RESEARCH PAPER

Energy-Conscious Clustering and Routing Protocols in IoT: A Review

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ABSTRACT

The Internet of Things (IoT) has emerged as a key enabling technology for diverse domains such as environmental surveillance, smart healthcare systems, and industrial automation. Despite its widespread adoption, the effectiveness of IoT networks is largely limited by the restricted energy capacity of sensor nodes. As a result, improving energy efficiency has become a major research focus to ensure prolonged network operation and dependable data delivery. This survey reviews various energy-efficient techniques employed in IoT systems, including clustering-based routing protocols, optimized data aggregation methods, duty-cycling mechanisms, and low-power communication strategies. Well-known protocols such as LEACH and PEGASIS are discussed for their role in reducing transmission overhead through structured data forwarding. By minimizing redundant communication and balancing energy consumption among nodes, these approaches significantly enhance network lifetime. The survey provides a consolidated overview of existing solutions and emphasizes the importance of energy-aware designs for sustainable and long-term IoT deployments.

Keywords: IoT, Clustering, Energy Efficient, LEACH, Clustering

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1. Introduction

The IoT world is a very new and advanced one. It gives a completely new meaning to communication because now every object can be connected to the Internet with the help of sensors, software, and other technologies. Users can now transfer data to other devices over the Internet. This is a network of devices connected together, including smart cities, industrial automation, healthcare, agriculture, and environmental monitoring that are all joining to create a more data-driven world [1][2]. Over the period of time choose IoT, it is also connected with the problem of energy consumption, which is a big technical & operational issue. Energy efficiency in IoT is not a mere technical issue; it is a very important aspect that defines the feasibility and sustainability of IoT deployments. Considering the billions of devices that are likely to be connected in the future, the total energy consumption of IoT networks may become a serious problem. Most IoT devices are powered by batteries and are used in places where it is not feasible to replace or recharge the batteries. Thus, making batteries longer lasting by producing and operating devices in an energy-efficient manner is necessary to ensure that these devices are durable and reliable [3][4].

A crucial obstacle to the implementation of energy efficiency in the Internet of Things is in the multitude of applications and deployment scenarios. IoT devices differ from micro sensors with very little energy budget to more complicated nodes that need considerable amount of processing power and communication capabilities. The difference in these devices forces the use of different energy management techniques that are suitable to the needs of different applications. To illustrate, in smart home appliances, communication protocols that consume less power and low-power sensing technologies are necessary, while industrial IoT might focus on optimizing data transmission and processing to minimize energy consumption [5][6]. The issue of IoT energy efficiency is primarily the need to find a balance between the devices' power consumption and functional requirements. This balance can be achieved by hardware and software innovations. Hardware wise, the development of lightweight microcontrollers, energy-saving sensors, and the use of new energy-harvesting techniques have contributed to the emergence of devices that can run on very little power for a long time. Software wise, the use of algorithms that minimize communication overhead, schedule power states effectively [7][8], and optimize data processing are some of the contributors to the energy efficiency of IoT systems.

Through its communication protocols IoT can achieve higher energy efficiency. Conventional communication protocols exhibit a characteristic of demanding high power for IoT applications. Therefore, new low-power communication protocols have been developed that are designated for IoT only. This includes protocols Zigbee, LoRaWAN, and Bluetooth Low Energy (BLE), which first of all seek to have low energy consumption with reliable data transmission. Moreover, duty cycle optimization, data transmission frequency decrease [9][10], and adaptive communication methods use can be the major reasons behind IoT networks energy consumption reduction. Apart from these two applications, energy harvesting is also among the principal research fields where devices can grab, for instance, solar, thermal, or kinetic energy and transform it to electrical power to run IoT devices. By harvesting the extra energy from IoT devices, it is possible to have them last forever with the need for battery replacements reduced which in turn will make IoT sustainable. Moreover, data management and processing in IoT systems can have a profound impact on the energy consumption of such systems. Edge computing is the type of computing which refers to situations when data processing happens next to the place of the data instead of sending it to centralized cloud servers. This is one of the ways by which this technology can help cut down on the energy cost which is related to data transmission and processing. One of the main advantages of edge computing is the fact that this technology can filter and aggregate data before transmission, thus removing the need for high-energy transmission, which also affects the energy needed for communication [11][12].

1.1 Classification of Energy Efficient techniques

There are five primary classes of energy-efficient techniques in IoT.

i. Data condensation: The method seeks to reduce the volume of data generated, processed, and sent. Data compression and data aggregation are some of the techniques that are included in this category

ii. Protocol Overhead Reduction: The objective here is to improve the protocol performance by cutting out unneeded parts. Adaptation of the message sending periods based on the stability of the network or the distance to the source of the information is among the various methods [13]. Cross-layer approaches to the development of communication protocols are designed taking into consideration the application needs while well-designed flooding consumes less communication resources.

iii. Energy-efficient routing: The main purpose of routing protocols in a network is to extend the lifetime of the network by the least use of energy in the end-to-end transmission and by avoiding the nodes with low residual energy. Different strategies are available, such as protocols opportunistically benefiting from the mobility of nodes or utilizing broadcast communications, geographical routing using node coordinates, hierarchical routing to reduce and simplify the overhead, and data-centric protocols that are only aimed at the nodes that are interested in the communication.

iv. Duty cycling: This is about regulating the portion of time during which nodes are on throughout their lifetime. Techniques in this category include synchronizing the sleep/active schedule of each node with the application needs [14]. Whereas high granularity techniques allow among the all-deployed sensors to select the active nodes, low granularity techniques entail switching off/on radio of the nodes when communication is/is not needed, which is closely associated with medium access protocols.

v. Topology control: This technique is about curtailing the usage of energy by reducing the amount of transmitted power but keeping the network well connected.

1.2 Routing Protocols for Reducing Energy consumption in IoT assisted WSN

The interconnectedness of things in our world, which includes cars, buildings, and any other object that has embedded electronics, software, sensors, actuators, and other components, is referred to as the Internet of Things, or IoT. Through the Internet of Things, these intelligent things can share and collect data for different purposes. One of the most used types of Internet of Things networks is the wireless sensor network (WSN), where sensors are used to monitor and identify the area of the network. Microelectromechanical systems (MEMS), systems on a chip (SoC), wireless communications, and low-power embedded technologies are the components making up WSNs. WSNs are currently being used in many fields such as intelligent transport, military applications, and the civilian domain. Besides, WSNs can be utilized for IoT data collection.

Such a vast network has the capability to significantly raise the convenience question in our everyday lives thanks to cloud computing. The advantages of IoT integration within WSN in a wired network include low-cost [15], effortless deployment, and good scalability. The imperfections, nevertheless, cannot be overlooked. However, the hindrance with the energy source that is the greatest risk should not be forgotten. Energy control poses a significant problem for WSN that employs IoT because sensor nodes are mainly operated by batteries that cannot be conveniently supplied with the required energy due to the extreme conditions where they operate. Node component replacement is economically infeasible, as the sensors have a brief lifespan. Hence, the two major aspects to be considered for the improvement of the efficiency of WSN routing protocols are prolonging the network's lifespan and managing the energy resources throughout the whole network. The routing protocols can be categorized into three main types:

i. Location based routing protocols: Such protocols take into consideration both physical distance and nodes' distribution which are the key factors for network performance. In this case, the nodes are assumed to have the information of the positions of their neighbouring nodes. The protocol proceeds from the message origin to the destination's location using routing trees to send the query in a localized manner, thus, avoiding the addition of transmission channels. It allows for the use of currents permitting the geo-sensor networks to route queries without adding more transmission channels. These algorithms command the nodes to first stop by and broadcast hello messages to their nearby nodes for location awareness. The Location-based routing is a technique that does not require the use of routing indices, which means that its operations are solely based on the destination's location. The moment the destination's location is known, all functions are performed locally, with each node only tracking its immediate neighbours. The main protocols in this category are Distance Routing Effect Algorithm for Mobility (DREAM) and Implicit Geographic Forwarding (IGF).

ii. Hierarchical Protocols: his type of routing protocols imposing a structure on the network leads to energy saving, stability, and scalability. These protocols organize the network nodes into clusters with the node that has more remaining energy being the one selected as the cluster head [16]. The cluster head is in charge of the operations within the cluster and he also forwards the information between the clusters. Clustering technique can be applied for the purpose of reducing energy consumption and extending the existence of the network. The protocols provided are the ones that have a high distribution ratio and scalability and can equally balance the energy consumption. Nodes nearby sink or cluster head will spend their resources sooner than other nodes. Network disconnection is an issue due to which some parts of a network may be out of the reach. Some popular routing protocols in this category are Virtual Grid Architecture Routing (VGA) and Multihop Virtual Multiple Input Multiple Output (MIMO) and LEACH (Low Energy Adaptive Clustering Hierarchy).

iii. Data Centric Protocols: The fundamental distinction between these protocols and others lies in the data sent from one point to the endpoint directly. All nodes at the source send data independently to the sink producing data-centric protocols that can be used to process data. These protocols include a procedure for collecting data from multiple source nodes and then transmitting it between the source and base station which is high energy efficient. Two protocols that are among the most popular in this category are Sensor Protocols for Information via Negotiation (SPIN) and directed diffusion.

2. Literature Review

A. Jaiswal, et al. (2024) offered a novel WPT (wireless power transfer) solution with the help of UAVs situated in an IoT-enabled RAN [17]. The strategy included K-means clustering, a modified Ant Colony Optimization (ACO) algorithm, and Radio Frequency Energy Transfer (RFET) zones to enhance the charging of dispersed IoT Nodes (INs). RFET zones were used to surround INs, and K-means was used to cluster nodes based on their energy demands and distance. After that, the ACO algorithm designed efficient UAV paths by considering UAV capacity and node deadlines. The proposed strategy was able to enhance energy efficiency and deadline adherence while decreasing UAV usage by 22.22% and 36.36%, respectively, when compared to EUP-ACS and IA-DRL.

M. Abdullah, et al. (2024) addressed the difficult trade-offs in the fields of network performance, energy efficiency, and equitable resource distribution across IoT devices making it a successful solution [18]. The proposed strategies, chiefly the Outer Approximation Algorithm (OAA), were successful in the optimization of the use of resources and the uninterrupted transfer of information. The main concern, a concave fractional programming problem, is transformed into a concave optimization enigma by the Charnes-Cooper transformation. This is where the methodology of outer approximation started to work, determining the complicated paths of concave optimization. The efficiency of the epsilon-optimal solution was analyzed in respect to the arrangement of IoT devices, their connections, fairness considerations, and the allocation of resource blocks in an equitable manner. This contribution opened up new avenues not only to the research community but also to the infinite potential of satellite-assisted Internet of Things networks.

M. Bani Irshaid, et al. (2023) presented a novel energy-saving multiple channel Cross-layer MAC architecture for 6G-IoT networks with CR enabled using a non-persistent CSMA protocol [19]. By utilizing jointly adapting the physical and MAC layer settings, the framework talked about enhancing the energy efficiency (EE) of the IoT networks. The researchers, in particular, developed an analytical and closed-form solution, which includes various design constraints, of the per-bit EE maximization problem. The numerical results revealed that the offered multi-channel cross-layer framework outperformed a reference single-channel cross-layer design by as much as 50% in network energy efficiency.

M. E. Al-Sadoon, et.al (2023) introduced a Dual Tier Cluster-Based Routing (DTC-BR) protocol for partitioning the network region into virtual zones [20]. A cluster-head mechanism was put forward to choose the appropriate Sensor Node (SN) to be exploited as a Cluster Head (CH). Moreover, virtual zones were helped to cover the whole network region according to a DTC technique. MATLAB was considered to quantify the introduced protocol regrading energy usage, lifespan of network, and scalability. The experiments revealed that the introduced protocol offered longer lifespan of network around 6% against DDR algorithm, upto 21% against mobility-aware centralized clustering algorithm (MCCA), 25% against low-energy adaptive clustering hierarchy-mobile energy efficient and connected (LEACH-MEEC), and 37% against Low-Energy Adaptive Clustering Hierarchy Mobile (LEACH-M) protocol.

L. Liu, et.al (2022) recommended a blockchain and deep reinforcement learning (DRL)-empowered system called H-IoT for mitigating the energy utilization [21]. This system was secured and worked energy-efficiently in healthcare services for controlling the spread of the COVID-19. A permissioned blockchain technique was assisted in ensuring that the recommended system was robust. The imperfect energy constraint was handled using the mobile edge computing (MEC) technique for offloading the computing operations which alleviated the computation burden and energy usage. An Energy Harvesting (EH) technique was also put forward for enhancing performance. The simulation outcomes revealed that the recommended system was efficient for enhancing the security and proved energy-effective.

S. Firdous, et.al (2022) suggested a novel Power-Efficient Cluster-based Routing (PECR) algorithm [22]. This algorithm employed a K-Means Clustering (KMC) algorithm for clustering the data and to arrange the Cluster Heads (CHs) and a Main Cluster Head (MCH) prior to choose the exact route, establish the communication with an energy utilization model, alter the CHs and MCHs according to Residual Energy (RE). The suggested algorithm was useful to diminish the traffic overburden, mitigate the energy utilization, and augment the duration of network. The experimental results indicated that the suggested algorithm worked effectively to diminish the traffic overhead and deploy the energy assets. Furthermore, this algorithm was helped in improving the efficacy around 44%.

Rani, et.al (2022) projected a new approach called social relationship-based Energy Efficient Routing (SEER) for the Opportunistic Internet of Things (IoT) in which the routing decisions were made according to feasibility degree, residual energy (RE), and buffer ability of motes [23]. The degree of capturing these metrics were helped to choose the process of transmitting the data. The Opportunistic Network Environment (ONE) simulator was applied to compute the projected approach. The results indicated that the projected approach offered superior Message Delivery Probability (MDP), average hop count, and lower overhead ratio. Besides, this approach provided a method to preserve the power of node after making a conditional choice to transmit the data to a nearby node.

B. Safaei, et.al (2021) devised an energy-efficient cross-layer OF (ELITE) model based on a novel routing parameter called Strobe Per Packet Ratio (SPR) [24]. This parameter was effective for defining the quantity of transmitted SPR. The devised model was employed to choose a route at which least strobe broadcasting was executed to its nodes. The devised model was quantified using Cooja simulator. According to experiments, the devised model worked robustly to alleviate the average volume of required SPR up to 25% and energy usage around 39% in contrast to the customary approaches. Besides, the supremacy of this model was proved over other methods concerning computation time.

R. Yarinezhad, et.al (2021) investigated a tree-based routing protocol that enhanced the energy consumption [25]. Two methods were exploited to secure the network. The primary method was a modified version of the geographic routing (GR) algorithm that transmitted at higher reliability and consumed least energy. The second was a tree-based structure which utilized a lower number of control packets to create this algorithm and an efficient process was put forward for updating it. The simulation results proved that the investigated protocol led to mitigate the energy consumption and delay, and enhance the duration of network and throughput.

B. O. Soufiene, et.al (2020) formulated a Priority-based Energy-Efficient Routing Protocol (PEERP) to transmit the clinical data reliably in IoT [26]. This protocol was useful for classifying the health information into 2 classes assigning consistent priorities: Emergency Situation and Vital Health Data. The initial was the highest priority data and it was transmitted quickly. The latter one was a data which the doctors had requested to monitor the patients continuously. The direct communication was executed for crucial data when the Multi-hop communication was assisted in transmitting the significant health data. The simulation results exhibited that the formulated protocol was assisted in enhancing the energy of the sensor nodes and prolonging the duration of network concerning higher Packet Delivery Ratio (PDR) and dependability.

2.1 Comparison of State-of-Art Energy Efficient Security Solutions

Author & Year	**Technique Used**	**Parameters**	**Simulator**	**Results**	**Limitations**
A. Jaiswal et al. (2024)	K-means Clustering, Modified Ant Colony Optimization (ACO), Radio Frequency Energy Transfer (RFET) Zones	UAV Capacity, Node Deadlines, Energy Requirements	MATLAB	22.22% and 36.36% reduction in UAV usage compared to EUP-ACS and IA-DRL; Enhanced energy efficiency and deadline adherence	Specific scalability or real-time application scenarios not discussed
M. Abdullah et al. (2024)	Outer Approximation Algorithm (OAA), Charnes-Cooper Transformation	Network Performance, Energy Efficiency, Resource Distribution, Concave Optimization Problem	MATLAB	Efficient resource optimization, enhanced fairness in resource allocation, and improved energy efficiency	Complexity in real-world implementation; Potential for performance degradation with highly dynamic IoT networks
M. Bani Irshaid et al. (2023)	Energy-saving Multiple Channel Cross-layer MAC, Non-persistent CSMA Protocol, Closed-form Solution for Per-bit EE Maximization	Energy Efficiency, Physical and MAC Layer Adaptation, Design Constraints	MATLAB	Up to 50% improvement in network energy efficiency compared to single-channel designs	Limited to theoretical and simulation analysis; Applicability in varied IoT environments not extensively validated
M. E. Al-Sadoon, et al. (2023)	Dual Tier Cluster-Based Routing (DTC-BR)	Energy consumption, network lifetime, and scalability	MATLAB Environment (2021a)	The experiments revealed that the introduced protocol offered longer lifesp	The issue of data complexity was occurred in real time.

				an of network around 6% against DDR algorithm, upto 21% against MCCA, 25% against LEACH-MEEC, and 37% against LEACH-M protocol.	
L. Liu, et al. (2022)	Blockchain and deep reinforcement learning (DRL) -based system	Energy efficiency, delay	Python-based PyCharm platform	The simulation outcomes revealed that the recommended system was efficient for enhancing	This system was lack of more factors and inapplicable in complex applications.
				the security and proved energy-effective.	
S. Firdous, et al. (2022)	A new Power-Efficient Cluster-based Routing (PECR) algorithm	Traffic overburden, energy usage and lifespan	MATLAB	The experimental results indicated that the suggested algorithm worked effectively to diminish the traffic overhead and deploy the energy properties.	The suggested algorithm was not effective in real time scenarios.
Rani, et al. (2022)	Social Relationship based Energy Efficient Routing	Message delivery probability (MDP), average hop	Opportunistic Network Environment (ONE)	The results indicated that the projected approach	The projected approach had performed poorly with respect to

	(SEER)	count (AHC), and overhead		offered superior message delivery probability (MDP), average hop count, and lower overhead ratio.	some components of security.
B. Safaei, et al. (2021)	ELITE	Strobes per packet, energy utilization, computation time	Cooja	According to experiments, the devised model worked robustly to alleviate the average volume of required SPR up to 25% and energy usage around	The overheads were found higher to extract information and it had slight complexity.
				39% in contrast to the customary approaches.	
R. Yarinezhad, et al. (2021)	A tree-based routing protocol	Energy consumption, network lifetime, delay, and throughput	OMNeT++	The simulation results proved that the investigated protocol led to mitigate the energy consumption and delay, and enhance the duration of network and throughput.	This protocol was not applicable in some applications of green-IoT networks where several mobile sinks were present.
B. O. Souffiene, et al. (2020)	Priority-based Energy-Efficient Routing Protocol	Network lifetime and energy utilization	MATLAB	The simulation results exhibited that the formulated proto	The memory usage of this protocol was found higher.

	(PEERP)			col was assisted in enhancing the energy of the sensor nodes and prolonging the durati	

				on of network concerning higher packet delivery ratio (PDR) and dependability.	

Conclusion

In conclusion, energy-efficient schemes are pivotal for the sustainable operation of Internet of things (IOTs). These networks are integral to various applications, yet their effectiveness is often limited by the finite energy supplies of individual sensor nodes. Through the implementation of advanced routing protocols like LEACH and PEGASIS, energy consumption can be significantly reduced by optimizing data transmission paths and clustering strategies. Duty cycling techniques further enhance energy conservation by alternating nodes between active and dormant states, thus aligning energy usage with network demands. Data aggregation minimizes redundant transmissions, cutting down on unnecessary energy expenditure. Moreover, energy-efficient communication methods, including low-power transceivers and adaptive modulation, play a crucial role in reducing energy usage during data exchange. As technology evolves, the integration of more advanced algorithms and energy-efficient hardware promises to further extend the lifespan and functionality of IOTs.

References

[1] M. K. Singh, D. Saxena, A. Rai and D. Kushwaha, "Energy Management Techniques of Wireless Sensor Networks for Internet of Things Applications," 2023 International Conference on IoT, Communication and Automation Technology (ICICAT), Gorakhpur, India, 2023, pp. 1-6, doi: 10.1109/ICICAT57735.2023.10263766.

[2] T. M. Behera, S. K. Mohapatra, U. C. Samal, M. S. Khan, M. Daneshmand, and A. H. Gandomi, "Residual energy-based cluster-head selection in WSNs for IoT application," IEEE Internet of Things Journal, vol. 6, no. 3, pp. 5132–5139, Jun. 2019.

[3] T. M. Behera, U. C. Samal, and S. K. Mohapatra, "Energy-efficient modified LEACH protocol for IoT application," IET Wireless Sensor Systems, vol. 8, no. 5, pp. 223–228, Oct. 2018.

[4] W. T. Hartman, A. Hansen, E. Vasquez, S. El-Tawab and K. Altaii, "Energy monitoring and control using Internet of Things (IoT) system," 2018 Systems and Information Engineering Design Symposium (SIEDS), Charlottesville, VA, USA, 2018, pp. 13-18, doi: 10.1109/SIEDS.2018.8374723.

[5] M. A. A. Ghamdi, "An Optimized and Secure Energy-Efficient Blockchain-Based Framework in IoT," in IEEE Access, vol. 10, pp. 133682-133697, 2022, doi: 10.1109/ACCESS.2022.3230985.

[6] S. Chhikara and S. Kumar, "An Integrated Approach of Clustering Based Trust Management with Energy Consumption for Service Oriented IoT," 2019 International Conference on Applied Machine Learning (ICAML), Bhubaneswar, India, 2019, pp. 102-107, doi: 10.1109/ICAML48257.2019.00028.

[7] M. Bukhsh, S. Abdullah, A. Rahman, M. N. Asghar, H. Arshad and A. Alabdulatif, "An Energy-Aware, Highly Available, and Fault-Tolerant Method for Reliable IoT Systems," in IEEE Access, vol. 9, pp. 145363-145381, 2021

[8] A. Ahmed, S. Abdullah, M. Bukhsh, I. Ahmad and Z. Mushtaq, "An Energy-Efficient Data Aggregation Mechanism for IoT Secured by Blockchain," in IEEE Access, vol. 10, pp. 11404-11419, 2022

[9] M. A. A. Ghamdi, "An Optimized and Secure Energy-Efficient Blockchain-Based Framework in

IoT," in IEEE Access, vol. 10, pp. 133682-133697, 2022

[10] D. Ray, P. Bhale, S. Biswas, P. Mitra and S. Nandi, "A Novel Energy-Efficient Scheme for RPL Attacker Identification in IoT Networks Using Discrete Event Modeling," in IEEE Access, vol. 11, pp. 77267-77291, 2023

[11] S. Lee, H. Choi, T. Kim, H. -S. Park and J. K. Choi, "A Novel Energy-Conscious Access Point (eAP) System With Cross-Layer Design in Wi-Fi Networks for Reliable IoT Services," in IEEE Access, vol. 10, pp. 61228-61248, 2022

[12] M. Elhoseny, M. Siraj, K. Haseeb, M. Nawaz, M. Altamimi and M. I. Alghamdi, "Energy-Efficient Mobile Agent Protocol for Secure IoT Sustainable Applications", Sustainability, vol. 14, pp. 128-135, 2022

[13] M. Li and N. Zhang, "Trajectory-Based Authenticated Key Establishment for Dynamic Internet of Things," in IEEE Access, vol. 10, pp. 111419-111448, 2022

[14] K. Aravind and P. K. R. M, "Optimized Fuzzy Logic Based Energy-Efficient Geographical Data Routing in Internet of Things," in IEEE Access, vol. 12, pp. 18913-18930, 2024, doi: 10.1109/ACCESS.2024.3354174.

[15] D. Princy, D. Kalaivani and T. Vijayaraghavan, "A Design Thinking Approach of Metaheuristic Empowerment for Energy-Efficient and Optimized Routing protocol in IoT-Enabled Wireless Sensor Networks," 2023 Third International Conference on Smart Technologies, Communication and Robotics (STCR), Sathyamangalam, India, 2023, pp. 1-6, doi: 10.1109/STCR59085.2023.10396880.

[16] D. Grover, "An Optimized RPL Protocol for Energy Efficient IoT Networks," 2023 International Conference on Data Science and Network Security (ICDSNS), Tiptur, India, 2023, pp. 01-05, doi: 10.1109/ICDSNS58469.2023.10245333

[17] A. Jaiswal, S. Shivateja, A. Hazra, N. Mazumdar, J. Singh and V. G. Menon, "UAV-Enabled Mobile RAN and RF-Energy Transfer Protocol for Enabling Sustainable IoT in Energy-Constrained Networks," in IEEE Transactions on Green Communications and Networking, vol. 8, no. 3, pp. 1118-1127, Sept. 2024, doi: 10.1109/TGCN.2024.3403662.

[18] M. Abdullah, Humayun Zubair Khan, Umair Fakhar, Ahmad Naeem Akhtar, and S. Ansari, "Satellite synergy: Navigating resource allocation and energy efficiency in IoT networks," Journal of Network and Computer Applications, vol. 230, pp. 103966–103966, Oct. 2024, doi: https://doi.org/10.1016/j.jnca.2024.103966.

[19] M. Bani Irshaid, H. Bany Salameh, and Y. Jararweh, "Intelligent multichannel cross-layer framework for enhanced energy-efficiency in 6G-IoT wireless networks," Sustainable Energy Technologies and Assessments, vol. 57, p. 103211, Jun. 2023, doi: https://doi.org/10.1016/j.seta.2023.103211.

[20] M. E. Al-Sadoon, A. Jedidi and H. Al-Raweshidy, "Dual-Tier Cluster-Based Routing in Mobile Wireless Sensor Network for IoT Application," in IEEE Access, vol. 11, pp. 4079-4094, 2023

[21] L. Liu and Z. Li, "Permissioned Blockchain and Deep Reinforcement Learning Enabled Security and Energy Efficient Healthcare Internet of Things," in IEEE Access, vol. 10, pp. 53640-53651, 2022

[22] S. Firdous, N. Bibi, M. Wahid and S. Alhazmi, "Efficient Clustering Based Routing for Energy Management in Wireless Sensor Network-Assisted Internet of Things", Electronics, vol. 11, no. 23, pp. 566-570, 2022

[23] Rani and A. Malik, "A social relationship-based energy efficient routing scheme for Opportunistic Internet of Things", ICT Express, vol. 9, no. 4, pp. 697-705, 18 October 2022

[24] B. Safaei, A. M. H. Monazzah and A. Ejlali, "ELITE: An Elaborated Cross-Layer RPL Objective Function to Achieve Energy Efficiency in Internet-of-Things Devices," in IEEE Internet of Things Journal, vol. 8, no. 2, pp. 1169-1182, 15 Jan.15, 2021

[25] Yarinezhad and S. Azizi, "An energy-efficient routing protocol for the Internet of Things networks based on geographical location and link quality", Computer Networks, vol. 193, no. 4, pp. 118-122, 15 April 2021

[26] B. O. Soufiene, A. A. Bahattab and H. Youssef, "PEERP: An Priority-Based Energy-Efficient Routing Protocol for Reliable Data Transmission in Healthcare using the IoT", Procedia Computer Science, vol. 175, pp. 373-378, 6 August 2020