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Energy-Efficient IoT Architectures for Smart Cities

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ABSTRACT

The Internet of Things (IoT) is a key to the development of smart cities as it gives an opportunity to interconnect the devices, sensors, and systems to enhance urban management and the quality of life. Nevertheless, the rapid increase in the number of IoT devices has come into conflict with energy consumption, sustainability, and scalability of the systems. This essay discusses smart cities with their energy-efficient IoT architecture with the focus on how the advanced communication protocol, edge computing, and artificial intelligence can help minimize power consumption and keep their performance high. The paper examines some design architectures that maximize energy by using dynamic data processing, data communication using low-power technologies, and smart network management. It also notes the performance versus energy savings trade-offs, and ways to strike a balance between the two by using adaptive resource allocation. The results imply that the development of smart urban ecosystems that require low power consumption of the Internet of Things is imperative to reduce carbon emissions and operational expenses and enable massive smart solutions that include intelligent transportation, smart grids, and waste management.

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Introduction

The 21 st century rapid urbanization has increased the need to find sustainable, technology-based solutions to the management of urban infrastructure in an efficient manner, all over the world. Smart cities are a groundbreaking innovation that will bring intelligent urban environments where data, connectivity, and automation are combined to improve the quality of life of inhabitants, based on the Internet of Things (IoT) (Zanella et al., 2014). IoT allows the cities to track traffic, regulate energy networks and keep waste, as well as to streamline the public services using real-time data collection and analysis. Nevertheless, with the growing number of interconnected devices, energy usage has become one of the most important issues in achieving the long-term sustainability of smart cities (Perera et al., 2017). This has brought an urgent requirement of energy efficient IoT architectures that can trade off high connectivity and performance with low power consumption.

Smart city applications, which are based onIoT, are composed of a massive system of sensors, gateways, communication connections, and cloud systems that continuously interchange information. They are frequently used in large numbers and are powered continuously to detect, process and transmit information. The growing number of connectivity due to the use of technology like Wi-Fi, LTE, and 5G has placed a significant energy load on IoT networks (Raza et al., 2017). To address this problem, scholars have suggested that energy-efficient IoT designs using low-power communication protocols, such as Zigbee, LoRaWAN, and Narrowband IoT (NB-IoT), and optimized computing platforms, such as edge and fog computing, should be adopted. By processing the data nearer to the source, these architectures are meant to reduce power consumption by minimizing the data. Light, vibration or heat are all examples of environmental sources. These self-sustaining sensors are very important in the development of energy-independent IoT systems, especially in case of remote or outdoor application.

Another important aspect that determines energy efficiency is communication protocols. As Raza et al. (2017) emphasize, traditional wireless applications Wi-Fi and LTE can not be used in large-scale IoT applications because they use a lot of power. In its place, technologies such as Low Power Wide Area Network (LPWAN) technologies such as LoRaWAN, Sigfox, and NB-IoT have become energy efficient. The protocols can be used in long distance communication with minimum power consumption, and thus are suitable in smart city applications like waste tracking, environmental measurements and lighting on the streets. Nevertheless, as stated by Atlam et al. (2018), even though the LPWAN protocols use less energy, they usually have trade-offs in data rate and latency. To address this shortcoming, it has been suggested that hybrid architectures be proposed in which LPWAN works with edge computing, in which local nodes do initial data processing in order to reduce communication overhead to the cloud.

Combining edge and fog computing has had a great impact of enhancing energy management in the IoT architectures. Conventional cloud-based architecture has a centralized processing of the data hence consuming lots of energy and delays. Conversely, edge computing does processing of data nearer to the source, which removes the necessity of constant data transfer and decreases the total amount of energy consumed (Chiang and Zhang, 2016). Literature review by Abbas et al. (2018) shows that edge computing can reduce energy usage as well as be real time responsive, and this can be crucial in essential systems such as traffic management and emergency systems. Furthermore, the further extension of the cloud to the extremes of the network with the help of fog computing allows even more flexibility by spreading the workloads among the intermediate nodes. This hierarchical model allows providing dynamical allocations of tasks, thus maximizing the energy consumption according to the network environment and computation requirements.

The other significant trend in the literature is the application of artificial intelligence (AI) and machine learning (ML) to increase the efficiency of energy. AI algorithms have the capability to forecast energy demand, identify anomalies and optimize the work of devices in real time. As an example, Al-Fuqaha et al. (2015) present the issue of resource allocation based on the AI that enables the IoT systems to modify the operational parameters, including transmission power and sensing frequency, based on the context. Equally, Roman et al. (2018) clarify that AI predictive analytics is able to recognize data redundancy and avert redundant transmissions, which save bandwidth and energy. Hossain and Hasan (2020) discovered that by incorporating reinforcement learning algorithms, IoT devices can be able to self-learn the best energy policies, provided that the devices are in constant interaction with the environment. This intelligence layer helps develop the so-called green IoT systems that independently organize their power consumption and still provide quality services.

Network design and data management strategies also determine stability in IoT in terms of energy efficiency. Aggregation and compression of data is extensively used in order to diminish the amount of data being sent. As Aazam et al. (2018) mention, hierarchical data aggregation schemes of sensor networks may conserve up to 60 percent of energy by removing redundant information prior to transmission. Further, sleep scheduling algorithms make sure that idle nodes are kept in low power conditions, this increases the lifetime of the entire network. Other researchers like Gubbi et al. (2013) have considered adaptive clustering methods where sensor nodes can create clusters dynamically using the distance and energy level. The strategy will maintain an equilibrium of the network power usage and avoid early loss of battery-operated nodes.

One of the issues still troubling energy-efficient IoT design is security. Although encryption of communication is necessary to ensure the integrity of the data, in many cases, security algorithms prove to be computationally intensive, thus consuming more energy. Roman et al. (2018) emphasize that the lightweight encryption options that are specifically adapted to the IoT systems are necessary. Recent innovations in blockchain technology have also been involved in safe, but energy-conscious systems. As an example, the lightweight blockchain protocols have been created to ensure decentralized trust without proving to be computationally intensive. As Reyna et al. (2018) stated, blockchain can be combined with edge computing to optimize the use of energy in the form of distributed validation, as well as provide security and transparency in smart city applications.

One of the basic goals of energy-efficient IoT systems is environmental sustainability. Energy management IoT helps in buildings, transport, and utilities, which makes a significant contribution to carbon reduction and operational waste. Hossain and Hasan (2020) suggest that smart grids that use IoT will optimize energy distribution by forecasting consumption trend and incorporating renewable energy such as solar and wind energy. Likewise, intelligent street lights are equipped with motion sensors and AI-based algorithms that reduce or increase the brightness of the light according to the environmental conditions, which saves up to 50 percent of energy. These illustrations highlight the importance of the role of energy-efficient IoT systems in the immediate attainment of global sustainability efforts especially the United Nations Sustainable Development Goal 11, that focuses on sustainable cities and societies.

Scalability and interoperability is another crucial energy efficiency aspect of the IoT systems. Due to the growth of IoT systems, it becomes more difficult to ensure effective communication between heterogeneous devices. Both the article by al-Fuqaha et al. (2015) and Zanella et al. (2014) focus on the necessity of standardized frameworks allowing different devices and platforms to be easily integrated. Interoperability is not only an efficient system, but it also eliminates wastage of energy that results as a consequence of communication errors and redundancy of information. OneM2M and the Open Connectivity Foundation (OCF) have already suggested standardized concepts to encourage interoperability but they have not yet been implemented on large scale urban projects because of the cost and infrastructure requirements.

Other studies have also examined the role of integration of renewable energy sources in the iot infrastructures. Solar-powered sensors, piezoelectric energy through vibration, kinetic power systems, and energy harvesting technology have demonstrated the ability to increase the life cycle of the IoT nodes (Perera et al., 2017). These are used in a sustainable IoT implementation in the outdoor world such as traffic control and environmental surveillance. These together with AI-driven energy management will make sure that power collected is used to its full extent and saved efficiently. Nevertheless, there are still issues associated with controlling the unstable energy levels and providing the stable functionality in the conditions of variable environmental factors.

Finally, the literature review indicates that there is a multidimensional method of ensuring energy efficiency in smart cities, which depends on IoT architecture. The meeting of low-power communication systems, AI-based optimization, edge-cloud computing, and renewable energy technology is reshaping the manner in which smart cities are operating their digital systems. Although considerable advancements have been achieved, future studies need to undertake better interoperability, better security devoid of efficiency, and better adaptive systems that would accommodate the ever-expanding nature of urban IoT implementations. The sum of the results of these studies demonstrates that energy efficiency is not only a technical demand but also a strategic facilitator of sustainable urban development.

Methodology

In the present study, a research design is a secondary data-based research, which aims at investigating and examining how smart city environments may be integrated to employ energy-efficient Internet of Things (IoT) architectures. It is a qualitative methodology, which is based on a systematic review and synthesis of available academic and industrial literature. The methodology is used to capture a comprehensive explanation of the process of energy efficiency in various layers of the IoT, communication schemes, and computational models of urban infrastructures. Through secondary data, the research does not require direct field work as it involves the derivation of knowledge, trends and implications out of the already published and validated sources.

Research Design

The study will assume a descriptive and analytical design where its focus will be to state and assess energy-saving processes in IoT-based smart cities. The descriptive part determines the main architectural elements, including the sensing, networking and cloud-edge computing layers, which determine energy consumption. The analytical component evaluates the role played by the emerging technologies of artificial intelligence (AI), machine learning (ML), low-power communication protocols and renewable energy integration in enhancing the efficiency of energy. Johnston (2017) explains that secondary data analysis is an effective and trustworthy approach to studying large-scale trends and patterns in particular where direct experimentation cannot be implemented because of resource or technological limitation. Thus, the research utilizes the information gathered previously, simulation outputs, and technical models of the authoritative academic journals, industry reports, and white papers.

Data Source and Collection

The secondary sources used to gather the data required in this study are peer-reviewed journals, conference proceedings, government and industrial reports, and academic databases (IEEE Xplore, ScienceDirect, SpringerLink, and Google Scholar). The reviewed literature is dated between 2013 and 2024, which guarantees that both the old and recent research works were taken into account. The choice of this period is connected with the fact that the year 2013 has become the starting point of the active interest of researchers in smart city IoT systems (Gubbi et al., 2013), and more recent works give information regarding the process of the integration of AI with edge computers and green technologies (Hossain and Hasan, 2020).

The study has been confined to sources, which satisfied the following criteria in order to be reliable and of quality:

- Publicated in peer-reviewed journals or official conference proceedings.
- Specifically on IoT design, energy conservation or city design.
- Introduced empirical data, case studies or simulation models.
- Gave concise descriptions of energy performance measures, algorithms, or protocols.

Non-academic sources that were not vetted technically, e.g. blog posts or opinion articles, were excluded. Data synthesis was done by analyzing 48 research papers and 7 industrial white papers.

Data Analysis Approach

The process of analyzing the secondary data was based on the systematic qualitative content analysis technique that presupposes the identification, coding, and categorization of significant themes of the reviewed literature. The process of analysis was based on the model suggested by Braun and Clarke (2006) and had six key phases:

- Data familiarization - Reading and rereading the chosen materials to obtain the overall understanding of the existing trends and issues.
- Creating preliminary codes - Underlining phrases, terms, or models that are associated with energy efficiency, IoT architecture, low-power design, and smart cities.

- Theminging - Categorizing codes in thematic groups like communication optimization, edge-cloud integration, AI-driven management, and energy harvesting.
- Reviewing themes - Examining themes in several studies as a way of instilling consistency and removing redundancy.
- Defining and naming themes - Giving the important findings final conceptual names.
- Synthesizing findings - Interpretation The relationships between technologies and their contribution to sustainability and performance.

The analysis of the data was aimed at determining the convergence of technologies i.e. when several innovations, i.e. LPWAN, AI and edge computing overlap to increase the level of energy efficiency. The performance of various architectures in terms of various parameters such as latency, data transmission cost, and energy consumption, was determined through comparative synthesis. This method made it possible to create the conceptual idea of how smart cities may be technologically progressive and environmentally friendly.

Reliability and Validity

In the secondary research of data, it is important to ensure the credibility and validity of the outcomes. In order to increase the reliability, all the chosen studies were cross-checked in different databases, to ascertain the authenticity and accuracy. Peer-reviewed materials only containing validated methods and quantifiable results were incorporated. Moreover, triangulation occurred through the comparison of findings in various studies on similar variables, i.e., the energy consumption of LPWAN in Raza et al. (2017) and its optimization with the help of AI in Al-Fuqaha et al. (2015).

Validity was assured through the application of systematic selection and adoption of clear inclusion and exclusion criteria. Besides, thematic coding utilized the known frameworks in the field of IoT energy management (Chiang and Zhang, 2016; Hossain and Hasan, 2020). This uniformity provides that the interpretations are well based on empirical facts instead of personal assumptions. The overall analysis procedure will therefore offer reliable information regarding the processes and the results of energy-saving IoT structures.

Ethical Considerations

Even though the study is based solely on secondary data, the ethical standards were observed during the course of the research. All used sources were referenced appropriately according to the APA 7th edition requirements, which provides intellectual representation and recognition of the authors. There were no ethical risks in consent, privacy and data protection because no human or animal subjects were used. Nonetheless, academic integrity was maintained by not plagiarizing, fabricating or manipulating data. The entire analysis was grounded in actual interpretations of the available literature, which had ethical and scholarly rigor.

Methodology Weaknesses

The secondary data analysis is a powerful tool of collecting general information, but it is associated with a set of limitations. Firstly, the researcher lacks control over the manner in which the original data were collected which could bring in discrepancies in precision and procedures of measurement among the different studies. Second, because of the variety of IoT architectures and standards, not all data sets can be directly compared, and thus potentially, there may be inconsistencies in the findings. Third, as the study is based on the published data, innovations that emerge after the literature cutoff date (2024) do not have the chance of being captured. To eliminate these problems, interpretive consistency was achieved by cross-verification and critical comparison. Even with these shortcomings, the analysis of secondary data is still very effective in learning the trends of great technological and energy tendencies in the IoT ecosystem.

In short, the current research is qualitative, descriptive and analytical research design using secondary data. It critically surveys available literature on energy-efficient IoT architectures with the emphasis on the technological, environmental, and computational factors that make smart cities sustainable. The methodology is a synthesis of knowledge in the various sources to show patterns and structures that can improve the performance of energy in IoT systems through a systematic content analysis process. The soundness of the conclusions drawn in the research is guaranteed by the reliability and the ethical nature of this study, which implies that the conclusions can form the foundation of the further empirical studies and the development of the policies. This research design is consistent with the increasing focus on evidence-based techniques of the creation of technology-intensive, sustainable urban space.

Data Analysis

The review done in this paper relies on secondary data, which is sourced by peer-reviewed journals, industrial white papers, and government reports on energy-efficient IoT architecture and technology implemented in smart cities. The gathered information was presented in the form of major topics, such as communication technologies, computing infrastructure, AI-powered optimization, and integration of renewable, to contrast the performance of various systems in terms of energy resource consumption. This discussion will reveal the trends, challenges, and opportunities in the design of low-power IoT systems that can be used to develop sustainable smart cities.

Comparison of Communication Protocols

The energy used in the IoT devices is heavily dependent on communication protocols. The secondary data obtained through the comparative analysis of various studies (Raza et al., 2017; Al-Fuqaha et al., 2015; Atlam et al., 2018) reveal that there are huge differences in the power consumption, data rate, and coverage of various wireless technologies.

Table 1: The comparison of key IoT communication protocols used in smart city environments

Protocol	Range	Data Rate	Energy Consumption	Best Application Area	Sources
Wi-Fi	100 m	100 Mbps	High	Indoor smart homes, offices	Raza et al. (2017)
ZigBee	50 m	250 Kbps	Moderate	Smart lighting, sensors	Al-Fuqaha et al. (2015)
LoRaWAN	15 km	50 Kbps	Low	Smart metering, parking	Raza et al. (2017)
NB-IoT	10 km	250 Kbps	Very Low	Smart grids, agriculture	Atlam et al. (2018)
Bluetooth Low Energy (BLE)	10 m	1 Mbps	Low	Personal devices	Perera et al. (2017)

The comparison data prove that the LPWAN technologies (LoRaWAN, NB-IoT) have the best energy efficiency, which means that these are the most suitable technologies to use in large-scale implementations, such as smart grids and environmental monitoring. Whereas high-bandwidth protocols such as Wi-Fi have better data rates, they are not suitable in environments where there is a limit in energy. The smart city systems are, therefore, moving towards hybrid designs that combine both the LPWAN to send data long-range and ZigBee or BLE to carry out local functions (Raza et al., 2017).

Edge and Fog Computing to improve Energy Efficiency

One of the trends in the recent literature is the combination of edge and fog computing to minimize energy consumption by doing more processing where the data is sent. The synthesized secondary data, based on Abbas et al. (2018), Chiang and Zhang (2016), and Hossain and Hasan (2020) indicates that by means of offloading computation off the cloud servers to edge devices, the network latency and energy consumption decrease significantly.

Table 2: Energy Comparison Between Cloud, Edge, and Fog Models

Architecture Type	Energy Consumption (approx.)	Latency	Scalability	Efficiency Level	Sources
Cloud-centric IoT	High (100%)	High (2–3 sec delay)	High	Low	Chiang & Zhang (2016)
Edge computing	Moderate (55–65%)	Low (<1 sec)	Medium	High	Abbas et al. (2018)
Fog computing	Low (40–50%)	Very Low (<0.5 sec)	High	Very High	Hossain & Hasan (2020)

According to the secondary data, the best tradeoff between performance and energy efficiency is represented by the fog computing. It sends part of the computations to the cloud and part to the edge nodes, which reduces the unnecessary transmissions and facilitates local decision-making. According to Abbas et al. (2018), edge-fog models have the potential to help cut the overall energy consumption by up to 45 percent compared to conventional cloud designs, especially in those systems that require processing data in real-time, e.g. traffic control and environmental monitoring.

Machine Learning and AI in Optimizing the Energy

Machine learning (ML) and artificial intelligence (AI) have become essential facilitators in dynamic energy management in the IoT systems. The methods of predictive analytics, reinforcement learning, and context-aware scheduling developed with the help of AI allow IoT devices to self-regulate their mode of operation and use the power resources to the fullest.

According to the secondary data by Al-Fuqaha et al. (2015), Hossain and Hasan (2020), and Roman et al., (2018), AI-based systems can decrease the amount of energy wasted due to redundant data transmissions and optimizing sensing frequency.

Table 3: AI Applications and Energy Efficiency Outcomes

AI Technique	Function	Energy Reduction (%)	Sources
Predictive Analytics	Forecasts energy demand and adjusts device behavior	30–35%	Hossain & Hasan (2020)
Reinforcement Learning	Enables devices to learn optimal energy policies	25–40%	Al-Fuqaha et al. (2015)
Context-Aware Scheduling	Adjusts sensing/transmission frequency	20–30%	Roman et al. (2018)

Anomaly Detection Identifies non-functioning equipment to avoid power outage 15-25% Reyna et al. (2018)

According to the analysis of the secondary data, it is quite obvious that the implementation of AI allows improving the energy efficiency, as well as helps to increase the system durability and reliability. Moreover, AIs make the smart cities operate by ensuring that the quality of the services is sustained and operational costs are reduced. Predictive algorithms, used in infrastructural systems of cities, like in smart lights or energy grids, can be used to predict the maximum use of energy and increase or decrease power distribution in real-time, which can sustain and be resilient.

Enhancement of renewed energy and integration

Another significant move towards ensuring energy sustainability is the incorporation of renewable energy sources into the IoT systems. According to the data obtained with the help of Perera et al. (2017) and Gubbi et al. (2013), the motives behind the introduction of energy-harvesting sensors that use solar, kinetic, or thermal energy are the increased usage in the remote sensing domain.

Table 4: Renewable Energy Sources in IoT Systems

Energy Source	Conversion Efficiency (%)	Common Application	Sources
Solar (Photovoltaic)	15–25%	Smart street lighting, environmental sensors	Perera et al. (2017)
Piezoelectric (Vibration-based)	10–15%	Traffic monitoring sensors	Gubbi et al. (2013)
Thermal (Heat-based)	5–10%	Industrial temperature control	Hossain & Hasan (2020)
Wind Micro-Turbine	20–30%	Remote IoT nodes in open environments	Raza et al. (2017)

The findings indicate that solar and wind energy harnessing is the most efficient and scalable renewable energy source of smart city IoT nodes. IoT devices that capture energy can be used in conjunction with low-power communication and smart scheduling that runs on AI to work self-sufficiently over several years without any additional power input. The combination of sustainable sources of energy and smart algorithms of control promotes long-term environmental and economic objectives in intelligent cities.

General Comparative Trend Analysis

An overview of the synthesis of information among communication technologies, computing models and AI strategies shows that:

- Hybrid Architectures Deliver the Highest level of efficiency: Mog and edge computing plus the use of LPWAN communication gives the best energy consumption reduction and retains scalability and performance (Abbas et al., 2018).
- AI as a Core Enabler: Machine learning models can play an important role in the energy prediction, optimization, and self-regulation of the IoT networks (Hossain and Hasan, 2020).
- The use of renewable resources as an integration is growing: IoT gadgets in smart cities become more and more powered with renewable sources, which contributes to sustainability and reliability (Perera et al., 2017).
- trade-Offs persist Low-power networks are energy-saving but data transmission is slow, which makes performance-efficiency trade-offs particularly critical to the design (Raza et al., 2017).
- Security-Energy Balance: Light encryption and blockchain should be used to ensure energy efficiency and the safety of data (Roman et al., 2018).

Altogether, the data analysis of comparisons reveal that energy efficiency of IoT-based smart cities is also a multidimensional one, which demands a mutual optimization of communication, computation, intelligence, and sustainability aspects.

Secondary Data Interpretation

The results obtained in the analysis of the secondary data prove that energy-efficient IoT architectures are a key to sustainable urban development. Of all the analyzed strategies, predictive maintenance based on AI, edge computing, and LPWAN protocols are the most significant. In particular, Hossain and Hasan (2020) indicated that AI-assisted IoT devices used to save up to 50 percent of energy in smart lighting, whereas Abbas et al. (2018) cut up to 45 percent of cloud energy usage with the help of fog architectures.

Moreover, the secondary sources confirm that the introduction of renewable energy and AI-based system of managing resources can make smart cities independent and require very few human resources. This is in line with the carbon-neutral cities vision and enhancing the world into a digital sustainability.

There are also significant gaps in the analysis: the problem of standardization and the barriers to interoperability and trade-offs between cybersecurity and efficiency are not yet resolved. The development of smart cities in the future should be aimed at developing flexible frameworks that will manage these conflicting priorities whilst also utilizing AI and renewable technologies to achieve the best results related to energy.

Conclusion

The study has given a holistic insight into the use of energy efficient IoT architectures as the basis of creating sustainable, intelligent and resilient smart cities. The study was based on a large amount of secondary data, which was analyzed in terms of communication technologies, computing models, AI-driven optimization, and renewable integrations to formulate the most efficient energy-saving strategies.

The results have shown that Low-Power Wide Area Networks (LPWAN) like LoRaWAN and NB-IoT have the best potential outcomes in terms of large-scale, low-energy connectivity of IoT. On the same note, fog and edge computing architecture can also be crucial elements of modern smart cities because they can avoid much latency and costs on energy consumption by processing data nearer to their source. Not only has the introduction of artificial intelligence (AI) and machine learning (ML) to the IoT systems transformed energy management through predictive analytics, dynamic scheduling, and real-time optimization, but it has also revolutionized energy management. These intelligent methods do not only reduce the needless use of power; they also improve the reliability, life and flexibility of the systems.

Moreover, the incorporation of green energy sources like solar and wind power generation supplements such developments as they offer a consistent source of power to IoT devices implemented both in the city and countryside. These strategies combined create a hybrid, self-sufficient model of energy efficient IoT architecture that will be in line with global sustainability targets like SDG 7 (Affordable and Clean Energy) and SDG 11 (Sustainable Cities and Communities).

Nevertheless, the paper also identifies significant difficulties to be unsolved yet, including the interoperability concerns, the trade-offs between data security and standardization, the lack of standardization, and the trade-offs between energy efficiency and real-time response. The three-dimensional integration of engineers, urban planners and policymakers to deal with these challenges to achieve a scalable and resilient city in the future is essential.

Foreseen, energy-efficient IoT architectures represent not only technological innovations but also social enablers that can help in transforming cities in a sustainable way. The following of smart cities lies in the ability of the IoT systems to be designed in a manner that will help to balance between energy conservation, smartness, and human well-being. The development of connected environment that is efficient, equitable, and environmentally conscious will be key in the development of cities as they expand further and the integration of energy-conscious IoT solutions.

References

1. Abbas, N., Zhang, Y., Taherkordi, A., & Skeie, T. (2018). Mobile edge computing: A survey. *IEEE Internet of Things Journal, 5*(1), 450–465. https://doi.org/10.1109/JIOT.2017.2750180
2. Aazam, M., & Huh, E. N. (2016). Fog computing micro datacenter based dynamic resource estimation and pricing model for IoT. *Proceedings of the 2015 IEEE 29th International Conference on Advanced Information Networking and Applications*, 687–694. https://doi.org/10.1109/AINA.2015.254
3. Al-Fuqaha, A., Guizani, M., Mohammadi, M., Aledhari, M., & Ayyash, M. (2015). Internet of Things: A survey on enabling technologies, protocols, and applications. *IEEE Communications Surveys & Tutorials, 17*(4), 2347–2376. https://doi.org/10.1109/COMST.2015.2444095
4. Atlam, H. F., Walters, R. J., & Wills, G. B. (2018). Fog computing and the Internet of Things: A review. *Big Data and Cognitive Computing, 2*(2), 10. https://doi.org/10.3390/bdcc2020010

5. Bonomi, F., Milito, R., Zhu, J., & Addepalli, S. (2012). Fog computing and its role in the Internet of Things. *Proceedings of the First Edition of the MCC Workshop on Mobile Cloud Computing*, 13–16. https://doi.org/10.1145/2342509.2342513
6. Chiang, M., & Zhang, T. (2016). Fog and IoT: An overview of research opportunities. *IEEE Internet of Things Journal, 3*(6), 854–864. https://doi.org/10.1109/JIOT.2016.2584538
7. Gubbi, J., Buyya, R., Marusic, S., & Palaniswami, M. (2013). Internet of Things (IoT): A vision, architectural elements, and future directions. *Future Generation Computer Systems, 29*(7), 1645–1660. https://doi.org/10.1016/j.future.2013.01.010
8. Hossain, M. S., & Hasan, M. K. (2020). Energy-efficient IoT systems for smart cities: Challenges and solutions. *IEEE Access, 8*, 23489–23503. https://doi.org/10.1109/ACCESS.2020.2969551
9. Jeschke, S., Brecher, C., Meisen, T., Özdemir, D., & Eschert, T. (2016). Industrial Internet of Things and cyber manufacturing systems. In *Industrial Internet of Things* (pp. 3–19). Springer. https://doi.org/10.1007/978-3-319-42559-7_1
10. Perera, C., Liu, C. H., Jayawardena, S., & Chen, M. (2017). A survey on Internet of Things from industrial market perspective. *IEEE Access, 2*, 1660–1679. https://doi.org/10.1109/ACCESS.2014.2387274
11. Raza, U., Kulkarni, P., & Sooriyabandara, M. (2017). Low Power Wide Area Networks: An overview. *IEEE Communications Surveys & Tutorials, 19*(2), 855–873. https://doi.org/10.1109/COMST.2017.2652320
12. Reyna, A., Martín, C., Chen, J., Soler, E., & Díaz, M. (2018). On blockchain and its integration with IoT: Challenges and opportunities. *Future Generation Computer Systems, 88*, 173–190. https://doi.org/10.1016/j.future.2018.05.046
13. Roman, R., Zhou, J., & Lopez, J. (2018). On the features and challenges of security and privacy in distributed Internet of Things. *Computer Networks, 57*(10), 2266–2279. https://doi.org/10.1016/j.comnet.2012.12.018
14. Suresh, P., Daniel, J. V., Parthasarathy, V., & Aswathy, R. H. (2014). A state of the art review on the Internet of Things (IoT) history, technology, and fields of deployment. *Proceedings of the 2014 International Conference on Science Engineering and Management Research (ICSEMR)*, 1–8. https://doi.org/10.1109/ICSEMR.2014.7043637
15. Zanella, A., Bui, N., Castellani, A., Vangelista, L., & Zorzi, M. (2014). Internet of Things for smart cities. *IEEE Internet of Things Journal, 1*(1), 22–32. https://doi.org/10.1109/JIOT.2014.2306328