STM JOURNALS

Research & Reviews: Journal of
Embedded System & Applications

https://journals.stmjournals.com/rrjoesa

ISSN: 2395-6712 (Online)
ISSN: 2321-8533 (Print)
Volume 12, Issue 1, 2024
January—April
DOI (Journal): 10.37591/RRJoESA

Review RRJoESA

Review on Energy Efficient MIMO-based 5G Communication Network

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Abstract

As we near the advent of fifth-generation (5G) communication networks, prioritizing energy efficiency (EE) in design becomes increasingly vital for sustainable progress. A pivotal element facilitating 5G is massive multiple-input multiple-output (MIMO) technology, wherein base stations (BSs) are equipped with a vast array of antennas to achieve significant spectrum and energy efficiency improvements. This article delves into a comprehensive examination of the latest strategies aimed at optimizing EE enhancements offered by massive MIMO (MM). Initially, we present an introduction to MM systems and explore techniques for constructing customized power consumption models suitable for these systems. We summarize and highlight a few of the most well-known EE-maximization strategies that are presently documented in the literature.

Keywords: 5G networks, heterogeneous networks, massive MIMO, energy efficiency, millimeter wave, energy harvesting

INTRODUCTION

With the goal of connecting almost every place on Earth to the internet, fifth-generation (5G) networks are quickly being developed by the information and communication technology (ICT) industry. A multitude of interconnected networks, such as augmented reality centers, smart cities, and vehicle networks, will cohabit under 5G.

In terms of technology, 5G networks are expected to accommodate a large volume of internet-of-things (IoT) devices within each square kilometer, offering peak data speeds reaching 20 Gbps and average data rates surpassing 100 Mbps. The development of 5G networks must take energy usage into account because mobile communication networks have a substantial carbon impact worldwide. By 2020, the ICT industry is predicted to emit over 250 million tonnes of greenhouse gases annually, based on trends [1, 2]. Therefore, 5G networks need to achieve tremendous capacity expansion while consuming zero energy in order to guarantee sustainability.

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Received Date: March 22, 2024
Accepted Date: April 01, 2024
Published Date: April 04, 2024

Citation: Navneet Kaur, Shalini Sahay, Mehajabeen Fatima, Jyoti Jain. Review on Energy Efficient MIMO-based 5G Communication Network. Research & Reviews: Journal of Embedded System & Applications. 2024; 12(1): 19–23p.

GENERATION OF COMMUNICATION NETWORK

Over the past few decades, there have been significant technological developments in mobile communication on a global scale. The conceptual paradigm for mobile communication systems was first presented by Bell Labs in 1979 [1]. Since then, there have been four generations of mobile communication systems, and the current generation, which is entering its fifth generation, is incredibly complicated and dense, but it is also incredibly efficient and data-rich. Speed rose from 2.4 Kbps in

1G to 100 Mbps in 4G. In 5G networks, approximately 1000 times faster data speeds, or 10 Gbps, are anticipated [3–5].

The 1980s saw the introduction of the first generation (1G) mobile networks, which had a maximum data rate of 2.4 kbps and employed analog transmission. As a result, it might provide voice-only services with poor quality and little capacity.

During the early 1990s, two second-generation (2G) mobile networks emerged: the European Global System for Mobile Communications (GSM) in Europe and the Interim Standard 95 (IS-95) in North America. Digital circuit- switching networks, or 2G systems, might handle voice services in addition to low-bandwidth applications and could carry data at up to 384 kbps. The system's capacity and quality were significantly boosted over 1G due to the intrinsic qualities of digital transmission, which led to a market boom. The universal mobile telecommunications system (UMTS) and code division multiple access (CDMA) technologies were used to construct the third generation (3G) system in 2001. Digital networks that are both packet- and circuit-switched, 3G systems can transfer data at up to 2 Mbps [6]. The key components of 3G technology include enhanced capacity, quicker data transfer, and support for multimedia applications. The year 2009 saw the establishment of fourth-generation (4G) mobile standards in response to 3G's problems [7].

Besides facilitating phone services via internet protocol (IP), long term evolution (LTE) 4G mobile systems also lowered resource expenses, enhanced network capacity, and accelerated data transmission [8]. With the integration of multiple-input multiple-output (MIMO) and orthogonal frequency division multiple access (OFDMA), 4G networks can now achieve significantly higher data rates, reaching up to 100 Mbps. 4G is a major improvement in mobile networks, even if wireless mobile internet represents a great leap in mobile technology. Figure 1 shows the various wireless mobile network generations. Machine-to-machine (M2M) communication, the IoT, and the growth of multimedia-rich apps have boosted the demand for data communication significantly in recent years [9].

As per Cisco's 2018 forecast [10], there is a projection that global data traffic from mobile devices will more than double between 2017 and 2022, exhibiting a compound annual growth rate (CAGR) of 46%. The significance of mobile network traffic is steadily increasing. Furthermore, it was anticipated that by 2022, approximately 20% of total IP traffic will originate from global data traffic on mobile communication networks, with 79% of internet traffic expected to be carried through Wi-Fi and mobile networks. Additionally, it was anticipated that by 2022, the world would have 14.6 billion connections, 28.5 billion network devices, anda around 4.6 billion Internet users [10]. In certain countries (e.g., China, India, and the United States), smartphone users have surpassed 100 million [11], owing to customers' need for constant wireless connectivity. The global market for mobile data and internet traffic is growing. The increasing demand for mobile data traffic exceeds the capacity of currently installed 4G LTE wireless networks. Thus, novel wireless mobile communication technologies with increased spectrum and data transmission rates are required quickly. Mobile communication has advanced to fifth-generation (5G) networks [12]. 5G networks are intended to provide 1000 times the network capacity and link trillions of devices.

It has the capability to offer uninterrupted access to a range of services, such as phone and data services, video calls, mobile TV, multimedia messaging (MMS), digital video broadcasting (DVB), high-definition television (HDTV) content, and entertainment devices. 5G is intended to be quicker and more responsive, with the ability to link anything and everything. It guarantees high bit rates, a minimal probability of outages, maximum throughput, and high spectral efficiency [12, 13].

RELATED WORK

Summary of literature review is shown in Table 1.

Table 1. Summary of literature review.

S.N.	Title of the Paper	Methodology	Gain	Research Gap
1.	An energy-efficient power allocation scheme for massive MIMO systems with imperfect CSI [1]	Decomposing the expression of the non-convex objective function, an energy-efficient power allocation algorithm that maximizes the energy efficiency is developed based on the difference of convex programming.	Having energy-efficient power allocation scheme	Underachieve downlink rate utilizing maximum-ratio transmission (MRT)
2.	Energy efficiency investigation in massive MIMO 5G system using Nakagami-m fading channel [7]	Energy efficiency of massive MIMO systems for different distributions using MMSE (minimum mean square error) detector in Nakagami-m fading channel	High energy efficiency can be exploited in hybrid system compared to other system compared to other two MIMO distributions.	Spectral efficiency and energy efficiency with signal-to-noise ratio (SNR) is also needed to be portrayed for different distributions.
3.	Massive MIMO system lower bound spectral efficiency analysis with precoding and perfect CSI [8]	Investigate the performance of the downlink ma-MIMO system with ZF and MMSE precoding schemes and considering SSF and LSF in Rayleigh channel model.	Algorithm-1 always performs much better than the other two, and also the ZF precoding technique is superior to MMSE in the SE performance.	Asymptotic lower bound expressions for the SE are not derived.
4.	Pilot-decontamination in massive MIMO systems using interference alignment [10]	Propose a novel approach based on interference alignment (IA) to remove PC. Uses linear zero-forcing (ZF) and needs no continuous cooperation between the base stations (BSs).	Outperforms the conventional PC precoding algorithms significantly, particularly in heavy-loaded networks.	Avoids zero-forcing (ZF) and needs no continuous cooperation between the base stations (BSs).
5.	Pilot optimization for estimation of high-mobility OFDM channels [11]	Pilot optimization technique to determine the optimal placement of pilots within the OFDM symbol.	Lead to more accurate estimation of channel parameters in high-mobility OFDM systems, reducing errors in data transmission.	Need for more reliable and efficient wireless communication in dynamic scenarios.
6.	An efficient design of doubly selective channel estimation for OFDM systems [12]	To achieve efficient channel estimation, the researchers might have optimized the placement of pilot symbols within the OFDM symbol and allocated resources for pilot transmission appropriately.	Optimizing the placement of pilot symbols and resource allocation, the proposed method is likely to improve the spectral efficiency	Limiting their practicality for implementation in resource-constrained devices.
7.	Position-based compressed channel estimation and pilot design for high-mobility OFDM systems. Methodology. [13]	Exploit the special characteristics of the wireless channel and employ compressed sensing techniques to efficiently estimate channel parameters with reduced pilot overhead.	Provide more accurate estimates of the wireless channel in high-mobility scenarios, leading to improved data recovery and reduced errors	Need to explore the potential benefits of using special information and compressed sensing techniques for channel estimation

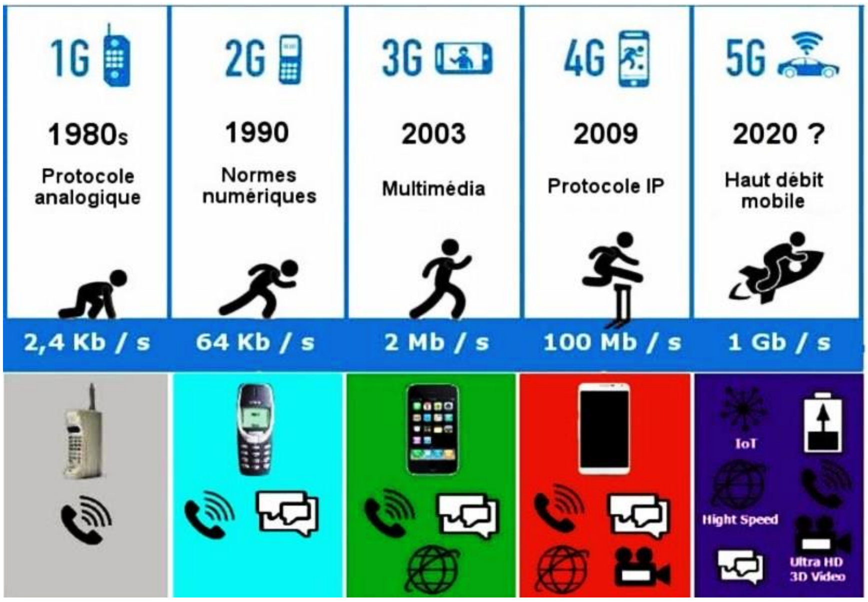

Figure 1. Generations of mobile wireless networks.

RESEARCH GAP

Massive MIMO is a novel wireless technique that will be used in 5G. Before implementing this new technology, many factors must be examined. This research looked into two factors that can affect large MIMO performance. The first factor affecting huge MIMO performance is channel quality. High channel correlation has been found to reduce the capacity and energy efficiency of huge MIMO systems. To lessen the influence of such channel circumstances, increase the transmit power to boost SNR. Increasing the antenna array spacing and adding more antennas at the base station (BS) can improve the channel capacity and EE. Many studies also looked into the impact of user allocation on massive MIMO capacity. Increasing the number of antennas in the BS expands the capacity to accommodate more terminals within the cell. Too many users can reduce large MIMO's capacity. Massive MIMO is a new technology with many unknowns. So many research avenues exist. Listed below are some prospective research directions in massive MIMO:

1. Increase the number of BS antennas and analyse the effects of different estimate methods.
2. Comparing massive MIMO performance in multi-cell scenarios to current small cells.
3. Pilot contamination stands out as a factor capable of influencing the performance of massive MIMO systems. The issue of other cells interfering with the training period is a highly important study direction. Larger frequency reuses factors help reduce pilot contamination. This reduces the pre-log factor and thus the spectral efficiency. The intensity of the signal inside the cell is substantially stronger than interference from other cells; hence increasing cell size helps reduce pilot contamination. The issue is that consumers at the cell's edge may not be able to obtain adequate service. The size of the cell and the pilot reuse factor should be explored to decrease the influence of pilot contamination.

CONCLUSION

Because of the exponential surge in demand for data traffic, mobile wireless network operators face mounting pressure to expand network capacity while simultaneously keeping electricity consumption and operational costs consistently low. With the widespread deployment of small cell base stations (SCBSs) in the densely packed 5G architecture, there is considerable strain on the power grid. Renewable energy emerges as the optimal solution for powering small cell networks within the framework of 5G infrastructure, as it mitigates dependence on the grid and fosters positive environmental outcomes. This article conducts an extensive examination of the existing literature on strategies involving renewable energy for powering mobile networks. Topics covered include renewable energy–enabled BSs, methods for scaling renewable energy sources, mechanisms for energy exchange between base stations, and the integration of the mobile network with a smart grid. Additionally, this report shows the numerous energy-efficiency measures employed by mobile network operators.

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