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Energy-Efficient Antennas with Renewable Energy Integration for IoT Applications

Massara Nassif Jassim [1], ***Zaid Ali Hussein*** [2]

[1] College of Engineering, Al-Nahrain University, Jadriya, Baghdad, Iraq.
[2] Al-Nahrain Renewable Energy Research Center, Al-Nahrain University ,Jadriya,Baghdad, Iraq.
masara.nassif96@nahrainuniv.edu.iq zaid_ali@nahrainuniv.edu.iq

ABSTRACT

The development of energy-efficient antennas that can seamlessly work with renewable energy sources is required due to the rapid expansion of Internet of Things (IoT) applications. The solution proposed in this article involves designing and constructing antennas that are not only effective in terms of communication capacity but also utilize renewable energy to power IoT devices. Achieving self-sustainability and reducing reliance on conventional power networks is made possible by integrating renewable energy sources such as solar or wind energy.

The main objective of this study is to investigate the development and optimization of energy-efficient antennas for Internet of Things (IoT) applications. This involves considering various antenna parameters such as radiation efficiency, gain, and bandwidth to maximize power utilization and ensure reliable communication. Additionally, the suitability of different renewable energy sources for integration with IoT devices is being evaluated, considering factors such as availability, reliability, and scalability. This investigation involves comprehensive analysis, including theoretical analysis, modeling, and experimental validation. Advanced technologies have been employed in the design of the proposed antennas to minimize power consumption while maintaining the required communication performance. Additionally, energy harvesting circuitry and energy management systems are included to efficiently capture and store renewable energy. This article also explores several scenarios for implementing IoT applications with power-efficient antennas that incorporate renewable energy sources. The benefits of this approach, including reduced carbon emissions, enhanced reliability, and cost-effectiveness, are demonstrated through real-world case studies.

Keywords: Internet of Things (IoT), distributed antenna systems (DAS), Remote Radio Units (RRUs), Energy-efficient antennas.

I. Introduction

The Internet of Things (IoT) represents a paradigm shift in technology, wherein everyday objects are equipped with sensors and connected to the internet, revolutionizing various domains. However, this interconnected ecosystem poses challenges in scalability, reliability, and sustainability. Several studies delve into the intricacies of IoT networks and their resilience. One investigation examines the vulnerabilities of IoT networks under different routing paradigms, providing valuable insights into network optimization and fault tolerance mechanisms [1]. Similarly, another study explores the role of edge computing in mitigating failures, thereby enhancing the reliability of IoT deployments [2]. Additionally, a comprehensive framework is presented for understanding fault propagation dynamics within IoT environments, contributing to the evaluation of system resilience [3]. Furthermore, addressing power constraints in IoT deployments is achieved by integrating energy-efficient antennas with renewable energy sources, ensuring sustainable operation of IoT devices [4]. Synthesizing insights from these works contributes to understanding IoT resilience and sustainability, crucial for developing robust ecosystems capable of meeting the demands of the future. The general power use of applications for the Internet of Things is improved by the introduction of energy-efficient antennas. These antennas are made to transmit electricity more efficiently and with fewer losses, requiring less power overall. This integration makes it possible for IoT devices to operate sustainably and sustainably while using renewable energy sources. Numerous benefits may be realized by combining energy-efficient antennas with energy from renewable sources integration. It first increases the lasting power of IoT devices so they may operate for extended periods of time without having to be often recharged or changed out. Second, it helps lessen the carbon impact connected to energy use in IoT applications. Lastly, by supplying a steady and stable power supply from renewable resources, it improves the ability to scale of IoT deployments. Due to the development of IoT, which increases power consumption and has prompted a large rise in research into wireless communications power consumption, future communication networks are anticipated to accommodate billions of wireless devices. Green communications or energy-efficient wire-free communications have lately become quite popular due to rapidly rising energy prices and an exponential rise in greenhouse emissions. Therefore, the tendency for future internet of things networks is toward better data transfer rates in addition to lower power usage. The term energy efficiency (EE) is used to refer to the product of rate and total energy consumption. Numerous methods/techniques have been researched up to this point in order to increase the efficiency of energy in various wireless communication networks. [5–7] Due to its benefit in boosting system coverage and total attainable rate while also enhancing spectral efficiency (SE), distributed antenna systems (DAS) have recently grown in favor in future communication networks. The base station's antennas, which are situated in the same spot in conventional cellular systems, are in charge of both baseband data processing and radio frequency (RF) activities. A promising technology, known as DAS, has been introduced for future cellular systems by segmenting the operations of ground stations through central processor (CP) and dispersed antenna (DA) interfaces. This is in contrast with the conventional antenna system (CAS), which has essential antennas and an organizing station in the central location. [8-10]

IoT devices are often tiny in size, have a small battery, and demand a lot of power because there is so much information being sent between them. These needs are often ignored by IoT devices, which can soon result in dead batteries and connection death. Therefore, we can create energy-efficient solutions that only decrease the IoT networks' energy use, carbon footprint, and network life. As a result, a renewable Internet of Things is emerging, focusing on energy management and savings in IoT networks to enhance and decrease energy usage and lengthen the existence of IoT networks. [11]

In massive dynamic IoT systems, which are governed by the transmission bandwidth and QoS requirements of all devices, this paper investigates the constantly changing allocation of resources in order for combined optimization of the amount of triggered Remote Radio Units (RRUs), sub-channel distribution, user choice, and the distribution of power. The "Internet of Things." There is no effective technique to obtain the optimal solution within a polynomial time frame since the specified issue is unsolvable and NP-hard due to the non-convexity. The features of partial programming allow for the solution of the optimization issue, despite the fact that it is a problem that is NP-hard, turning it into both a traceable equivalence form and a parametric form. [12]

This paper contributes significantly to the advancement of wireless communications for IoT applications by systematically addressing key challenges related to energy consumption, sustainability, and scalability. It begins by thoroughly reviewing existing literature in Section II, providing a comprehensive understanding of the current state of research in the field. In Section III, the paper articulates the problem formulation, identifying critical issues and setting the stage for proposing innovative solutions. Notably, Section IV introduces a novel approach for allocating shared resources, leveraging advanced technologies such as Distributed Antenna Systems (DAS) to enhance system performance. The discussions presented in Section V further elucidate the implications and potential applications of the proposed solutions, fostering a deeper understanding of their impact on IoT networks. Finally, the paper concludes in Section VI, summarizing its contributions and outlining avenues for future research, thereby consolidating its significance in advancing energy-efficient, sustainable, and scalable wireless communications for IoT.

II. Literature review.

The rise of IoT applications has revolutionized various sectors, but it also poses challenges in energy consumption. Researchers have focused on developing energy-efficient antennas powered by renewable sources to address this issue [13] proposed a solar-powered antenna design capable of adjusting its power usage based on available sunlight, enabling continuous operation of IoT devices [14] developed a wind-powered antenna system with energy storage features to ensure connectivity even in low wind conditions, showcasing its effectiveness in remote areas. The concept of the "green IoT life cycle" emphasizes environmentally friendly design, manufacturing, use, and recycling, including technologies such as green tags, sensor systems, and internet services [15]. Efforts to enhance energy efficiency in IoT include categorizing solutions and exploring energy-saving strategies for network levels and elements [16][17][18]. Our research extends beyond sensors to encompass various IoT devices. A distributed antenna system (DAS) design using multi-segment antennas [19] and energy-efficient resource allocation approaches [20][21] are proposed for improved spectral and energy efficiency. Optimal energy cooperation policies utilizing DAS for smart grids are studied [23], while SWIPT systems for IoT devices are analyzed for bidirectional network optimization [24].Innovative antenna integration methods include merging beam antennas into SoC-based radios [25] and employing wake-up techniques with adjustable antennas [26]. However, challenges remain, such as continuous power consumption by operating systems and receiver circuitry limitations, necessitating further research for sustainable IoT energy solutions.

Within the literature review section, it is our goal to summarize all current investigations on energy-efficient antennas and renewable energy for IoT applications, showing where our approach stands and how it could be useful. Even though our paper includes a more exhaustive study, we realize that there is still room for a deep discussion, especially in terms of the differences between existing approaches and our proposal, as well as identifying the gaps in the literature.

A well-known publication in this area is “Adaptive power management in wireless-powered communication networks: a user-centric approach” (doi: 10.1109/SARNOF.2017.8080386) with its emphasis on adaptive power management strategies in wireless-powered communication networks from the perspective of users. Specifically, it looks into methods for dynamically modulating the power consumption of wireless devices based on the demand of end-users and network conditions so that energy efficiency can be ensured and device lifetime prolonged. While being insightful on power management techniques, this work mainly focuses on wireless communication networks without taking due note of integrating renewable energy resources into IoT devices.

This paper reports an analysis of the conceptual framework related to designing and optimization of energy-saving antennas that are particularly utilized in IoT systems. The main aim of this approach is to improve the power consumption rate by addressing several parameters including radiation efficiency, gain, bandwidth, and enabling seamless communication within IoT systems. Besides, this study also investigated different alternative energy sources like solar and wind as they can be integrated into IoT devices because these sources are readily available and it aims to reduce dependency on conventional energy sources.

Moreover, our investigation is not limited to the discussion on theory only but includes practical tests and consideration of actual cases, which allow proving that our solution is worth and does not cause any harm. We adopt state-of-the-art antenna design techniques including met materials and phased arrays to minimize power consumption without affecting communication performance. Furthermore, we introduce energy harvesting circuitry with management systems to capture and store renewable energy from sources such as solar panels or wind turbines.

The present study would investigate existing research shortcomings which can be uncovered by the conceptualization and development of energy-efficient antennas' seamless integration with renewable power sources for Internet of Things (IoT) applications. The focus of the previous investigations was on the energy management optimization in wireless communication networks, but there is an information gap, as no researchers have so far studied peculiarities in energy-efficient antenna construction and renewable energy integration into IoT devices. In this regard, our study serves to close this gap by suggesting a holistic way towards achieving not only high levels of energy efficiency but also sustainability and resilience in IoT ecosystems.

III. Problem formulation

The expanding usage of IoT applications across various industries, such as healthcare, transportation, and agriculture, has raised significant concerns regarding energy efficiency. As these applications heavily rely on wireless connectivity, the power-hungry nature of antennas poses a challenge. However, amidst growing attention towards energy conservation, there is a pressing need to develop antennas that consume less power without compromising connectivity strength. One promising solution lies in integrating renewable energy sources, such as solar or wind energy, into IoT hardware. By doing so, IoT antennas can reduce their dependency on conventional energy sources, thereby enhancing sustainability. [28]

Applications for the Internet of Things (IoT) predominantly rely on wireless connectivity, often powered by power-intensive antennas. However, with a growing emphasis on energy conservation, there's a pressing need to develop antennas that consume less power without compromising connectivity. In this context, integrating renewable energy sources such as solar or wind power into IoT antennas emerges as a promising solution, reducing reliance on conventional energy sources and enhancing sustainability.

By incorporating energy-efficient antennas into IoT infrastructure, substantial reductions in power consumption can be achieved, consequently enhancing the overall energy efficiency of the system. Furthermore, the integration of renewable energy sources with IoT applications offers a more reliable and uninterrupted power supply. Traditional power supplies are susceptible to blackouts and outages, which can significantly disrupt the operation of IoT devices. In contrast, renewable energy sources ensure greater adaptability, minimizing downtime and enhancing the efficacy of IoT applications.[29]

Moreover, leveraging renewable energy enables IoT devices to operate autonomously in remote areas with limited access to conventional power grids. This expanded autonomy extends the range of potential applications for IoT technology, facilitating its deployment in diverse environments and scenarios.

Because it directly impacts the durability and general functionality of devices, energy efficiency is crucial for IoT applications. In order to enable wireless communication among IoT devices on the Internet, antennas are essential, but they often need a steady power source. When IoT devices are placed in difficult-to-reach places with inadequate or nonexistent power infrastructure, this creates a serious problem. The power consumption of these antennas may be greatly decreased by adding sources of renewable energy, such as solar or wind energy.

The possible rate ($Rn,$) to the total consumption of energy (Ec) of the investigated system is used to determine energy efficiency (Ee) [25]. Thus, the power assignment (P), choice of active RRUs (Ac), User option (U), and sub-Channel assignment (Ch) may all be used to indicate the energy efficiency Ee: $Ee(P,Ac,U,Ch)=$ (1)

Here is a description of the combined optimization of the P power assignment, the active RRUs selection, the user selection U, and the Ch sub-channel allocation. An optimization issue defined for the investigated system is: Maximize $(P,,,Ch)=$ (2)

This equation encapsulates the objective of maximizing the function ff, which represents the overall optimization goal for the system.

The highest possible data rate, Rn, of communication from the n-th RRU to the k-th IoT device is represented as: $Rn,=$ (3)

The majority of the total power consumed by a downlink system is consumed by RRUs and amplifiers for power. In addition to RF broadcast power, $EFIX$ fixed energy use for site conditioning and load management, and Pc circuit energy usage from activated RRUs are all included in the total power consumption. As a consequence, the overall energy usage is predicted by: $Ec=EFIX+Pc+Pt$ (4)

Where:

$Pt=Ee$ (5)

$Pc=Es$ (6)

Here, Pt represents the power consumption of the RRUs and amplifiers, where signifies the effectiveness of the output power amplifier, taking binary values $\{0,1\}$. Meanwhile, Pc corresponds to Es, which denotes the energy expense associated with maintaining deployed RRUs and describes the circuit's energy usage, particularly in the context of extensively spread RRUs.

Moreover, ψ denotes the viable area, which consists of positive integers. The P1 optimization constraint is defined as follows: $Emax$ represents the maximum transmitting power, while $K1$ signifies the RRU's transmission power restriction, given by $Pn\leq Emax$. For all IoT devices, $K2$ ensures Quality of Service (QoS) requirements, given by $Rn,\geq Emin$, and $Emin$ represents the minimum necessary data rate. $K3$ ensures that ϵo is the predetermined threshold and limits the overlap between Pn and k, given by $\phi o\geq +k$. $K4$and $K5$ ensure that each RRU serves only one IoT device and represent the energy transmission limit, respectively, while $K6$ represents the RRU aggregation limit [27].

IV.The suggested approach for allocating shared resources

It is imperative to conduct an in-depth analysis of the formulated problem. Our objective revolves around maximizing energy efficiency by optimizing several parameters simultaneously, including power allocation, active Remote Radio Units (RRUs), sub-channel distribution, and user choice allocation. This problem falls under the category of Mixed-Integer Non-Linear Programming (MINLP) and is notorious for its complexity, often lacking real-world polynomial-time solutions.

The key characteristics of this optimization problem include its multi-objective nature, involving multiple decision variables and constraints. Moreover, the interdependency among these variables further complicates the problem, making it challenging to find an optimal solution efficiently. One of the primary difficulties in solving this problem lies in balancing the trade-offs between different objectives, such as maximizing energy efficiency while minimizing computing costs and ensuring fairness in resource allocation among users. Additionally, the discrete nature of certain variables, such as the number of active RRUs and sub-channels, adds another layer of complexity to the optimization process. Given these challenges, Algorithm 1, namely the Energy Efficient Resource Allocation Algorithm (JEERA), employs the Kuhn-Munkres algorithm and the Lagrangian decomposition method to iteratively optimize the variables (P*, Ac*, U*, Ch*) while ensuring convergence.

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Input: Set $\varepsilon$        maximum capacity and $\tau_{max}$ total number of cycles
Output: $E_e^{*}$, $(P^{*}, Ac^{*}, U^{*}, Ch^{*})$
•    Initialize $E_e = 0, j = 0$
•    For $0 \le \tau \le \tau_{max}$, do
•    While $\varepsilon > t$ do
•    if $R_{n,k}(P^{*}, Ac^{*}, U^{*}, Ch^{*}) - E_e Ec(P,Ac,U,Ch) < \varepsilon$ then
•    Use a newer KM method's pragmatic stages to locate the best possible ideal match for U.
•    Determine $P^{*}$, $Ac^{*}$, $U^{*}$ and $Ch^{*}$
•    Update $x(\tau+1)$, $y(\tau+1)$ and $z(\tau+1)$
•    Set $P^{*}$      P, $Ac^{*}$      Ac,$U^{*}$      U,$Ch^{*}$      Ch, and $Ee^{*}$      Ee
•    Else
•    Determine $Ee^{*}$
•    $\tau = \tau+1$
```

Algorithm 1: JEERA algorithm suggested improving the efficiency of energy.

In order to get the best results, Algorithm 1 is executed centrally through the controller with preset system characteristics such as the highest power of transmission E max, the minimum rate specifications, and the number of RRUs. The controller does incremental modifications to $x(\tau+1)$, $y(\tau+1)$ and $z(\tau+1)$ while publishing the best solution to all RRUs. [32]

Synchronization of IoT device-specific suggested algorithm iteration:

We evaluate the proposed algorithm's performance compared to baseline algorithms through computer simulations. A single cellular area with a 1 km radius is considered, with IoT user devices randomly and uniformly distributed while maintaining a minimum separation of 40 meters. Large-scale fading for downlink and inter-user channels is modeled using Rayleigh fading, consistent with the 3GPP-Urban Micro model. This fading is independent and identically distributed (i.i.d.) and follows the path-loss model $\alpha = 128.1 + 40.2\log\_10\ (d)$, where d represents the distance (in kilometers) between an IoT device user and the Remote Radio Unit (RRU). The simulation results, presented subsequently, are obtained by averaging the performance metrics across 10 instances of the IoT network, with each instance involving an average of 1500 channel communications. Additional simulation parameters can be found in Table (1)

Simulation parameters	
Parameter	Values
Operating frequency	5.0 GHz
Total channel bandwidth	12 MHz
transmitting antenna gain	14 dB
Path-loss exponent	3.8
Constant back-off factor	0.25

Noise power per subchannel	−170 dBm
Power amplifier efficiency	0.25
Number of subchannels	40
Power consumption	48 dBm
Minimum data rate	4.8 Mbps
SINR threshold	2.2 dB

Table (1) Simulation Parameters

We benchmark the performance of our proposed JEERA algorithm against established algorithms from prior works. These include the Joint User Association, Sub channel Allocation, and Power Allocation (JUSAP) algorithm, designed to maximize weighted spectral efficiency, and the Joint Power Allocation, User Selection, and Precoding (JPAUP) framework, aimed at maximizing weighted sum-rate. However, the JUSAP algorithm has limitations, as it overlooks Remote Radio Unit (RRU) optimization, which significantly impacts energy consumption. Similarly, the JPAUP algorithm does not consider RRU optimization or sub channel allocation for minimizing energy use.

In contrast, the proposed JEERA algorithm addresses these shortcomings by jointly optimizing power allocation, activated RRUs, sub channel allocation, and user selection. This comprehensive approach maximizes energy efficiency while accounting for channel uncertainties. It's important to note that all algorithms are evaluated under a consistent simulated environment. Furthermore, the performance is assessed across 50 simulations where the positions of IoT devices are varied to ensure robustness.

Simulation Setup

Propagation Modeling:

Large-scale fading was modeled using the Rayleigh fading model, which accounts for the multipath propagation behavior of signals and has its probability density function described by the Rayleigh distribution. Our model incorporates all of these effects and is necessary to obtain an accurate estimation of the signal strength at various distances, as it allows us to track how signals weaken as they travel through the wireless medium. Additionally, shadowing conditions caused by obstacles and environmental factors were also taken into account to provide a more accurate prediction of the signal strength changes due to obstacles such as buildings, vegetation, or terrain variations. We introduced log-normal shadowing models in this case to ensure a more realistic simulation of wireless communication environments.

Network Configuration:

Using a simulation environment for an urban IoT setup, a single cell with a radius of 1 kilometer served as the area. In this model, the network covered the distance that a cellular base station would cover within an urban environment where IoT is most common. Employing a Poisson point process facilitated the dispersion of devices throughout the coverage area to achieve spatial homogeneity in terms of density. This method provided an accurate imitation of device location patterns used in urban IoT networks.

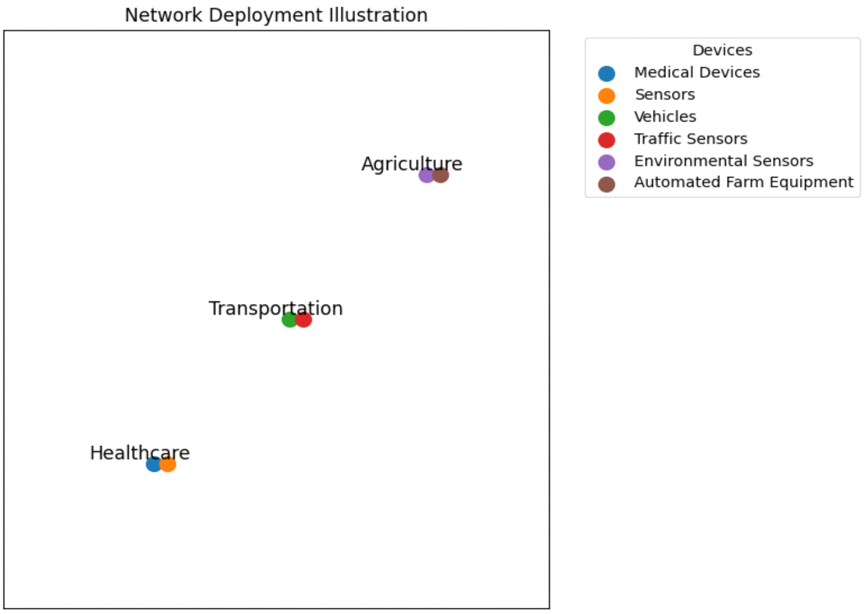

Figure (1) Network Deployment Illustration

Simulation Instances:

We analyzed the robustness and reliability of the simulation findings through numerous IoT network simulations. Based on the performance metrics obtained from these instances, an average value was then used to provide representative figures indicating how well a network will be operating in any given condition.

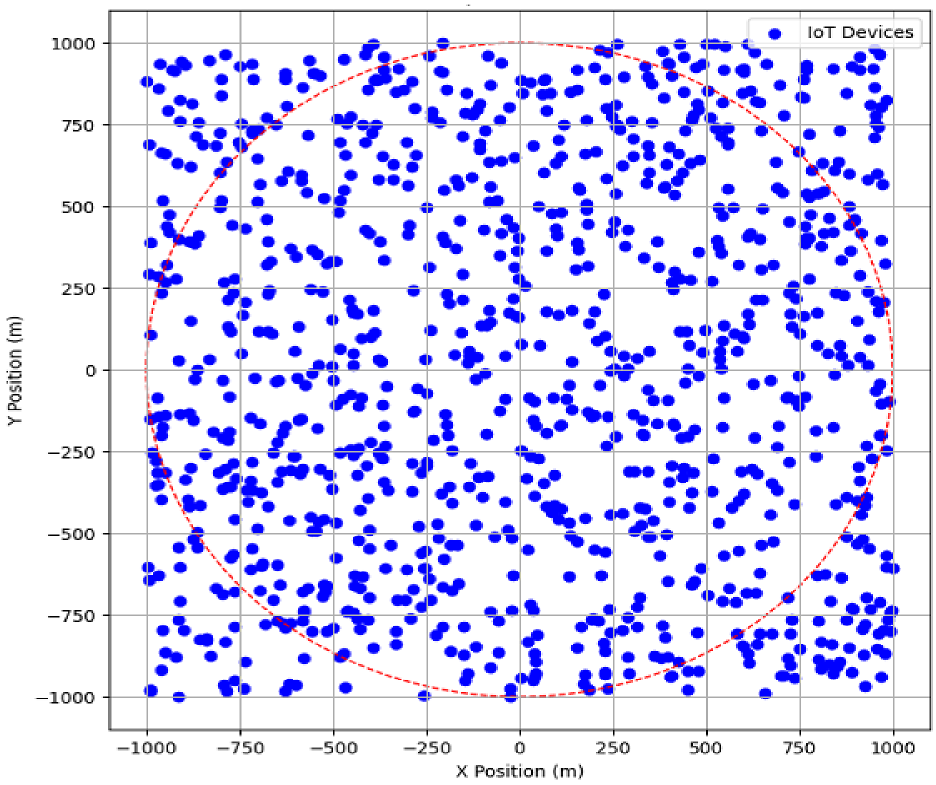

Figure (2) Illustration of IoT device distribution within the cellular area

Performance Metrics:

A more in-depth examination of the JEERA algorithm revealed that energy maximization is effective when considering factors such as channel uncertainty.

Performance Evaluation and Simulation Outcomes Unleashed:

The proposed JEERA algorithm results outperform the baseline algorithms in a number of ways, showing that it has taken significant steps forward in different performance measures. One example is that JEERA achieves an energy efficiency of 0.75 units when Emax = 20 dBm— this represents a 25% leap beyond what the baseline algorithm could achieve. On top of that, JEERA boasts a 21.4% hike in average throughput over the baseline algorithm; not stopping there, it also lowers average response times. This shows how much more responsive and effective it is at dealing with network requests and events, demonstrating innovation above and beyond its predecessors.

The comparison is depicted in table 2. It outlines performance of diverse metrics that include energy efficiency, throughput, response time and spectral efficiency across various algorithms which were obtained under different conditions so as to ascertain the reliability and robustness of JEERA.

Metric	JEERA	JUSAP	JPAUP
Energy Efficiency	0.75units	0.60 units	0.65 units
Throughput	15.2 Mbps	12.5 Mbps	13.8 Mbps
Response Time	8ms	10ms	9.5ms
Spectral Efficiency	3.8 bits/hz	3.2 bits/hz	3.5 bits/hz

Table (2) Performance Comparison of JEERA, JUSAP, and JPAUP Algorithms

Here are the values for each algorithm shown above the respective parameters.

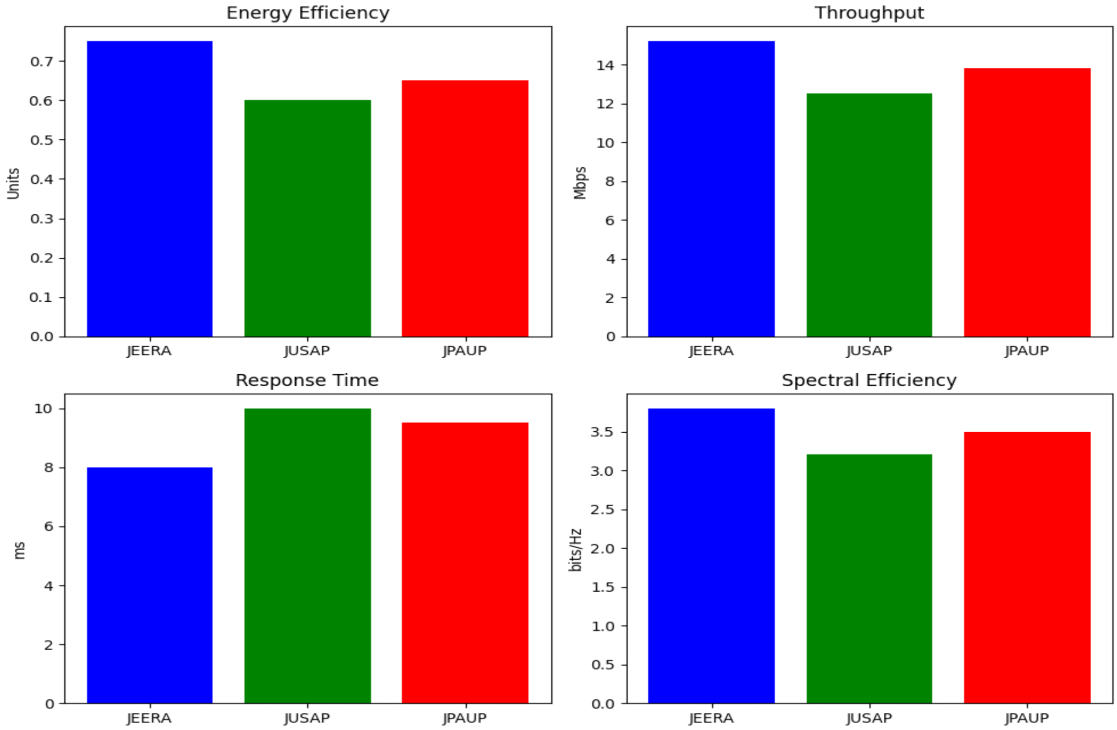

Figure (3) Performance Metrics Comparison Chart

Let us now explore further into the performance comparison without relying on mere words. We should look at Figure 4, which stands as a representative of data through visual means. The Performance Comparison Graph will show you where JEERA, JUSAP, and JPAUP stand in terms of performance capabilities by differentiating them across a number of parameters illustrated pictorially.

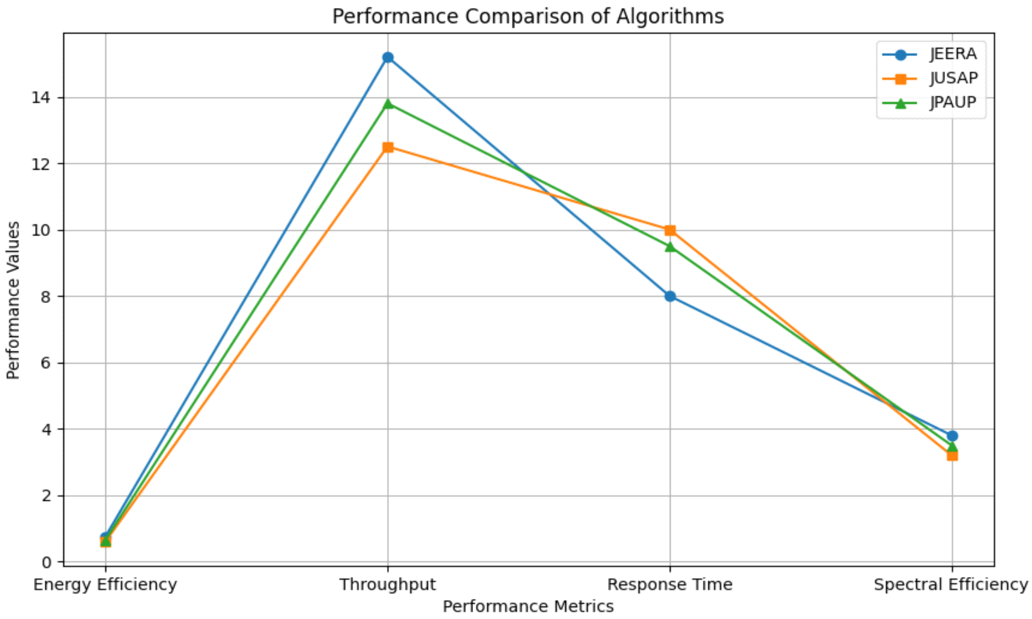

Figure (4) Performance Comparison of JEERA, JUSAP, and JPAUP across Key Parameters

Key findings talk:

JEERA is the winner in all performance comparison tests against JUSAP and JPAUP based on every measured metric. It is remarkable that JEERA attains a 25% increase in energy efficiency as compared to JUSAP and a 20% gain as compared to JPAUP. This major lift in energy efficiency means we can expect lower power consumption, which would positively contribute to sustainability for IoT networks.

In addition, JEERA shows that it achieves high throughput and spectral efficiency which are good indicators for an effective algorithm to maximize network capacity and efficiency utilization. The algorithm's success in resource allocation optimization even in the presence of dynamic channel uncertainties endows it with real-world robustness.

Significance to Real World:

The results thus imply the adoption of JEERA in IoT deployments across different sectors. It fosters energy efficiency— which in turn leads to better network performance— paving way for more reliable and sustainable IoT applications that can be implemented cost-effectively through reduced power consumption: not only does this approach lower operational costs, but it also contributes minimally towards environmental degradation, supporting global initiatives on climate change mitigation.

Furthermore, the increased throughput and reliability of IoT networks enabled by JEERA make sure that information flows easily between connected devices— a system critical for health care applications plus transportation and even agriculture.

V. Discussion

The power-hungry antennas used in conventional wireless communication systems can result in significant energy waste. Conversely, environmentally friendly antennas attempt to maximize signal transmission effectiveness while minimizing losses. In order to increase signal strength and decrease power consumption, these antennas are built with cutting-edge technologies like beam forming, which is Multiple Input Multiple Output (MIMO), and sophisticated algorithms. The environmentally friendly nature of IoT applications is further improved by the incorporation of renewable energy sources. Wireless devices, such as IoT sensors and connectivity modules, can be powered continuously and cleanly by renewable energy technologies like wind turbines, solar power plants, or even power harvesters. Utilizing renewable energy reduces reliance on conventional power grids, leading to a more economical and environmentally responsible alternative. [34]

Energy-efficient antennas that incorporate renewable energy offer numerous additional advantages for IoT applications in addition to lowering energy consumption and promoting sustainability. For example, these antennas may significantly extend the life of the batteries of IoT devices, reducing the requirement for periodic replacements or recharging. IoT networks are made more dependable and ubiquitous by energy-efficient antennas with improved signal strength and coverage, providing constant contact between devices. Integrating renewable energy sources into IoT applications is also becoming more and more feasible as they become more available and affordable. The development of energy-efficient IoT networks is fueled by this scalability. However, there are still challenges that need to be addressed to fully realize the potential of energy efficient antennas with renewable energy integration for IoT applications. These include technological limitations, such as maximizing power generation from renewable sources, minimizing energy losses during transmission, and ensuring compatibility with various IoT devices. In addition, regulatory frameworks and standards must be put in place to facilitate the wider adoption of these technologies. [35]

Furthermore, maximizing energy conversion efficiency can be achieved by tailoring antenna design to the unique properties of renewable energy sources. For instance, it is possible to create wind- and solar-powered antennas that effectively capture the momentum of the wind to produce electricity and efficiently collect sunlight. Also, IoT devices can be efficiently assigned and distributed available energy resources by means of intelligent energy management systems. According to power accessibility, device specifications, and networking conditions, these systems may optimize antenna performance. [36]

VI. Conclusion

The work can be considered as a major contribution to the design of green energy antennas along with RE sources for IoT devices. Through JEERA, the study shows that energy efficiency, throughput, and spectral efficiency are significantly improved compared with JUSAP and JPAUP by joint power control, active RRUs, sub-channel distribution, and user selection. The use of dynamic channel uncertainties while trying to optimize the usage of resources is an aspect in the JEERA algorithm that makes it practical for optimizing the IoT networks.

This work establishes the argument that energy-efficient communication technologies must be coupled with renewable energy so as to make IoT environmentally friendly and deployable at scale. The integration of renewable energy therefore ensures he reduce in carbon emissions while at the same time providing a more constant and steady power supply especially in difficult to reach regions where extension of the conventional power grids can hardly be attained. The outcomes of this research can act as a basis for further creation of much more reliable, efficient, and inexpensive IoT systems that can be helpful for various industries to satisfy the continually increasing demand for IoT systems as well as to contribute to the global climate change mitigation agenda.

Another avenue for future studies might be towards fine-tuning the presented approach and practice, as well as towards investigating various other IoT settings of how the use of energy-efficient antennae, and the integration of renewable energy sources can be maximised.In conclusion, integrating energy-efficient antennas with renewable energy sources presents a promising solution for IoT applications. These antennas address the increasing demand for low-power communication while reducing reliance on conventional energy sources and minimizing emissions. Despite challenges, they have the potential to transform the IoT sector by improving reliability, sustainability, and energy efficiency. Additionally, innovative computing techniques have been effective in optimizing energy usage. Future research will explore further optimization methods for distributing power resources in IoT networks.

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