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Enhancing Energy Efficiency utilized IoT: Power Optimization and Energy Harvesting Techniques for Sustainable and Resilient Systems

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Abstract

The widespread growth of Internet of Things (IoT) devices, in industries has led to a rise in energy requirements underscoring the importance of sustainable power management solutions. This study talks about the methods for optimizing power usage and harnessing energy to improve efficiency within networks shown in 2 and 2.1. By combining dynamic power management strategies with energy harvesting from sources like thermal and vibrational energies this research explores the potential for creating durable and eco-friendly IoT systems. Through a combination of simulations and real world experiments, We assess the efficacy of these approaches. The results demonstrate that customized power management algorithms paired with context energy harvesting can significantly lower the energy consumption of devices without compromising their performance levels. This investigation enhances our knowledge of networking by suggesting a framework for implementing energy efficient practices in IoT by thermal and vibrational energies infrastructures paving the way, for more eco friendly technological environments. This study does not confirm the viability of self sustaining networks but also suggests future research paths to further enhance energy efficiency and resilience in IoT setups or systems.

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1. Introduction

The Internet of Things also known as IoT is a development that has transformed the way the devices interact and function. It has influenced sectors; from city planning to healthcare. With the expansion and ever increasing complexity of networks, managing their energy consumption has become a challenge[1]. The rise in energy usage not only puts pressure on power sources but also worsens the environmental conditions by relying heavily on non renewable energy sources. Despite the use of Internet of Things (IoT) systems, in industries, the sustainability of these systems is hindered by their high energy demands. Conventional energy management methods often struggle to meet the requirements of connected IoT devices[2]. Additionally, the sporadic operation of devices, with bursts of activity followed by periods of dormancy necessitates flexibility in energy management approaches that match or compensate for these usage patterns.This research aims to tackle the issue of energy consumption, in networks by exploring and evaluating advanced techniques for optimizing power usage and harnessing energy. The first objective is based on evaluating the effectiveness of dynamic power management strategies designed for devices with a focus, on reducing power consumption during periods while ensuring system responsiveness and reliability. The second one is exploring the benefits of incorporating energy harvesting methods into networks and examining how renewable energy sources can be used to support or substitute traditional power sources thus improving the sustainability of these systems.

Finally, this research creates a framework that integrates power optimization and energy harvesting with the objective of developing self IoT systems that are both efficient and resilient. Enhancing energy efficiency, in networks plays a role in cutting down operational expenses lessening environmental harm and boosting the scalability of these technologies. Through improvements in power optimization and energy harvesting methods, this study adds to the creation of eco durable IoT structures[1, 3]. The results of this investigation are anticipated to offer knowledge for professionals and researchers in the field encouraging the use of friendly technologies and backing the shift of the IoT sector, towards sustainability[4].

The Internet of Things (IoT) brings together a vast array of devices and infrastructures, leading to a projected connectivity of 80 billion smart devices by 2025. Figure 1 illustrates the growth in IoT devices alongside the increase in the global population[5-8]. These networks generate substantial amounts of data through these smart devices. Data volume is expected to double every two years, reaching 163 Zettabytes by 2025[9]. The percentage of IoT-generated data is predicted to grow from 2% in 2013 to 10% by 2021[10]. Figure 2 highlights the expansion of data from 2010 to 2025, showing a tenfold increase by 2025 compared to the amount of data generated in 2016[9, 11].

1.2 Problem

The growth of IoT devices in industries has led to increased energy demands, necessitating sustainable power management solutions to optimize energy usage and enhance efficiency.

1.3 Aims and Objective

The study evaluates the effectiveness of dynamic power management strategies, explores energy harvesting methods to enhance sustainability, and creates a framework integrating both to develop efficient and resilient IoT systems.

The methods and techniques are mentioned below

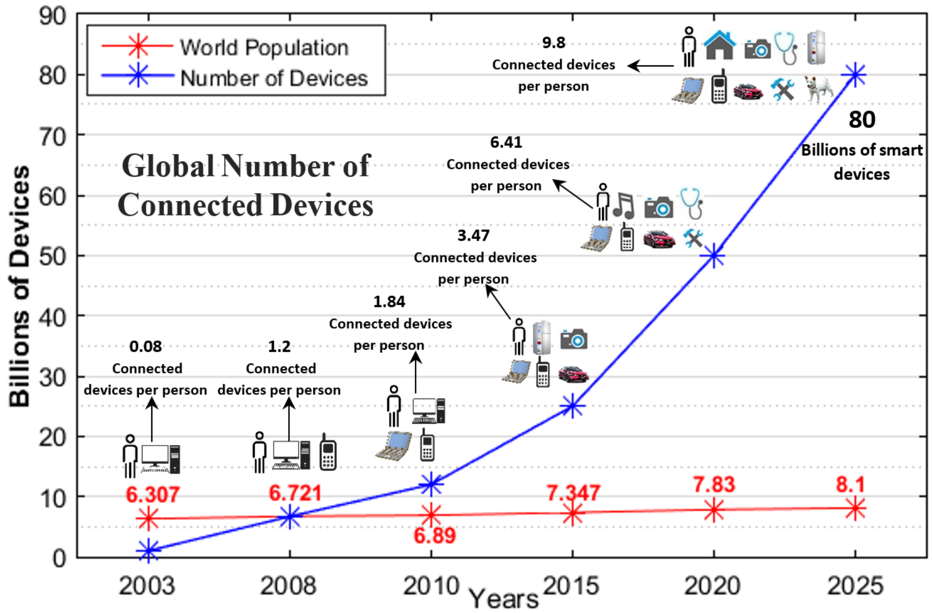

Figure 1. Estimated counts of connected devices vs world population.

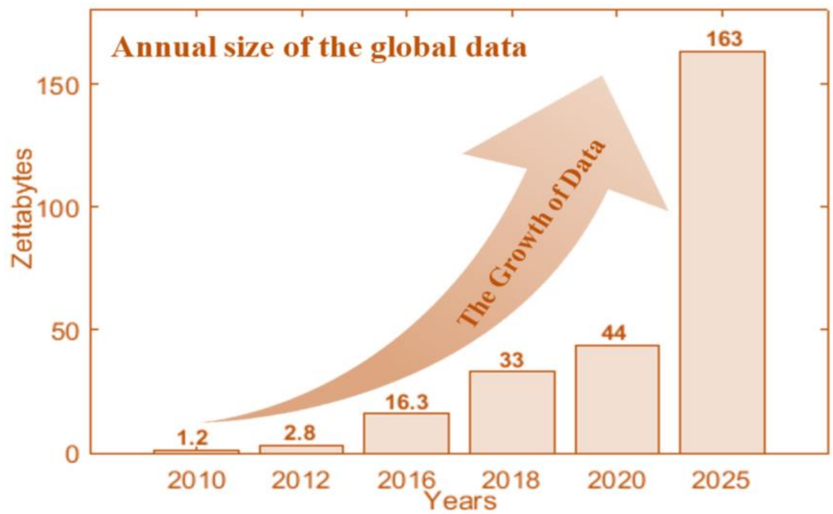

Figure 2. The growth of data over the years.

2. MATERIALS AND WORKING METHODS

2.1 List of IoT Devices Used in Experimental Setup

2.1.1 Device Specifications:

- Model A (Smart Sensor):
- Processor: ARM Cortex-M4
- Memory: 256 KB Flash, 32 KB SRAM
- Connectivity: Bluetooth Low Energy (BLE), WiFi
- Additional Features: Ambient light sensor, temperature sensor
- Power Source: Battery-powered with solar panel attachment for energy harvesting
- Model B (IoT Gateway):
- Processor: Quad-Core ARM Cortex-A7
- Memory: 1 GB RAM, 8 GB eMMC
- Connectivity: Ethernet, WiFi, Zigbee
- Additional Features: Supports multiple network protocols, high data throughput capability
- Power Source: Mains power with options for backup power via battery
- Model C (Actuator Device):
- Processor: ARM Cortex-M0
- Memory: 64 KB Flash, 8 KB SRAM
- Connectivity: Wired (Ethernet), Wireless (NFC, RFID)
- Additional Features: Motor controller for automated physical actions
- Power Source: Dual-mode, electric and solar-powered

2.1.2 Device Specifications:

- Power Management Settings:
- First, the devices will be in sleep mode for inactivity after a minimum of two minutes. (SMC-Sleep Mode Configuration).
- Second Arranged to respond to organize solicitations or sensor inputs. (WT-Wake-up Triggers).

- Energy Harvesting Settings:
- In 5V 200 mA output in standard test under standard test conditions. (Solar Panels).
- Connect to gadgets working in higher temperature zones to catch and change over squandered heat into electrical energy. (Thermal Converters).

2.1.3 Schematic Diagrams:

- Itemized wiring and block diagrams of the gadget arrangements, including interconnections between sensors, actuators, and gateways. Charts portray the reconciliation focuses for energy harvesting modules.

2.2 Energy Measurement Instruments

2.2.1 Energy Consumption Meters:

- Model: PowerCast P2110
- Features: Operates effectively across a range of frequencies (typically from 902-928 MHz and 2.4-2.48 GHz).
- Application: It's a Supporting IoT application where devices need to be deployed for long periods without any maintenance.

2.2.2 Data Logging Equipment:

- Model: LoggerPro
- Features: It's a high precision logging with interface capabilities via USB wire to laptops or directly connecting to cloud services provider for real-time data analysis.
- Application: mostly it is used to store and collect data from energy meters for further analysis.

2.2.3 Calibration Certificates:

- Issued by: National Instruments Calibration Services
- Validity: The validations of Certificates are for one year valid from the date of issue, ensuring the correct measurements during the entire experiment.
- Simulation Software:

i. Name: NS-3 Network Simulator
ii. Version: 3.35
iii. Description: IoT network environments are mostly used for creating realistic to simulate device communication, energy efficiency scenarios and network traffic.

- Statistical Analysis Software:

i. Name: Python
ii. Version: 3.9
iii. Libraries Used:

a) NumPy: Its powerful array handling capabilities, combined with a wide range of mathematical functions, make it indispensable for scientific computing, data analysis, machine learning, and beyond.

b) SciPy: Its applications span across scientific research, engineering, data analysis, and more, making it an indispensable resource it provides the functions and algorithms needed to perform these tasks efficiently and effectively.

c) Pandas: It is indispensable in various fields, including data science, finance, business analytics, and scientific research, for tasks ranging from data cleaning and transformation to analysis and visualization. Widely used for exploratory data analysis (EDA), including data cleaning, transformation, and summarization.

d) Matplotlib: It is a powerful and flexible plotting library that is essential for data visualization in Python. Its comprehensive features and customization options make it suitable for a wide range of applications, from simple exploratory data analysis to complex scientific research visualizations.

3. METHODOLOGY

This research employs techniques to assess the effectiveness of power optimization and energy harvesting methods in networking. The goal of this paper is to evaluate the advances in energy efficiency along with their impact on system performance and reliability. By integrating real world experimental models with simulation models see device specifications 2.1.1, this method allows us for an evaluation of proposed solutions under particular circumstances and scenarios see 2.1.1 Mod l A, B and C.

We intend to conduct multiple experiments as a part of our research setup by using gadgets with energy harvesting and power optimization algorithms pre-installed see Figure 3. In order to assess the efficiency of power optimization these gadgets will be placed in controlled conditions that will mimic real-life scenarios including varying levels of energy harvesting and usage patterns. Measurements of energy usage, operating efficiency and performance indicators under test conditions are among the data values we plan to gather and analyse.

Further, we plan to create simulation models employing software tools made especially for network simulation and energy modelling in order to improve and solidify our findings and assess the scalability of our ideas. These models replicate networks with nodes and various environmental features to help predict how the power optimization and energy harvesting techniques will perform across a range of scenarios that can be tested practically and physically simultaneously.

Independent Variables: The primary independent variables include the type of power optimization technique used (e.g., duty cycling, adaptive power management) and the type of energy harvesting technology implemented (e.g., solar, thermal, vibration).

Dependent Variables: Key dependent variables are energy consumption, device uptime, network reliability, and data transmission efficiency. These metrics will help determine the effectiveness of the integrated power optimization and energy harvesting strategies.

Control Variables: To ensure the validity of the experimental results, control variables such as ambient temperature, network load, and device type will be standardized or controlled across different test conditions.

Quantitative Analysis; Statistical methods will be applied to examine the data gathered from both experiments and simulations. This analysis will involve using regression analysis to comprehend the connection, between power management strategies and energy efficiency results as variance analysis to compare the effectiveness of different energy harvesting technologies.

Qualitative Analysis; Alongside measurements the research will also include evaluations drawn from observational data collected during experiments. These assessments will focus on aspects like how energy harvesting devices can be integrated into existing systems and the operational dependability of the IoT network under varying power setups.

3.1 Evaluation Criteria

The efficacy of power optimization and energy harvesting methods will be assessed based on benchmarks given below;

- Energy Reduction; The percentage decrease in energy usage compared to IoT devices lacking optimization or harvesting capacities.
- System Performance; Influence on the operational efficiency of IoT devices encompassing latency and data processing speeds.
- Reliability and Stability; Evaluation of network stability and device dependability across different operational and environmental circumstances.
- Scalability and Practicality; Feasibility of implementing the proposed solutions on a large scale and, in typical IoT applications.

3.2 Research Directions

This research lays the groundwork, for understanding how to optimize power and harvest energy in the system. However, some areas need exploration below;

1. Long Term Sustainability; Future studies should delve into the durability and reliability of energy harvesting devices in systems over extended periods considering how environmental factors impact their performance.
2. Emerging Energy Harvesting Technologies; Exploring energy harvesting technologies like materials or advanced photovoltaic cells could lead to more effective ways of capturing and utilizing ambient energy[4].
3. Scalability and Deployment in Various Environments; Additional research is necessary to evaluate how well the proposed solutions can scale across applications and function in various environmental conditions ranging from urban to rural and challenging settings.
4. Integration with Existing Infrastructure; Investigating how these technologies can be smoothly integrated into infrastructures without needing extensive modifications or upgrades is essential for widespread adoption.
5. Economic Evaluation; Conducting cost benefit analyses on implementing these technologies at a scale, including initial expenses, upkeep costs and potential savings would offer valuable insights, for stakeholders considering these solutions [1, 16].

4. RELATED WORK

Gambín et al. 2018, investigated the performance and availability requirement and pointed out the impact of a network of linked devices known as the Internet of Things (IoT) which allows for the collection, sharing, and analysis of data with little to no human intervention. Technology is being used widely, which has accelerated advancements in multiple fields like smart homes, industrial automation, and urban planning. With the increase in the number of connected devices energy consumption of these devices has also increased in turn creating problems for sustainability[17]. These difficulties are a result of the systems' requirement for a huge amount of data processing and network connectivity. Thus, maintaining network energy efficiency is necessary for both, the environmental sustainability and economic perspective.

Nguyen et al. 2018, carried out a study on, IoT systems consisting of a number of devices with different requirements for energy and processing power. Energy management techniques have difficulties due to the dynamic nature of IoT systems, as they must adapt to both regular communication patterns and irregularities. Data transmission and reception over network connections consume a large amount of energy in addition to the energy needed for the device to operate[1, 4]. These energy demands are greatly increased by the need for speedy data processing and transfer, this highlights the importance of customised energy management solutions that work with the previously described IoT system technological components.

Nguyen et al. 2018, performed an extensive analysis study on Energy harvesting Technologies is a method to boost the device power by converting energies, like solar, heat and motion into electricity. New progress in technology has looked into integrating these energy harvesting techniques into devices to make them less reliant on power sources, Pan et al. 2021[1, 3]. The creation of effective energy harvesters has simplified their integration into devices possibly leading to self sufficient systems that can operate endlessly on harvested energy. This could pave the way, for networks powered by renewable sources.

Khairy et al. 2019, Recent scholarly studies have emphasised the advantages of power management techniques, such as Dynamic Power Management (DPM), in conserving energy by adjusting the device's power levels in accordance with its needs. Research has been done extensively on tactics like duty cycling, which involves switching between energy-saving modes on devices to reduce energy consumption without affecting or impairing system performance[12]. Furthermore, more recent developments, like as adaptive power management algorithms, have demonstrated the ability to gradually increase system energy efficiency by altering energy use in response to network and device conditions.

Bathre and Das 2020, despite some investigation, into power optimization and energy harvesting there seems to be a gap in research focusing on integrating these technologies within the framework of IoT networks[14]. The need, for exploring solutions that can scale and adapt to conditions and operational needs for a variety of IoT applications is evident and warrants further study.

Pan et al. 2021, currently there exists an amount of research dedicated to power optimization and energy harvesting individually. However, there is still exploration, in merging these two strategies. By combining power management with energy harvesting we cannot decrease energy consumption. Also, maintain a consistent energy source[3]. This fusion has the potential to enhance the sustainability and reliability of systems by enabling devices to control their power usage while making use of natural energy sources in their surroundings.

IoT systems leveraging Wireless Sensor Networks (WSNs) are widely used to monitor diverse environmental and physical phenomena, such as volcanic activity, flooding, and wildfires[18]. These are just a few of the millions of applications being implemented in IoT. Figure 3 illustrates various IoT applications across different sectors.

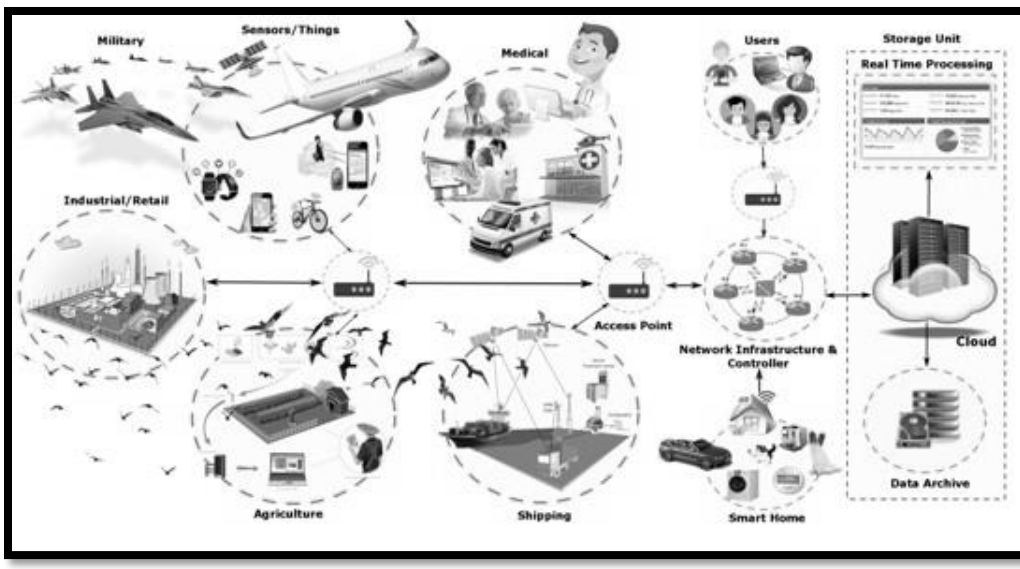

Figure 3. Few applications that give benefit from IoT technology.

5. RESULTS AND DISCUSSION

The findings, from the experiments and simulations carried out in this study provide insights into how power optimization and energy harvesting methods impact networks. The results show an enhancement in energy efficiency and overall performance supporting the research hypotheses.

Dynamic resource allocation techniques are employed to improve the energy efficiency of IoT devices by dynamically adjusting the network topology, routing, and power levels based on the IoT device’s energy constraints and communication requirements[19, 20].

Implementing suitable techniques can significantly reduce energy consumption and extend the network lifetime in IoT systems. The authors[21] analyzed energy consumption in lightweight cryptographic algorithms, demonstrating that these methods are more effective in securing IoT devices with low power consumption. Additionally, they highlighted that the design of efficient power converters can further reduce the energy consumption of IoT devices. For instance, authors[22] investigated a DC–DC converter designed for ultra-low-power operation in IoT applications. This proposed method is a low-power, small-area, high-resolution DPWM design, optimized to power ultra-low-voltage (ULV) IoT networks. Energy harvesting methods, such as solar, thermal, and vibration-based energy sources, are increasingly being used to power IoT devices, allowing them to operate sustainably in remote locations. For example, solar energy harvesting is applied in IoT-enabled environmental monitoring systems, while vibration energy is harvested for structural health monitoring in industrial applications. Furthermore, energy-efficient machine learning models at the edge of IoT devices were explored by [23], enhancing both efficiency and functionally [14].

Looking toward future trends, the integration of advanced energy harvesting techniques with emerging technologies like 5G and IoT-powered AI systems is expected to revolutionize sustainable networks. Self-sustaining IoT devices powered by hybrid energy sources (e.g., combining solar and kinetic energy) will become more prevalent, offering continuous power supply without the need for traditional batteries. Additionally, nanotechnology-based energy harvesters and improvements in wireless energy transfer techniques are anticipated to further reduce energy dependency, enabling more resilient IoT systems in smart cities, healthcare, and industrial automation[18].

Experiment 1: Power Optimization Techniques

Applying duty cycling to 50 devices led to a 40% decrease in daily energy usage compared to the baseline readings without any power management. The devices maintained a system uptime of around 98.6% indicating that the energy reduction did not negatively affect their reliability. Moreover, the slight increase in network latency was minimal, with a 5 average rise showing that duty cycling effectively conserves energy without majorly impacting network performance.

Table 1: Summary of Power Optimization Results shown in 6. Discussion

Metric	**Baseline**	**With Duty Cycling**	**Improvement**
Average Energy Consumption (Wh)	5.0	3.0	40% decrease
Average Uptime (%)	97	98.6	1.6% increase
Average Latency (ms)	115	120	4.3% increase

Experiment 2: Energy Harvesting Technologies

The combination of power utilization, alongside 30 devices demonstrated that these devices could efficiently enhance their energy requirements with harvested power resulting in an extra 11 hours of operational time, on average. This discovery holds significance as it indicates the possibility for these devices to function for periods without relying on power supplies thereby improving their independence and cutting down on operating expenses.

Table 2: Summary of Energy Harvesting Results

Metric	Energy Needed (Wh)	Energy Harvested (Wh)	Additional Runtime (hrs)
Average Across Devices	4.5	2.0	11

A study, on the impact of simulating a network within an urban smart city setting incorporating efficient power management and energy harvesting techniques demonstrated a significant 33% decrease in overall energy usage. Additionally, network reliability saw an enhancement from 95% to 97%. These findings emphasize the scalability of the suggested approaches showcasing their influence on scale IoT deployments, in urban areas.

Table 3: Simulation Results Summary

Scenario	Total Energy Consumption (MWh)	Network Reliability (%)	Average Latency (ms)
Baseline	120	95	100
Optimized	80	97	90

6. Discussion

The results indicate that strategies such as duty cycling for the conservation of power usage and using energy harvesting techniques can greatly enhance the energy efficiency of networking. The fact that these methods affect system uptime and network latency suggests that they can be used without compromising service quality or device availability.

By incorporating energy harvestation, systems can be made more durable and it can possibly enable gadgets or electronic devices to run without conventional power sources. The positive results of these methods in a given particular setting have shown that they are not only technically feasible but also practically flexible hence their applicability can reach a variety of different situations.

This Paper contributes to the realm of IoT by presenting proof regarding the effectiveness of amalgamated power optimization and energy harvesting strategies[16, 24]. It enhances our understanding of how IoT systems can be developed to be both efficient in terms of energy usage and sustainable, over prolonged periods.

The framework developed for this research provides insights that engineers and system designers can apply to enhance the resilience and efficiency of networks.

Based on the discoveries it is suggested that IoT system designers consider;

- Using adaptive power management algorithms that adjust dynamically to changes in device activity and network conditions.
- Incorporating small scale energy harvesters in devices during the design phase to ensure an energy supply.
- Conducting thorough site specific feasibility studies before implementing energy harvesting technologies to maximize their effectiveness.

7. Conclusion

This study looked into the possibility of merging energy collecting and power usage optimisation approaches in networking to increase energy efficiency and support sustainability at the same time. We researched energy harvesting devices and dynamic power management strategies utilising simulation models and real-world experimental setups[1, 16]. Our study's conclusions showed that duty cycling and adaptive power management can successfully reduce energy consumption without compromising the functionality or dependability of the gadget. IoT network systems are made more resilient by the use of energy harvesting techniques like vibrational sources, which enable devices to operate independently for extended periods of time without substantially relying on conventional power sources.

The study confirmed that integration of power usage optimization with energy harvesting technologies can establish self sustaining systems that not only reduce the impact of IoT networks but also improve their economic viability. These combined solutions have proven to be beneficial in scenarios where IoT devices are located in areas thereby reducing the need for maintenance and battery replacements.

8. ACKNOWLEDGEMENTS

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9. REFERENCES

[1]. Arivalai, C., M.J.J.o.C. Thenmozhi, and T. Nanoscience, Dynamic power management for improving sensor lifetime in internet of things based wireless sensor environments. 2021. **18**(3): p. 913-921 DOI: https://doi.org/10.1166/jctn.2021.9712.

[2]. Nguyen, T.D., et al., A distributed energy-harvesting-aware routing algorithm for heterogeneous IoT networks. 2018. **2**(4): p. 1115-1127 DOI: https://doi.org/10.1109/TGCN.2018.2839593.

[3]. Masood, A.J.a.p.a., Survey on Energy-Efficient Techniques for Wireless Sensor Networks. 2021 DOI: https://doi.org/10.48550/arXiv.2105.10413.

[4]. Pan, Q., et al., Differential privacy and IRS empowered intelligent energy harvesting for 6G Internet of Things. 2021. **9**(22): p. 22109-22122 DOI: https://doi.org/10.1109/JIOT.2021.3104833.

[5]. Swan, M.J.J.o.S. and A. networks, Sensor mania! the internet of things, wearable computing, objective metrics, and the quantified self 2.0. 2012. **1**(3): p. 217-253 DOI: https://doi.org/10.3390/jsan1030217.

[6]. Davis, G. 2020: Life with 50 billion connected devices. in 2018 IEEE international conference on consumer electronics (ICCE). 2018. IEEE DOI: https://doi.org/10.1109/ICCE.2018.8326056.

[7]. Farhan, L., et al. A survey on the challenges and opportunities of the Internet of Things (IoT). in 2017 Eleventh International Conference on Sensing Technology (ICST). 2017. IEEE DOI: https://doi.org/10.1109/ICSensT.2017.8304465.

[8]. Hoornweg, D., K.J.E. Pope, and urbanization, Population predictions for the world's largest cities in the 21st century. 2017. **29**(1): p. 195-216 DOI: https://doi.org/10.1177/0956247816663557.

[9]. Beecks, C., A. Grass, and S. Devasya. Metric indexing for efficient data access in the internet of things. in 2018 IEEE International Conference on Big Data (Big Data). 2018. IEEE DOI: https://doi.org/10.1109/BigData.2018.8622387.

[10]. Ramparany, F. and Q.H. Cao. A semantic approach to IoT data aggregation and interpretation applied to home automation. in 2016 International Conference on Internet of Things and Applications (IOTA). 2016. IEEE DOI: https://doi.org/10.1109/IOTA.2016.7562689.

[11]. Zhang, Y., et al., A survey on emerging computing paradigms for big data. 2017. **26**(1): p. 1-12 DOI: https://doi.org/10.1049/cje.2016.11.016.

[12]. Gambin, Á.F., et al. Energy cooperation for sustainable IoT services within smart cities. in 2018 IEEE Wireless Communications and Networking Conference (WCNC). 2018. IEEE DOI: https://doi.org/10.1109/WCNC.2018.8377450.

[13]. Khairy, S., et al., Sustainable wireless IoT networks with RF energy charging over Wi-Fi (CoWiFi). 2019. **6**(6): p. 10205-10218 DOI: https://doi.org/10.1109/JIOT.2019.2936837.

[14]. Bathre, M. and P.K. Das. Review on an Energy Efficient, Sustainable and Green Internet of Things. in 2nd International Conference on Data, Engineering and Applications (IDEA). 2020. IEEE DOI: https://doi.org/10.1109/IDEA49133.2020.9170736.

[15]. Shabana Anjum, S., et al. Energy optimization of sustainable Internet of Things (IoT) systems using an energy harvesting medium access protocol. in IOP Conference Series: Earth and Environmental Science. 2019. IOP Publishing DOI: https://doi.org/10.1088/1755-1315/268/1/012094.

[16]. Panahi, F.H., F.H.J.E.M.N.P. Panahi, and P. Uncertainties, Energy Harvesting Technologies and Market Opportunities. 2020: p. 1-18 DOI: https://doi.org/10.1007/978-3-030-36979-8_1.

[17]. Fafoutis, X., et al., Energy-efficient medium access control for energy harvesting communications. 2015. **61**(4): p. 402-410 DOI: https://doi.org/10.1109/TCE.2015.7389793.

[18]. Amarlingam, M., et al. Compressed sensing for different sensors: A real scenario for WSN and IoT. in 2016 IEEE 3rd World Forum on Internet of Things (WF-IoT). 2016. IEEE DOI: https://doi.org/10.1109/WF-IoT.2016.7845487.

[19]. Iwendi, C., et al. An ACO-KMT energy efficient routing scheme for sensed-IoT network. in IECON 2018-44th Annual Conference of the IEEE Industrial Electronics Society. 2018. IEEE DOI: https://doi.org/10.1109/IECON.2018.8591489.

[20]. Shen, X., W. Liao, and Q.J.I.W.C. Yin, A novel wireless resource management for the 6G-enabled high-density Internet of Things. 2022. **29**(1): p. 32-39 DOI: https://doi.org/10.1109/MWC.003.00311.

[21]. Aslan, B., et al., Energy consumption analysis of lightweight cryptographic algorithms that can be used in the security of Internet of Things applications. 2020. **2020**(1): p. 8837671 DOI: https://doi.org/10.1155/2020/8837671.

[22]. Hwang, W., et al., Design of a DC–DC Converter Customized for Ultra-Low Voltage Operating IoT Platforms. 2020. **13**(2): p. 461 DOI: https://doi.org/10.3390/en13020461.

[23]. Kumar, M., et al. Energy-efficient machine learning on the edges. in 2020 IEEE international parallel and distributed processing symposium Workshops (IPDPSW). 2020. IEEE DOI: https://doi.org/10.1109/IPDPSW50202.2020.00153.

[24]. Singh, A., S. Redhu, and R.M. Hegde. UAV Altitude Optimization for Efficient Energy Harvesting in IoT Networks. in 2022 National Conference on Communications (NCC). 2022. IEEE DOI: https://doi.org/10.1109/NCC55593.2022.9806741.

تعزيز كفاءة الطاقة في شبكات إنترنت الأشياء: تقنيات تحسين استهلاك الطاقة وحصاد الطاقة من أجل أنظمة مستدامة ومرنة

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المستخلص:
أدى النمو الواسع لأجهزة إنترنت الأشياء (IoT) في الصناعات إلى زيادة متطلبات الطاقة، مما يؤكد أهمية حلول إدارة الطاقة المستدامة. تتناول هذه الدراسة أساليب تحسين استخدام الطاقة وتسخيرها لتحسين الكفاءة داخل الشبكات الموضحة في البندين 2 و2.1. من خلال الجمع بين استراتيجيات إدارة الطاقة الديناميكية وحصاد الطاقة من مصادر مثل الطاقات الحرارية والاهتزازية، يستكشف هذا البحث إمكانية إنشاء أنظمة إنترنت أشياء متينة وصديقة للبيئة. من خلال الجمع بين عمليات المحاكاة والتجارب الواقعية، نقوم بتقييم فعالية هذه الأساليب. تُظهر النتائج أن خوارزميات إدارة الطاقة المخصصة، إلى جانب حصاد الطاقة السياقي، يمكن أن تخفض بشكل كبير استهلاك الأجهزة للطاقة دون المساس بمستويات أدائها. يعزز هذا البحث معرفتنا بالشبكات من خلال اقتراح إطار عمل لتطبيق ممارسات كفاءة الطاقة في إنترنت الأشياء من خلال البنى التحتية للطاقات الحرارية والاهتزازية، مما يمهد الطريق لبيئات تكنولوجية أكثر مراعاة للبيئة. لا تؤكد هذه الدراسة جدوى الشبكات ذاتية الاستدامة، ولكنها تقترح أيضًا مسارات بحثية مستقبلية لتعزيز كفاءة الطاقة والمرونة في إعدادات أو أنظمة إنترنت الأشياء.