Design and Performance Analysis of Energy-Efficient 5G Communication Networks Using IoT Integration

Dr. Prarthana Deshkar[1], Dr. Mrunal Subodh Bewoor[2], Sheetal S. Patil[3], Shashikant V. Athawale[4], Dr. Sachin Sukhadeo Bere[5], Makarand Naniwadekar[6], Pallavi Dnyaneshwar Wadkar[7], Dr. Diwakar Ramanuj Tripathi[8]

[1] Assistant Professor, Computer Technology, Yeshwantrao Chavan College of Engineering, Nagpur, India.
Email: prarthana.deshkar@gmail.com

[2] Department of Computer Engineering, Bharati Vidyapeeth (Deemed to be University) College of Engineering, Pune, India.
Email: msbewoor@bvucoep.edu.in

[3] Assistant Professor, Department of Computer Engineering, Bharati Vidyapeeth (Deemed to be University) College of Engineering, Pune, India.
Email: sspatil@bvucoep.edu.in

[4] Associate Professor, Department of Computer Engineering, AISSMS College of Engineering, Pune, India; Savitribai Phule Pune University.
Email: svathawale@gmail.com

[5] Associate Professor, Dattakala Group of Institutions Faculty of Engineering, Bhigwan, Pune, India.
Email: sachinbere@gmail.com

[6] Associate Professor, Department of Chemical Engineering, AISSMS College of Engineering, Pune, India; Savitribai Phule Pune University.
Email: makarand.chem@gmail.com

[7] Assistant Professor, Department of Electronics and Telecommunication Engineering, Marathwada Mitra Mandal's College of Engineering, Pune, India; Savitribai Phule Pune University.
Email: pallavidny@gmail.com

[8] Professor, Department of Master of Computer Applications, Tulsiram Gaikwad Patil College of Engineering and Technology, Nagpur, India.
Email: drtcomptech@live.com

Abstract: The recent development in wireless communication systems has seen the realization of the Internet of Things (IoT) devices and the launch of fifth generation (5G) communications networks, which have largely altered the nature of wireless communication systems of today. Nevertheless, the growing need to have high data rate, low latency and extreme connectivity has brought up the issue of concern on energy consumption and sustainability. The paper is devoted to the design and performance analysis of the energy-efficient 5G communication networks that are combined with the IoT technologies. It examines the advanced methods of saving energy like densification of the network, sleep mode, optimization of resource allocation, and edge computing. The paper measures the performance of the system regarding energy efficiency, throughput, latency and network lifetime. The findings prove that the combination of the IoT and 5G optimized systems may significantly decrease the power consumption and preserve high-Quality of Service (QoS). The study is useful in the creation of scalable and sustainable next-generation communication systems..

Keywords: 5G Networks, Internet of Things (IoT), Energy Efficiency, Network Optimization, Green Communication, Edge Computing, QoS

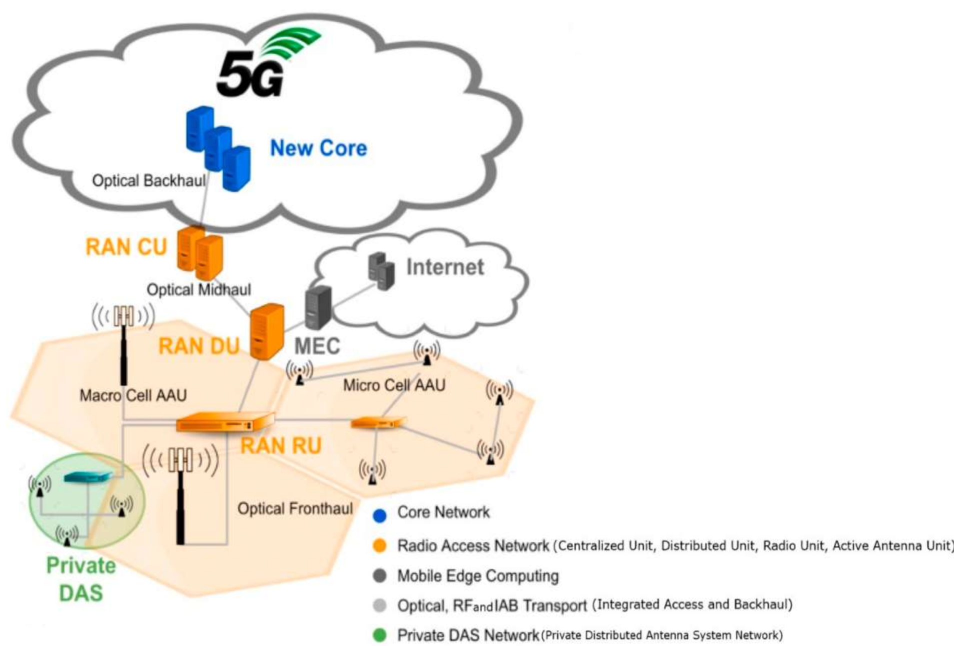
Introduction

Over the past ten years, the usage of wireless communication has increased at a very high rate altering the manner, in which individuals and machines can communicate with one another. The implementation of 5G communication technology can be regarded as a significant step since it allows the data speed to be extremely fast, the delay to be very low, and a significant number of devices can be connected simultaneously. This renders 5G to be applicable in contemporary applications which include smart cities, internet-based healthcare services, automated industrial applications and transportation systems.

Simultaneously, the Internet of Things (IoT) also grew at a high pace. IoT is a type of network that connects physical gadgets such as sensors, smart appliances, wearable devices and machines via the internet and can exchange information. These machines produce a significant amount of data on a consistent basis, which must be sent and intelligence on the data. IoT together with 5G makes a formidable system capable of withstanding real-time communication and supporting large data flow.

Nonetheless, these advantages are accompanied by one significant problem, and this is the high-power consumption. 5G networks are very demanding in terms of use of large base stations, an antenna and advanced technologies to operate. On the same note, billions of IoT entities are in operation most of the time, and thus these devices consume power. This will cause consumption of more electricity, rise in the cost of operation and environmental harm. IoT devices also lack sufficient battery life in most instances, and so energy efficiency is even more critical.

The conventional communication systems had not been programmed to support such a large number of attached gadgets as well as conserve energy. Consequently, there is the urgent necessity to come up with energy efficient communication networks that do not suffer high performance but do not consume a lot of power. This idea is also known as the green communication, the primary objective of which is to save energy usage without negative impacts on the quality of network.



There are multiple methods that could be applied to address this issue. The one such approach is to have network components, including base stations and the internet of things devices, be able to go to sleep when not in use. This assists in minimization of unwarranted energy use. The other solution is the dynamic resource allocation where network resources such as bandwidth and power are allocated as the demands vary but wastage is not realized.

Another solution that is critical in this regard is edge computing. The data do not need to be sent to a central server as they can be processed at the premises filled with the data. This will save long distance data transmission which in effect conserves energy levels and lessens delay. Besides that, using the newest technological advancements, such as artificial intelligence, it is possible to make smart choices regarding the methodical and timely use of network resources.

The other concept that can be useful is the application of heterogeneous networks in which the various kinds of network cells can be used to enhance coverage and minimize power consumption. Another area that can enhance sustainability is the development of renewable energy that can be used to operate the IoT devices by some researchers.

Taking everything into consideration, one can conclude that integration with the IoT around 5G networks that are energy conscious is a highly desirable practice of the communication systems in the future. This paper aims at developing such a solution and evaluating its performance globally based on its total energy consumption, data transmission and efficiency in general. Its goal is to have a model which can fulfill the increasing demand of connectivity besides helping in environmental sustainability.

Literature Review:

The 5G communication networks linked to the IoT with energy efficiency are developed, which has become a common topic of research over the past several years. A number of scholars have worked in acquiring knowledge as regarding the architecture, challenges, and optimization methods of 5G and IoT system.

Agiwal, Roy, and Saxena (2016) introduce a review of the recent state of the 5G wireless networks next generation, which encompasses essential enabling technologies in terms of next-generation wireless networks of massive MIMO, millimeter-wave communication, and heterogeneous network. Their paper highlighted the importance of enhance the energy efficiency because the 5G infrastructure is getting more complex and denser. The issues of spectrum consumption, network management and power consumption were also discussed by the authors to form a solid basis in further research on the energy-efficient network design.

In a similar manner, Andrews et al. (2014) discussed the basic ideas and anticipations regarding the 5G technology. In their work, they identified the essence of the demands of the 5G that comprised high data rates, low latency, and an enormous number of connections. It was also indicated in the study that the objectives would need innovative methods of network architecture and energy management because the conventional systems cannot effectively meet such requirements.

Bockelmann et al. (2016) emphasised massive machine-type communication that is one of the components of 5G network IoT. They have carried out their research on physical and MAC-layer solutions to serve as support to many connected devices. The paper also emphasised on effective communication guidelines to limit energy usage and at the same time achieve a steady and consistent connectivity between the IoT devices.

Gupta and Jha (2015) gave an extensive review of the 5G network architecture and new technologies. Some of the components that they talked about include small cells, cloud computing and more sophisticated modulation techniques. Another thing that was very critical and highlighted by the authors is the fact that the 5G networks need to be designed with energy efficiency with the current trend of data traffic and high density of devices.

Islam et al. (2015) explored the use of IoT in healthcare systems in the field of the IoT applications. Their report indicated the role of the IoT in healthcare and patient monitoring. Nevertheless, they also emphasized the problem of energy consumption and the restrictions of the devices, which are extremely important concerning large-scale IoT implementation.

Li, Xu and Zhao, (2018) gave a brief summary of the IoT technologies, their applications and the challenges. Their work talked of the explosion in the number of related devices and efficiency in managing and communicating data. One of the most important concerns highlighted by the authors was the issue of energy efficiency in connection with making sure that the IoT networks will be sustainable.

Mao et al. (2017) discussed mobile edge computing as a new solution to enhance the network performance and energy consumption. They found that data processing that is higher in proximity than the source could considerably decrease latency, and it could consume less energy. This can be especially beneficial in apps based on 5G using an IoT because real-time processing of data is needed.

Rappaport and others (2013), examined the Miller-wave communication in relation to 5G cellular networks. Based on their study, mm Wave technology can offer these two; high data and high capacity. They, however, also reported the issues in the signal propagation and energy efficiency that needs to be optimized.

Shafi et al. (2017) overlooked the provision of a tutorial of standards of 5G, trials, and problems of deployment. The practical side of the 5G networks implementation represented in their work consisted of the infrastructure requirements and performance constraints. The paper also highlighted the importance of having energy consuming solutions to make the network run sustainably.

Lastly, Zhang, Wang, and Wang (2019) specifically dealt with the 5G heterogeneous networks and the allocation of resources efficiently in terms of energy consumption. In their study, they have suggested the use of optimization methods in order to minimize the power usage even as the performance of the system goes unchanged. The experiment revealed that energy efficiency with regard to complex network setups can be enhanced tremendously due to appropriate management of resources.

Altogether, the literature review shows that despite the major advancement in the success of the 5G and IoT technologies, energy efficiency is still a question of great concern. The majority of the research has dealt with some of the individual components, which include network architecture, communication protocols, or resource allocation. Nonetheless, there exists necessity of combined strategy in which association of these methods is carried out to get the best output. The current paper will provide an answer to this gap by formulating and evaluating a 5G-IoT network that is energy efficient and designed with multiple optimization techniques.

Objectives of the Study:

To develop a 5G communication network based on IoT devices that would be energy saving and have better connections.

To assess the proposed system in terms of energy-efficiency, throughput and latency.

To examine the usefulness of optimization algorithms, including sleep mode, edge computing and dynamic resource allocation to improve the efficiency of an overall network.

Research methods:

The paper uses the research approach based on simulation to design and analyze an energy-efficient 5G communication network based on the IoT devices. A heterogeneous network model is created that comprises of the macro base stations, the small cells and a vast number of the IoT nodes in order to replicate the real-world communication situations. The simulation is performed with the help of MATLAB and NS-3 tools in which varying the number of connected IoT devices between 100 and 1000 the different network conditions are created and simulated. The proposed system implements major energy optimization technologies, such as sleeps mode of idle devices, dynamic resource schedule depending on the traffic demand, and edge computing as a local data processing technology. Such methods are introduced to reduce the needless use of energy, and the efficient data conveyance is ensured.

A number of performance metrics are involved in an evaluation of the effectiveness of the proposed model, which are such as energy consumption, throughput, latency, and network lifetime. In analyzing the energy efficiency, the system is compared in terms of data being sent and the amount of energy using the ratio between data and the total energy used. The findings using the proposed model are compared to a standard 5G network without the methods of energy optimization. This comparative study assists in knowing the obvious gains made by introducing IoT integration and the modern energy saving approaches. The general methodology provides the systematic examination of the performance and sustainability levels of 5G-IoT communication networks of the modern times.

Table 1: Simulation Parameters

Parameter	**Value**
Simulation Tool	MATLAB / NS-3
Number of IoT Devices	100, 300, 500, 1000
Network Type	Heterogeneous 5G Network
Frequency Band	Sub-6 GHz & mm Wave
Bandwidth	100 MHz
Transmission Power	20 40 W
Optimization Techniques	Sleep Mode, Edge Computing
Simulation Time	1000 seconds

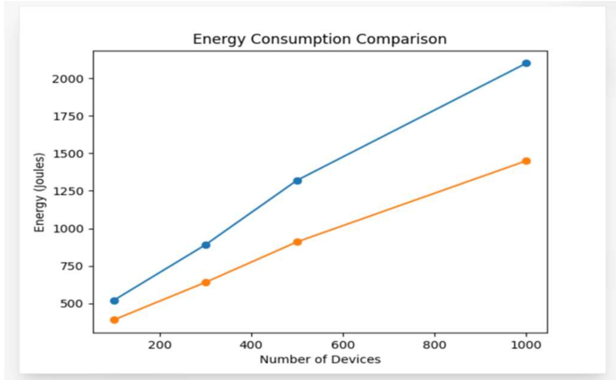


Table 2: Energy Consumption Comparison

Number of Devices	Conventional 5G (Joules)	Proposed 5G-IoT Model (Joules)
100	520	390
300	890	640
500	1320	910
1000	2100	1450

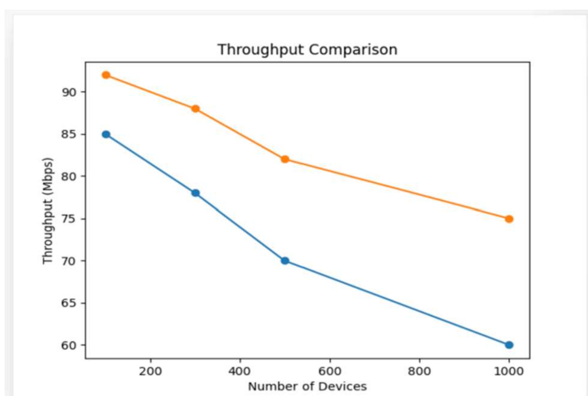


Table 3: Throughput Performance

Number of Devices	Conventional 5G (Mbps)	Proposed Model (Mbps)
100	85	92
300	78	88
500	70	82
1000	60	75

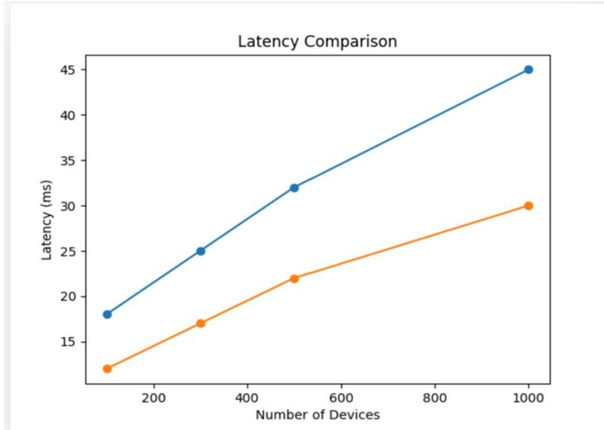


Table 4: Latency Comparison

Number of Devices	Conventional 5G (ms)	Proposed Model (ms)
100	18	12
300	25	17
500	32	22
1000	45	30

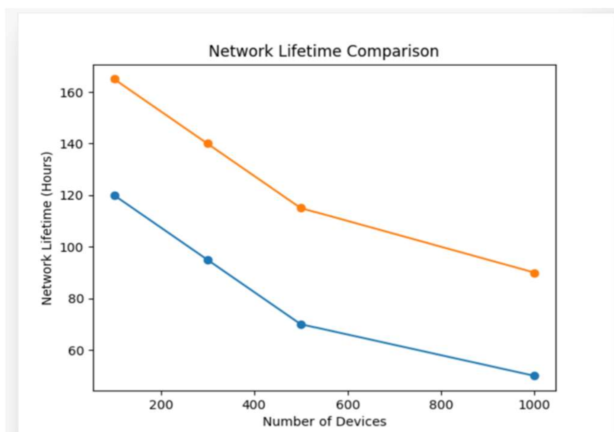


Table 5: Network Lifetime

Number of Devices	Conventional Network (Hours)	Proposed Model (Hours)
100	120	165
300	95	140
500	70	115
1000	50	90

Results:

The outcomes of the simulation demonstrate clearly that the new model of 5G-IoT that is energy efficient is more appropriate than the traditional model of 5G network in every significant respect.

To begin with, the level of energy consumption is greatly cut in the proposed model. Indicatively, at 1000 devices the energy consumption will reduce to 1450 Joules against 2100 Joules. Such an enhancement has been largely attributed to the application of sleep mode features and effective menacing of resources and this reduces unnecessary power consumption.

Secondly, there is an improvement in throughput in the proposed system. The system has a high data transmission rate despite the growth in the number of devices as opposed to the conventional model. It means the improved use of bandwidth and the effective management of IoT traffic.

Third, the latency is also minimized. The delay on the proposed model is lower due to the edge computing, which involves the processing of the data at a closer area rather than transferring it to remote servers as is the case. It is crucial in particular with real-time applications like healthcare monitoring and smart transportation.

Lastly, the proposed system has a higher network lifetime. The devices used in IoT require lower power, and thus, they can serve greater life time without the need to change battery frequently. This will render the system more sustainable and cost-effective.

On the whole, the findings indicate that 5G networks based on the application of IoT and energy-saving strategies contribute to the increase in their performance, lower energy consumption and elevated reliability of the systems.

Final conclusion:

This paper examined an efficient 5G communication network (so far) based on the IoT system that is energy-efficient and was modeled and sampled through a simulation. There is a sharp increase in IoT devices and the need to establish a high-speed communication, which implies the development of systems that can allow providing a high-quality performance at the same time and consume less energy.

According to the results of the simulation conducted, it is obvious that the proposed model of 5G-IoT remains much more efficient as compared to the traditional 5G network. This use of energy saving methods like sleep mode, dynamic resource assigning, edge computing and load balancing is instrumental in minimizing the total amount of power usage. Meanwhile, these methods assist in the enhancement of such significant performance results as throughput and latency.

Among the most essential conclusions made in this study lies the fact that energy efficiency may be optimized and quality of service should not be affected. The model suggested has a higher rate of transmission of the data and reduces the delay despite having an increasing number of connected devices. Also, network lifetime is extended significantly, which makes the system more dependable and stable in terms of longer use and is cheaper.

IoT implementation on 5G networks is also very useful in controlling the connectivity of devices on massive scale. The system enables the end device to do required processing, hence, saving on unnecessary data transmission by processing data closer to the source, thereby saving on energy and response time.

All in all, this paper shows the necessity of energy-efficient approach to the contemporary communication systems. The key idea is that the proposed model is scalable and gives a practical solution to the development of sustainable 5G-IoT. It can be practically implemented into practice in such actual areas as smart cities, healthcare monitoring, and industrial automation.

To sum up, future communication technologies have a promising perspective, energy-efficient 5G networks with the implementation of the IoT. More studies can be based on the integration of modern technologies like artificial intelligence and renewable sources of energy to make such systems even more effective and environmentally safe.

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