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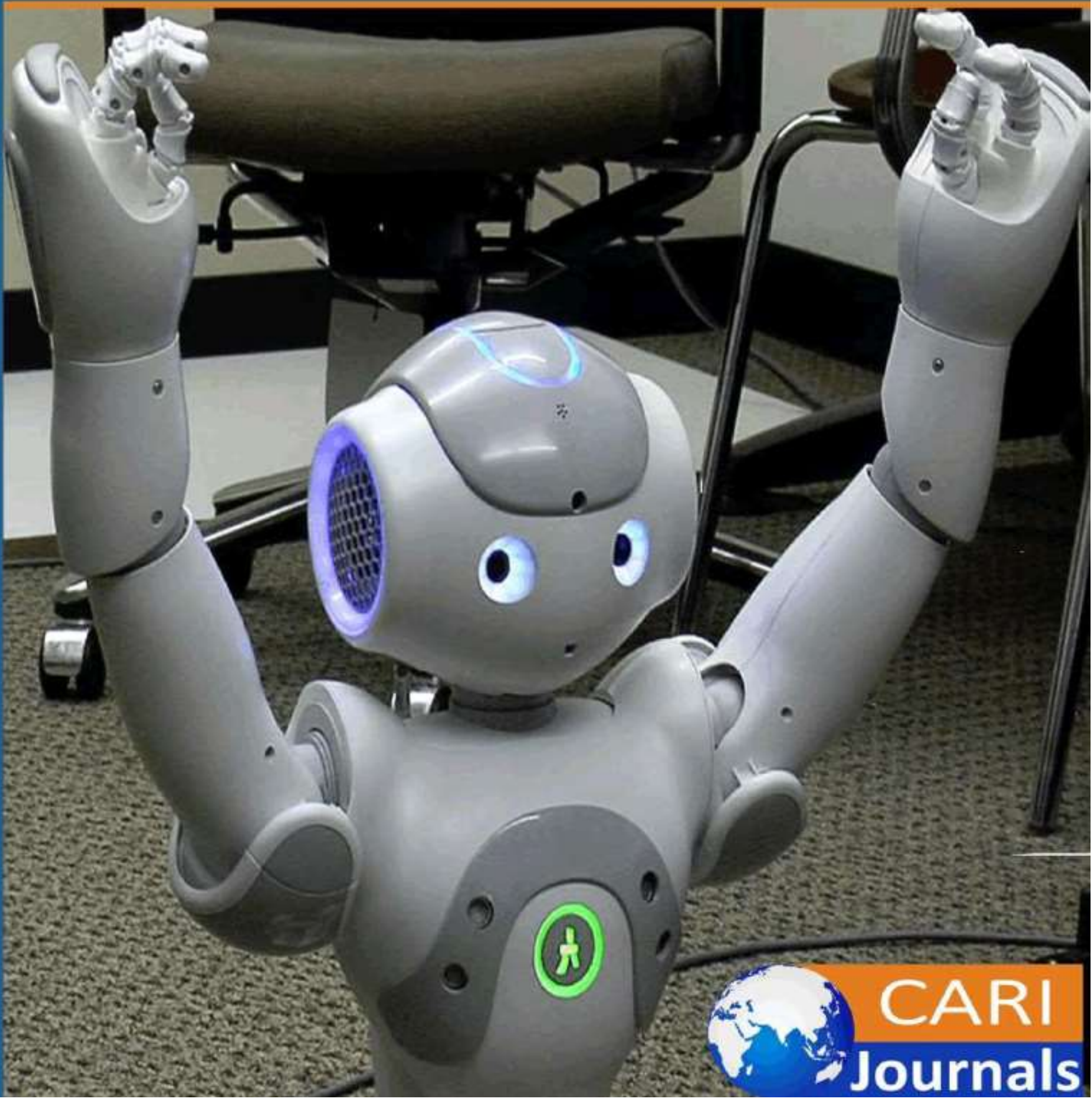

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Artificial Intelligence and Energy Efficiency of 5G Radio Access Network

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Abstract

Purpose: This paper is a pioneering study that investigates the integration of Artificial Intelligence (AI) to enhance energy efficiency in 5G Radio Access Networks (RANs). This paper aims to identify AI-driven strategies that can significantly optimize energy consumption in the rapidly evolving 5G network infrastructure, which is essential for meeting the increasing demand for high-speed connectivity.

Methodology: The methodology used for this research is a detailed review and analysis of the 5G RAN architecture and its energy dynamics, alongside the exploration of AI applications in optimizing network operations. The study focuses on AI techniques such as resource allocation, traffic prediction, adaptive sleep modes, and fault detection, proposing a holistic approach to energy management in 5G networks. A key contribution of this research is its in-depth examination of AI's role in 5G energy efficiency, highlighting its practical implications and potential for future applications. The paper offers novel insights into the implementation of AI in real-world 5G scenarios and addresses the challenges in transitioning from theoretical models to practical solutions.

Findings: The findings reveal that AI integration is a vital step towards reducing the environmental footprint of 5G networks, with AI-based solutions showing promise in enhancing efficiency beyond the inherent capabilities of current 5G technologies. Despite many AI applications being in nascent stages, their potential impact on energy efficiency is significant.

Unique contributor to theory, policy and practice: This paper is a valuable guide for researchers, industry professionals, and policymakers in telecommunications and environmental sustainability. It provides a clear roadmap for leveraging AI in 5G networks, emphasizing the synergy between technological innovation and ecological responsibility.

Keywords: *5G Radio Access Network, Artificial Intelligence, Energy Efficiency, Network Optimization, Sustainable Telecommunications.*

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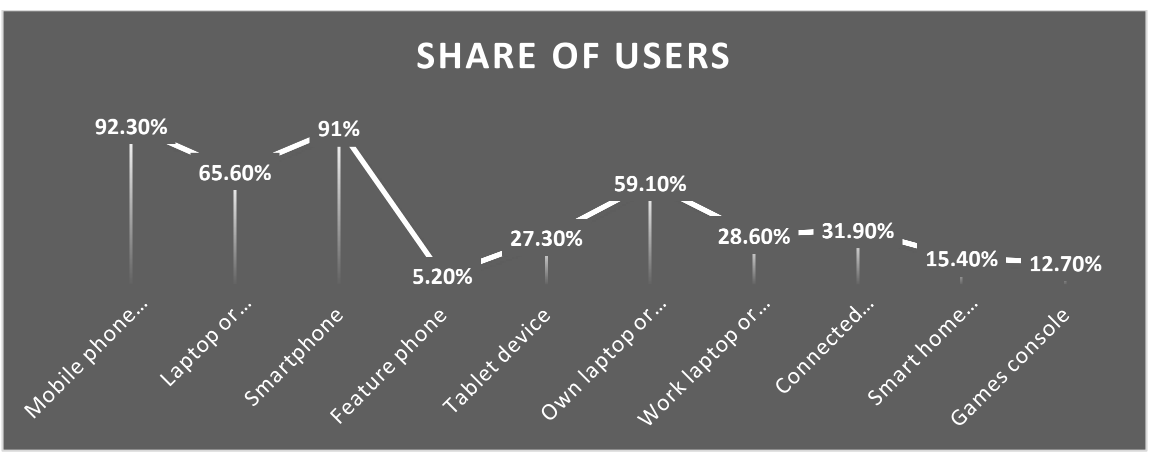
Introduction

The invention of the internet is considered a watershed moment in civilizational development as it ushered in the era of enhanced connectivity and digitalization (Petrunenko., et al., 2022). The internet has allowed profound and multidimensional connectivity at a global scale for social, political, and corporate purposes. Other than dismantling geographical barriers for people, businesses, and governments, the internet has improved access to information and democratized it considerably (Abdumajidova, 2021). This has led to more informed decisions, which are strongly result-oriented. For instance, businesses can access data related to markets more easily to make various strategy and operations-related informed decisions. Similarly, consumers can retrieve information about products and services through relevant online platforms and search engines. The scholarly literature on the subject also reveals that the prevalence and quality of the aforementioned benefits of the Internet improved gradually (Salih et al., 2020). We learn that internet connectivity enhanced and expanded over the years through technological leaps such as Broadband, Third Generation (3G), Fourth Generation (4G), and Fifth Generation (5G).

In recent years, the use of the mobile internet has increased tremendously all around the world. The statistics related to Mobile Devise Internet Usage (MDIU) divulge that around 93% of internet users access the internet through their mobile devices either using 3G, 4G, or 5G services (GS, 2023). Also, there are around 4.32 billion active mobile internet users. Therefore, telecommunication-based data services have become a major focus.



https://gs.statcounter.com/platform-market-share/desktop-mobile/worldwide/#yearly-2011-2022

The most recent telecommunication-based data connectivity development and service is 5G, which is designed to not only enhance connectivity but also improve energy efficiency as a reduced human footprint on the environment is one of the major priorities of policymakers. Although 5G networks are extremely efficient compared to previous *wireless data communication* (WDC), they still consume enormous energy. In this paper, we will discuss the *radio access network* (RAN) design for 5G and explain how Artificial Intelligence (AI) can improve its energy

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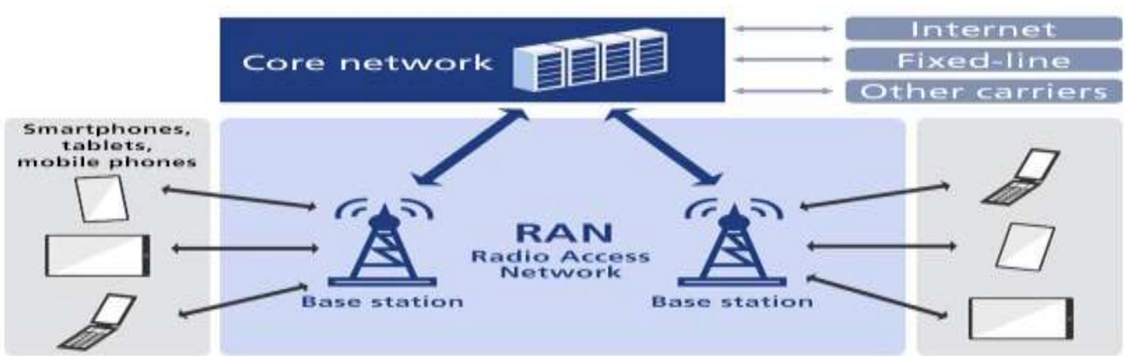
consumption and emissions.

Radio Access Network Across Mobile Data Generations and Energy Consumption

Radio Access Network (RAN) is critical for enabling data transmission/reception between the network infrastructure and mobile phone devices (Singh et al., 2020). The major components of RAN are *Base Stations* (cell sites), *Radio Frequency Components, Radio Controllers, Backhaul Networks, Cell Coverage Area, Handover Management, Signal Quality Management, Spectrum Allocation,* and *Support for Multiple Technology*. It is essential to learn about the composition of RAN to comprehend how RAN has evolved across various generations of mobile data connectivity and how its evolution affects energy consumption. Base Stations are large towers equipped with antennas and transceivers (radio frequency components), which are primarily responsible for transmitting and receiving radio signals to and from mobile devices. Radio controllers (RCs) are designed to regulate various base stations in a particular area through resource allocation, handovers between cells, etc. RCs' framework to control base stations could be fully or partially automated (Singh et al., 2020). The link between the core network and RAN is established through the Backhaul Network, which can be based on fiber optic cables, satellite links, or microwave links. The dissertation to use a particular technology for linkage is of a telecommunication company. Cells in a RAN are used for coverage of the areas. The size and arrangement of these cells have a profound impact on the coverage capacity (Singh et al., 2020). The inbuilt handover management system of RAN ensures that the handover across the cell's coverage area remains seamless. Spectrum Allocation under RAN is concerned with interference prevention and optimizing network capacity. For instance, Spectrum Allocation under RAN designates radio frequencies to different coverage cells and users to avoid disruption.



https://medium.com/@fthcknmz/radio-access-network-ran-1fb033b708f1

Note: The above figure is of basic RAN architecture for data connectivity networks.

When we review various generations of WDC, we find a stark difference in their radio access networks (RANs) characterized by architecture, priorities, functionality, and energy consumption. For instance, the architecture of 2G networks was hierarchical with its base stations connected to *mobile switching centers* (MSCs) and *home location registers* (HLRs). The priority and functionality of 2G networks were limited to voice mails and text messages. Therefore, these networks did not consume much energy for their operations or services. Compared to 2G Mobile Data Networks (MDNs), 3G networks are complex. In 3G mobile data networks, packet-switching was introduced so that the system could transmit data at a fairly high speed. The components were added to 2G networks for the purpose were Serving GPRS Support Nodes commonly referred to as SGSNs and Gateway GPRS Support Nodes (GGSNs). The energy consumption of 3G networks is high compared to 2G networks, especially during the use of data-intensive applications. Its reason is that data processing is exponentially high compared to 2G with a RAN architect that lacks advanced components such as microcells. The RAN architecture for 4G was although geared toward high-speed data services, it was more energy-efficient than the previous generation. The RAN architecture is based on All Internet Protocols. Furthermore, it has eNodeBs as base stations, whereas improved Pack Core (EPC) for data routing. Though 4G data connectivity is energy efficient compared to previous generations because of architectural advancement and improved signal processing, it still contributes quite significantly and adversely to the environment.

The major components of the RAN structure belonging to 5G are gNodesB, Small Cells, Multiple Input-Multiple Output (MIMO), Beamforming, Network Slicing, Virtualization, Multi-Access Edge Computing, Encryption, Backhaul/Fronthaul Networks, etc. gNodesB is a base station, and thus, the foundation of 5G RAN. The distinct characteristics of gNodesB are superior data rates (up to 20 gigabits per second), lower latency (reduced to 1 millisecond), and increased connectivity. Small cells are another prominent aspect of 5G RAN, which allows it to perform better in urban populations by increasing its capacity. Generally, a dense layout of small cells is preferred for realizing the aforementioned objective. The MIMO and Beamforming components of 5G RAN make the transmission and receiving of data expansive and precise. RAN's band-related operations are also wide-ranging. For instance, 5G networks operate between low, mid, and high frequencies. This allows 5G RAN to regulate its coverage and capacity to some extent.

5G RAN is strongly oriented toward energy efficiency, which is evident from its energy consumption comparisons with the previous generations of WDC for mobile phones (Säily et al., 2020). However, many studies claim that the performance of 5G in terms of energy efficiency can improve considerably if AI is emphasized. The switching to AI for enhanced energy consumption performance is essential not just for the short-term but also for the medium and long term as the load on 5G RANS will increase substantially because of population increase and Internet-of-Things (IoTs) (Quy et al., 2023).

How Artificial Intelligence Can Make 5G Radio Access Network Energy Efficient?

Artificial Intelligence (AI) is generally understood and defined as a segment of computer science that is concerned with developing those machines or systems, which mimic human intelligence (Duan et al., 2019). In the last two decades, AI has advanced at an exponential rate. Consequently, its application across disciplines and systems has also increased. Recently, several

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scholarly papers have suggested strategies and measures to optimize 5G RAN for energy efficiency by using AI. These studies propose that AI aspects such as machine learning can be leveraged to optimize RAN for enhanced performance related to energy consumption. In this section, we will discuss how AI can enhance energy efficiency through interrelated measures.

Optimized Resource Allocation: The usage of data services does not remain consistent throughout a particular period such as a day. However, RANs WDC work at their full capacity throughout the period. This is also true for 5G RAN networks to some extent; however, this can be addressed by devising and employing relevant AI algorithms. For instance, AI algorithms can review network traffic across base stations and then adjust resources such as power and bandwidth accordingly and in real-time. It should be mentioned that bandwidth is correlated positively with power consumption. Therefore, bandwidth changes are bound to impact energy consumption and emissions. Mughees et al., (2020) endorses the machine learning approaches for dynamic and automated resource allocation for energy efficiency in 5G RAN architectures.

The review for dynamic resource allocation under the energy efficiency framework can be 1) predictive or 2) real-time. AI can employ historical and current data to predict when the traffic network will change and how much. There are several predictive analysis models, which AI can use for this purpose. In their study, Tan et al. (2022) suggest that all leading candidates for statistical predictive analysis related to network trafficking should be tested for their robustness and preciseness. For instance, Tan et al. (2022) propose that predictive analysis algorithms based on linear regression, autoregressive integrated moving average mode (ARIMA), Long-Short Term Memory (LSTM), and Second-order Exponential Smoothing (SOES), etc. should be employed to predict network traffic accurately. Based on the application of these predictive algorithms, the researchers found that these models can predict network traffic with almost 90% accuracy. However, the 10% error is quite significant in terms of quality of services across the base stations. The following are linear regression and ARMIMA mathematical models for predictive AI algorithms (Kochetkova et al., 2023);

$y = a_0 + b_1 + b_2 + b_3 \ldots + e_t$ ……. (Multiple Linear Regression Model)

The term y in the mathematical model is the dependent variable Network Traffick, whereas b_1, b_2, and b_3 are the independent variables that we believe affect network trafficking. The term a_0 predicts the impact of all those variables on the dependent variable that we failed to include, whereas the term e_t represents a margin of error in the model. It is imperative to state here that the linear regression analysis can be univariate.

y_t=c+ϕ1ydt−1+ϕpydt−p+...+θ1et−1+θqet−q+et…. (ARIMA)

In the above equation, *yt* is the differenced series or value *y* at point *t*, whereas the ϕ1 is the coefficient of the first autoregression term. The alphabet *p* represents the lagged values that are yet to be included in the model, while the alphabet *q* the total lagged varies for the error term represented by et. The term *c* in the ARIMA model is the constant for the model, whereas the term *d* represents the time the collected data must be differenced to produce the signal with a consistent mean (stationary signal).

The real-time changes to resource allocation based on network trafficking will also require predictive analysis; however, a restrictive one. For instance, the AI will pick up the trends related to network traffic to make changes in real-time. The only issue with such an approach is related to the agility. Can RANs for 5G networks make changes to WDC based on the current network traffic trends in extremely short periods? Since contemporary RANs can respond to AI directions very quickly because of technological advancements, the challenge is neither significant nor stubborn.

Smart Sleep Modes: Another viable AI-based solution, in the context of energy efficiency, is sleep modes. As per the concept, certain components of RAN should be put to sleep based on the network usage or traffic by the users. The concept of putting some of the RAN components to sleep is not novel but rather quite old and implemented across several types of machines and networks. Its most common example is a computer in its sleep mode when not being used by the user. The viability of the solution (AI-directed sleep modes) has been tested in several recent studies through simulations. Kooshki et al. (2022), for instance, ran sleep-mode simulations to learn how viable the solution was. The concept of AI-based energy efficiency models has three (3) prime emphases; 1) increased transmission rate per energy unit, 2) consistent performance during the switching in and out of the sleep modes, and 3) cell-less RAN architecture. The model proposed by the researchers activates two sleep modes, which are classified as a certain phase and a conditional phase, by switching the access points to sleep based on the trends and predictions from AI. In addition, the scheme or model optimizes energy consumption during peak and off-peak hours through bandwidth manipulation and other resource-related allocations. The model simulations performed by the researchers revealed that dual sleep modes improved energy efficiency by up to 60% compared to those AI-based energy efficiency models in which all access points were active (no sleep mode was used).

A similar sleep mode-based solution is proposed in the studies by Slalmi et al. (2019), Zhang et al. (2022), and Belaid et al. (2022). However, the approach to the sleep mode solution for energy efficiency is distinct.

Service Awareness: Another AI-based solution that the scholarly literature proposes for improved energy efficiency in 5G RANs is *service awareness*. Under the service-awareness framework for energy efficiency, AI reviews the types of WDC services that users consume profoundly and systematically. The inferences drawn by the AI regarding energy efficiency across different services are then emphasized to determine the energy requirements in real time across user segments. Consequently, energy distribution throughout the base stations is optimized, which improves energy efficiency. As per Tan et al. (2022), the steps required to enhance energy efficiency across RANs based on user redistribution are three (3). The first step in implementing the framework is *targeting network or band selection*. The second measure is related to *selecting a suitable user*, while the third measure is *consequent user direction*. As per the researchers, AI identifies the most efficient band or network for the user by using its algorithms, which leads to subjective energy efficiency. Since users' consumption of WDC varies considerably during a period, AI starts optimization based on service awareness/redistribution numerous times during that period.

Fault Detection and Self-Healing: RAN architectures for 5G are large and complex. In these complex architectures, various types of faults can occur. These faults could either be minor, standard, or major in their scale or ability to harm the system. Irrespective of their nature or size, these faults can impact the energy utilization of 5G RAN networks immensely. The traditional methods for fault detection and self-healing are time-consuming, and thus; poorly correlated to energy efficiency techniques. Therefore, several studies have proposed closed-loop automation of 5G networks along with self-management. For instance, Benzaid et al. (2020) propose an AI-based fault-detection and self-healing mechanism. In the suggested system, AI detects the anomalies in 5G RANs by using the deviation technique, whereas the diagnosis of the problem is carried out using case-based reasoning (CBS). From this information, it is apparent that the automated framework for fault detection and its solving is based on machine learning.

Other than these aforementioned AI methods, 1) Traffic Offloading, 2) Threshold Criterion, 3) Traffic Optimization, etc. have also been suggested to make 5G networks more environment friendly. In the case of *traffic offloading*, the AI can effectively identify the opportunities to offload the data traffic from cellular networks to those networks, which are considered lower-power such as Wi-Fi. This reduced considerable load off a 5G RAN. Traffic optimization is also possible, convenient, and effective through AI models or frameworks as they can locate the most energy-efficient pathways. Also, they can minimize unnecessary data transfers to the users. AI-based threshold criterion works by using clustering algorithms, which identify the most suited energy-saving threshold setting for 5G RAN (Ahmed et al., 2022).

Conclusion

A detailed discussion on AI-enabled energy efficiency solutions for 5G RANs has brought forth interesting insights. One of the insights is that 5G RANs are more energy-efficient than their predecessors as their architecture was designed while keeping environmental goals in view. However, it is also a fact that 5G RANs still have a large and adverse footprint on the environment. WDC companies can reduce RANs' energy footprint on the environment significantly by using AI-based solutions. One of the most applicable solutions is dynamic or optimal resource allocation throughout RANs. To implement the solution, AI must review and predict network traffic data precisely. AI can use Linear Regression and ARIMA algorithms for predicting network trafficking for optimal resource allocation. The other highly practical and promising AI solution is smart sleep modes, which put access points or base stations to sleep based on the traffic load. All the AI solutions, which are proposed in this paper for energy efficiency in 5G RANs, are primarily framed upon data analysis and machine learning (interrelated). The more effective data analysis and machine learning processes will be; therefore, the more the likelihood that these AI-based solutions will be highly oriented toward their objective. The other insight is that almost all AI-enabled energy-efficiency solutions are in their infancy stage. For instance, they are only tested through various simulations. The real data about their effectiveness is still to be produced. On this basis, we can determine definitively whether the AI solutions are truly effective.

It is also essential to understand and acknowledge that a mix of AI-based solution companies may be required to optimize 5G RANs.

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