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Article

A Comprehensive Review of Energy-Efficient Routing Protocols for Next-Generation IoT Networks

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Abstract: Internet of Things (IoT) is a technology link to the objects that interact between themselves to provide better services for users in an unbelievable way and makes everything easy. The applications of IOT include healthcare monitoring, smart city, smart retail, smart home and agriculture. Wireless Sensor Networks (WSN) plays a vital role in IoT as it includes data processing, connectivity, sensing, and data acquiring. A wireless, self-configuring, and multi-hop network is called a mobile ad-hoc network (MANET). The node of the MANET acts as a router and is always connected to WSN. Hence, the interface between IoT and MANET opens new ways for service facilities in smart environments. The main challenging issue of MANET-IOT is energy balancing over nodes. The IoT technology works on various wireless sensors and so the main aim of MANET protocols is to find the shortest path to be more efficient. Many researchers have designed energy-efficient routing protocols for improving network lifetime and due to the lack of composite solution over MANET-IoT networks, we plan to review the novel energy-efficient routing protocols that can provide a composite solution for routing over the MANET-IoT networks. This survey reviews the different types of routing protocols based on its topological structure, and energy efficiency characteristics. The performance metrics used to evaluate the efficiency of the routing protocols are also presented.
Keywords: NA

1. Introduction

Internet of Things (IoT)[4,11] is a system formed by a network of heterogeneous and interconnected objects that can transfer information via a stable internet connection without any manual intervention. The objects of an IoT environment can be anything such as sensors, smartphones, computing devices, mechanical equipment, animals, humans, or a non-living thing, and they are identified by a Radio-Frequency Identification (RFID). By 2025, the increase in IoT devices (24.8 billion) will be twice the amount of the whole human population (8.1 billion). A group of interconnected wireless sensor nodes forms a Wireless Sensor Network (WSN) and not every node present in the WSN is connected to the internet. In WSN, the nodes are not directly connected to the internet but every node is connected to a centralized node or a router that has an active internet connection. The IoT and WSN can be interconnected using this router and when it is integrated it connects a massive amount of

wireless sensors to the internet. The interconnected sensor nodes communicate with each other to monitor the environment. The WSN [7] technology is often utilized by IoT and IoT provides high-end services when compared to WSN.

The Mobile ad-hoc network (MANET) is an interconnection of mobile nodes and the interconnection is not held with an existing infrastructure or router. The MANET is often called as the IoT network's backbone. The nodes of the MANET can revolve around the IoT network and gather data for processing mainly from the mobile nodes, sensors, RFID attached objects, or any other fixed wireless nodes. The processed data is sent via an Internet gateway with the help of some MANET nodes. Both the wireless sensor nodes and MANET nodes serve as a chief component in various IoT applications. The self-configuring nature of both the sensor and MANET nodes paves the way for large scale deployment. The MANET nodes can be placed between the sensors and internet gateway to avoid direct connection of the wireless sensor nodes to the internet. The MANET node plays the main role in various smart city applications to provide services to the inhabitants, environment monitoring, garbage collection, etc. The IoT network interacts with the MANET and WSN and offers efficient services to its users by developing a novel MANET-IoT[3,5,12] system. The MANET-IoT system [1] offers users high mobility and decreases the deployment cost.

The energy balancing of the nodes should be considered as a critical aspect in the MANET-IoT[6] system because of the heterogeneous wireless sensors and MANET protocols used. The main role of the MANET protocol is to select the shortest path for data transactions. To ensure seamless network connectivity, the battery of the sensor nodes should be efficiently utilized. Energy Consumption is a major issue faced by the MANET-IoT network. The battery-powered IoT devices are the major reason for energy consumption. To increase the network lifetime various researchers [8, 9] are focusing on developing an energy-efficient protocol. Since the MANET protocols cannot be directly applied to the IoT network due to computational limitations, resource constraints, Human node interaction, and the vast density of sensors deployed. This arise the need for a composite solution in the MANET-IoT network for efficient routing which reduces the energy consumption of nodes and increases the network's lifetime.

The paper is categorized into eight sections. Section 2 illustrates the various concepts related to energy balancing in the MANET-IoT environment. Section 3 reviews the different types of routing protocols and energy-efficient routing protocols present in the MANET-IoT environment based on different characteristics. Section 4 analyzes some of the energy-efficient routing protocols present in MANET. Section 5 inspects the different performance metrics used to evaluate the performance of the routing protocol. Section 6 describes the various strategies used in paper formation and clarifies the concept based on the different parameters. Section 7 discusses the open issues and future research directions. Section 8 summarizes the paper in brief.

2. Energy balancing in MANET-IoT network

The dynamic topology of MANET gives rise to various energy consumption issues. In the MANET-IoT system, the energy consumption of the entire network is equally distributed among all the nodes present in the network. The energy consumption of the MANET-IoT network is explained using a scenario held on the WSN network as shown as follows. In a traditional WSN, a sensor node sends *X* number of packets to the gateway *G* which is far from a distance *D*. Thus, the energy consumption of the WSN network to send the X number of packets to the internet is estimated using *Econsumption.*

$$E_{consumption} = C \times X \times D^2 \tag{1}$$

Here C is the proportionality. If there exist *x* intermediate nodes in the path that lies between the gateway and the WSN, then the data packets are forwarded only using the shortest path and the energy is estimated as follows.

$$E = C + x\,(d_1^2 + d_2^2 + d_3^2 + \dots\dots\dots\dots\dots + d_{x+1}^2) \tag{2}$$

Here dx+1 denotes the shortest path that exists between the gateway and the first WSN node. Similarly, d1 is the distance between the gateway and the first WSN node.*E* indicates the composite solution occurred Now the shortest path in WSN is found as follows.

$$D^2 > (d_1^2 + d_2^2 + d_3^2 + \dots\dots\dots\dots\dots + d_{x+1}^2) \tag{3}$$

From the above three equations, it is clear that *E*>*Econsumption*. Energy balancing in a MANET-IoT network can be analyzed using the following constraints.

- **Study of sensor nodes energy consumption**

The energy consumption of the nodes based on the sensing, communication, and processing components. The node consumes a huge amount of energy in the emission stage and less amount of energy in the sensing stage. The energy consumption of the nodes can be reduced by sending the idle nodes to the sleep state. To reduce the energy consumption and satisfy the real-time application constraints, the processing and communication components should be sent to the sleep state as much as possible.

• Power Control Technology

To reduce the energy consumption various steps have been taken and among them, the topology control is very effective when limiting the amount of transmission power of each node in the network. This is known as a topology control technology. In this way, the topology can be adjusted as per the dynamic changes of the network. An efficient topology that improves the network connectivity fully utilizes the efficiency of the protocol along with the node's energy. In this way, it improves the lifetime of the network. When there is an exponential rise in the number of nodes, each node decreases its transmission power to minimize the number of nearby nodes. The transmission power of the nodes is mainly

controlled to reduce the number of communication links between the unnecessary nodes and limit long-distance communication. When the energy consumption of each node present in the network is controlled, it automatically reduces the total energy consumption.

• Structural Control Topology

It is one of the main areas of research in topology control technology [13]. The nodes in the network are layered into different levels of hierarchy based on the topological structure. The two main technologies used here are cluster topology [14] and dominating set hierarchy topology [16]. The two topologies share the same ideas. The cluster tree [15] is constructed in an iterative process where an initial node created as a parent associated with it and in the next stage it creates its children. The dominating set hierarchy topology [17] is a very effective approach because the searching space is reduced by only creating a path for the nodes present in the set. A set is said to be dominating if every node present in the network is a member of the set of adjacent nodes in the set. Each node in the network needs to satisfy various roles and functions and efficiently utilize its divisions and cooperative activities.

• Data Fusion Technology

Data Fusion [18] reduces the redundant data in the sensors and integrates the data to yield more valuable information and satisfy the requirements of the application layer. When the amount of redundant data is reduced it increases the efficiency of the data transmission, enhances the accuracy of information processing, reduces the node's energy consumption, and eliminates the interferences and noisy data. When the amount of data fusion is increased it reduces the amount of data transmission to a great extent and leads to efficient memory management.

3. Routing protocols in MANET-IoT

The energy efficiency is a significant parameter that determines the MANET-IoT network's survivability because every node that operates in this network has limited battery power.

A. Routing protocols for MANET based IoT applications

The MANET comprises of mobile nodes where each node is interconnected with wireless links. The limitation of the MANET is mainly the energy consumption of nodes, the absence of base stations, dynamic topology, and its wireless link's bandwidth. The routing protocols designed for wired networks cannot be directly applied to the wireless networks, hence the MANET routing protocols are mainly designed based on the following characteristics: topology, location, multicast, multipath, and geometric.

• Topology Based Routing Protocol

Topology based routing protocols is mainly divided into three types namely Reactive/ On-demand Routing protocol, Proactive/ Table-driven Routing protocol, and hybrid routing protocol.

a) Reactive/ On-demand Routing protocol

The reactive routing protocols are also known by the name on-demand routing protocol. During transmission, the sender utilizes a route discovery technique to find a new route to the destination. Here regular network topology information is not maintained every time. A routing path is discovered only when there is a demand for connection establishment. Here the routing messages are neither constantly updated nor exchanged between every node present in the network. The reactive routing considers the route discovery and route maintenance as the significant steps to yield an efficient reactive routing approach. The reactive routing protocols used in the MANET-IoT network are shown below.

Temporally Ordered Routing Algorithm (TORA) is a popular on-demand routing protocol used in MANET's. Even though TORA is said to be robust it suffers from high overhead, improved routing maintenance, high delay, and it is not very suitable for the areas subjected to frequent disasters and emergencies. Liu Si et al. [20] presented an adaptive repair algorithm for the TORA routing protocol intended for the flood control strategy (AR-TORA-FCS). The steps of the AR-TORA-FCS algorithm are illustrated as follows. In the initial stage, the self-repair process of the self-configuring nodes presented in the Directed Acyclic Graph (DAG) of TORA is changed to an optimal search problem to identify the optimal nodes. To yield an optimal solution based on the optimal nodes a ray algorithm is used. The self-repair process is conducted by a conditional algorithm used in the next step. A mapping relationship is established between the repair process of the self-configuring node and the node distance. The routing paths are repaired before any path failure occurs using a flood control algorithm. The AR-TORA-FCS approach enhances the packet delivery rate, average end-to-end delay, and reduces the control overhead.

MouadBenzakour et al. [21] developed a routing protocol known as IoTAdhoc on-demand distance vector(IoT-AODV) to enhance the behavior of an AODV protocol to suit a highly dense mobile environment. They applied this approach using an NS2 simulator. The IoT AODV protocol uses two different schemes for processing the Route Request Packet (RREQ) received from the nodes of the MANET network. The first scheme is the Power of the Overhead Packets (PPO) and the next scheme is Power Threshold Learning (PTL). The PPO stores the power of the receiver packet and generates the power value of the adjacent nodes to pass it to the next scheme. The role of the DTL is to evaluate the threshold power and apply it to each rescue RREQ packets. To efficiently implement this protocol an approximate way to estimate the parameters of the PTL needs to be found. Thomas Clausen et al. [22] presented a reactive protocol known as Lightweight on-demand Ad-hoc Distance-vector Routing Protocol for Next Generation (LOADng). Even though it is a reactive protocol it doesn't maintain a routing table for every sink present in the network. A Route discovery operation is initiated only when data needs to be transferred to the destination. In this way, it reduces memory consumption and routing overhead. The modular LOADng protocol can be extended to support smart route requests and expand the ring search.

Alwi M. Bamhdi et al. [27] presented a Dynamic Power-AODV (DP-AODV) to alter the transmission power dynamically in the MANET network based on node density. The DP-AODV improves the throughput of the network while simultaneously decreasing the interference of the nodes in a densely populated region. Ashwani Kush et al. [23] evaluated the performance of Associative Based Routing in MANET. To initialize the communication between the networks every routing protocol finds the route between two nodes. An efficient MANET routing protocol should establish a reliable path between two nodes such that the packets are delivered within the deadline. In a dynamic topology the path generated at a time '*T*' becomes invalid at time 'T+1' due to the continuous movement of the nodes. This problem is overcome by using the associative routing protocol which only considers the stable link between two wireless nodes which exists for a longer period of time. In this way, the associative ticks are calculated and the route with the maximum threshold is chosen. The Associative based routing is one of the shortest path routing algorithms and it is loop-free, deadlock-free, and also safeguards from packet duplication.

Parveen Kumari et al. [24] proposed an Energy-Efficient Clustering Based Routing Protocol (EECP) to overcome the energy consumption of the MANET environment. In MANET every mobile node present is non-identical and they have their own energy restrictions. The network coding induced into the cluster heads tends to minimize the transmission power and improve the lifetime of the network. In this way, the energy-saving strategy is implemented by minimizing the number of transmissions. The simulation results observed using the NS-2 simulator prove that the EECP is better than the Clustering Based Routing Protocol.

N. Prasath et al. [25] analyzed the performance of the Optimized Dynamic Source Routing (ODSR) in MANET. The optimal path that exists between two nodes is identified using the modified Dynamic Source Routing (DSR) protocol by the firefly algorithm. The DSR is a widely used protocol for MANET's route discovery process. In the DSR reactive protocol, the periodic flood of the network is not updated to the table. It uses the route cache to reduce the control overhead. The firefly algorithm is modeled mainly based on the behavior of the original fireflies and its brightness. The firefly algorithm improves the MANET’s routing performance through an efficient packet transfer between the source and the destination. The parameters used here are end to end delay, link quality, and node mobility.

De-gan Zhang et al.[28] used a Genetic Algorithm(GA) based Bacterial Foraging Optimization(BFO)(GA-BFO) to select an optimal route for the DSR routing protocol. This process is initialized by selecting multiple routes to the destination node and then the GA algorithm is applied. The GA algorithm finds the maximum probability value rapidly and gives it to the BFO algorithm. The BFO algorithm takes the path found by the GA algorithm as the initial position and searches the extreme value and optimal path by overcoming the low accuracy of the GA algorithm. The control overhead is overcome by considering the node's energy information before discovering the route.

Abdellatif Serhani et al.[26] developed an Adaptive Q-learning Routing protocol(AQ-Routing) based on the Reinforcement Learning algorithm for the MANET-IoT environment. The protocol has the capability to analyze the level of mobility at various time intervals which helps the node to update the routing metric based on that. The foundation is laid upon two concepts in which one detects the mobility of the nodes using a Q-learning model and another one is a Q-metric which analyzes the dynamic network topology to update the static and dynamic routing metric. Based on the mobility detection model the protocol improves the network mobility using preemptive behavior. This protocol increases the packet delivery ratio of the IoT-MANET systems. The summary of the reactive protocols used in the MANET-IoT environment is presented in Table-1.

Table-1: Study of the Reactive Routing Protocols for MANET supported IoT environment

Author	**Name of the protocol**	**Merits**	**Limitations**	**Protocol Type**	**Performance Metrics**	**Energy Efficiency**	**Simulation platform**
Liu Si et al. [20]	AR-TORA	• Overall performance improvement in terms of packet delivery rate and an end to end delivery	The flooding problem needs to be solved	TORA	• Average end to end delay • Topology Control overhead • Packet Delivery Rate	Medium	MATLAB
MouadBenzakour et al. [21]	IoT-AODV	• Reduction in Routing Traffic Load	Increased Routing Overhead	AODV	• Normalized Routing Load • Routing Overhead • Packet Delivery Ratio • Packet Loss Rate End To End Delay.	Low	Network Simulator (NS)-2
Thomas Clausen et al. [22]	LOADng	• Significant reduction in Route Overhead • Shortest Delay	Increased Route Discovery Delay	AODV	• Point to Point Traffic • Point to Multipoint traffic • Lossy network scenario	Medium	NS2
Alwi M. Bamhdi et al. [27]	DP-AODV	• Improved Network Performance • Improved packet delivery and throughput • Minimized Interference	Increased Control Overhead	AODV	• Jitter • Control Overhead • Packet Delivery Fraction • End to End delay • Throughput	High	NS2.34

Ashwani Kush et al. [23]	Associati ve Based Routing	• Maximizes Energy Efficiency	Increased power consumption due to periodic beaconing. Increased Signaling Traffic	Associati ve Based Routing	• Control Overhead • Data Throughput • End to End delay	High	-
Parveen Kumari et al. [24]	EECP	• Network Lifetime Improvement • Energy Saving	Less Robust due to network Coding	Clusterin g Based Routing Protocol	• Network Size • Packet Delivery Rate • Average Energy sent	High	NS2
N. Prasath et al. [25]	ODSR	• Improved throughput • Reduces the end to end delay of retransmission	Increase in the number of hops to the destination because of optimization	DSR	• Throughput • End to end delay • Number of Hops and retransmitted packets to destination	Mediu m	MATLA B
De-gan Zhang et al.[28]	GA-BFO	• 18% improvement of control overhead	Needs route discovery optimization	DSR	• Packet Delivery Rate • Control Overhead • Average end to end delay	High	MATLA B
Abdellat i f Serhani et al.[26]	AQ Routing	• Increase in Packet Delivery Ratio • Enhanced stability of links	Needs an energy-aware protocol to maximize network lifetime	Stability based adaptive RP	Mean Packet Loss Ratio, End-to-End delay	Low	NS3(3.26) for the Internet Sys.

b) Proactive/ Table-driven Routing protocol

Proactive Routing is also known as the table-driven routing. Here every node present in the network maintains its routes to every other node by synchronizing the routing information regularly. Here the routes are always available at the time of need but it comes with higher overhead. Optimized Link State Routing Protocol (OLSR)[29] belongs to the proactive routing protocol where every node present in the network sends its routing table information periodically to help the nodes in the network to get a view of the network topology. But these periodic features of the OLSR suffer from a higher overhead and there is also a restriction in the number of mobile nodes to transmit the traffic to the network. Mostly the OLSR protocol uses the Multipoint Relays Scheme (MRS) to forward the packets and optimize the flooding operation. The MRS supported mobile nodes can support the flooding traffic and minimize the size of the control messages. De-gan Zhang et al. [30] presented a Quantum Genetic OLSR (QG-OLSR) protocol for MANET to save the maximum utilization of network resources. The QG-OLSR also uses the MRS mechanism used by OLSR and it is formed by integrating the Q-Learning algorithm along with the OLSR to optimize the MRS set selection. The MANET nodes are initiated and encoded using a quantum gene bit. The network topology control consumption and the time delay are considerably reduced by the QG-OLSR protocol and it also increases the data packet delivery.

The proactive landmark Adhoc routing protocol (LANMAR) uses the idea of a logical node grouping technique and comprises the data of the nodes. Every logical group of the node has a leader based on the landmark and the leader is the one who is responsible for distributing packets to the node present in the group. The LANMARK protocol uses a Fish Eye Routing to measure the hop distance and locations are deployed based on the distance vector mechanism. In the LANMAR protocol when the parameters are tuned based on the dynamic behavior of the network, it affects the overall performance and this is known as the time series problem. To solve this problem, AnveshiniDumala et al. [31] developed a fuzzy-based LANMAR protocol which computes the fisheye updating interval parameter dynamically using soft computing techniques.

Destination Sequence Distance Vector (DSDV) is a proactive routing protocol in which every connection paths are already presented in the table. It is mainly applied to the routing loop problem. The available links are presented in the form of even sequence numbers and the unavailable links are presented in the form of odd sequence numbers in the routing table. It is mainly based on the Bellman-Ford Algorithm [32]. Abdellah Nabou et al. [34] analyzed the performance of DSDV protocol along with DSR, AODV, and OLSR in terms of transmission power and they observed that the change in the transmission power significantly

improves the performance of the routing protocol. Harshit Prakash Patidar et al. [33] presented a reclustering scheme for the DSDV routing protocol in MANET. It is mainly used to identify the changing key server. If the key server is changed from the old one to the new one then it needs to regenerate and distribute the keys to every node present in the group. The on-demand weighted clustering algorithm used for reclustering increases the flexibility of the handover process by taking the transmission power of node, battery lifetime, mobility, and its degree into consideration.

Topology Broadcast based on Reverse Path Forwarding (TBRPF) is a proactive link-state protocol that is similar to OSPF. Here each route advertises its correct state to its neighbors and maintains a partial map to estimate the route throughout the entire network. Whenever the state of the link is changed or a new node enters the network means a notification is sent throughout the network using a Link State Advertisement (LSA). D.B. Green et al. [36] presented a TBRPF routing protocol to test the Optimized Network Engineering Tool (OPNET) model of the IEEE802.116 Wireless Local Area Network (WLAN) for MANET. They mainly used the TBRPF because it gives less protocol overhead for a densely populated network. This model can be applied to the disaster affected areas and emergency environment and it utilizes less than 85% of bandwidth. The summary of the proactive protocols used in the MANET-IoT environment is presented in Table-2.

Table-2: Study of the Proactive Routing Protocols for MANET supported IoT environment

Author	**Name of the protocol**	**Merits**	**Limitations**	**Protocol Type**	**Performance Metrics**	**Energy Efficien c y**	**Simulation platform**
De-gan Zhang et al.[30]	QG-OLSR	• Transmission performance is increased • Reduced time delay and energy consumption	The network topology control cost is higher	OLSR	• The packet-to-packet delivery rate • Average end-to-end delay	High	MATLAB
Anveshini Dumala et al. [31]	LANMAR	• Improved Performance of the conventional LANMAR protocol	Low Scalability	Fisheye State Routing	• Jitter • Throughput • End to end delay • Control Overhead • Energy Consumption during transmit, receive, and idle mode • Number of control packets	High	EXata simulator/ emulator and MATLAB
Abdellah Nabou et al. [34]	DSDV	• Less Jitter Delay and performance improves with increasing transmission power	Less Packet Delivery Ratio	DSDV	• Throughput • Packet Delivery Ratio End-to-End delay • Jitter delay • Packet Loss	High	NS3

Harshit Prakash Patidar et al. [33]	Reclustering Scheme for DSDV	• Less energy consumption in the static and semi-dynamic category	High energy consumption in the dynamic category	DSDV	• Rekeying Cost • Energy Consumption	High	C++ language
D.B. Green et al. [36]	TBRPF	• Efficient Minimum Broadcasting • Efficient Neighbour discovery protocol • Utilizes less than 85% bandwidth	Propagation path loss	Link state routing protocol	• Routing Control Traffic • Maintenance Overhead	Medium	MIL3's OPNET 7.0

c) Hybrid Routing protocol

It integrates both reactive and proactive routing protocols to optimize the routing process. These protocols have mainly categorized the nodes based on the zones. Here the reactive protocol is used for route establishment and the operation is performed by core nodes. The proactive routing protocol maintains the routing information for the adjacent nodes which is known as the routing zone. The reactive routing protocol routes the packet to the destination beyond the routing zone. The widely used hybrid protocols in MANET supported IoT environment is listed below. The node in the MANET's are often subjected to high energy consumption and the culprits are overhearing, retransmission, idle listening, and generation of control packets. R.Shanthy et al.[37] proposed an Energy-Efficient and Load-Balanced Zone Routing Protocol(EELB-ZRP) integrated with sleep scheduling for MANET's. Here a group of nodes is combined to form zones and every zone has a zone leader which is elected mainly based on the following characteristics namely border node distance, remaining energy, link quality, and degree of connectivity. To perform load balancing the zone leader can select multiple paths starting from the border node to the sink and it transmits the traffic through these paths. To save the power of the border nodes an adaptive sleep duty cycling scheme is deployed.

Source Routing in MANET is subjected to various issues such as a dynamic change in the network topology which results in continuous link failures leading to a significant rise in route discovery requests. Baidaa Hamza Khudayer et al. [38] presented a Zone-Based Route Discovery Mechanism (ZRDM) and Link Failure Prediction Mechanism (LFPM) for the on-demand source routing protocols. The route request flood is managed by ZRPM while the LFPM deals with route failures and packet loss occurred by the mobility of the nodes. The ZRPM reduces the overhead occurred during the route discovery process by selecting a set of nodes to forward the RREQ's and in this way it identifies the reliable routes. Nassir Harrag et al. [39] presented a Particle Swarm Optimization (PSO) algorithm to detect the zone radius. The PSO algorithm allows the ZRP protocol to modify it according to the external environment dynamically by specifying a size to each node's routing zone. The PSO algorithm seeks an optimal configuration of the ZRP protocol and leads to an enhancement of the networks QoS.

The ZRP assumes that every node is moving in a uniform speed with a static zone radius which results in high-performance degradation. To overcome this problem B.Nithya et al.

[40] proposed an adaptive Mobility, density, and energy-based ZRP protocol (MDE-ZRP) utilizing the fuzzy logic to determine the dynamic zone radius. The MDE-ZRP efficiently identifies the optimal zone radius and improves the overall performance of the routing

protocol. The fuzzy controller can overcome the routing overhead that occurred during transmission by the ZRP protocol. Internet of Vehicles (IoV) belongs to the IoT category where each vehicle communicates with each other. The routing protocol is very efficient to solve various driving and traffic problems. The robust IoT application should offer a convenient QoS and improved Response times to the vehicles (nodes) in the network without inducing any additional overhead in the IoT network. In emergency scenarios, the additional load results in harmful outcomes. To overcome this problem Rim Gasmi et al. [43] proposed a Stable Link-based ZRP(SL-ZRP) is proposed to offer link stability function for the IoV application to identify the stable routes without compromising the QoS factors such as delay, speed, and destination.

Muhammad Umar Farooq et al. [41] presented a Core Enabled Hybrid Protocol (CEHR) which deploys only half of the nodes present in the MANET network to generate proactive topology broadcasts. But every node is taken into consideration when broadcasting the message packets which results in a reduction of topology messages generated. To reduce the retransmission of broadcast messages it makes use of the MRS and proactive routing zones. Here the topology information is identified within the minimum control traffic. The MRS reduces the impact of route discovery broadcasts. Takashi Hamma et al. [42] presented a Zone-Based Hierarchical Link State Routing (ZHLSR) using a Gateway flooding scheme (ZHLSR-GF). Here the network is categorized into non-overlapping zones and every zone constructs a routing table namely Inter-zone and intra-zone. Here the node link-state packet is flooded inside the zone and the zone link state packet is flooded throughout the network. But this process creates a huge communication overhead. Here, the proposed ZHLSR-GF overcomes this problem by flooding the zone link-state packet only to the gateways of the node.

Dhanalakshmi Natarajan et al. [44] proposed an Advanced OLSR (AOLSR) routing protocol using a modified Dijkstra's algorithm. It comprises two sets of functions where the first one creates multiple disjoint routes and the second one initiates the path and route discovery. The two cost functions can create link and node disjoint paths. The routing is mainly based on the mobility and lifetime of the links and nodes. The AOLSR protocol offers improved performance even in the case of high network traffic. The summary of the hybrid routing protocols used in the MANET-IoT environment is presented in Table-3.

Table-3: Study of the Hybrid Routing Protocols for MANET supported IoT environment

Author	**Name of the protocol**	**Merits**	**Limitations**	**Protocol Type**	**Performance Metrics**	**Energy Efficiency**	**Simulation platform**
R.Shanthy et al.[37]	EELB-ZRP	• Energy Efficient route selection • Less packet drop rate due to overload • Low delay rate • Reduction of the queue waiting time during congestion	The packet delivery ratio decreases when there is a rise in the number of nodes	ZRP	• End To End Delay • Throughput • Packet Delivery Ratio • Energy Consumption	High	NS2
Baidaa Hamza Khudayer et al. [38]	ZRDM LFPM	• Improvement in Packet Delivery rate • Significant reduction in Routing Load and Average End-To-End Delay	Additional traffic created during the route discovery process	ZRP	• Normalized Routing Load • Average End-To-End Delay • Packet Delivery Ratio	Medium	NS3
Nassir Harrag et al. [39]	PSO-ZRP	• Low control traffic overhead • High packet delivery ratio • Low end-to-end delay	Low convergence rate of PSO algorithm	ZRP	• Average end to end delay • Normalize routing load • Packet delivery ratio	Medium	NS2

B.Nithya et al. [40]	MDE-ZRP	• Improves the network lifetime • Minimizes overall routing overhead	Increased proactive routing overhead	ZRP	• Routing overhead • Jitter • Energy consumption • Packet delivery ratio loss • Collision rate	High	NS2
Muhammad Umar Farooq et al. [41]	CEHR	• Overcomes problems such as • A large Number of Transmitters • Huge Network Size • Higher node mobility	Less packet delivery ratio	CEHR	• Packet delivery ratio • Normalized routing load	Low	NS-2
Takashi Hamma et al. [42]	ZHLSR	• Reduces Communication overhead	The energy-saving strategy is not implemented	ZHLSR	• Communication overhead	Low	-
Rim Gasmi et al. [43]	SL-ZRP	• Improved Response Time • Low network overhead	It is not scalable for a smaller number of regions	ZRP	• Packets Delivery Ratio • Network Overhead • End -to-End Delay	Medium	NS3, SUMO, and MOVE
Dhanalakshmi Natarajan et al. [44]	AOLSR	• Improved network lifetime • Enhanced performance • Improved scalability and reliability		AOLSR	• Average end-to-end delay, • Packet delivery ratio • Average time in the first-in-first-out queue • Throughput	High	-

- **Location-based(Geographic) Routing protocol**

In geographical protocols, the main thing to note is the location of the nodes, and based on that the forwarding decisions are made. The geographic routing protocol is also known as position-based routing. To offer the geographical routing protocol an improved performance and an efficient routing experience, C.Nallusamy et al. [51] proposed a PSO based Resource Optimized Geographic Routing (PSO-ROGR) algorithm which enhances the resource optimization and provides optimal coverage performance. Every particle(mobile node) present in the MANET has its own local best position in the geographical location. Every mobile node interacts with each other through minimum energy. To perform the energy-efficient routing the mobile nodes with high fitness value are selected. The less energy consumption offered by the PSO-ROGR routing technique improves the network's lifetime.

Here the network's lifetime is improved by 22%, the delivery ratio is increased by up to 11%, and the average end-to-end delay is reduced by up to 46%. The PS-ROGR routing protocol reduces energy consumption by up to 16%.

The geographic routing protocol normally takes the load distribution and position update to yield a significant performance. The load distribution parameter is mainly taken into consideration when there is a large number of connections and huge traffic associated with the network. Santhi Venkatraman et al. [50] proposed a Load Balanced Adaptive Position Update (LAPU) for the geographic routing protocol. The proposed LAPU protocol solves both the load balancing and position updating problem in MANET. The load is distributed among two of the best nodes available near the destination. It also considers parameters such as queue length, node mobility, etc.

- ## Hierarchical Routing(Clustering) protocol

Fisheye State Routing (FSR)[35] is a hierarchical routing that minimizes the size of the information required to present graphical data. It is mainly based on the fish eye concept which captures the information with high precision when the pixels of the focal point are near. The details diminish when the distance between the focal point increases. For routing in the MANET's, it is mainly used to maintain the accurate distance information and the path quality of the nodes visible nearby. To overcome the energy consumption of mobile devices, Nithya Rekha Sivakumar et al.[52] presented a path vector computation using Fuzzy Logic and Rough Set Theory(FLRST). Here, the optimal path is mainly selected based on the energy consumption of the node. To identify the best route and compute the path vector and eliminate the discrete resources, the rules generated by using fuzzy and rough set methods were applied. The FSR algorithm was used to evaluate the fuzzy rules.

The Cluster Head Gateway Switch (CHGS) routing protocol is a hierarchical routing protocol. Here the MANET nodes are arranged into clusters and each cluster has a specific node known as the cluster head. The two clusters communicate with each other via a gateway. Maria Antony Sahaya Sheela et al.[53] integrated the Software-Defined Network(SDN) into MANET to assign tasks to the mobile nodes present in different Base Station. They used a PSO based CHGS scheme integrated with fuzzy rules (PSO-FCGHS) to perform this operation. To transmit the data into SDN, the two main problems in MANET namely networks lifetime and battery's energy consumption should be considered. Here the low power mobile nodes transfer the data from the source to the base station. The fuzzy rules are applied for packet transformation and the CGHS selects the cluster head based on the PSO algorithm. The PSO-FCGHS routing protocol enhances the lifetime of the network and battery along with less energy consumption.

- ## Geocast Routing protocol

Here the packet is sent to the entire nodes present in a particular geographic region. Fatima Zohra Bousbaa et al. [45] presented a geo-cast routing protocol for the fleet of Unarmed Aerial Vehicles (Geo-UAVs). Here the data is delivered to a specific number of UAVs based on its geographical location. The UAVs are used to monitor the wildfire by

replacing manual intervention and saving human lives. The UAV factors considered here are the dynamic changing topology due to the 3D movement, reliability, and mobility. The average delay is improved by more than 61% along with an enhanced packet delivery rate and throughput. The GeoUAV protocol suffers from data loss mainly due to collision and overhead. Aydin Rajaei et al. [46] presented a geographic protocol named Geocasting Spray and Flood (GSAF) for opportunistic networks. The opportunistic networks are a part of MANET's. In the GSAF protocol, the message moves randomly and reaches the destination cast. They also present a privacy-preserving mechanism known as direction aware GSAF. Here the mobile devices are only provided with the direction details and not anything else.

- ## Multicast Routing protocol

In the multicast routing protocol, a packet is sent to a group of nodes. Yu-Hsun Chen et al. [66] presented a Bandwidth-Satisfied and Coding-Aware Multicast Routing Protocol (BCMRP) to satisfy the bandwidth requirements of the requested and constant flows. A routing protocol that satisfies the user's QoS demands should always consider the bandwidth consumption. The bandwidth applied to the network coding as well. To identify the bandwidth consumption of the coding host is a complex task in the MANET. The coding conditions related to the coding host are identified using a random access method. The total bandwidth consumption of the MANET network is reduced by deploying the coding mechanism in multicast routing. The multicast routing protocols work well in minimum load Adhoc networks but the problem mainly arises when it is applied to maximum load Adhoc networks. The issues are mainly due to a large number of packet drop and poor robustness offered by the multicast tree-based protocols. To address this issue S. Jebakumar Gomer Rajadurai et al. [49] proposed a Multicast-AODV (MAODV) protocol that utilizes the Genetic Algorithm (GA) to select backup paths. The GA algorithm selects the best path based on the fitness value to transmit the packets when the route selected is subjected to failure. Hence the tree-based multicast protocols efficiency is increased by inducing a network structure in terms of backup path. The merits offered by the scheme are improved reliability and minimized control and data overhead.

• Multipath Routing protocol

The multipath routing protocol creates multiple paths from the source to the destination. The multiple paths created to broadcast the traffic to the intermediate nodes. These multiple routes present increases bandwidth utilization, improved fault tolerance, efficient load balancing, and yields higher reliability. Zheng Chen et al. [47] developed a routing protocol named Topological change Adhoc On-demand multipath distance vector (TA-AODMV) for the MANET environment to improve the QoS by supporting the high-speed mobile movement. The TA-AODMV protocol has a stable path algorithm associated with it and it provides improved QoS by addressing the congestion and mobility issues. The path selection algorithm considers the nodes link stability probability along with the other parameters such as remaining energy, queue length, and bandwidth. A link interrupt prediction mechanism can handle the dynamic change of topology by the periodic update of the link stability.

Meysam Zarei et al. [48] proposed a Gray System Theory-Based Multipath Routing (GSTMPR) for the IoT environment. The GSTMPR protocol is an improved version of the AOMDV protocol by adding additional fields like Energy, Signal to Noise Ratio (SNR), and expiration time. The GSTMPR algorithm involves three techniques namely a distributed cluster discovery, a set of algorithms, and isotropic energy propagation. The cluster discovery can identify the nodes automatically. The set of the algorithm can find novel ways to adjust the cluster and cluster head to a centralized position. The energy loss that occurs during a long-distance communication is minimized using the isotropic energy propagation. The lifetime of the network is mainly reduced slightly due to the high energy consumption and depletion of nodes energy. The summary of the geographical, hierarchical, geo-cast, multicast and multipath routing protocols used in the MANET-IoT environment is presented in Table-4. The summary of the overall routing protocols used in the MANET-IoT environment is presented in Figure-1.

Table-4: Summary of geographical, hierarchical, geo-cast, multicast, and multipath routing protocols

Name of the Author	**Year**	**Protocol Name**	**Type**	**Energy Efficiency**	**Simulation Environment**	**Performance metrics used**
Fatima Zohra Bousbaa et al. [45]	2020	Geo-UAV	Geo-cast	Low	NS3	Packet Delivery Ratio Minimization Delay Throughput
Aydin Rajaei et al. [46]	2018	GSAF	Geo-cast	Low	WiFi 802.11ac, Bluetooth 802.15 v4.0	Message delivery ratio Latency Network overhead
Zheng Chen et al. [47]	2020	TA-AODMV	Multipath	High	NS2	Packet delivery rate End-to-end delay Throughput
Meysam Zarei et al. [48]	2020	GSTMPR	Multipath	High	NS3	Throughput, Packet Delivery Rate

						End To End Delay Average Residual Energy Network Lifetime
Yu-Hsun Chen et al. [66]	2020	BCMRP	Multicast	Medium	NS2.33	Receiving Ratio Admission Ratio Total Bandwidth Consumption
S. Jebakumar Gomer Rajadurai et al. [49]	2017	MAODV with GA algorithm	Multicast	High	NS2	Packet delivery ratio Latency Energy consumption
Santhi Venkatraman et al. [50]	2018	LAPU	Geographic	High	NS2	End -to-end delay of packet transmission Energy consumption Throughput Routing overhead
C.Nallusamy et al. [51]	2019	PS-ROGR	Geographic	High	NS2	Packet Delivery Ratio, Average End To End Delay Energy Consumption Network Lifetime
Nithya Rekha Sivakumar et	2017	FLRST	Hierarchical	High	NS2	Total Energy Consumed Average Energy
al.[52]						Consumed Overall Residual Energy Average Residual Energy
Maria Antony Sahaya Sheela et al.[53]	2020	PSO-FCGHS	Hierarchical	High	NS2	Network Lifetime Packet Delivery Ratio Time Complexity

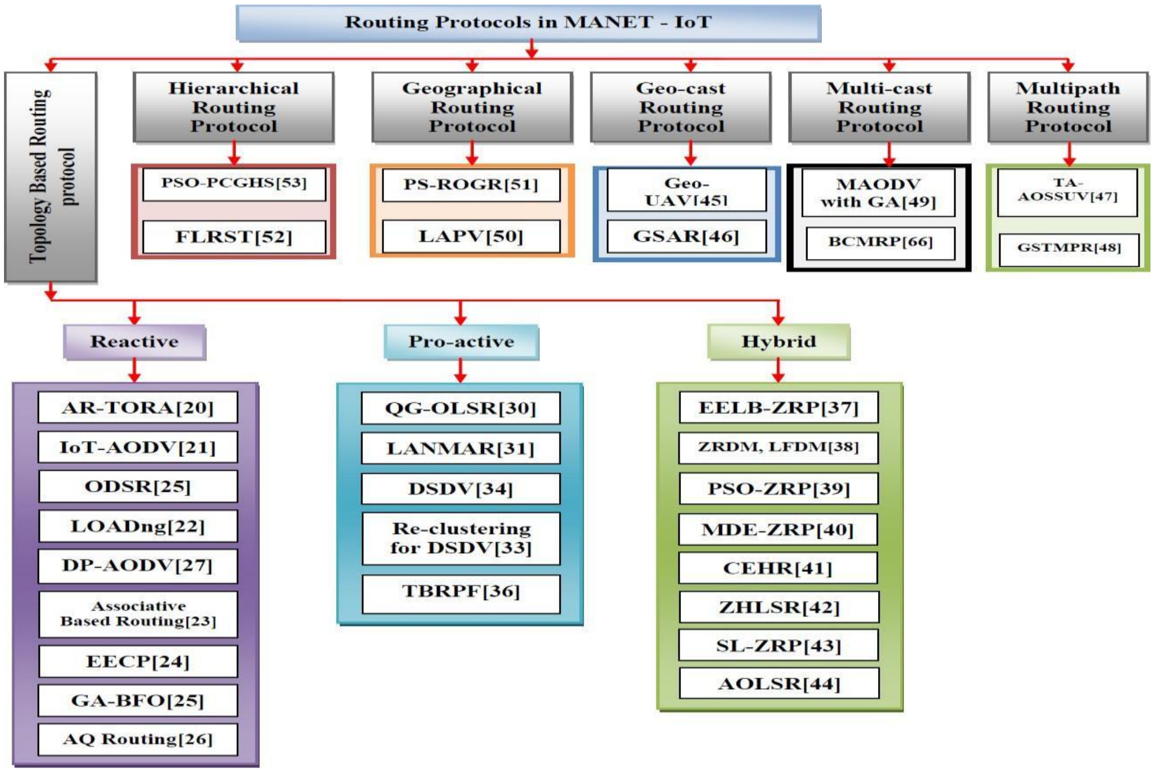

Figure-1: Summary of MANET-IoT Routing protocols

B. Energy Efficient protocols in MANET-IoT

To make the MANET-IoT network continue its seamless operation then the routing protocol implemented should find the approximate and correct route between a pair of objects(nodes). To accomplish the goal the energy consumption of the nodes should be reduced both in the active and idle state. Various researchers have conducted studies to minimize the energy of the nodes both in idle and active mode and some of them are listed below.

- **Shortest Path Metrics**

To obtain an energy-efficient solution for the routing problem one of the widely used techniques is the shortest path metrics. The Dijkstra [44] and the Bellman-Ford Algorithm (BFA)[33] are the widely used techniques for determining the shortest path. Some of the recently developed techniques for shortest path metrics are illustrated here. Chrispen Mafirabadza et al.[54] proposed an Energy-Efficient Power-Aware AODV(EPA-AODV) routing protocol to minimize the delay and improve the network lifetime by selecting the shortest path where the nodes energy is high. In MANET's two nodes exchange the messages without the use of a router. Here if a node's energy depletes it will no longer be able to send

or receive the messages and it breaks the existing network topology. So the shortest path with a long energy lifetime of the nodes can overcome this problem and it can be achieved with EPA-AODV efficiently.

In Cloud-Assisted MANET's (CA-MANET) there are a large number of users and data transmission with the aid of the Fifth Generation (5G) mobile networks. The connection disruption between the two nodes mainly occurs due to low battery power, mobility, communication overhead, and link failure. To enable device-to-device communication in this scenario consumes a huge amount of energy while searching for the nodes. To overcome this problem, Riasudheen H et al. [55] proposed an Energy Efficient Cloud Assisted Routing(EECAR) mechanism for the CA-MANET environment. To minimize the energy consumption a fast local route recovery scheme is used. The energy consumption is measured using the residual energy computed by the BFA algorithm between two peer nodes. The EECAR method offers less computational cost but increases the routing cost.

- **Transmission Power Control Method**

The energy consumption and transmission range of MANET's are directly related to the transmission power. The dynamic change of the nodes distance and topology doesn't affect the transmission power and it remains the same. The high transmission power increases the energy consumption and a very low transmission power results in network disconnection and a high range of packet loss. An efficient transmission power control method limits energy consumption and some of the transmission power control models are illustrated here. Rashmi Chaudhry et al.[59] presented an optimal Power Central scheme using the Gabriel Graph algorithm(PCG) to establish an optimal transmission power for MANET nodes. It is a clustering-based scalable topology control technique and it selects the path with minimum transmission power. The transmission power of each node in the network is adjusted based on its battery's lifetime and probabilistic mobility predictions. To form a cluster the weighted clustering scheme takes the residual energy into account thereby reducing the message overhead and balancing the energy consumption. The Gabriel graph with the clustering approach reduces the message overhead and balances the transmission power.

B. Devika et al.[60] presented a Chronological Earthworm Optimization Algorithm(CEOA) for effective clustering and energy conservation. The cluster head is selected using a CEOA algorithm after the graph is clustered. Here, the nodes with maximum power are selected for transmission and the distance parameter is considered as a crucial parameter. The clustering scheme reduces the interference created for the nodes within the same transmission power. To reduce the transmission power, the node in the cluster constructs the Gabriel graph to improve the network connectivity. Hence, the cost of energy is minimized and the least delay occurs.

- **Battery cost lifetime Aware Routing**

The battery cost lifetime aware routing works in two different steps. In the first step, the number of nodes used for routing is minimized and in the second step, the nodes and routes

with less remaining battery lifetime are considered. M.Fareena et al.[61] proposed a Distributed Fuzzy Multicast Routing Protocol(DFMRD) for MANET mainly to improve the network lifetime. The fuzzy logic selects the optimal path to transmit the data and it also has a local repair link that can be used in case of network failure. To improve the network lifetime the DFMRD protocol eliminates the nodes with less battery power in the route discovery process. In this way, the number of dead nodes is eliminated and the optimal path is achieved. This routing scheme improves the lifetime of the network by up to 60%.

R Aruna et al. [62] designed an Optimized Energy Efficient Route Assigning Protocol (OEERA) protocol to improve the stability of the routing path in a MANET environment. The node discovery algorithm created finds the node for a specific route to start a predictable packet transfer. In this way, the energy is minimized and the network's lifetime is improved. Sanjay Das et al. [63] designed a backup node using the triangular technique to offer improved area coverage in the MANET and overcome the issue of energy depletion. The triangular technique used reduces the communication overhead and improves the lifetime and energy efficiency of the network. In this way, the battery power is reduced and better connectivity is offered.

- **Load Distribution Methods**

The load distribution technique in MANET mainly reduces the congestion of the data packets during transmission. The energy-efficient load balancing technique improves the network's lifetime. Hesham A Ali et al.[56] an on-Demand Power And Load Aware Multipath Node-Disjoint Source Routing(DPLAM-DSR) scheme for the MANET. Here they solve the problem of high power consumption in MANET's which is mainly raised due to the unbalanced distribution of traffic loads. The overloaded nodes affect the network's lifetime, operations, and causes link failures. If the loads and tasks are equally distributed among nodes then it prevents node overloading. The significant objective of this work [56] is to maximize the network's lifetime. Here the power and energy of every node are exhausted at the same time. The network lifetime is increased 30% for low load network and 40% for high load network using this routing protocol. Linda F Mohaisen et al.[57] presented a bandwidth estimation scheme to improve the network load balancing in a WSN-Vehicle Adhoc Network Environment(VANET). To balance the load they are measuring the link quality of every node present in the network using Interference Ratio (IR) and Loss Rate (LR). The bandwidth estimation is mainly based on the link aware routing method which balances the load in the network. This protocol enhances the packet delivery rate up to 73% and consumes less energy which prolongs the lifetime of the network.

- **Sleep/Power down methods**

This technique helps to save the energy of the nodes even in the inactive period of communication. It is done by using a low amount of nodes during communication to save the power of the remaining nodes. Yeong-Sheng Chen et al.[58] proposed an Adaptive Quorum based Power Saving(AQPS) protocol for wireless Adhoc networks. A grid quorum based scheme determines the sleep awake pattern of the modes. To minimize the energy

consumption, the grid size of each node is set as per the nodes active ratio. A fixed column selection scheme is used where a node can randomly select one row of quantum interval and select the same column for every cycle. In quorum intervals, the nodes are mainly awake and they enter the power saving mode (sleep) in non-quorum intervals. In non-quorum intervals, the node consumes less energy/power. If a node has a large amount of data to send means it selects the smaller grid size to reduce the non-quorum ratio and vice-versa. The summary of the energy-efficient routing protocols used in the MANET-IoT environment is presented in Table-5.

Table-5: Summary of the energy-efficient protocols deployed in MANET-IoT environment

Name of the Author	**Year**	**Protocol Name**	**Type**	**Energy Efficiency**	**Simulation Environment**	**Performance metrics used**
Chrispen Mafirabadza et al.[54]	2016	EPA-AODV	Shortest Path Metrics	High	NS2.35	Average Energy Consumption Percentage Of Dead Nodes Packet Delivery Ratio Throughput
Riasudheen H et al.[55]	2020	EECAR	Shortest Path Metrics	High	NS3	Average Dissipated Energy Residual Energy
Hesham A Ali et al.[56]	2018	DPLAM-DSR	Load Balancing	High	NS-2.34	Network lifetime Average end to end delay
Linda F Mohaisen et al.[57]	2017	Bandwidth Estimation Scheme	Load Balancing	High	NS3	Packet Delivery Ratio Throughput Energy Consumption Average end to end delay Normalized Routing Overhead Number of Dropped Packets
Yeong-Sheng Chen et al.[58]	2015	AQPS	Sleep/Power down	High	C language	Sleep ratio Energy consumption

						Neighbor discovery time Efficiency of awakeness Transmission Latency
Rashmi Chaudhry et al.[59]	2018	PCG	Transmission Power Control	High	OPNET 18.0 modeler	Transmission power Energy consumption per node Network delay
B.Devika et al.[60]	2019	CEOA	Transmission Power Control	High	NS2	Terms Of Remaining Battery Power Mobility Throughput Delay And Connectivity
M.Fareena et al.[61]	2020	DFMRD	Battery cost lifetime Aware Routing	High	NS2	Packet Delivery Ratio Packet delivery delay Network lifetime Control overhead
R Aruna et al.[62]	2019	OEERA	Battery cost lifetime Aware Routing	High	NS2.34	Energy consumption End to end delay Packet Delivery Ratio Network lifetime
						Packet Integrity rate Detection efficiency
Sanjay Das et al. [63]	2019	triangular technique	Battery cost lifetime Aware Routing	High	Matlab	Energy consumption

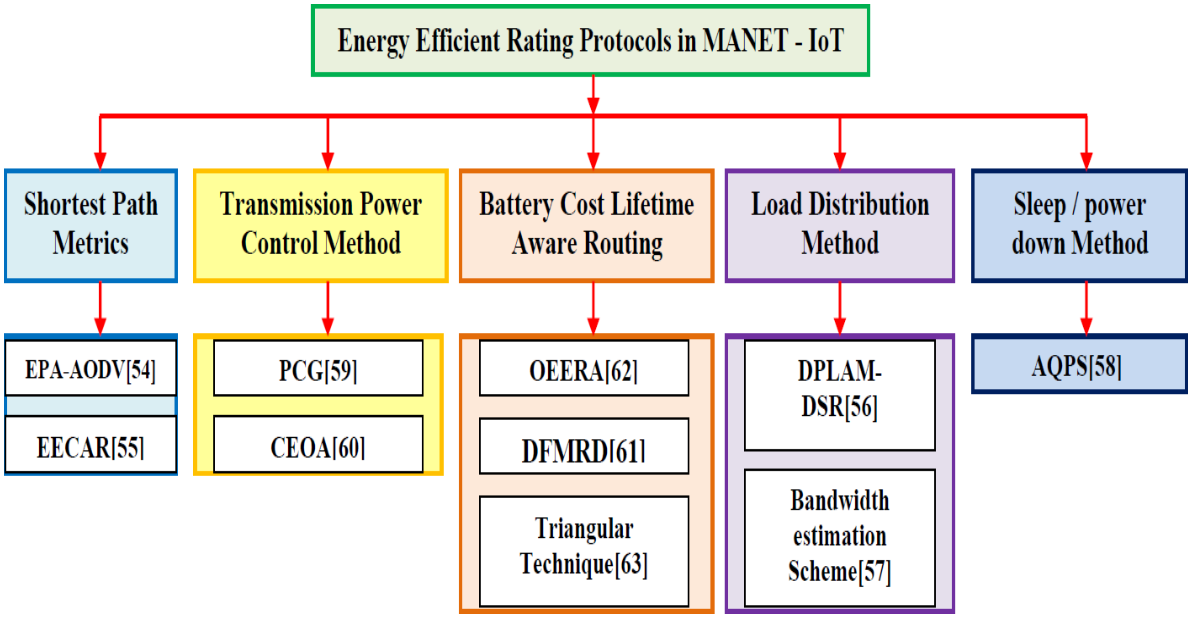

Figure 2: Summary of energy-efficient MANET-IoT Routing protocols

4. Routing Protocols in IoT

The energy-efficient routing protocols used in IoT are discussed in this section. Amol V. Dhumane et al.[64] presented a Multiobjective Fractional Gravitational Search Algorithm(MFGSA) to improve the object's lifetime of the IoT network. The MFGSA identifies the cluster head in iterative motions and then it is evaluated based on the fitness function. Here a multiobjective fitness function is used which should improve the energy, lifetime of the links, delay, and distance. Kavita Jaiswal et al.[65] presented an Energy-Efficient Optimal Multipath(EEOM) routing protocol to deal with large traffic load in the WSN aided IoT applications. To find the optimal three important parameters namely traffic intensity, reliability, and lifetime are used. S. K. Sathya Lakshmi Preeth et al. [10] proposed a Fuzzy Rule-Based Energy-Efficient Clustering and Immune Inspired Routing (FEEC-IR) protocol for WSN aided IoT networks. To reduce the energy consumption the cluster-based routing is used. To solve the complex problem of cluster head selection a multi-aware decision-making approach is used. The Fuzzy analytic hierarchy (FAH) process and Technique for order preference by similarity to an ideal solution (TOPSIS) is integrated into the multi-criteria approach. Mingqiang Zhu et al.[2] designed an Improved Kernel Tree Routing Protocol (IKTRP) for a smart collaboration in delay-sensitive applications used in IoT. The IKTRP comprises two sub-protocols namely generation tree protocol and maintains tree protocol. The generation tree protocol is an initialization phase where every node joins the kernel tree. The process is performed by sending three messages namely Join-request,

join-reply, and join-report. The maintain tree protocol implements fault tolerance operations in the Industrial-IoT. The three main operations performed here are hello, update, and click. The summary of the routing protocols used in the IoT environment is shown in Table-6 and the abbreviations used in this paper is shown in Table-7.

Table-6: Summary of the routing protocols used in the IoT environment

Author and Year	**Purpose**	**Simulation Environment**	**Protocol used**	**Performance Metrics**	**Energy Efficiency**
V. Dhumane et al.[64], 2019	To identify the optimal cluster head	MATLAB	MFGSA	Delay Distance Link Lifetime Energy	High

Kavita Jaiswal et al.[65], 2019	To create multiple routes based on optimality factor	NS2	EEOM	Packet delivery ratio Throughput Energy consumption End to end delay Network lifetime	High
S. K. Sathya Lakshmi Preeth et al. [1], 2018	Cluster head selection	Matlab	FEEC-IR	Network Lifetime Packet Delivery Ratio Throughput Packet Loss Ratio Energy Consumption Channel Load Jitter Bit Error Rate Buffer Occupancy End To End Delay	High
Mingqiang Zhu et al.[2], 2020	To maintain the workflow and application scenarios of this protocol	Media Access Control (MAC) layer	IKTRP	End-To-End Data Packet Delay Routing Overhead Packet Delivery Rate	High

Table-7: List of Abbreviations used in this paper

IoT	Internet of Things
MANET	mobile ad-hoc network
RFID	Radio-Frequency Identification
TORA	Temporally Ordered Routing Algorithm

AR-TORA-FCS	adaptive repair algorithm for the TORA routing protocol intended for the flood control strategy
DAG	Directed Acyclic Graph
IoT-AODV	IoTAdhoc on-demand distance vector
RREQ	Route Request Packet
PPO	Power of the Overhead Packets
PTL	Power Threshold Learning
LOADng	Lightweight On-demand Ad-hoc Distance-vector Routing Protocol for Next Generation
DP-AODV	Dynamic Power-AODV
EECP	Energy-Efficient Clustering Based Routing Protocol
ODSR	Optimized Dynamic Source Routing
DSR	Dynamic Source Routing
GA-BFO	Genetic Algorithm based Bacterial Foraging Optimization
AQ-Routing	Adaptive Q-learning Routing protocol
OLSR	Optimized Link State Routing Protocol
MRS	Multipoint Relays Scheme
QG-OLSR	Quantum Genetic OLSR
LANMAR	landmark Adhoc routing protocol
DSDV	Destination Sequence Distance Vector
TBRPF	Topology Broadcast based on Reverse Path Forwarding
OPNET	Optimized Network Engineering Tool
EELB-ZRP	Energy-Efficient and Load-Balanced Zone Routing Protocol
ZRDM	Zone-Based Route Discovery Mechanism
LFPM	Link Failure Prediction Mechanism
PSO	Particle Swarm Optimization
MDE-ZRP	Mobility, density, and energy-based ZRP protocol
SL-ZRP	Stable Link-based ZRP
CEHR	Core Enabled Hybrid Protocol
ZHLSR	Zone-Based Hierarchical Link State Routing
ZHLSR-GF	ZHLSR-Gateway flooding scheme
AOLSR	Advanced OLSR
PSO-ROGR	PSO based Resource Optimized Geographic Routing

LAPU	Load Balanced Adaptive Position Update
FSR	Fisheye State Routing
FLRST	Fuzzy Logic and Rough Set Theory
CHGS	Cluster Head Gateway Switch
PSO-FCGHS	PSO based CHGS scheme integrated with fuzzy rules
Geo-UAVs	geo-cast routing protocol for Unarmed Aerial Vehicles
GSAF	Geocasting Spray and Flood
BCMRP	Bandwidth-Satisfied and Coding-Aware Multicast Routing Protocol
MAODV	Multicast-AODV
TA-AODMV	Topological change Adhoc On-demand multipath distance vector
GSTMPR	Gray System Theory-Based Multipath Routing
EPA-AODV	Energy-Efficient Power-Aware AODV
CA-MANET	Cloud-Assisted MANET’s
EECAR	Energy-Efficient Cloud Assisted Routing
PCG	Power Central scheme using the Gabriel Graph algorithm
CEOA	Chronological Earthworm Optimization Algorithm
DFMRD	Distributed Fuzzy Multicast Routing Protocol
OEERA	Optimized Energy Efficient Route Assigning Protocol
DPLAM-DSR	on-Demand Power And Load Aware Multipath Node-Disjoint Source Routing
AQPS	Adaptive Quorum based Power Saving
MFGSA	Multiobjective Fractional Gravitational Search Algorithm
EEOM	Energy- Efficient Optimal Multipath(
FEEC-IR	Fuzzy Rule-Based Energy-Efficient Clustering and Immune Inspired Routing
IKTRP	Improved Kernel Tree Routing Protocol

5. Performance Metrics to measure energy efficiency in IoT-MANET

The performance metrics used to evaluate the energy efficiency of the IoT-MANET network is given as shown below.

- **Network Lifetime:** Network Lifetime is an important performance metric in the MANET-IoT network. It is the time taken for the energy depletion of the first node. In simple terms, it can be defined as the time interval between the node's initialization and exhaustion of energy. The power-aware routing protocols alter the routing path to adjust the dynamic power level of the nodes present in the IoT-MANET environment. Some routing protocols select the longest path with high energy consumption instead of the shortest path for conserving the other nodes' lifetime which eventually leads to the overall lifetime improvement of the network. To improve the network’s lifetime the power conservation serves as an important factor. So, one should optimize the overall power consumption of the nodes present in the network to save the network from depletion.

$$Network\ Lifetime(\%) = \frac{Nodeswithlessenergyconsumption}{Total\ Numberof\ nodes} \times 100\% \tag{4}$$

- **Energy Consumption:** It is calculated mainly based on the total energy consumption of the IoT-MANET network during the transformation of information. The node's communication overhead is often related to energy consumption. It occurs when a large amount of false information is injected into the IoT-MANET network.

$$AverageEnergyConsumption\ per\ packet = \frac{Total\ EnergyConsumed}{Total\ Numberof\ Packetsreceived} \tag{5}$$

- **Quality of Service(QoS):** An efficient and effective communication of data transfer from the sender to the receiver determines the success of the IoT-MANET network and it is measured by the QoS parameter. The overall performance of the MANET-IoT network is known as QoS and to achieve that the full power of the sensors should be utilized. QoS manages network functionality and resources to provide an IoT connection based on a trustworthy backbone. It can be also used to measure the performance of a particular service given to the user.

- **Normalized Routing Overhead:** It indicates the total number of control packets generated for each data packet sent to the destination.

$$NormalizedRoutingOverhead = \frac{Numberof\ packets}{Numberof\ Packets + Numberof\ packetstransmitted} \tag{6}$$

- **Normalized Routing Load:** It is the ratio measured between data traffic and control traffic

$$NormalizedRoutingLoad = \frac{Total\ Numberof\ packetstransmitted}{Total\ Numberof\ Packetsreceived} \tag{7}$$

- **Packet Delivery Ratio:** It is the ratio of the packets sent by the sender and received by the receiver.

$$Packet\ DeliveryRatio = \frac{RoutingPacketsreceivedbydestination}{RoutingPacketsreceivedby\ source} \times 100 \tag{8}$$

- **End to End delay:** The time interval calculated during the transfer of the data packet from the source node to the destination.

$$End - to - End\ delay = \left| EndTime_i - StartTime_i \right| \tag{9}$$

- **Average End-to-End delay:** The average difference in time during sending and receiving packets is called average end-to-end delay.

$$\text{Average End - to - End delay} = \frac{\sum^{M} \left(\mathrm{Re}\ ceived_{PID} - Sent_{PID} \right)}{M} \tag{10}$$

Here, M is the total number of packets successfully transmitted over MANET, and PID is the packet ID. The R*eceivedPID* and *SentPID* indicate the time of the reception and transmission of the packet.

- **Packet Loss Rate:** The number of packets lost during the transmission based on the total number of packets sent is measured using the Packet Loss Rate.

$$Packet\ Loss\ Rate = \frac{Numberof\ packetssent - Numberof\ packetsreceived}{Total\ Numberof\ packetssent} \tag{11}$$

- **Resource Utilization Ratio:** The ratio of the total number of resources allocated to the node for the period of the entire simulation.

- **Jitter Delay:** It is the difference between the delay observed for each packet received. To yield improved performance in the MANET network the delay observed during the packet arrival time should be small.

$$JitterDelay_i = \left|(A_{i+1} - A_i) - (B_{i+1} - B_i)\right| \tag{12}$$

Where *Bi* is the transmission time of the packet *i* from the source and *Ai* is the arrival time of the packet *i* to the destination.

- **Throughput:** It is one of the main performance metrics used to evaluate the IoT MANET network. In the IoT network, the end to end throughput is used to balance the transmission rate and packet error. A packet transferred between the source and destination doesn't always

represent data. Because each packet carries a different number of overhead bits to represent the data payload. In some packet transferred the entire packet comprises of overhead bits instead of data. The throughput is interchangeably used as goodput and it is used to represent the transfer of packets in the nodes application layer for a certain time period.

T*hroughput*= *SimulationTime* × 8 ×1000*kbps*×*Total Numberof bytesreceived* (13)

6. Discussion

This section analyzes the existing literature works of various authors on energy-efficient protocols used in the MANET-IoT environment. The first step describes how the articles are selected based on the different types of routing protocols used.

6.1 Strategy for Paper Search

The main aim of this study is to identify the research gap in the existing literature which is not investigated before. Initially, papers beginning with the following keywords are searched on the web namely "Internet of Things", "MANET-IoT"," Energy-efficient routing protocols in IoT-MANET", Energy-efficiency", and "Energy Efficiency in IoT-MANET". The research articles are collected from a time period of 2003-2020. In the next step, the articles that are classified as a thesis, survey papers, student articles, redundant, etc are filtered. Totally 46 articles are selected for technical analysis from the existing literature. The pictorial representation of the research articles taken for technical analysis is shown in Figure

3. Figure 3 demonstrates the articles taken from different journals based on the corresponding year. The number of research articles taken from different journals is categorized as shown in Table 8.

Table-8: Categorization of Research articles used in this paper

Journal Site	Number of papers retrieved	Number of papers relevant

Elsevier	1475	12
Springer	1500	20
IEEE	1254	9
Wiley	157	2
Others(ACM, preprint, inderscience)	50	3
Total	4436	46

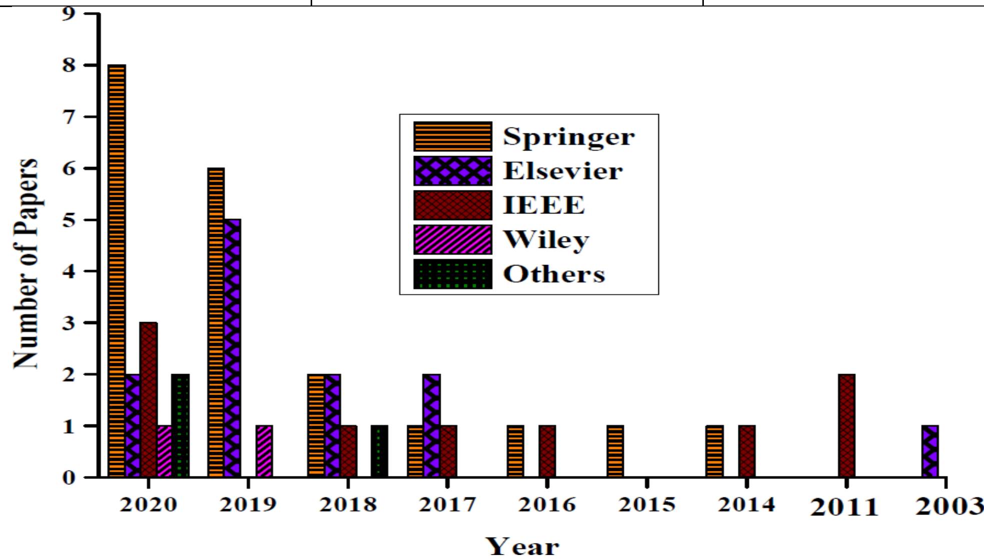

Figure 3: Categorization of research articles from different journals based on the year Based on the systematic literature review, the following queries have been designed

depending on the energy-efficient routing protocols used in the MANET-IoT environment.

Query-1: How are the routing protocols classified in this paper?

Query-2: What are the widely used simulation tools in the existing literature?

Query-3: Which performance metrics are widely applied to the energy-efficient routing protocols?

Query-4: In what characteristics the energy-efficient routing protocols rely on?

6.2 Query Evaluation

In this section, the Query Evaluation process is performed by evaluating the results found in the existing literature.

Query-1: How are the routing protocols classified in this paper?

The routing protocols are mainly categorized by dividing it into three main sections. In the first section, the routing protocols are divided mainly based on topology, location, hierarchy, geo-cast, multicast, and multipath. In the next section, the protocols are divided based on energy-efficiency. The energy-efficient routing protocols are categorized based on shortest path metrics, battery cost lifetime aware routing, load balancing, and sleep/power down techniques. The third section comprises the routing protocols used in IoT. Figure 4 shows the routing protocol classification based on different divisions.

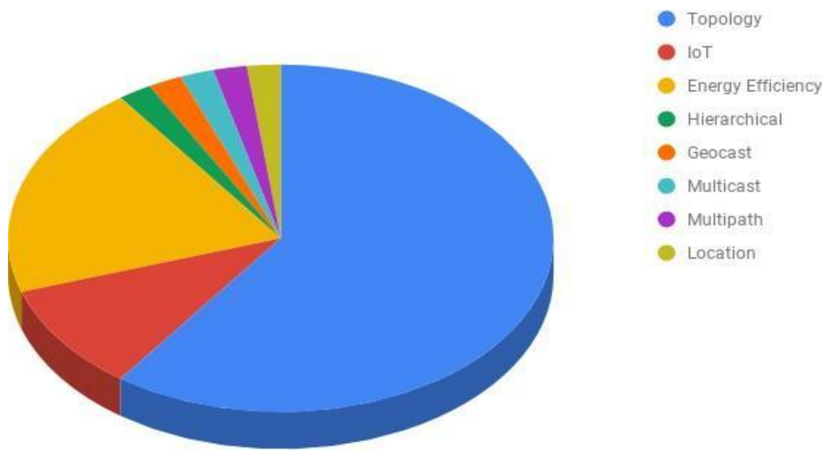

Figure 4: Classification of routing protocols

Query-2: What are the widely used simulation tools in the existing literature?

From the literature, it can be easily identified that NS2 and NS3 are the simulators that are mostly used to perform routing in the MANET-IoT environment. The next simulation environment used is Matlab. The remaining are MIL3's, C language, C++ language, WiFi 802.11ac, Bluetooth 802.15 v4.0, OPNET 7.0, and 18.0. The NS2 is an open-source simulator tool mainly used for routing and multicast protocols. It runs on a Linux platform. Matlab is a multiparadigm programming interface created by Mathworks and it is used to run the routing structure in MATLAB.OPNET simulator can simulate the behavior of the MANET-IoT network. The summary of the simulation platform used in the MANET-IoT network is shown in Figure 5.

Query-3: Which performance metrics are widely applied to the energy-efficient routing protocols?

The widely used performance metrics are Packet Delivery Ratio(90%), End-to-End delay(70%), Jitter(40%), Network Lifetime(50%), Energy consumption(50%), Throughpit(45%), Delay(24%), Routing overhead(25%), and normalized routing load(30%). Figure 6 compares widely used performance metrics used in energy efficient routing process.

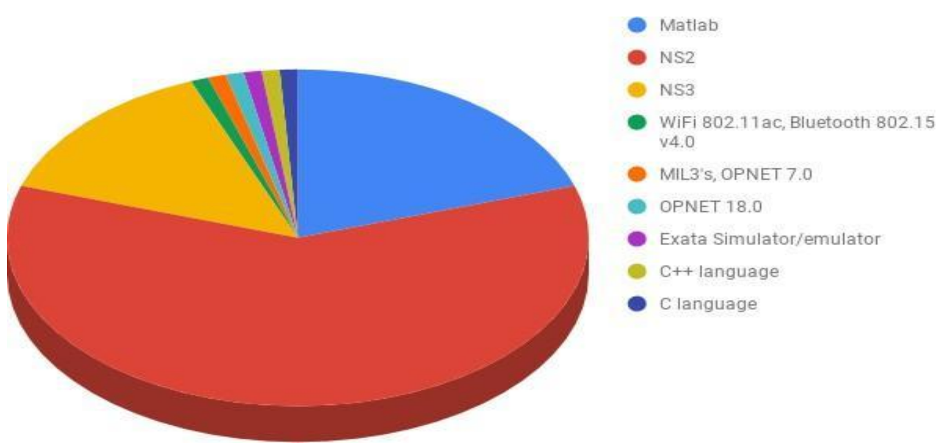

Figure 5: Summary of the Simulation platform used in MANET-IoT environment

Query-4: In what characteristics the energy-efficient routing protocols rely on?

The energy-efficient protocols mainly rely on the following characteristics namely throughput, bandwidth utilization, energy depletion of nodes, congestion, traffic load, energy consumption, link lifetime, node lifetime, packet delivery rate, transmission power control, and delay.

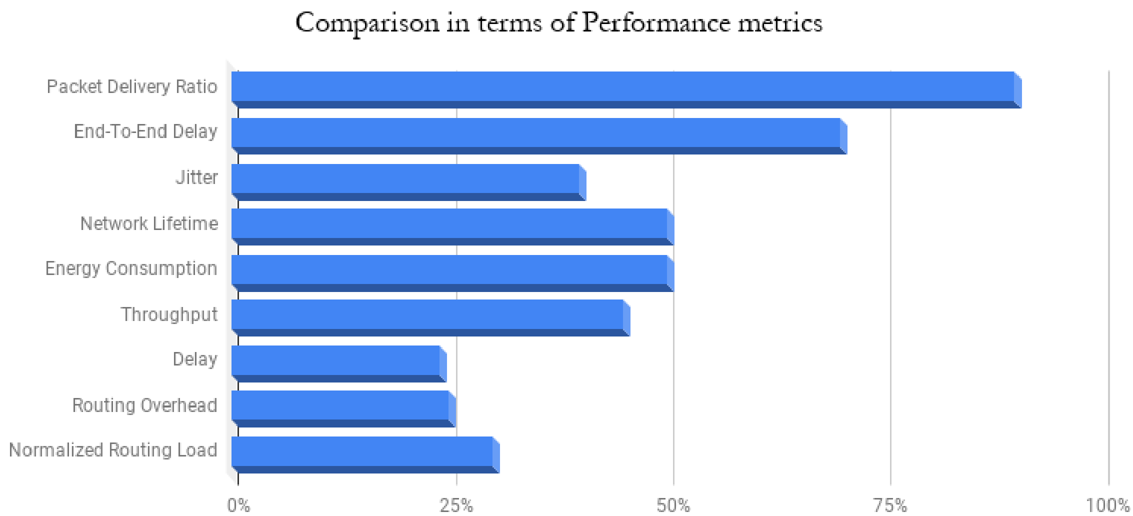

Figure 6: Comparison in terms of performance metrics

7. Open Issues and Future Research Directions

The open issues identified in IoT can be also applied in future direction research. The MANET and WSN play a main role in the IoT applications. Both the MANET and WSN are a part of the IoT network and the challenges that exist in the MANET and WSN environment also lie in the IoT environment. The growth of the IoT is hindered by the following issues:

Context Awareness: To make smart routing decisions the external environment should also be considered as a crucial parameter. The context-awareness of the routing protocol can be improved by adding the storage requirements, link quality, and processing power.

Scalability: If billions of devices are connected by the IoT, the size of the network expands vastly. If the size of the IoT network increases then the management of the huge network with a massive amount of interconnected devices becomes complex. To overcome the scalability issue the maintenance costs and operational costs should be considered.

Mobility: The mobile nodes of the IoT move along with the objects they are attached to. In the modern world, the majority of enterprises use wearable devices to keep track of and monitor objects and humans. The energy-efficient protocols to handle the mobility of the nodes are an important issue to be focused on.

Load Balancing: The massive amount of interconnected devices in IoT increase the traffic in the network. The load balancing schemes play a major role in IoT for effective resource

utilization by distributing the workloads among multiple devices. The workload traffic along with the congestion control needs to be focused.

Dynamic Topology: The dynamic changing topology of IoT decreases the performance of the system, hence efficient protocols should be deployed to overcome this problem.

Data Security and Big data management: The wireless communication network is vulnerable to frequent potential attacks and theft of information. To safeguard the information and protect confidentiality, Integrity, and Availability, secure policies should be implemented in the IoT environment. The billions of devices generated produce huge volumes of data that should be managed effectively to gain insights. The big data management and data fusion techniques implemented in IoT helps to process a huge volume of data efficiently.

Others: The other issues to be considered are the interoperability, trust management, fault-tolerance, and access control mechanisms in IoT.

8. Conclusion

MANET-IoT system is formed by incorporating WSN and MANET environments into the IoT network. The MANET-IoT environment offers many beneficial uses to their users but it struggles without an energy-efficient route discovery mechanism to improve the lifetime of the networks. In this article, we analyzed the energy efficiency of cognitive MANET-IoT routing protocols. Totally, 46 research articles were taken for technical analysis. The different types of routing protocols used in MANET namely proactive, reactive, hybrid, geographical, hierarchical, multicast, multipath, and geo-cast routing protocols are extensively analyzed. The energy-efficient routing protocols in the MANET-IoT environment are categorized based on the shortest path metrics, transmission power control method, load distribution, battery lifetime aware routing, and sleep power down methods. The energy-efficient routing protocols mainly suffers from the issues like high traffic load, the energy depletion of nodes, throughput, bandwidth utilization, low packet delivery rate, delay, and reduced lifetime of the network. The performance metrics used to measure the effectiveness of the IoT-MANET network are also provided in this paper. This paper also elaborates on the strategies used for the paper search along with a systematic literature review. Finally, open research issues and future research directions are highlighted in this paper.

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