IMPACT OF 5G TECHNOLOGY ON ENERGY EFFICIENCY

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Abstract*—This technical survey explores the intricate interplay between 5G technology and energy efficiency, emphasizing the imperative of balancing enhanced connectivity with environmental sustainability. The paper delves into the impact of 5G on energy consumption, presenting key enablers such as Device-to-Device Communication (D2D), Massive MIMO, advanced sleep modes, and heterogeneous networks. It addresses challenges and trade-offs, including infrastructure costs, millimeter-wave technology constraints, and the delicate balance between energy efficiency and Quality of Service (QoS). Through a comprehensive review of existing research, the survey contributes insights into strategies for a sustainable digital future in the era of 5G.

Keywords*—5G Technology, Energy Efficiency, Connectivity, Sustainable Development, Device-to-Device Communication (D2D), Massive MIMO, Heterogeneous Networks (HetNets), Renewable Energy, Internet of Things (IoT), and Quality of Service (QoS)

I. INTRODUCTION

5G, or fifth-generation wireless technology, represents the latest standard in mobile communication, offering faster data speeds, lower latency, and increased connectivity compared to its predecessors (3G and 4G). Understanding the impact of 5G on energy efficiency is crucial for balancing the benefits of enhanced connectivity with the need for sustainable and eco-friendly technological solutions. Ongoing research and industry initiatives will continue to shape the future of 5G in the context of energy consumption and environmental impact. In the relentless pursuit of technological advancement, the emergence of 5G technology stands as a milestone, promising unprecedented capabilities in wireless communication and internet-related activities. Nevertheless, like any revolutionary advancement, the introduction of 5G into our digital environment comes with its set of challenges, especially in the domain of energy efficiency. The incorporation of 5G technology presents exciting possibilities along with apprehensions, prompting discussions about its impact on the environment and the potential strain it might impose on energy resources. The produced data is shared by enabling the communication between two parties: 1) the Key Enablers for Energy Efficiency in 5G which explores the technologies and techniques that contribute to energy efficiency in 5G networks and 2) the Challenges and Trade-offs, which addresses the concerns associated with achieving energy efficiency in 5G networks, it discusses issues such as increased complexity, trade-offs between performance and energy efficiency, and regulatory considerations.

Advanced antenna technologies, massive MIMO, beam-forming, and other discussed techniques in this survey play a crucial role in enhancing energy efficiency in 5G technology. Recognizing the critical interplay between technology and energy efficiency, this technical survey paper delves into the intricate nuances of the Impact of 5G on Energy Efficiency. As we embark on this exploration, we confront the dual imperative of harnessing the capabilities of 5G while mitigating its potential environmental impact.

In this age of heightened environmental consciousness, the telecommunications industry bears a dual obligation – fulfilling the growing need for connectivity while mitigating the environmental impact. Though the telecommunications business contributes 2% of CO_2 to the environment when compared to other industries this figure is projected to rise if appropriate measures are not taken ahead of time. The need for energy efficiency in 5G is not merely a technical consideration but an ethical imperative In order to ensure a robust and sustainable digital future, the development of energy-efficient 5G networks becomes essential, carefully balancing technological innovation with environmental stewardship.

The discourse presented here is not merely speculative; it is rooted in an extensive review of existing research. Numerous studies have scrutinized the challenges posed by 5G technology to energy efficiency, yielding a spectrum of proposed solutions. Our journey through these research findings aims to distill insights into viable strategies that balance the transformative power of 5G with a judicious approach to energy consumption.

Throughout this survey, we navigate the intricacies of 5G's influence on wireless networks, Internet of Things (IoT) ecosystems, and broader communication frameworks. This exploration is not confined to a binary analysis of positive and negative impacts; rather, it seeks to unearth nuanced solutions that pave the way for a harmonious coexistence of cutting-edge technology and energy conservation.

As we unravel the pages of this technical survey paper, we will unravel the complexities surrounding 5G and energy efficiency, evaluating proposed solutions that range from the exploration of future technologies like 6G to the optimization of 5G through the implementation of advanced technologies such as Multiple Input Multiple Output (MIMO), advanced sleep modes, and strategic wake-up protocols. Through this comprehensive investigation, we aim to contribute valuable insights to the discourse on sustainable technology adoption in the era of 5G.

II. A BRIEF OVERVIEW OF 5G TECHNOLOGY AND ENERGY EFFICIENCY

In the last few decades, the global market for mobile communication has undergone transformative technological growth. Bell Labs first developed the conceptual paradigm of mobile communication systems in 1979. Since then, mobile communication systems have gone through four generations, and they are now in their fifth, incredibly dense, complex, but very efficient and data-rich telecommunication generation. It progressed from 2.4kbps in 1G to 100Mbps in 4G, and a 1000-fold increase in data rate, i.e. 10Gbps, is projected in 5G networks.

The emergence of 5G technology stands as the culmination of this evolutionary process, promising a holistic revolution in the dynamic interplay between society and industry. This next generation of wireless cellular technology boasts a speed faster than we've ever seen, faster data transfer rates, lower latency, and increased device connectivity. The introduction of 5G is not only a step forward for current technologies; rather, it is a catalyst for a significant shift in direction, particularly given the growing demand for high-performance networks with high bandwidth and low latency. According to Statistica (2023)[1] report, Fig. 1, the Internet of Things (IoT) is set to skyrocket with over 75.44 billion global connections by 2025.

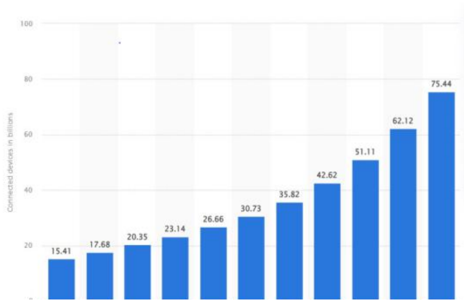

Fig. 1: Timeline for IoT
Source: *Statistica 2023*

As the world ushers into the new era of connectivity, 5G unlike its predecessors, heralds a comprehensive revolution in communications, from the frequency bands used to the architecture of the network itself. The proliferation of small cells, massive MIMO (Multiple Input, Multiple Output) systems, and the increased density of network infrastructure Coupled with the increase in connected devices necessitates a great amount of transmit power hence a huge quantity of energy being consumed. As a result, optimizing energy consumption is required. Energy efficiency in 5G has emerged as a critical and significant aspect that requires attention and innovation to ensure that projected advancements in connectivity do not come at the expense of environmental sustainability.

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[1] This growth, from 12 billion in 2020, promises transformative impacts on areas like autonomous vehicles and healthcare services. Fig. source: https://www.statista.com/statistics/1183457/iot-connected-devices-worldwide/

III. IMPACT OF 5G TECHNOLOGY ON ENERGY EFFICIENCY

Optimizing energy consumption stands as a pivotal element in sustainable development, presenting a spectrum of advantages, from financial savings to fortifying the resilience and dependability of the electric grid. The subsequent sections delve into strategies for leveraging 5G to amplify energy efficiency, alongside an exploration of the challenges entailed by these methodologies.

a. *Key Enablers for Energy Efficiency in 5G*

In the quest for energy efficiency in 5G, identifying and leveraging key enablers is paramount. These encompass cutting-edge technologies and methodologies that form the backbone for optimal energy efficiency in 5G networks. A strategic exploration of these enablers, emphasizing advanced techniques, is central to the overarching goal of minimizing energy consumption. Beyond enhancing performance, these enablers herald a paradigm shift toward sustainable and resource-conscious telecommunications. The identification and comprehension of these enablers serve as the linchpin for unlocking the full potential of energy-efficient 5G networks, constituting the bedrock upon which the foundation of 5G energy efficiency is firmly established. In this section, we will intricately examine and analyze the enablers, unveiling their nuanced contributions and synergies. This exploration seeks to offer a thorough comprehension of the dynamic ecosystem that forms the foundation of energy-efficient 5G technology.

One key enabler is Device-to-Device Communication (D2D) as proposed by the authors in [3], according to M. A. Inamdar et al, D2D is a technology which ensures that devices have the liberty to exchange data directly when the distance between them is less and ensure that traffic is reduced. The illustration of the architectural perspective[2] of D2D is depicted in Fig. 2, D2D communication in 5G plays a significant role in improving energy efficiency by reducing the reliance on centralized base stations, enabling localized communication, optimizing spectrum usage, reducing signal propagation distances, and enhancing the overall reliability and latency of communication.

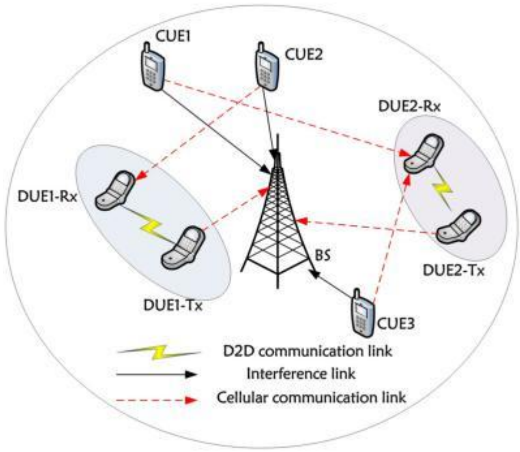

Fig. 2 D2D communication
Source: Online Library

In the realm of 5G technology, Multiple Input Multiple Output (MIMO) stands as a pivotal innovation, significantly enhancing both energy efficiency and overall network performance. MIMO harnesses the power of multiple antennas at both transmitting and receiving ends, offering a transformative boost to the capacity and reliability of wireless communication systems. Notably, the integration of massive multi-input multi-output (Massive-MIMO) systems, commonly deployed in base stations, emerges as a critical strategy for amplifying Spectral Efficiency (SE) within mobile cells. As elucidated by recent research [2], Massive-MIMO configurations hold the potential to markedly elevate SE, consequently influencing Energy Efficiency (EE) compared to scenarios involving single-antenna communication.

$$\textit{Energy Efficiency (EE)}^{3} = \frac{\textit{bit rate(bit/s)}}{\textit{consumed power(watts)}}$$

O. Shurdi et al. in [1] advocate for a pivotal innovation in 5G—advanced "Sleep" Modes. These modes selectively power down devices during inactivity, conserving energy without perceptible impact on user experience. Operating on intervals of 5-100 ms without transmission, this strategy achieves substantial energy savings, marking a significant stride in 5G efficiency.

The strategic deployment of a heterogeneous network, as advocated in [4], emerges as a pivotal facilitator in advancing energy efficiency within the realm of 5G technology. The integration of Heterogeneous Networks (HetNets), characterized by a blend of macrocells and Small Cell Based Stations

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[2] These factors contribute to a more sustainable and energy-efficient wireless network. Image source: https://ietresearch.onlinelibrary.wiley.com/

[3] The ratio of bit rate to consumed power, underscores the profound impact of Massive-MIMO in optimizing resource utilization and propelling advancements in wireless communication networks.

(SCBSs), constitutes a deliberate effort to optimize energy consumption across the system. This amalgamation of diverse base stations is expressly designed to minimize the distance of data transmission between the serving Base Station (BS) and end-users. The inclusion of SCBSs in this heterogeneous mix proves instrumental in curtailing the requisite energy consumption. Notably, the illustration in Fig. 3[4] vividly depicts the nuanced dynamics of this technique.

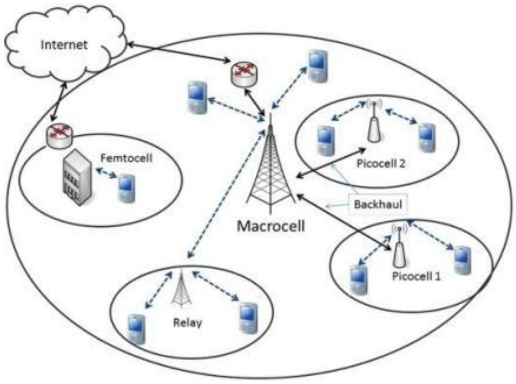

Fig. 3 Heterogeneous Network
Source: Online Library

M. A. Inamdar et al., as highlighted in [3], introduce a compelling approach to significantly enhance energy efficiency in 5G and IoT communication. By capitalizing on Renewable Energy and Green IoT principles, their proposed technique integrates cellular partition zooming and a pre-caching mechanism in tandem. This dynamic combination not only optimizes resource allocation but also introduces an innovative strategy for enhancing energy efficiency in IoT by intelligently transitioning redundant and irrelevant nodes into a sleep mode.

b. *Challenges and Trade-offs*

The previous sections highlight the emerging 5G mobile technology and energy efficiency techniques from different perspectives. This survey also addresses several issues concerning the energy efficiency of the 5G Mobile Network. This section provides emphasis on certain technological problems related to energy efficiency in the 5G mobile network. The challenges and trade-offs include;

In [3], the author noted that methods like heterogeneous networks involve new infrastructure requirements, which are more expensive than those of the current systems. The deployment and maintenance of HetNets and tiny cells may result in extra energy consumption due to the requirement for more equipment and back-haul connectivity, even if this can improve network performance. Devices that use energy-efficient technologies may use more power, which raises the cost of the product.

According to Adil Israr et al. [4], millimeter-wave technology is the line-of-sight technology required for offering high capacity at SCBSs. When a millimeter-wave-powered base station (BS) is turned off, a problem occurs. In such instances, nearby BSs suffer challenges adjusting for coverage loss due to significant propagation losses and obstructions producing blockages. Furthermore, if numerous base stations operate within the same frequency band, the switching on or off of a base station has a negative impact on the interference pattern, presenting a significant challenge in the 5G environment.

The authors in [4] further talked about 5G network constraints due to the extremely high millimeter wave(mmW) frequency. These extremely high mmW frequencies cause several propagation losses (e.g., atmospheric and rain absorption, significant blockage effects, and high path attenuation) that create new challenges to guarantee Quality of Service (QoS). They also stated that the use of Resource on Demand (RoD) techniques (e.g., sleep mode, traffic offloading) to assure EE may compromise QoS due to greater latency and interference pattern mismatch in surrounding SCBSs. In addition, because the capacity factor of photovoltaic (PV) panels is limited by clouds, shade, solar eclipse, darkness, and relative movement of the sun, QoS of Renewable Energy (RE) SCBSs may decline.

IV. RESEARCH PROPOSAL

The advancement of 5G networks introduces unprecedented challenges related to the efficient allocation of resources and energy consumption. The escalating density of network infrastructure, coupled with the proliferation of connected devices, necessitates a substantial amount of transmit power, leading to a significant energy consumption. Consequently, there is a pressing need to optimize energy usage. While the preceding sections have outlined techniques to mitigate energy consumption, they also highlight potential challenges in implementing these strategies. Addressing one of these limitations involves the application of machine learning-

[4] The illustration highlights the efficacy of HetNets in fostering energy-efficient operations within the broader 5G infrastructure. Image source: https://ietresearch.onlinelibrary.wiley.com/

driven algorithms to improve the activation and deactivation processes of base stations, thereby ensuring optimal network performance and energy efficiency.

As data traffic bursts occur at a higher frequency, the development of effective BS activation and deactivation radio resource management algorithms will be an active research field in 5G networks to assist effective network energy management. The dynamic management of Small Cell Base Stations (SCBSs) is important due to the variability of traffic loads over time and space. In scenarios where traffic distribution needs to be anticipated, machine learning methods, such as neural networks, can be applied. Understanding traffic behavior, determining traffic load type, and identifying end-user distribution can all contribute considerably to the prudent deactivation of base stations without affecting Quality of Service (QoS). Exploring machine learning algorithms for resource allocation and control strategies focused on energy efficiency is an attractive potential research path.

The utilization of machine learning algorithms facilitates real-time operation, enhancing the precision of predictions such as power consumption patterns, Distributed Generators' (DGs) output generation, and electricity prices. This allows for prompt responses through suitable steps in energy management and network operations. Recognizing the inherent complexity of managing 5G Ultra-Dense Networks (UDNs) with a large number of Small Cell Base Stations (SCBSs), reinforcement learning and deep reinforcement learning algorithmic solutions emerge as promising approaches for achieving advanced system management and optimal control functionalities of the base stations which in turn manages the energy use efficiently.

V. EVALUATION TOOLS

In our quest to comprehend the impact of 5G on energy efficiency, the selection and application of robust evaluation tools become paramount. As the telecommunications industry navigates the dual responsibility of meeting escalating connectivity demands while minimizing ecological footprints, the choice of evaluation tools becomes pivotal in shaping sustainable technological solutions. Various simulation tools used include; Base Station power consumption meter which measures the power consumption of individual base stations, aiding in the assessment of energy efficiency at specific locations. The MATLAB program was also utilized for in-depth analysis and enhancement of the impact of 5G technology on energy efficiency, it serves as a versatile platform for nuanced data interpretation and the formulation of strategies to bolster energy efficiency.

VI. CONCLUSION

As the implementation of advanced technology presents both benefits and challenges, addressing energy efficiency in 5G networks is critical. While the transition to 5G holds the promise of unprecedented data speeds, low latency, and widespread connectivity, there is a corresponding concern about the potential rise in energy consumption. This report presents a detailed literature review on techniques to reduce energy consumption in 5G. The survey delves into various energy-efficient techniques, including the deployment of small cells and the utilization of millimeter-wave frequencies, as progressively suitable methods for meeting the energy efficiency needs of 5G networks. It also highlights the challenges and trade-offs associated with this techniques. Additionally, the paper discusses a research proposal and introduces new perspectives in the quest for energy efficiency in the evolving landscape of 5G technology. Balancing the need for high-performance networks with the need to reduce environmental effect remains a difficult task. However, as 5G networks continue to evolve, the commitment to enhancing energy efficiency will remain a crucial priority in constructing a telecommunications infrastructure that is both sustainable and resilient.

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