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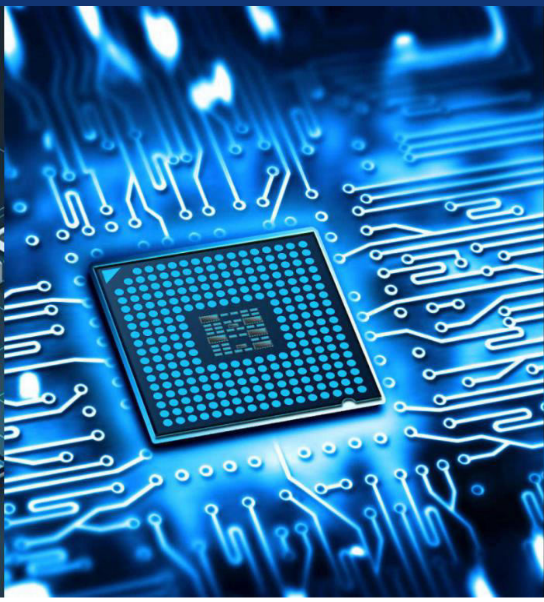


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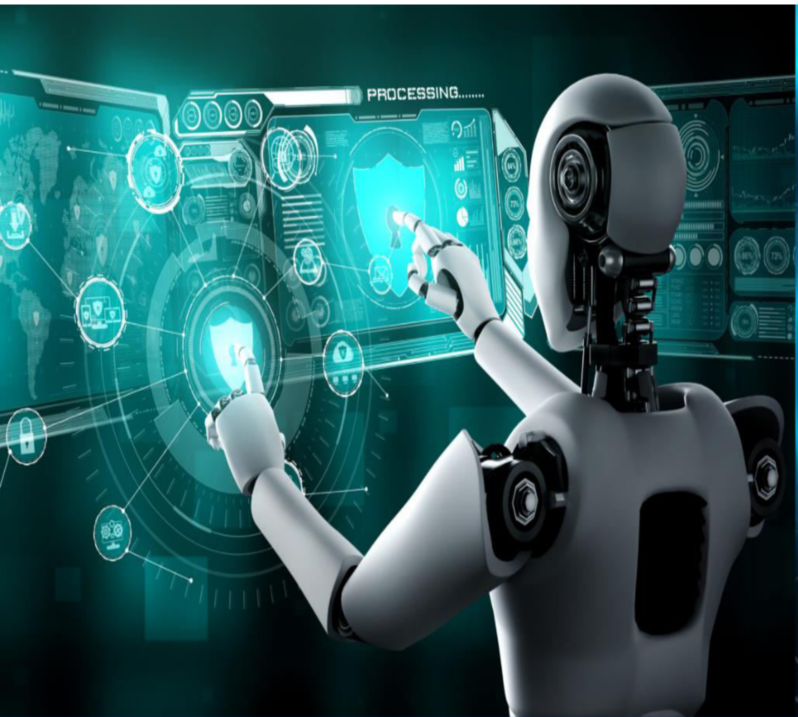

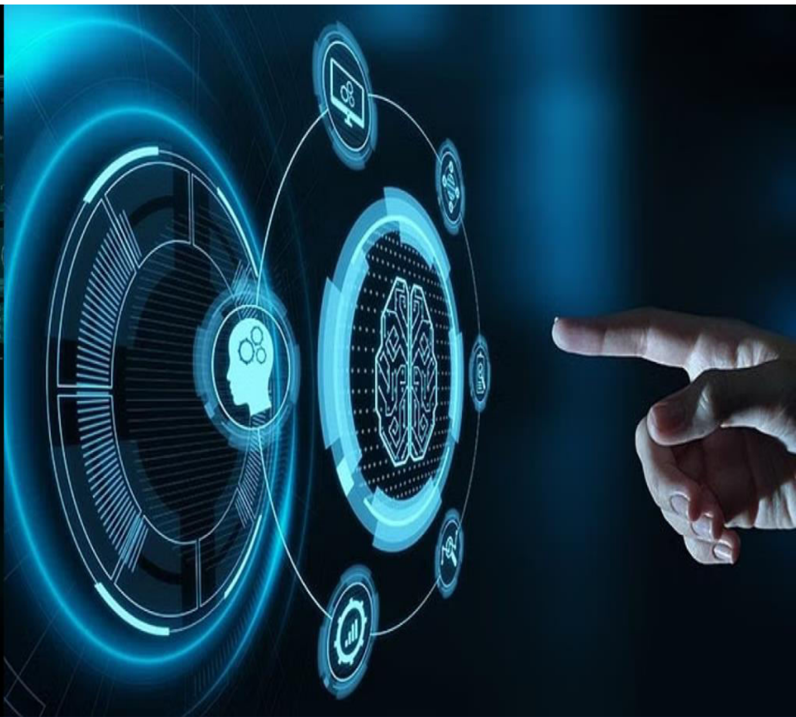

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Energy Centric Routing Protocols for IOT Networks: An Overview

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ABSTRACT: The Internet of Things (IoT) is an emerging domain of technologies that finds vast applications in the current generation of industridization i.e. industry 4.0, including the service sector. The IoT is a strong contender to act as key component in a variety of applications like cyber physical world, next generation telecommunications (5G & 6G), healthcare, agriculture, commerce & finance, aviation, smart cities, home automation etc. The IoT is a global network of devices, sensors, actuators and processors that provides machine-to-machine or device-to-device communication for various applications using cloud computing without human intervention. It is estimated that more than ten billion devices/machines are presently interconnected and sharing data through dedicated IoT networks with cloud storage and computing applications. The devices/machines/sensors generate extensive volume of data every second that need to be processed and stored at ultra-light speed. Routing of IoT data consumes significant energy/power at each sensor node. It means IoT networks are energy limited therefore development of energy efficient routing strategies and protocols are of utmost importance. The energy harvesting techniques for IoT routing may reduce the energy issues of IoT networks. This review paper presents the advanced energy centric and energy harvesting schemes for IoT routing protocols. The paper focuses upon the issues, challenges and probable solutions to address energy perspectives of IoT routing protocols.

KEYWORDS: Internet of Things (IoT), Wireless harvesting energy, Clustering, Energy Efficiency, MIMO, Wireless sensor network, Routing protocol

I. INTRODUCTION

The Internet of things (IoT) has accomplished significant progress in last couple of years paving the way for numerous applications in variety of fields that includes intelligent transport system, agriculture, healthcare, smart cites, smart buildings, and smart grids, as well as in fields like education, industry, entertainment, and monitoring the environment. As of 2023, there is around 15 billion internet of things (IoT) devices (or 1500 billion linked devices) in use across the globe. These devices include applications in smart homes, smart cities, manufacturing process flow, agricultural technology, smart factories and health care. India's percentage of the global total is less than 1%. This figure is expected to rise at an exponential rate of 12–15% annually [1]. Wireless sensor networks (WSN) are the foundational IoT technology that the entire IoT system is dependent on them. The next generation of the Internet, also known as the expansion of Internet and World Wide Web, is thought to be the IoT which assumes a significant number of connected objects that would allow direct machine to machine (M2M) communication. The sensors are the most crucial component of the IoT since they serve as the system's ears and eyes and act as the foundation for WSNs even though every component, be it software or hardware is still significant [2].

To some extent IoT networks are extended form of WSN. The WSN supports the growth and development of the IoT by allowing low-end devices with less resources and providing game-changing services. It employs a large number of sensors, between tens and thousands that are connecting with one another through wireless technology. In order to deliver smartness in small-to large-scale appliances, advancements in sensor technology have made it possible to accomplish inexpensive, miniature wireless sensors that are IoT-enabled. These areas encompass both secure and trustworthy communication as well as the measurement of significant environmental variables, such as humidity, temperature, light, pressure, and others [3, 4].

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Next to, multiple-input multiple-output (MIMO), is a technique that can increase capacity and decrease transmission energy depletion, is becoming more and more popular for IoT devices. The next-generation networks along with vehicular ad-hoc networks, mobile ad-hoc networks (MANETs), cognitive radio, WSNs, IoT, 5G networks, etc. favor for using a peer-to-peer model instead of a client-server model because it provides more flexibility and scalability [5]. The internet or the cyber environment can also be extended into physical spaces by WSNs [6]. In wireless communication technologies, 5G is widespread with the exponential advancement of smart devices and a huge amount of information exchange between users and has features like lower latency, higher capacity, and increased bandwidth unlike conventional cellular networks.

Wireless sensor networks are now recognized as a critical IoT enabler, further cementing the close relationship between IoT and WSN. In any type of communication network, Routing has been consistently an essential factor. IoT networks use a variety of devices. Starting energy, use of energy, remaining energy, linking resources, recognizing capability, along with communication distance all contribute to the heterogeneity or diversity. The degree of flexibility needed in diverse IoT networks can't actually be accommodated by homogeneous network standard routing techniques. That's why it becomes important to create protocols for routing for IoT networks based on heterogeneous WSNs [7]. Due to the restricted energy, computing power, and communication range of sensors, the researchers are having a squeaker task implementing the routing algorithm.

Routing protocols for sensor-based IoT frameworks can be categorized based on different factors as illustrated in Figure 1.

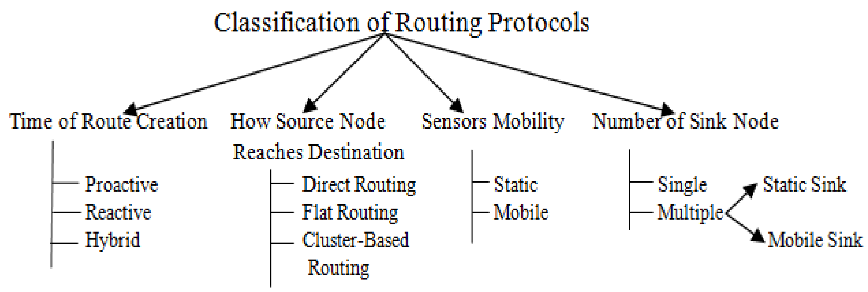

Fig. 1: Classification of Routing Protocols of Sensor-based IoT

IoT applications formulated on WSNs are various and different plus accomplishing the everyday life of people's simple. A number of protocols for routing are being offered by the IoT networks, including positioning-based routing algorithms, reactive, cluster based (CBR), proactive as well as geographic based techniques [8].

II. ENERGY HARVESTING IN IOT: PURPOSE AND MOTIVATION

Energy economy and high battery lifetime are of critical attention when designing and creating wireless sensors (IoT devices). Even though there have been ground-breaking advancements in operating systems, communication protocols, robust power management techniques, extremely effective MAC (medium access control), and routing protocols have all made significant strides, batteries eventually run out of juice. With the goal of creating sustainable and energy-efficient systems, there is currently a generalized tendency to lessen the environmental effects of technology used in information and communication which also applies to wireless sensors. Batteries can be entirely replaced by these energy harvesting parts, or they can perform as backup power sources. Thus, when it comes to the general adoption of IoT, one of the biggest problems is the operation of wireless sensors over a long period of time and independently, is ensured [9]. Exploring energy harvesting's (EH) possibilities in IoT networks is crucial.

Harvesting energy is a procedure for collecting energy through multiple supplies which aren't frequently used. Aside than the direct electricity distribution, there are multiple additional methods to produce certain amounts of energy. Among the most common EH sources are light, radio signals, solar power, kinetic power and heat as well. EH may be essential for enabling equipment to operate in situations when direct power sources are not available. Not only does

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harvesting provide energy, it also accumulates enough of it so that the device may continue to run in the event that the power source is not available. The source (the outside energy that is captured), the architecture of harvesting (the systems), and the load (the end user) are the three parts that make up a typical energy harvesting system [10].

Figure 2 depicts the two distinct topologies, such as using the harvest and storing the harvest, for a wireless sensor node with harvests energy elements. EH therefore appears as the answer to the problems with IoT device's battery life. These devices may enhance their functioning, location and services through use of EH, resulting in a desirable effectiveness. IoT devices that have the potential to be powered can reach maximum lifespan and do away with the necessity of power cables or battery chargers.

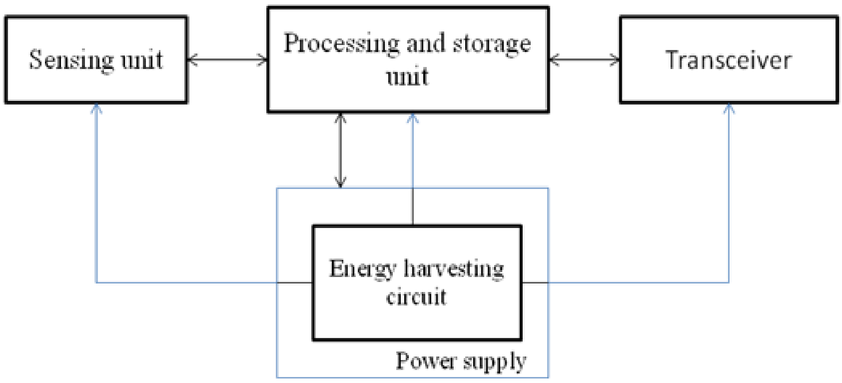

Fig. 2(a): Energy-harvesting wireless sensors (Internet of Things): Harvest-Use

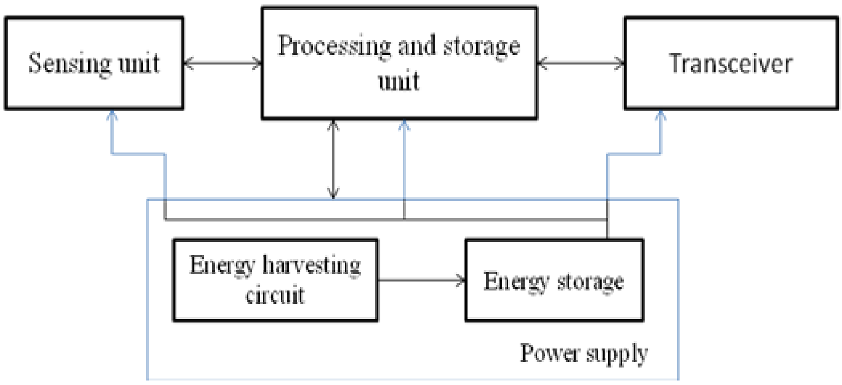

Fig. 2(b): Energy-harvesting wireless sensors (Internet of Things): Harvest-Store-Use

III. ENERGY HARVESTING TECHNIQUES FOR IOT

Outside sources provide energy and acquired energy is transformed to generate electric power through collecting energy equipment throughout the energy harvesting process. The primary driver behind the expansion of energy harvesting industry is the replacement of battery-operated power sensors accompanied by rechargeable wireless sensors that rely on energy harvesting. For IoT domain applications to prolong, the energy harvester must produce output power of at least the milliwatt range. When operating sensor nodes continuously without interruption, an energy storage unit is essential. More energy harvesting modules will be implemented as the IoT sector expands, which will lower the price. A number of energy sources likely to be advised for energy harvesting [11].

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Table 1: Energy Harvesting Method's Simplification

Energy source	Technology	Power density	Advantages	Disadvantages	Application domains
Solar	PV cell	10 - 100 mW / cm^2 (outdoor) < 100 µW / cm^2 (indoor)	High-output voltage, Affordable manufacture, Predictable	Unavailable at night, non-controllable	Environment monitoring, healthcare, agriculture
RF	Antenna	0.01 - 0.1 µW / cm^2 1- 10 mW / cm^2	Available anywhere, anytime, Predictable, Controllable	Distance dependent, Low-power density	Environment monitoring
Mechanical vibrations and pressure	Piezoelectric	4 - 250 µW / cm^3	Powerful density, Without an external power source, Simplicity in production and design, Controllable	Extremely varied results, Unpredictable	Infrastructure monitoring, automotive
	Electromagnetic	300 - 800 µW / cm^3	High-output currents, Strongness, Affordability, Controllable	Generally big size Unpredictable	
	Electrostatic	50 – 100 µW / cm^3	Higher output voltage, comparatively greater output power density, ability to create inexpensive devices, Controllable	Necessary bias voltage Unpredictable	
Human heat	Piezoelectric Pyroelectric	< 35 µW / cm^2	Sustainable and reliable, Available, Controllable	Low-power density Unpredictable	Healthcare
Biomechanical	Electromagnetic Piezoelectric Triboelectric Electrostatic	< 4 µW / cm^3 < 300 µW / cm^3	Available, Controllable	Low-power density, Unpredictable	Healthcare
Bio	Metal electrodes	Extremely low wattage	Available, Controllable	Very low wattage, Appropriate for electrical devices on the nanoscale	Environmental sensing in agricultural applications

One of the main technologies that allow both field-formation WSNs and IoT applications is energy harvesting (EH) technique [12]. One important aspect of deploying big IoT devices is energy harvesting (EH). When deployed, nodes can harvest energy via environmentally friendly sources such as solar, vibration, along with RF electromagnetic energy while employing the EH mechanisms to power up their energy sources throughout their usage. This method greatly improves wireless network reliability while protecting information from monitoring without requiring upper-layer encrypted data.

IV. EXISTING ROUTING PROTOCOLS FOR IOT NETWORKS

The most recent advanced routing protocols have been reviewed in this work, along with their shortcomings and potential directions for additional research.

In [13], the authors presented Review of routing protocol for low power and lossy network in the internet of things. Key industries including the smart environment, medical cares as well as essential technologies have seen difficulties as a result of the expansion of IoT devices or applications. The largest problem is maintaining privacy of smart devices, connections, and architecture. In order to provide smooth transmission of data between a number of linked objects, the IoT uses RPL, a routing protocol designed for low-powered lossy network. Therefore, this research addresses the inner workings of RPL, including its design and applicability for the IoT, as well as its methodology preferences, and goal functionality. It examines a number of aspects such as energy consumption, overload, accessibility, resilience, safety, with handling keys.

A 5G balanced energy-efficient protocol based on Intelligent MIMO [14], suggested that increasing network longevity and lowering energy usage are the fundamental problems with sensor-based IoT networks. The primary tactic for the upcoming wireless communication system that successfully supports the IoT system operation is to optimize the present wireless network’s performance standards. Collisions induced by random access when huge-scale devices desire a network access are the main cause of the limited consumption of restricted data for IoT devices. While this is happening, 5G broadcasts demand the integration of MIMO antennas in many IoT applications in order to provide improved bandwidth within a multipath spectral scenario. The designed intelligent MIMO-based 5G algorithm is balanced in terms of secure the network from growing hotspot difficulties as well as extend the network’s longevity in the context of 5G, this work aims to propose a centralized approach or Quality of Experience (QoE) for transmission to combining IoT communication devices in an imbalanced structure of hybrid clusters [15].

A D2D based Multicriteria-Aware Routing method for the IoT 5G Network (MBMQA) [16], introduced the IoT 5G network-based D2D communication systems possesses an opportunity with the aim of recognizing widespread and smart applications that will enhance the quality of life for those who live in an interconnected world. Energy usage, waiting time, and device accessibility are just a few of the variables that make up this suggested Mobility, Battery, and Queue length Multipath-Aware (MBMQA) routing protocol. The mobility of the device also causes a random change in the network topology, which has an impact on the reliability of established routes [17].

For route computations, an algorithm which is known as back-pressure (BP) algorithm [18] was developed that is formed on each node’s accessible parameters which includes the mobility information, battery’s energy level, as well as the size of the device’s queues that is deployed to divert packet flow and give information about the estimated value of the device choice. Additionally, a multiple attributes route selection (MARS) metric is conferred in order to quantify the information in order to aid in choosing the best path out of several options for the target device during load balancing.

According to research work of Novel energy harvesting clustering protocol (NEHCP) [19], Energy management is the main challenge of WSNs. To resolve the limitation of the sensor battery, an alternative solution has been observed called energy harvesting (EH). The hierarchical clustering routing method gave rise to the NEHCP, a protocol that adopts solar EH. In the clustering approach, sensor nodes are grouped into discrete units, or clusters, each of which has a coordinator who serves as the cluster head (CH), with the remaining sensor nodes serving as the cluster members (CMs).

An intelligent routing protocol (IRP) based on artificial neural network (ANN) for WSN Based IoT Networks [20], proposed an energy-conscious, loose virtual clustering mixed ANN (artificial neural network) heterogeneous network routing technique that can operate under the nose of ambient energy sources is one of the purposes of this research. An energy back-off method was introduced whose goal is to extend the back-off period. As a result of doing this will give the node additional time to wait and gather energy from nearby energy sources. The end-to-end (E2E) delay of the system will grow as long as until there is a transmission window, the node must wait longer, at the same time as because fewer data packets are being broadcast from the nodes, the system throughput will fall as a result. The “energy back-off” mechanism is in charge of ensuring that the diverse energy source-powered nodes carry out their energy harvesting activities with integrity, as a result increasing the network lifetime. This routing approach discloses two

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issues such as clustering and routing. The suggested technique, when combined with ANN training, promotes node longevity plus network service quality (QoS) in erratic the volume of traffic and energy availability situations.

To whelm hotspot issues, the MIMO-UCC, a novel centralized energy-balancing using the unequal concentric chain clustering technique for the IoT system allowing for the 5G environment [21] is proposed. This is computed for the efficient gathering of data carried out by the sensing environments though each node for each cycle holds a package of information that must be transmitted up to the base station. It also adjusts the cluster head diameter based on the energy output and the base station's location in order to lessen the load on the cluster head. This technique selects a probability-based suboptimal multi-hop path. MIMO-UCC works with principal vector projection approach that examines the location of the base station to form an unequal concentric chain clustering. Its groupings the networks within certain unequal constrict chains and also get suboptimal multi-hop routes over the cluster heads through seeing the cost of using the path and residual energy or also use these routes casually when transmitting data.

The label "concentric clustering" points toward how sensor networks are rated within certain clusters and how a cluster is shaped like a concentric chain. This suggested protocol has four features, including creating a usable chain topology, correlating energy depletion amid cluster heads, reducing the energy usage of cluster nodes, and selecting an appropriate communication interface from a variety of options assigned to an IoT sensor. The outcomes of the simulation exhibit improved network lifetime and balanced energy usage in the context of 5G cluster heads against UN-LEACH.

According to an effective strategy for IoT applications based on WSN [22], another modifying routing technique for locating energy-efficiency improved paths in a WSN with Energy Harvesting is introduced in this paper as part of the MDDA-EHWSN as Malleable Directing Scheme with Data Aspect. This research presents a special technique to identify most consistent data quality for collecting approximation data in a wireless sensor network with several hops that harvests energy. The amount of power needed by sensor nodes is continuously adjusted due to renewable energy source's accessibility, the requirements for network routing, along with restrictions on application quality.

In the following, modifying routing approach is offered that is capable of locating and maintaining energy-efficiency improved paths between any source node and its destination node or base station. Routes that are energy-optimized prevent nodes from travelling on too little energy, making it possible for these nodes to replenish their energy level over with the use of energy harvesting. When comparing energy costs for the transport of data packets, the suggested routing protocol has an edge over competing routing protocols.

An efficient energy-harvesting-aware routing algorithm for IoT applications based on WSN [23], main objective is to develop routing protocols that are sensitive to energy production for heterogeneous IoT systems using WSN that work with ambient energy sources. With the integration of a new variable named "extra backoff", the routing scheme that EHARA is proposing is farther improved. The suggested method changes the quality-of-service (QoS) in situations of variable traffic load along with energy availability, as well as the lifespan of sensor nodes.

Three approaches to capturing energy as using solar energy, RF-based EH, and based on moving vehicles EH have been considered in this work in the context of EE and QoS challenges for IoT applications. The EHARA routing technique has been offered as a solution to the heterogeneity of heterogeneous WSN-based IoT systems in terms of function. Furthermore, this approach can also be made available with the fewest adjustments in any IEEE 802.15.4-based IoT applications.

A more advanced energy efficient routing algorithm for Link Recovery in IoT [24], there are numerous machine to machine (M2M) communication-required IoT apps that offer services that are generally available everywhere. The movement of nodes and traffic flow play a big role in this kind of communication. Maintaining dependable connectivity is a crucial issue in IoT when the nodes are mobile. Routing Over Low Power and Lossy Networks (ROLL) faces additional difficulties with energy efficiency because LLNs are restricted networks.

This suggested algorithm is an expansion of MAEER (Mobility Aware Energy efficient or power saving Routing method), which enables node movement plus also provides a second technique for connection recovery. Device-to-device communication requires the use of a link recovery approach since mobile nodes occasionally move out of radio

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range, breaking links. Network performance is impacted by this link breakdown. As a result, data packets are lost and energy is wasted. In this research, a routing strategy is presented that can address the energy depletion and connection failure problems. Along with that, it also cuts down on propagation latency.

Most of the routing protocols are for wireless transmitters or sinks, optimized node implementation, harvesting energy, the beamforming process, clustering or routing, communication dependence, along with different optimum approaches [25]. To extend the lifetime and dependability of WSN-assisted IoT networks, numerous methods are put out in the existing literature, according to table 2 whereas table 3 presents performance comparison of existing routing protocols.

Table 2: Qualitative Analysis of Various Routing Protocols

Protocol	Used technique	Advantages	Parameters	Limitations
Optimal Cluster-Based Routing (Optimal-CBR) (Jothikumar et al. 2021)	Optimal cluster-based routing and k-means algorithm	• Energy distribution • Maximum transmission • Prolonged network lifespan	• Energy dissipation • Packet delivery ratio • End-to-end delay	• Security mechanism in the implementation
A C-LMS Prediction Algorithm for Rechargeable Sensor Networks (MA et al. 2020)	Correlation Least Mean Square (C-LMS) prediction model	• Significantly improved prediction accuracy • Low complexity • Predicting charging can increase the network lifetime	• Network lifetime • Data throughput	• Practical application schemes of solar charging sensor networks or EH-WSN
Enhanced Three Layer Hybrid Clustering Mechanism (ETLHCM) (Faizan et al. 2019)	Hybrid Hierarchical Clustering Approach (HHCA) and distributed approach	• Low control message overhead • Efficient energy usage	• Residual energy • Distance to BS	• proposed method is for few diverse applications-specific networks and further can evaluate it for large-scale networks
Energy aware multi-hop routing (EAMR) (Cengiz and Dag. 2018)	Distributed dynamic cluster head selection scheme for energy-efficient routing protocol	• Minimizing the excessive overhead • Increased scalability • Relay nodes decrease optimum communication distances	• Network lifetime • Loss of network energy • Data transferred to the BS or PDR	• Large-sized WSN or heterogeneous node type in the implementation
Fuzzy logic–based unequal clustering and ant colony optimization (ACO)-based routing hybrid (FUCARH) (Arjunan and	• Fuzzy logic based Unequal clustering • Ant colony optimization (ACO) based routing and	• Transmits data in a hybrid manner • Load balancing • Enhances network lifetime • Eliminates hot spot problem	• Average energy consumption • Network lifetime	• Extended for the network with mobile nodes and multiple sinks, with additional parameters such as link quality, coverage

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Sujatha 2018)	hybrid protocol			redundancy
Unequal Clustering Scheme Based LEACH for Wireless Sensor Networks (Ren et al. 2010)	• Improved LEACH protocol • Distance matrix created to modify transmission power • Distance and residual energy to CS considered for CH election	• Enhance the stability of network • Prolong network lifetime • Good load balancing • Doesn't support fault tolerance	• Network lifetime	• Complexity issues in implementation

Table 3: Performance comparison of existing routing protocols

Parameters	Protocols					
	EHARA	**MDDA-EHWSN**	**NEHCP**	**MIMO-UCC**	**MBMQA**	**IMIMO 5G-based BEE**
N/w Lifetime	After 8,000-second period of simulation, remaining battery level is 50%	Increases based upon Quality-of-Service parameters	71.8%	High	Maximum	Protect the network from increasing hotspots issues and lengthen the lifespan of the network in the 5G scenario
Latency	Medium	Low	-	Decrease	Minimal	Very low
N/w stability & security	Maintain the stability	-	Stable region	-	Maintaining network stability	Maintain network stability & supports security mechanism
Average energy consumption	Reduces average consumed energy at each node	Maintain energy optimized routes by allowing nodes to regain their energy level through energy harvesting	Gives maximum energy efficiency in term of energy consumption	Consumes less amount of energy using chain schema	Consume less battery energy or higher energy efficient network	Lessen energy utilization or balanced energy depletion
N/w throughput	High	Medium	Maximum	Maximum	Enhances	High

V. CONCLUSION

In the operation of energy efficient networks, Routing protocols possess a significant role, just as concluded through their adaptability and effectiveness. Energy usage as well as efficient data transmission techniques is undoubtedly needed as that of WSN or IoT-related uses spread globally. Furthermore, MIMO transmission has always been crucial to RF-based networking. Because of that, this is a promising research area. To assure energy-efficiency toward extend the network lifetime, different routing protocols have been actualized which admitting to consideration of energy

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consumption and network design. This paper contributes an extensive survey on various routing protocols that uses less energy as well as MIMO based routing protocols for IoT applications and also for 5G networks in order that use WSNs. Additionally, choosing protocols for network communication that give preference to cost or energy optimization in addition to providing strong encrypted data throughout communication is crucial for boosting the long-term viability or longevity of IoT systems as well networks. In this study, the key points, architecture, and frameworks of various energy efficient sensor routing techniques were conferred.

REFERENCES

1. Hassebo A. and Tealab M. "Global Models of Smart Cities and Potential IoT Applications: A Review", IoT, 2023; 4: 366-411. 10.3390/iot4030017.
2. Faizan UM., Imtiaz J.and Maqbool KQ. "Enhanced three layer hybrid clustering mechanism for energy efficient routing in IoT", Sensors 2019; 19(4): 829.
3. Faheem M., and Gungor VC. "Energy efficient and QoS aware routing protocol for wireless sensor network-based smart grid applications in the context of industry 4.0", Appl Soft Comput 2018; 68: 910–922.
4. Khalid M., Ullah Z., Ahmad N., Adnan A., Khalid W. and Ashfaq A. "Comparison of localization free routing protocols in underwater wireless sensor networks", Int J Adv Comput Sci Appl (IJACSA) 2017; 8(3): 080356.
5. Djamaa B., Senouci MR., Bessas H., Dahmane B. and Mellouk A. "Efficient and Stateless P2P Routing Mechanisms for the Internet of Things", IEEE Internet Things J. 2021; 8: 11400–11414.
6. Sanislav T., Zeadally S., Mois G. D. and Folea S. C., "Wireless energy harvesting: Empirical results and practical considerations for Internet of Things", Journal of Network and Computer Applications, 2018; vol. 121, pp. 149-158.
7. Kumar S.V., Biradar R.V. and Patil V.C. "Design and Performance analysis of hybrid energy harvesting and WSN application for more life time and high throughput", International Journal of Circuits, Systems and Signal Processing, 2022;16: 686–698.
8. Abuashour A. "An efficient Clustered IoT (CIoT) routing protocol and control overhead minimization in IoT network", Internet of Things, Elsevier, 2023; 23: 100839.
9. Atat R., Liu L., Wu J., Li G., Ye C. and Yang Y. "Big Data Meet Cyber-Physical Systems: A Panoramic Survey", IEEE Access, 2018; vol. 6, pp. 73603-73636.
10. Sudevalayam S. and Kulkarni P. "Energy Harvesting Sensor Nodes: Survey and Implications", IEEE Communications Surveys & Tutorials, 2011; vol. 13, no. 3, pp. 443-461.
11. Sanislav T., Mois G. D., Zeadally S. and Folea S. "Energy harvesting techniques for internet of things (IoT)", IEEE Access 2021, vol. 9, pp. 39530-39549.
12. Nguyen TD., Khan JY. and Ngo DT. "An effective energy harvesting-aware routing algorithm for WSN-based IoT applications", In: Proc. of IEEE International Conference on Communications (ICC), 2017; 1–6.
13. Ali M.S., Anwar S.L., Khalil A., Al-Shareeda M.A. and Manickam S. "Review of routing protocol for low power and lossy network in the internet of things", Indonesian Journal of Electrical Engineering and Computer Science, 2023; 32(2): 865–876.
14. Dogra R., Rani S., Babbar H. and Krah D. "Energy-Efficient Routing Protocol for Next-Generation Application in the Internet of Things and Wireless Sensor Networks", Wireless Communications and Mobile Computing 2022; Vol 2022: pp. 1-10.
15. Iwendi C., Maddikunta PKR., Gadekallu TR., Lakshmanna K., Bashir AK., and Piran MJ. "A metaheuristic optimization approach for energy efficiency in the IoT networks", Software: Practice and Experience, 2021; vol. 51(12), pp. 2558–2571.
16. Tilwari, V., Hindia, MHD N., Dimyati, K., Jayakody, DNK., Solanki, S., Sinha, RS. and Hanafi, E. 2021. MBMQA: A Multicriteria-Aware Routing Approach for the IoT 5G Network Based on D2D Communication. Electronics, 10(23): 2937.
17. Golkarifard M., Chiasserini CF., Malandrino F. and Movaghar A. "Dynamic VNF placement, resource allocation and traffic routing in 5G", Comput. Netw. 2021; 188: 107830.
18. Sinha A. and Modiano E. "Throughput-Optimal Broadcast in Wireless Networks with Point-to-Multipoint Transmissions", IEEE Trans. Mob. Comput. 2019; 20: 232–246.
19. Sah D. K. and Amgoth T. "A novel efficient clustering protocol for energy harvesting in wireless sensor networks", Wirel. Netw, 2020, 26, 4723–4737.

20. Begam A. A. and Prema A. “Optimization of Eh Aware Routing Protocol for WSN Based IoT Networks”, SSRG International Journal of Electronics and Communication Engineering (SSRG – IJECE)-Special Issue ICFTESH; Feb 2019.
21. Baniata M., Ji H., Kim Y., Choi J. and Hong J. “Energy-balancing unequal concentric chain clustering (MIMO-UCC) protocol for IoT system in 5G environment”, Proceedings of international Conference on Research in Adaptive and Convergent Systems 2018; 68-74.
22. Sivakumar K. and Vasanthi V. “Efficient Energy Harvesting approach for WSN based IoT Applications”, International Journal of Pure and Applied Mathematics, 2018; vol. 119, no. 12, pp. 13669-13676.
23. Nguyen T. D., Khan J. Y. and Ngo D. T. “An Effective Energy-Harvesting-Aware Routing Algorithm for WSN-based IoT Applications”, 2017 IEEE International Conference on Communications (ICC); 2017, pp. 1-6.
24. Dahima V., Sisodiya M. and Joshi S. “Improved Mobility Aware Energy Efficient Routing Protocol for Link Recovery in Internet of Things”, 12th International Conference on Computational Intelligence and Communication Networks (CICN) 2020; 169-174.
25. Fu X., Pace P., Aloi G., Yang L. and Fortino G. “Topology optimization against cascading failures on wireless sensor networks using a memetic algorithm”, Comput. Netw., 2020; 177: 107327.