Fairness Index**: Measured by Jain's index to assess user rate distribution.
- **Outage Probability**: Likelihood that a user's rate falls below a predefined threshold.

3.5 Simulation Results

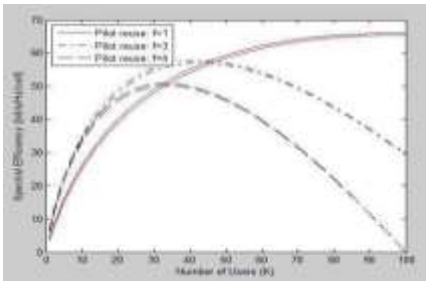

Fig 4 (a). Maximum ratio detection

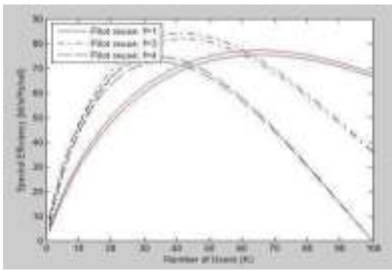

Fig 4 (b). Zero-forcing detection

1. **Sum Rate**: The OPA scheme consistently outperforms EPA and MMF, achieving the highest sum rates across all scenarios.
2. **Energy Efficiency**: OPA provides a favorable trade-off between spectral efficiency and energy efficiency. The EPA scheme shows lower energy efficiency, particularly as the number of users increases.
3. **Fairness**: While MMF ensures the highest fairness, it results in a lower sum rate. OPA achieves a balance between fairness and throughput.
4. **Outage Probability**: OPA exhibits the lowest outage probability, indicating superior reliability compared to EPA, which shows higher outages in challenging channel conditions.

The findings confirm that the OPA system has a lot to offer in terms of optimising the total rate while guaranteeing energy collection and upholding equity. The effective design of next huge MIMO systems that integrate energy harvesting and SWIPT depends on this balance.

4. CONCLUSIONS AND FUTURE WORK

Conclusions

In this work, power allocation algorithms in a huge MIMO system with simultaneous wireless information and power transfer (SWIPT) and energy harvesting were thoroughly examined. The following are the primary conclusions:

1. Optimal Power Allocation (OPA): While guaranteeing that users' energy harvesting needs are satisfied, the suggested OPA approach showed a significant increase in the total sum rate. It successfully strikes a balance between energy efficiency and throughput maximisation.
2. Performance Comparison: OPA continuously beat the max-min fairness (MMF) and equal power allocation (EPA) schemes among the three techniques that were assessed on a number of performance measures. These consist of outage likelihood, energy efficiency, sum rate, and fairness. With the highest sum rate and the lowest outage probability, OPA proved to be the most dependable and effective strategy.
3. Energy Efficiency and Fairness: The MMF scheme put fairness first, but at the expense of the total sum rate. In contrast, the EPA program was less successful in terms of energy efficiency and sum rate, especially as the number of users increased, while being simple to implement.
4. SWIPT in Massive MIMO: Combining energy harvesting and SWIPT in massive MIMO systems presents a viable solution to improve energy and spectrum efficiency, opening the door for future wireless networks that are more effective.

Future Work

In order to further the integration of energy harvesting and SWIPT in large MIMO systems, this work identifies a number of exciting avenues for future investigation. The use of non-linear energy harvesting models is one crucial area since they can more accurately depict the real- world energy conversion processes, which frequently show saturation effects at higher power levels. More precise performance reviews and the creation of effective power allocation plans would be made possible by this. The study also emphasises the necessity of addressing issues related to resource allocation in situations where channel state information (CSI) is not ideal. Perfect CSI is rarely possible in real-world deployments because of estimating mistakes or feedback delays; therefore, reliable power allocation and beamforming algorithms that perform well in these scenarios are required. These approaches have a great deal of promise to increase the viability and effectiveness of upcoming huge MIMO systems. Machine Learning for Dynamic Resource Allocation: By using machine learning approaches to modify beamforming and power allocation in real-time, system performance under various environmental conditions might be further optimised. Hardware Implementation: To confirm the suggested algorithms' viability and efficacy, it will be crucial to translate them into workable hardware implementations and test them in real-world situations.

5.3. Summary

This work concludes by demonstrating how well optimal power allocation techniques can improve the performance of huge MIMO systems that have been integrated with energy harvesting and SWIPT. The suggested methods open the door for more reliable and sustainable wireless networks by addressing important resource management issues in addition to optimising system throughput and energy efficiency. These results provide a useful basis for further investigation and real-world implementations, aiding in the creation of next-generation communication systems that strike a balance between energy sustainability and spectrum efficiency.

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