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A Survey of Power-Aware Routing Techniques for Mobile Ad-hoc Networks

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Abstract: Wireless technology presents intelligent solutions and offers high networking flexibility. Through wireless sensor networks, users can access their information remotely, anytime, and anywhere. In Mobile Ad-hoc Wireless Networks (MANETs), mobile nodes have limited energy and resources. Moreover, nodes able to leave or join the network liberally, which increases network complexity and design challenges. Consequently, several ad-hoc routing protocols have been evolved to conserve energy, amend network performance, and address the encountered design challenges. The literature presents a comprehensive variety of techniques and models that have been proposed for efficient, power-aware, MANETs. In this paper, we propose a new taxonomy that categorizes the most common MANET routing approaches published in the literature. The paper presents an in-depth comparative analysis of power-aware techniques to help researchers better understand the current research directions in MANET power-aware routing. The presented analysis highlights the advantages and disadvantages of each routing technique and discusses the impact of the findings on network design options.

Keywords: Wireless Sensor Network (WSN), MANET, Embedded System (ES), Power-aware routing protocols, Internet of Things (IoT), Genetic Algorithm (GA).

1. Introduction

The design and implementation of tiny sensors have improved significantly in the last few years due to innovative technological development. In several applications, sensors can be connected to form a WSN. Hundreds of connected nodes can move from one location to another, which leads to the implementation MANETs. Routing in MANETs is an actual challenge due to the intrinsic characteristics that discriminate these types of networks from traditional WSNs. Furthermore, utilizing unattended sensor nodes comes with several challenges that impact the performance of several applications such as weather monitoring, healthcare, security, intrusion detection, and disaster management. In the past few years, exhaustive research has been done to enhance data communication between sensor nodes. The need to conserve nodes' energy has grown significantly to prolong nodes and network lifetime. Owing to the diminutive battery-energy in MANETs mobile nodes, prolonging nodes' lifetime becomes the most important design challenge. Several MANET's power-aware models are proposed using both software and hardware techniques [1]. Software techniques are developed either by enhancing the existing traditional routing protocols or by using bio-inspired approaches. Bio-inspired approaches are highly efficient in multi-input complex problems. Consequently, Hardware techniques attempts to improve routing performance using improved low-power, high technology hardware in both the network infrastructure and nodes.

Several surveys on ad-hoc routing protocols have been presented in [2], [3], [4], [5], [6], and [7]. However, none of these surveys clearly presents a complete state-of-the-art taxonomy that categorizes current MANETs' power-aware approaches. More relevant categorization of broadcasting protocols is presented in [8], [9], [10], and [11]. However, the published categorizations do not thoroughly cover all the existing techniques. In this study, we introduce a new taxonomy that classifies the

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research in the power-aware routing for MANETs and categorizes the most relevant design approaches. The paper presents an exhaustive comparative exploration of the state-of-the-art techniques to help researchers better understand the current research directions in this field. The study highlights the advantages and disadvantages of each routing technique and exhibits the findings. Achieving power-aware routing in MANETs can be done using software and/or hardware approaches. The software approach is based on different techniques, such as traditional routing protocols enhancement and Bio-inspired techniques. Consequently, the hardware approach is based on utilizing state-of-the-art electronics technology on both network infrastructure and sensing nodes. Fig. 1 demonstrates a high-level classification of power-aware approaches in MANET routing.

The rest of this paper is structured as follows. In Section 2, We introduce a comprehensive study of power-aware routing for MANETs using software approaches. In Section 3, We demonstrate a detailed study of power-aware routing for MANETs using hardware techniques. In Section 4, we discuss the trade-off issues and the main findings of our survey. Finally, we draw our conclusion in Section 5.

2. SOFTWARE APPROACH

Several new approaches have been developed in MANETs' power-aware routing where energy awareness and power-management is an essential design issue. Figure1 depicts a taxonomy for MANETs' routing approaches based on a global overview of the most relevant existing techniques. The software approach is based on two main directions: enhancing the traditional routing protocols [4] and developing Bio-inspired techniques. The proposed protocol enhancement in the literature aims to achieve the best routing performance that guarantees the desirable quality of service. The traditional protocol-enhancement-approaches add specific new features to the protocol itself or merge other algorithms with the classic routing protocols to achieve better performance in terms of a particular metric [12]. On the other hand, the bio-inspired approach includes several techniques such as utilizing swarm intelligence [13], genetic algorithms [4], ant-colony, and water drop algorithms [14]. The following subsections study these two approaches in more details.

A. *Enhancement of Classic routing-protocols*

Classic routing protocols such as reactive, active, and hybrid, such as Ad-hoc On-demand Distance Vector (AODV), Dynamic Source Routing (DSR), Destination-Sequenced Distance-Vector (DSDV), Optimized link-state routing protocol (OLSR), and Zone Routing Protocol (ZRP), have been used for years in MANET routing. Several new MANETs' routing protocols have been submitted in the survey based on these classic protocols [15], [16], [17], and [18]. Table 1 exhibits a comparison between the MANET power-aware routing protocols based on classic protocols enhancements.

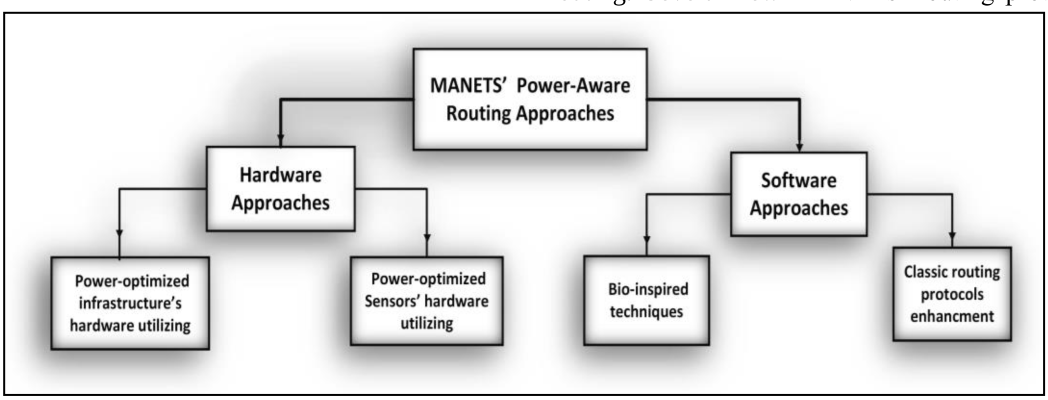

Figure 1. MANET Power-Aware Routing Approaches

S. Kumar et al. in [6] presented a comparative analysis of load balancing and energy-efficient approaches. The evaluations of these approaches are based on different specific performance metrics [6]. The proposed performance metrics include energy consumption, Packet Delivery Ratio (PDR), throughput, RBP, signal strength, number of alive nodes, End-to-End delay (E2E), packet loss, Quality of Service (QoS), network lifetime, routing overhead, and energy level. S. Kumar et al. concluded that the Energy Efficient Load Balancing AOMDV (EELB-AOMDV) is an efficient protocol. EELB-AOMDV enhances PDR and improves E2E delay compared to the other presented AOMDV approaches.

I. Das et al. analyzed the battery power consumption of individual nodes along a path during their communication and the relevant impact on network performance [19]. The authors analyzed the active mode in both sending and receiving states in the AODV protocol [19]. The simulation results showed that the nodes consume more energy during transmission mode than receiving mode.

A. Paveen et al. proposed a modified power-aware approach based on the AOMDV. The proposed protocol combines energy, delay, and throughput parameters to the Route Request Packet (RREQ). Every node has its own Energy Reduction Rate (ERR) table with an extra record called Threshold Value (TV) [4]. A node is avoided in discovery if its ERR value exceeds the TV value. Each RREQ packet has an extra field, namely Delay Energy Drain Rate (DEDR). The DEDR counter initiates at 0 and increments by 1 along the routing path through the intermediate nodes. The primary path is the route that has the least DEDR value [4]. The proposed approach increases network lifetime and decreases packet loss due to the avoidance of low energy nodes in routing discovery [4].

Zheng et al. focused on the nodes' mobility impact on the QoS in MANET [16]. The authors in [16] proposed a routing protocol called Topological Change Adaptive AOMDV (TA-AOMDV) that manages the movement of the high-speed nodes and adapts rapid change topology. The proposed algorithm considers node resources and the parameters of path selection. TA-AOMDV estimates the Path Stability probability (PSP) between nodes. TAAOMDV has an integrated mechanism for link interrupts' prediction [16]. The proposed protocol performance has been evaluated through PDR, E2E delay, and throughput. The simulation results' analysis shows that the TA-AOMDV presents better QoS compared to AOMDV, QoS-AOMDV, QoS aware weight Multipath Routing protocol (QMR) and link reliable Multipath routing protocols (LRMR) [16].

M. Anand et al. proposed a new routing protocol known as Intelligent Routing AODV (IRAODV). The proposed protocol optimizes the MANETs battery energy and provides an efficient packet transmission [12]. IRAODV protocol is a consolidated algorithm for the AODV protocol to determine the transmitter-receiver distance using the Received Signal Strength Indication (RSSI). The IRAODV has been simulated using NS-2.35 to evaluate its performance. The PDR, E2E delay, throughput, consumed energy, and residual energy are the suggested performance metrics [12]. The results show that the IRAODV provides enhanced performance compared to the AODV protocol.

Salama et al. have examined the AODV and the DSDV performance by mapping the network power consumption through changing the QoS parameters [18]. The proposed QoS parameters for the analysis are the average throughput, PDR, and energy consumption. Three different simulation scenarios have been directed to evaluate the influence of network size, mobility, and packet size on network performance. The simulation results show that there is not any protocol realizes the comprehensive network performance and achieves the full energy consumption optimization [18]. Moreover, no protocol can fully overcome network load effects and completely manage network high-mobility. The DSDV presents a reliable performance at high-mobility networks, while the AODV is better in heavy-traffic networks.

M. Mustafa et al. proposed a low energy consumption routing approach called Energy Efficient MANET (EEM) that keeps a strategic distance from the low number of nodes in a network [1]. The low energy consumption packet mechanism decreases the number of forwarding packets that can significantly decrease energy consumption. The authors in [1] presented a comparison between EEM and AODV routing protocols. The suggested evaluating parameters are path length, congestion cost, unavailability, delay, packet loss, and low energy consumption. The proposed approach is evaluated and simulated by NS2 [1]. The EEM shows a lower total cost based on the measured parameters compared with the AODV protocol.

S. Mostafavi et al. in [20] proposed a QoS-assured Mobility-Aware Routing protocol (QMARAODV) that is an enhanced model of the AODV to overcome mobility management challenges. The QMAR-AODV protocol supports QoS-guaranteed routing by analyzing a combination of stability and quality metrics. The metrics include the mobility ratio between two nodes within a path, power efficiency, and overcrowding burden to discover the steadiest and QoS-guaranteed paths [20]. The proposed protocol in [20] has been simulated by the OPNET 14.5. The Route instability, data reception ratio, E2E delay, PLR, re-transmission level, and throughput are the proposed performance evaluation metrics. These metrics have been utilized for evaluation and comparison to E2E Link Reliable Energy Efficient Multipath Routing (E2E-LREEMR) protocols. The results show that the QMAR-AODV protocol is more efficient than E2E-LREEMR. QMAR-AODV improves data reception by 5.1% and enhances throughput by 4.8% compared to the E2E-LREEMR. QMAR-AODV decreases route instability by 8.3%, E2E delay by 10.9%, data re-transmissions by 10.6%, and packet loss by 5.4% [20].

E. Pereira1 et al. have analyzed the performance of the DSR protocol [17]. The DSR stores alternative routes in case of primary route unavailability. A node transmits RREQ packets to its neighbors, the node that receives it responds with an RREP. In the case of failure detection, a RERR packet is sent, and the routing table is updated [17]. The protocol has been analyzed using the NS-2 with the two-ray ground and free-space propagation models, among TCP and UDP Protocols. The evaluation has been carried out in terms of delay, overhead, and packet loss metrics [17]. The simulation results showed that the two-ray ground model presents better performance than the two models based on the defined evaluation metrics. Node movement has a limited impact in free-space and two-ray channel models. Moreover, the node's localization and the effects of signal fading are not considered by DSR, the higher distance between nodes will reduce the possibility of receiving messages. The shadowing propagation model can manage fading environments but presents a lower PDR and a higher overhead in the building's environment. The results show a higher PDR percentage when nodes are moving, among TCP with a percentage above 95% [17]. The DSR is a suitable selection to work on-demand.

R. Sahu et al. proposed the Zone-Based Leader Election Energy Constrained AOMDV Routing Protocol (ZBLE) to enhance the network performance through the AOMDV protocol developing [21]. ZBLE considers the E2E delays, lifetime, energy consumption, and throughput. In the proposed protocol, a leader node is designated if its estimated value is above the threshold value. The election of leader nodes by checking their abilities in representing the signal by evaluating each node energy as well as its transmission possibility, and reception energy. The most reliable route has been determined through the Received Signal Strength (RSS) value. R. Sahu et al. evaluated the ZBLE, AOMDV, and AODV protocols in terms of energy consumption by applying four scenarios to evaluate nodes energy level using the NS-2 [21] The scenarios are based on experiment duration, nodes velocity, data size, and the quantity of nodes [21]. The simulation results showed that ZBLE is a better performance than AOMDV and AODV in all scenarios and presents an improvement in energy consumption. In [21], the simulation results have proved that ZBLE is an energy sensitive protocol. The efficient peer to eer protocol has to locate the best peers that share resources and could be reached in a dynamic energy-limited network.

S. Hamad et al. proposed the (CAQRP) Context-Aware Query Routing Protocol that based on the technique for order preferences by similarity to ideal solution (TOPSIS) instead of the commonly used Random Breadth-First Search (RBFS) method to manage the query flooding [22]. The TOPSIS was developed for supporting multiple-criteria decision making, considering all alternatives. The authors considered the mobility of peers, congestion, and energy consumption [22]. The proposed protocol routes the query to the best K neighbors that suitable, stable, lite-loaded, and higher remaining energy. The Analytic Hierarchy Process (AHP) method is utilized to determine the weight of different factors. The presented protocol has been simulated compared to the Gossiping- LB protocol using the NS2 simulator. The average file discovery, hit rate, and delay per query are the proposed performance metrics to evaluate results [22]. Gossiping - LB determines the forwarding probability for all neighbors and guarantees load balancing regardless of considering the mobility or the battery energy. The results show that CAQRP has a reduced discovery delay than Gossiping-LB. Further, increasing the network size causes increasing the discovery delay of both protocols. CAQRP outperforms Gossiping-LB in recall and hit rate under different network sizes. The proposed protocol CAQRP increases the hit rate.

R. Prasad et al. proposed the energy-aware on-demand routing protocol (EA-DRP) that considers the intermediate nodes' energy threshold value and updates the paths during the unavailability of any nodes [23]. EA-DRP considers an energy-saving mode mechanism in the four modes: Transmitter, Receiver, Idle, and Sleep to maximizing the routing performance. EA-DRP avoids source-destination direct transmission that consumes massive battery energy during data transmission. The proposed protocol has been simulated using NS-2 compared to the DSR and the Conditional Max-Min Battery Capacity Routing (CMMBCR) protocols. The PLR, PDR, average energy consumption ratio, and network lifetime are the proposed metrics. The study figures that the EA-DRP protocol is lower PLR with regard to the DSR and CMMBCR protocols, and the PDR of EA-DRP is better than CMMBCR. Moreover, EA-DRP presents enhancements in energy consumption compared to DSR and CMMBCR protocols. Further, EA-DRP increases the node lifetime. In low mobility, EA-DRP is higher performance than the DSR protocol. At a high-mobility network, DSR is a better performance than the CMMBCR protocol. In all mobility scenarios, the EA-DRP provides the best metrics' values compared to DSR and CMMBCR.

R. Patel et al. proposed an improved routing protocol based on the AOMDV to enhance network performance through E2E delay, load balancing, and throughput [24]. The developed algorithm is based on multipath finding and less congested route selection. A proposed counter for data-packets is an added record to each node routing table of. Further, a proposed node counter is ascended with each hop along the path to the destination. At the last hop, the load-matrix will be modified by the entire load. Data are transmitted over the route that has the least load. The system simulation has been done using NS-2.35 for performance assessment compared to the path efficient AOMDV (PE-AOMDV) protocol [24]. PDR, throughput, delay, and PLR are the planned performance metrics. The analysis shows that the PDR is slightly decreased with increasing the nodes' scalability but is higher than the PE-AOMDV protocol. The PE-AOMDV presents a better packet loss ratio and delay time compared to the PE-AOMDV protocol. Moreover, it shows a higher throughput while increasing the node scalability, where the throughput of PE-AOMDV goes down. The proposed system shows a fewer packet drop and a smaller overhead compared to PE-AOMDV. PE-AOMDV reduces the E2E delay and the PLR, increases the PDR, the throughput, and the normalized routing load [24].

S. Benatia et al. proposed a durable broadcasting model called Efficient energy aware and Link Stable Multipath Routing Protocol in urban areas (ESMRua) [25]. ESMRua algorithm comprises a choice pattern built on both signal quality and link stability, which are determined by three variants: standard deviation (ESMRua-SD), average absolute deviation (ESMRua-AAD), and exponentially weighted moving deviation (ESMRua-EWMD). The first node requests the best possible route by checking the routing table. The source node gets the path discovery in case of no suitable path is available. The authors considered 3-metrics: energy consumption, PDR, and the normalized routing overhead (NRO) [25]. S. Benatia et al. have utilized NS-2 to evaluate the ESMRua compared to the EESMR protocol. The results showed that the EESMR has a lower performance impact at low-speed moving nodes or a low number of MANET nodes. The greater number of nodes, the more energy consumption, and the more route failures. Similarly, the more speed, the more energy consumption, and the more route failures. The consumed energy in ESMRua is more limited than EESMR [25]. Moreover, the PDR of the ESMRua is greater than the EESMR in Manhattan's model. The ESMRua presents significantly lower NRO than the EESMR protocol. ESMRua adapts the routing in a constrained urban by electing the highest stable routes and choosing the best signal quality.

R. Bruzgiene et al. proposed an energy-efficient and safe-weighted clustering routing algorithm for MANET-IoT systems utilizing MANET-WSN philosophies [26]. The proposed mathematical model for energy cost function evaluation uses a combination of OLSR and LEACH (low energy adaptive clustering hierarchy) routing strategies [26]. A cluster head (CH) is in charge of sending, gathering, aggregating, compressing, and transmitting any information. LEACH selects CH randomly, using the proposed algorithm, the CH is the node with higher energy than a proposed threshold value [26]. The proposed algorithm applies a dynamical CH rotation that supports CH load-distribution across the system that extends the network lifetime [26]. The proposed algorithm assumes that a wireless sensor network is graphically described through vertices express nodes, and edges represent the interconnections between nodes. The non-CH determine their CHs for the existing process, then request for a new connection. Once a CH energy level goes below the threshold value, a loop to replace the CH node [26]. Three approaches for path deciding: NP (node place), BST (node battery state), and ER (energy resource) [26]. The NP aims to discover the least-hop path. BST selects the nodes with a more powerful energy condition. ER approach determines the entire network energy-resources. The system has been simulated using the MATLAB. The node energy and network lifetime are the proposed performance metrics for system evaluation [26]. According to simulation analysis, the NP and ER techniques, resource utilization is much alike. On the other hand, the BST method extends the first node dropping [26]. The simulation result shows that a combination method for routing increases lifetime. Determining the best route should consider a weight function for each sensor node and route cost function [26]. The proposed approach decreases energy consumption, improves accessibility, and prolongs network lifetime [26].

S. Mukherjee et al. in [27] proposed a solution for two IoT applications. The authors have considered a smart city, where IoT applications with different wireless policies and technologies, such as MANET, WSN, Radio Frequency Identifier (RFID). The proposed architecture is unconventional. It is composed of four layers: MANET nodes, WLAN, WSN nodes, and the internet.

S. Mukherjee et al. recommended IEEE.802.15.4 as well as Bluetooth Low Energy (BLE) as MAC protocols in the link tier for WSN sensors. Nodes requisite a unique IP address. The network layer uses IPv6 protocol for a wider IP-range availability. The sensor nodes also use IPv6 for optimized power consumption and better compatibility. The transport layer uses UDP because it is lighter than TCP. On the other hand, the application layer

uses the lightweight Efficient XML Interchange (EXI) protocol that needs the support of the Constrained Application Protocol (CoAP) for constrained Representational state transfer (RESTful) Environment [27]. Moreover, in a proposed healthcare application, each device is attached to the patient, specialists, and beds transmit packets to the gateway and nodes with different data formats [27]. Additionally, IoT football application, a proposed model, consists of some wearable health-care sensors that equipped with GPS and motion sensors to monitor players while playing [27].
The authors have applied the Street neighbor concept, where nodes use the Hello messages to seek out the neighbor using the GPS and the street map [27]. The authors have simulated the proposed architecture using Omnet++. The simulation has been considered 9-zone contain several sensors using BLE and IEEE802.15.4 [27]. The authors have used random way-point mobility with the proposed system mobility model. The evaluation metrics are the delay of the data packet, design cost, scalability, energy, and internet traffic. The results showed that the delay of packets decreases with the more number of gateways. On the other hand, the delay is direct proportional to the network load. The results show that the model efficiency has a better delay in IoT applications [27].

B. Wietrzyk et al. proposed the Energy Efficient Route Discovery (EERD) MANET protocol to offer incessant observing of animal-mobility and feed-consumption with warnings assisting in the case of low data traffic or high mobility [28]. The model contribution is: to identify the practical necessities for a wireless routing technique, to optimize the energy efficiency of control traffic, to realize the Passive Clustering with Delayed Intelligence (PCDI) concept [28]. The onto-animal sensors observe the animal and send information on the spot. The simulation uses the bovine movement model for a practical packet-level emulation at average data of 32B/update. The proposed protocol has been simulated using NS-2 [28]. The results showed that the EERD protocol decreases the average energy usage compared to DSR and ESDSR (48%-75%), respectively. Further, the results show that the EERD protocol is superior in balancing energy utilization than DSR and ESDSR [56]. In a higher number of mobile nodes condition, the EERD shows lower delays, better scalability, and lower overhead than DSR and ESDSR [28].

A. Alameri proposed an energy-efficient routing algorithm for the IoT and WSN [29]. The network topology changes with time, and if the CH energy goes below the proposed threshold value, another loop is handled to change the CH. This mechanism increases the network lifetime. The proposed system has been simulated in a MATLAB environment with three proposed routing models [29]. The author has considered the node's energy and network lifetime metrics to assess the proposed algorithm. The results prove that the combination of the proposed models extends the nodes' lifetime.

D. Ahmed et al. present a comprehensive study of MANETs application [30]. MANET applications have significant developments in several scenes, such as tactical networks, extended network connectivity, commercial and civilian environment, VANETs, VANETs, Personal Area Networks (PANs), Body Area Networks (BANs), WSNs, smart cities, mobile conferencing, IoT, education, entertainment, Internet-based MANET (IMANETs), and Flying MANET (FANET) [30]. The authors reviewed the most practical MANET challenges, such as limited Bandwidth, routing, routing overhead, mobility, dynamic Topology, IP address, battery constraints, radio interface, power management, security, device discovery, topology maintenance, robustness, reliability, heterogeneity [30]. D. Ahmed et al. described several research trends, such as secure and multicast routing QoS-aware routing as well as Geo-Protocols, and Hybrid Ad-hoc Network (HANET) [30].

J. Sobral et al. proposed the LOADng-IoT protocol that provides enhancements to the Lightweight On-demand Ad hoc Distance-vector -Next Generation (LOADng) protocol [31]. The proposed protocol enables to locate the nodes that are connected to the internet autonomously with no earlier information of a gateway. The LOADng routing protocol overcomes the complexity of the AODV and reducing the required resources by detaching the sending restriction of the intermediary path response messages and by evading of the control message [31]. In the LOADng, once a node desires to send a packet to creates a path, it starts a new discovery round. Consequently, the node transmits an RREQ to discover a route, where every node accepts an RREQ should forward it. That procedure lasts up to the RREQ arrives the destination that should send back an RREP to answer to the RREQ and forwards an RREQ to the source node to create a route [31]. LOADng-IoT consists of three modules: Internet path discovery process, Internet Route Cache (IRC) mechanism, and an innovative error code for RERR messages. The new proposed error code increases the possibility of informing the sensors in case of the internet failure. Therefore, nodes that aim to broadcast a data packet can obtain different that increase the routing success probabilities [31]. The PDR, energy consumed per data bit, control message load, and percentage of packets with low latency are the proposed performance metrics to evaluate the approach [31]. The proposed approach has been simulated compared to the LOADng, and LOADng-SmartRREQ approaches. The result analysis shows that the LOADng-IoT presents a better performance for mobile dense MANETs [31]. LOADng-IoT requires limited radio transmissions for route discovery and has a lower impact with the interferences and collision [31]. The proposed protocol enhances network QoS and reliability by enhancing the PDR and decreasing E2E delay [31].

T. Sunil et al. in [32] introduced an evaluation of the on-demand DSR and AODV routing protocols. DSR routing protocol is source-initiated rather than table-based. In DSR protocol each node owns a storage memory to save newly learned routes. On the other hand, the AODV routing protocol doesn't care the path maintenance process for every node. In the case of route unavailability, the AODV re-transmit the data message to the subsequent node. Also, the AODV starts a discovery process using RREQ and RREP [32]. The authors have employed some quantitative metrics for performance evaluating of a routing protocol for MANET. The PDF, NRL, E2E delay, and Packet Loss are the proposed evaluation metrics [32]. The performance evaluation has been carried out by applying the random way-point model and using the NS 2.34 with adopting IEEE 802.11 as the MAC layer protocol [32]. The results show that the DSR performance drops in high dense, high mobility networks [32]. The results showed that the AODV protocol is better in high dense networks. Moreover, the results confirm that in networks with few nodes and low mobility, the AODV is not a suitable solution. Still, AODV is better performance in high-mobility with high dense networks [32]. The results show that AODV is a suitable protocol in high-mobility MANETs with a large number of nodes. DSR performance decreases in the high dense with high mobility networks.

T. Bhatia et al. examines the performance of proactive protocols, reactive protocols, and hybrid protocol such as ZRP [15]. T. Bhatia et al. have proposed three different scenarios in the simulation by NS2 for performance and QoS evaluation. The throughput, PDF, NRL, E2E delay are the proposed performance metrics for comparative evaluation [15]. The results prove that the reactive protocols outperform the proactive in all scenarios in terms of throughput and PDF. On the other hand, the proactive protocols are better than reactive in terms of E2E delay and NRL. Moreover, AODV presents the outstanding performance compared to DSR and OLSR routing protocols. On the other hand, DSDV presented medium performance, and ZRP is the worst [15]. While changing speed in small networks, DSR indicated a high PDF. Accordingly, with on-demand protocol, there is a possibility of new effective routes to be discovered that leads to fewer packet loss but creates more routing packets and lightly more E2E delay. Growing the nodes' speed causes higher packet drop, more NRL, and more delay [15]. DSR works better in slight MANET but fails in high dense MANET where the AODV is greatly efficient. AODV and DSR appear improved performance than DSDV with high mobility MANET. ZRP can be more efficient by determining the proper zone radius [15].

R. Asokan et al. have proposed a scheme to improve MANET routing using the temporally-ordered routing algorithm (TORA) among self-healing and optimized routing techniques (SHORT) [33]. SHORT enhances routing through routes observing and updating. The proposed system monitors the routing route and tries to reduce the route length when it is possible to reduce the delay and improve the throughput [33]. The authors have proposed two models of SHORT: path-aware (PA)-SHORT and energy-aware (EA)-SHORT [33]. PA-SHORT optimization by maintaining routes to decrease the number of hops. The EA-SHORT is to maintain MANET power. EA-SHORT increases system lifetime. EA-SHORT utilizes the nodes with higher residual energy and avoids nodes with low battery energy. The proposed approach uses a self-healing mechanism to avoid over-used nodes while other nodes are idle by managing the traffic load [33]. Power-aware techniques are combined within the TORA protocol to shorten the routes but do not respond to little variations. The authors have simulated TORA-SHORT using the NS-2 and have analyzed the QoS in terms of throughput, packet loss, E2E delay, and energy.

The simulation results show that in high mobility, the two approaches present small deterioration in throughput as a result of high-link breakage. Further, throughput increases with growing the pause time. The results prove that while increasing the quantity of active mobile nodes, the delay increases. The more node velocity, the more packet loss [33]. The more the number of nodes, the more packet loss. Similarly, the more active nodes, the more overhead. The proposed protocol is better than the TORA in throughput, E2E delay, PLR, and lifetime [33].

TABLE I. MANET POWER-AWARE ROUTING PROTOCOLS COMPARISON

Reference	Protocol	Metrics	Simulator	Results
A. Paveen et al.[4]	Modified Power-aware AOMDV protocol	Energy, Delay, and Throughput, ERR and TV.	Unknown	Increases network lifetime and decreases packet loss. Offers higher reliability and better availability of alternative routes. On the other hand, increases the network overhead.
S. Kumar et al.[6]	EELBAOMDV and others	Energy consumption, throughput, RBP, signal strength, number of alive nodes, E2E delay, PLR, QoS, lifetime, routing overhead, and energy level.	NS2, NS3, Br-Sim, MATLAB, math. analysis	The study shows that the EELBAOMDV is better performance than the various energy aware protocols.
M.Anand et al.[12]	IRAODV	PDR, E2E delay, throughput, consumed energy, Residual energy, and RSS.	NS-2.35	The IRAODV provides better performance compared to the AODV protocol.
T. Bhatia et al. [15]	AODV, DSDV, DSR, OLSR, and ZRP	The throughput, packet delivery fraction, NRL, and E2E delay.	NS2	Reactive protocols exceed the proactive in terms of throughput and PDF. Proactive are better in terms of E2E delay and NRL. DSR shows improved performance in limited size networks. As density increases, it fails. AODV and DSR are more appropriate in high mobility.
Zheng et al.[16]	TAAOMDV	Remaining energy, BW, queue length, the number of nodes, node speed, data rate, QoS, and PSP between nodes.	NS2	The TA-AOMDV is efficient in MANET high-speed network applications.
E. Pereira1 et al.[17]	DSR	Delay, PDR, overhead, and packet loss.	NS-2	Better PDR is observed when TCP is used. Improves PDR percentage when nodes are moving and better battery power conserving.
S. Mostafavi et al.[20]	QMARAODV	Mobility Ratio, energy efficiency, QoS, and congestion load.	OPNET 14.5	QMAR-AODV improves data reception and enhances network throughput compared to the E2E-LREEMR.
R. Sahu et al.[21]	ZBLE	E2E delays, throughput, energy consumption, and network life, RSS	NS-2 Ver. 2.35	ZBLE is energy-sensitive protocol, provides a more dependable performance than AODV and AOMDV, improves energy consumption, and lifetime.
S. Hamad et al.[22]	CAQRP	Mobility, average file discovery, delay per query, and battery energy.	NS-2	CAQRP outperforms Gossiping-LB in recall. CAQRP has a better average file discovery delay.
R. R.Prasad et al. [23]	EA-DRP	PLR, PDR, average energy consumption ratio, and lifetime.	NS-2	Improves the routing performance, EA-DRP has lower PLR compared to the DSR and CMMBCR, improves the PDR, increases the nodes lifetime, and lower power consumption.
R. Patel et al. [24]	Efficient elay based load balancing routing protocol.	PDR, throughput, delay, and PLR.	NS-2.35	Smaller overhead, better PDR, increased throughput, decreased delay and decrease PLR in the proposed protocol compared to the PEAOMDV.
S. Benatia et al. [25]	ESMRua	Normalized Routing overhead, energy consumption, PDR, QoS, number of nodes, reliability, energy, and successfully received packets.	NS-2.35	ESMRua enhances the performance of MANETs, reduces the routing overhead, reduces energy consumption, increase network lifetime, increase PDR, and increase network reliability.

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TABLE I- CONTINUED FROM PREVIOUS PAGE

Reference	Protocol	Metrics	Simulator	Results
R. ruzgiene et al. [26]	Energy efficient, Safe-weighted lustering routing for IoT	Threshold value for energy of the node, node energy and network lifetime.	MATLAB	Using a combination method for information routing increases the sensors' lifetime due to the dynamical cluster head lecting. supports in the accessibility of services for a longer period.
S. ukherjee Et al.[27]	IoT model to anage apps. Via Wireless sensor	The delay of data packet, cost, scalability, energy, and traffic.	OMNET++	The model offers better energy efficiency with a reduced delay.
B. ietrzyk et al. [28]	EERD	Energy consumption, delay, success ratio, and calability.	NS-2	The protocol has a lower energy consumption and more balanced energy utilization than SR and ESDSR protocols and better delays and success ratio.
Alameri [29]	Energy efficient and safe weighted clustering routing for IoT	Node energy, and network lifetime.	MATLAB	The results prove that the combination technique in WSN routing extends sensor lifetime.
J. Sobral et al. [31]	LOADng-IoT	PDR, average consumed energy/received data bit, control message overhead, and latency.	Cooja	LOADng-IoT presented improved performance for high mobility, high density, and sparse MANETs. Offers better QoS, larger efficiency, and more reliability. LOADng-IoT offers the most suitable internet node to forward messages, and is lower impacted by the interferences.
T. Sunil et al. [32]	AODV, DSR	The PDF, NRL Average E2E Delay, and Packet Loss.	NS2 2.34	AODV is suitable for voice, video, and file transfer apps. The DSR performance drops in high mobility and high dense networks.
R. Asokan et al. [33]	TORASHORT, PASHORT, and EASHORT	The E2E delay, throughput, packet loss, and control overhead.	NS2	PA-SHORT, and EA-SHORT are better than the TORA in throughput, E2E delay, packet loss, and network lifetime.
S. Abid et al.[35]	DEERP	Remaining energy, energy consumption, energy efficiency and performance.	NS2	The results show that the framework improves energy efficiency and performance as compared to the other selected protocols, DEERP consumes minimum energy in Idle, TX, and RX modes compared to other protocols. DEERP has the maximum remaining energy as compared to other protocols.
T. Sabaa et al. [36]	SEF-IoMT	Network throughput, packet loss rate, E2E delay, and energy consumption.	NS3	The simulation proved that SEF-IOMT is energy-efficient and improves the security with lower delay.
J. Souza et al.[38]	Specific FANET routing Strategy	QoS, QoE, Mobility Level, Flight Autonomy, and RSSI.	NS-2	LOA consumes much energy during nodes' speed increasing, and LOA improves the performance. LOA offers better PDR, and grants better performance in packet drop metric.
S. Alani et al.[40]	LOA	PDR, remaining energy, and the dropped packets.	MATLAB	Smaller overhead, better PDR, increased throughput, decreased delay and decrease PLR in the proposed protocol compared to the PEAOMDV.
N. Kaur et al. [43]	BFOA	Energy consumption, The amount of saved energy, number of nodes, and the number of communications.	Unknown	BFOA reduces energy consumption by applying TORA-AHBFO approximately 85% , the adaptive TORA is better performance than the adaptive DYMO.
M. Vanjale et al.[46]	LMDSR	Network lifetime, energy consumption, PDR, and E2E delay.	XCTU	The measured values are lower than the estimated values, LMDSR provides efficient improvements in network lifetime, reduces energy consumption, and improves PDR.
H. Saha et al. [47], [48]	EMFBOD	PDF, the E2E delay, and NRL.	Arduino and Zig-Bee	EMFBOD in a benign environment is almost comparable to the existing protocols, but in a malicious environment, it is more .

Y. Chegra et al. introduced a comparison for routing of traditional MANET routing protocols, including those efficient in high dynamic conditions [34]. The authors compared ten different protocols along with their efficiency in mobility and the connection failure effect on performance. The authors show that reactive and flat protocols can provide high performance in highly-dynamic networks. On the other hand, proactive protocols do not submit high scalability due to repeated updating process that uses up a significant amount of bandwidth [34].

B. Kwak et al. proposed a flexible and consistent mobility measure scheme that can customize the mobility representation [37]. The proposed scheme matches the linear relationship of the link change rate with mobility model [37]. The consistency is the backbone of the proposed model because any change in the link reflects on the routing overhead. B. Kwak et al. have simulated the proposed model to evaluate its performance through several scenarios. The scheme has proposed several mobility models, for instance the Random Way-Point mobility (RWP) scheme, the random Gauss-Markov (RGM) model, and the Reference Point Group Mobility (RPGM) [37]. The simulation results show the strength of the scheme to recognize the link changes for all mobility situations. The scheme offers a combined method of measuring the mobility degree [37].

J. Souza et al. presented a routing protocol for FANET. Mobility of Unmanned Aerial Vehicles (UAV)s changes the network topology that reflects significant difficulties such as routes discovering and maintaining [38]. The Flying Ad-hoc Network (FANET) always serves in hard to reach infrastructure-less areas. The usage of devices such as UAV promotes flying networks [38]. The main challenge in FANETs is to place the UAVs in a proper direction to monitor the region [38]. Another significant factor is the autonomous flying of the UAVs. UAV observes a specific region by obtaining real-time images via Quality of Experience (QoE) metrics [38]. The QoS metrics do not reveal the user experience of a video. The authors have simulated the proposed strategy using the NS2 simulator [38]. The proposed protocol has been analyzed compared to the AODV and OLSR. The evaluation has been conducted by classic QoS and QoE metrics in terms of three input metrics: Mobility Level, Flight Autonomy, and RSSI [38]. The authors utilize the Gaussian fuzzifier because of its aptitude to decrease noise of input factors. In video simulation, the protocol gained 127% above the OLSR and 51% better than the AODV [38]. Moreover, the proposed protocol provides a visual assessment of the received files by the MSU Video Quality Measurement Tool Software [38]. Based on the visual evaluation, the Fuzzy Adaptive System improves the performance than other techniques. The proposed scheme improved the performance by 35% than AODV and OLSR [38].

Table I presents a comprehensive comparison of different power-aware routing protocols that are based on software enhancement that have been presented in the literature survey.

B. *Bio-inspired techniques*

Biologically inspired solutions are based on the natural response of individual populations. These inspired solutions offer reliable mechanisms and algorithms for improving several significant aspects. The natural behaviors can lead to the required optimization. Multiple types of bio-inspired techniques have been employed in obtaining successful solutions. As shown in Fig. 2, Ant Colony Optimization (ACO), Particle Swarm Optimization (PSO) algorithm, Genetic Algorithm (GA), Water Drop Algorithm and Bacterial Foraging Optimization Algorithm (BFOA) are examples of bio-inspired techniques used in the literature, [39], [40], and [41].

M. Agrawal et al. proposed a protocol to determine the path that has the minimum number of nodes with the highest value of residual battery power (RBP) based on GA [41]. The proposed fitness function to evaluate the obtained paths is [41]:

$$Fitness = \frac{(\frac{1}{N}+ARBP)}{2} \quad (1)$$

Where N is the number of nodes and the (ARBP)

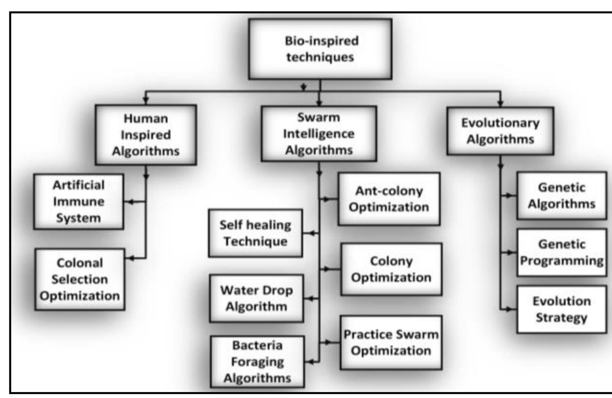

Figure 2. Bio-Inspired approaches

parameter is defined as the path nodes remaining battery power average. The algorithm has been simulated and evaluated [41]. The results showed that the proposed algorithm enhances network performance, enhances the network lifetime, increases PDR, and improves latency due to selecting the shortest route with fewer hops [41].

J. Shi et al. discussed the benefits of applying the GA approach in MANET [42]. The authors in [42] presented the various models that have utilized the GA approach in MANET successfully. GA is an evolutionary approach based on the natural selection of the best suitable genes from the whole population. GA selects the valid solutions which meet the algorithm criteria. J. Shi et al. introduced the various proposed fitness functions and metrics that are based on the nature of the problem and the network requirements [42]. The study proved that the GA approach is successful in solving different kinds of MANET problems, electing the best solution, and offering alternative solutions. Moreover, GA improves network performance and increases routing reliability as well as improves the QoS.

S. Alani et al. proposed a new technique to improve MANET routing efficiency called the Lion optimization algorithm (LOA) for determining the best route between a source and a destination [40]. Cost-efficiency and reliability are significant characteristics correlated with wireless networks. In MANETs, the node not only acts as a receiver and transmitter but also plays as a router for data packets [40]. For each lion, the best solution is determined to initiate sending data then modify transmission power accordingly for every node. The proposed algorithm assumes that the RREQ is sent by a source node, only to its one-hop neighbor nodes [40]. The proposed fitness function K-value list is kept in the Routing Table (RT) entry for every node. The source node stores the updated fittest path during the transmission of data. The LOA was simulated using MATLAB to evaluate its performance. The PDR, remaining energy, and the dropped packets are considered as the performance metrics [40]. The results showed that LOA provides better performance compared to other approaches due to using the route of the highest energy level. On the other hand, LOA consumes much energy with increased nodes' speed. Furthermore, LOA presents better PDR and enhanced packet drop ratio compared to the AODV [40]. Finally, LOA protocol presents better performance compared to AODV due to determining the shortest and highest energy routes.

F. Sarkohaki et al. stated that the OLSR does not consider the impact of some parameters, such as node energy level and link length [13]. Principally, OLSR concerns finding the shortest path with the conception of Multi-Point Relays (MPR) which reduces the network overload and submits a limited number of links to the network nodes. OLSR sends Hello packets to realize each node neighbors, store the addressed information in a table and assigns Topology Control (TC) messages in the network using MPR points [13]. The route selection process is provided based on the routes with higher energy and least hop counts by using the Dijkstra algorithm. F. Sarkohaki et al. proposed an improved model of the OSLR protocol called Artificial Immune System for OLSR (AIS-OLSR) utilizing the Artificial Immune System (AIS) [13]. The AIS-OLSR considers hop count, intermediate nodes' residual energy, and distance between nodes to correct the OSLR lacks. AIS-OLSR is developed with defined steps: negative selection algorithms, clonal G algorithms, affinity, mutation, colonization, and implementation [13]. The proposed protocol has been simulated by using the NS-2 to evaluate its performance. The results showed that the AIS-OLSR outperforms both the OLSR and the Energy Aware-OLSR protocol (EA-OLSR) protocols. OLSR improves PDR, throughput, end-end delay, and lifetime [13]. Several improved algorithms like GA and Evolutionary Programming (EP) are using the Particle Swarm Optimization (PSO) and Ant Colony Optimization (ACO) to accomplish their methodologies. BFOA has been applied to several domains successfully.

N. Kaur et al. have proposed a protocol based on the Bacterial foraging optimization algorithm (BFOA). N. Kaur et al. have presented an energy consumption comparison between Dynamic MANET on demand (DYMO) routing Protocol and the Adaptive Hello DYMO (DYMO-AH) [43]. Over the long-distance, DYMO consumes energy quickly for the hello communication messages, where the conserved energy is reduced as the number of communications is increased. TORA, the Adaptive Hello TORA (TORA-AH), DYMO, and DYMO-AH protocols have been utilized for the proposed algorithm performance evaluation. Energy consumption in TORA is growing with increasing the dense of nodes. Alternatively, in TORA-AH, the energy consumption rate is nearly constant with increasing the number of nodes. With the DYMO-AH algorithm, the unwelcomed hi messages get reduced as well as decreasing the consumed energy. The results prove that the DYMOAH performance is more reliable than DYMO, DYMO-AH use up less energy than TORA-AH [43]. DYMO-AH is more beneficial than TORA-AH, where DYMO-AH improves stability and optimizes the consumed energy. By utilizing the BFOA, the results are much better. The results proved that applying BFOA decreases energy consumption by approximately 85% [43].

D. Sensarma et al. proposed a QoS-aware routing algorithm (IWDRA) based on the Intelligent Water Drop (IWD) [14]. The IWD packet that propagates through the link that maintains a better quality will obtain

TABLE II. BIO-INSPIRED TECHNIQUES

Reference	Protocol	Metrics	Simulator	Results
F. arkohaki Et al.[13]	AIS-OLSR Artificial Immune	Hop count, intermediate nodes' residual energy, PDR, E2E delay, throughput, and distance between nodes	NS-2	AIS-OLSR outperforms both the OLSR and the EA-OLSR. OLSR improves PDR, throughput, E2E delay, and lifetime.
D. ensarma Et al. [14]	IWDRA Intelligent Water Drop	Throughput, QoS, lifetime, network stability, and PDR.	Unknown	IWDRA adaptive protocol convenient for the high mobility network, and IWDRA discovers multiple paths. IWDRA increases the throughput, offers better QoS that improves MANET lifetime and stability.
B. Devika Et al. [39]	C-EWA Earth Worm	Power, mobility, throughput, delay, and connectivity.	NS2	C-EWA approach offers supreme power, connectivity, and throughput. CEWA technique achieves the benefits of both the EWA and the chronological model.
S. Alani et al.[40]	LOA GA	PDR, remaining energy, and the dropped packets.TV.	MATLAB	LOA consumes much energy during nodes' speed increasing, LOA improves the performance, LOA offers better PDR, and grants better performance in packet drop metric.
M. Agrawal et al.[41]	GA	The number of nodes, QoS, Fitness value, and the ARBP.	Implemented JAVA software	The proposed GA improves Network performance and vercomes the delay.
J. Shi et al.[42]	A study for sveral protocols Based on GA algorithms	Different fitness functions, network reliability, energy, Mobility, PDR, E2E delay, routing cost and QoS.	Several	The GA approach is successful in solving problems, GA could optimize MANET performance, increases network reliability and improves the QoS.
N. Kaur et al. [43]	Bacterial Foraging ptimization Algorithm (BFOA)	Energy consumption, The amount of saved energy, number of nodes, and the number of communications.	Unknown	BFOA reduces energy consumption by applying TORA-AHBFO approximately 85% , the adaptive TORA is better performance than the adaptive DYMO.

more velocity than the other IWDs that support reaching the sink faster. The mathematical model of the proposed algorithm consists of route finding, route maintenance, and route failure management phase. The authors have simulated the proposed model to evaluate IWDRA QoS assurance. The results proved that IWDRA is an adaptive technique and appropriate for the high mobility network. IWDRA discovers multiple paths to a destination node that meet QoS metrics, such as the individual node's remaining energy, buffer spaces, and velocity [14]. IWDRA increases the throughput of the network, offers better network QoS, which increases lifetime, network stability, and PDR [14].

B. Devika et al. proposed a crossbreed system called Chronological-Earth Worm Optimization Algorithm (C-EWA) [39]. Using the NS2, the authors has simulated the C-EWA and the existing protocols, such as the Optimized Power Control (OPC), Local Tree-based Reliable Topology (LTRT), and distributed power management (DISPOW). The proposed evaluation metrics are: power, mobility, throughput, delay, and connectivity compared to the other protocols. The evaluation analysis shows that the proposed model has better results compared to the existing techniques [39]. The protocol has the extreme power, the most connectivity, and highest throughput. C-EWA has minimum mobility and least delay [39]. The model achieves the benefits of both the EWA and the chronological model. EWA approach creates better benchmark results and manages the real-world issues efficiently. EWA presents a balance between variants [39]. On the other hand, the Chronological concept updates the solution based on the history. Further, the power of the chronological concept offers events-time image. Accordingly, the integration of the Chronological conception with the EWA supports to discover the cluster head effectively [39].

Table II is a comparative summary of the Bio-Inspired techniques presented in our survey.

3. HARDWARE APPROACH

The hardware approach in the power-aware MANET routing attempts to improve network performance using improved low-power, high technology hardware in both the network infrastructure and nodes. This approach improves QoS in terms of power consumption, throughput, and PLR, etc. such as in [44] and [45].

M. Vanjale et al. introduced a modified algorithm called Least Max DSR (LMDSR) that considers the limited nodes energy and manages the nodes' residual energy on the probable paths to avoid node over-usage [46]. The LMDSR algorithm looks at the shortest path and the residual battery levels of the nodes to reduce routing failures. The authors in [46] have implemented a low-cost hardware circuit using the Arduino Mega and ZigBee transceiver. Four different communication scenarios have been utilized based on a static line of sight and mobility of nodes. The proposed model shows that the estimated and measured lifetimes are the highest when the nodes are stable with a clear line of sight. Further, the estimated and measured lifetimes are the lowest when mobility with a variable distance between intermediate nodes. The results show that the measured network lifetime is less than the mathematically estimated values in all test cases for both protocols [46]. Additionally, the measured values decrease may exceed the 39% from the estimated values with DSR protocol but almost reach 19% with the proposed LMDSR protocol. LMDSR algorithm provides an efficient improvement in the network lifetime by 35%and reduces energy consumption by 21% with a slight improvement in PDR. On the other hand, the E2E delay decrease has been observed with LMDSR protocol [46].

H. Saha et al. proposed a secured, energy-aware modified fidelity based on-demand (EMFBOD) protocol [47], [48]. The authors proposed three performance metrics: the PDR, the E2E delay, and the normalized routing load (NRL) [47], [48]. A node sends Neighbor Request (NREQ) packets, waiting for the Neighbor reply (NREP) packets arriving where the source node transmits an RREQ packet and waits for the RREP. Once the source node gets the RREP, it forwards it to the following hop once verified it and waits for the acknowledgment (ACK) packet. If ACK is not gained, the node will lessen the fidelity by one and transmit a report to the fail array (FAN) for that node. The node is recorded in a blacklist (BL) while detecting three different node recommendations. The system hardware has been implemented using the Arduino platform. A node includes Atmel 8-bit AVR microcontroller and a ZigBee to detect signals with the same PAN ID. The system has been evaluated compared to Trusted AODV (TAODV), Fidelity Based On-demand (FBOD), Secure AODV (SAODV), and Authenticated Routing for Ad-hoc Networks (ARAN) protocols [47], [48]. The EMFBOD presents a reduced PDF with a malicious environment where the TAODV PDF increases after the trust are built. FBOD, SAODV, ARAN protocols present instability in an innocuous environment. Moreover, TAODV presents better NRL in both environments where SAODV and ARAN present medium NRL. In contrast, FBOD cannot avoid the malicious nodes from the network. EMFBOD presents a limited increase in the E2E delay compared to other techniques. EMFBOD presents better PDF and lower delay in malicious environments, [47], [48]. A trade-off between the performance metrics is required.

A. Elbanna et al. presented the current and future trends of hardware improvements of mobile devices and their impact on MANET applications [49]. The wide range of mobile applications has enhanced hardware boundaries in micro-processing devices. Nodes in ad-hoc networks have several constraints, such as bandwidth, memory, power, and computational capability. The hardware improvements have solved several MANET difficulties. MANET real-time communications and Cryptography have been developed by hardware evolution.

P. Sarma et al. presented a low-cost Data Acquisition System (DAQ) to monitor sensor data using Arduino. DAQ acts as the bridge between analog and digital environments. Several components are related to DAQ, such as nodes, signal processors, PCs, databases, data acquisition applications. The proposed model focuses on a real-time DAQ for monitoring continuous data from a sensor [45]. The proposed model consists of a sensing unit, a Signal Processing Unit (SPU), and an Arduino UNO Development Board (AUDB) that transforms the output of the SPU into digital form. On the other hand, the AUDB output is transferred to the PC through a serial port for real-time monitoring [45]. The DAQ generates a series of data and charts for different time intervals, where a python program stores the generated data [45]. The proposed system is cost-effective compared to other DAQ models, power-efficient, where it consumes little power and will reduce measurement mistakes.

P. Lakshmi et al. in [44] demonstrated the importance of Embedded Systems (ES) to IoT that aims to establish extensive connections and deal with an expanded range of [44]. IoT allows a remote connection for ESs and smart objects through the internet. Arduino architecture core is an Atmel controller. A smartphone is an ES model with a Central Processing Unit (CPU) that manages the interior components and controls the output devices like wearable devices and supports a wide variety of sensors, such as accelerometer, ambient light sensors, and gyroscope. OPENIoT is an open-source platform to provide several services and deliver many Sensing as a Service (Se aa S) functions. Google joins location services through the cloud, and CloudAPI has an extensive capability in IoT for all architecture levels from firmware to hardware [44].

TABLE III. HARDWARE APPROACH

Reference	Contribution	Results
J.Thi et al. [3]	An efficient remaining-energy assessment model. The scheme considers the voltage, the temperature, and batteries' load features.	The proposed scheme improved the WSN performance and enhanced the unbalanced energy consumption and network lifetime .
P. Lakshmi et al. [44]	A study of the ES and IoT devices.	The paper discussed the ES architecture in general, Types of embedded boards, explained the importance of ES to IoT.
P. Sarma et al. [45]	A light weight, simple DAQ model implementing concerning the Cost and Power efficiency using Arduino.	The designed scheme is greatly cost-effective compared to other DAQ models, decrease measurement mistakes, and power-efficient.
M. Vanjale et al.[46]	LMDSR is an algorithm combined to a hardware improvement of routing performance in terms of lifetime, energy consumption, PDR and E2E delay.	The measured values are lower than the estimated values, LMDSR algorithm provides an efficient improvement in the network lifetime, reduces energy consumption and improves PDR.
H. Saha et al. [47], [48]	A hardware approach for routing improvement by using Arduino and ZigBee.	EMFBOD in a benign environment is almost comparable to the existing protocols, but in a malicious environment.
A. Elbanna et al. [49]	A study for the hardware development impact on MANET and resources.	Mobile devices, batteries, Cryptography, MANET, applications, and the micro processing devices have been impacted much by the hardware improvements in the last few years.
S. Kumar et al.[56]	Introducing a prototype of a wireless patient monitoring system considering the distance between the nodes metric using a hardware experiment and NesC programming.	The results show that the device is continuously monitoring the heart rate, sending messages, and calling the doctor successfully, a better range of routing nodes can be used in association with an improved routing algorithm to prolong the MANET's overage area.

J. Thi et al. proposed an efficient residual-energy assessment scheme. This scheme considers the voltage, the temperature, and the load characteristics of batteries [3]. However, a voltage-based estimation is frequently applied to evaluate remaining energy. In a battery-based sensor structure, batteries, sensors, and system characteristics should be considered [3]. J. Thi et al. proposed scheme uses less memory space and estimates remaining energy with lower calculation overhead [3]. Temperature and load are significant aspects to evaluate the remaining-energy. The residual-energy database considers four different temperatures and loads patterns among a tiny table. The simulation findings illustrate that the proposed scheme enhances the WSN performance compared to the voltage-based model. The results proved that the proposed model enhances the unstable power consumption and increases network lifetime [3].

Table III is a demonstrative table of the Hardware Approach of various routing protocols that have been presented in the literature survey. Moreover, many studies in different MANET applications such as healthcare, agriculture, underwater routing, and VANET using several approaches have been presented such as in [50], [3], [51], [52], [53], [54], and [55]. These studies are concerned with MANET routing power consumption direction.

4. DISCUSSION

In the previous sections, we have presented and classified the existing approaches of power-aware routing for MANETs. We can clearly observe that traditional routing protocols are inefficient with the networks that have intensive changeable structure. As we have seen, power-aware routing in MANET has been thoroughly studied. However, many issues have been analyzed, and others are still open. Next, we address some of these issues.

- The software approaches are widely utilized by either enhancing the traditional routing protocols or by using bio-inspired techniques.
- The traditional protocol improvements are achieved by adding context-aware query algorithms or adding new entries to the RREQ. These additional algorithms or packet entries aim to achieve a specific purpose such as network load balancing, network rapid change adapting, mobility control, battery-energy conserving, shortest-path finding, and avoiding the low-energy nodes.
- The research findings claim that bio-inspired techniques are effective and adaptive in multi-input problems.

- The GA technique is efficient in finding the best routing solution besides offering alternative routing solutions. These alternative solutions increase network reliability, stability, and QoS.
- The fitness function adjusts the value of the routing protocol parameters in real-time and increases routing performance.
- The hardware approaches are based on using state-of-the-art technology in electronics and applying them to network infrastructure and sensors' nodes. Thanks to the evolution of electronics components manufacturing that grant very tiny and low-power components besides the high-capacity batteries.
- Due to innovative hardware technologies in wireless such as Wi-Fi, Bluetooth, 5G, and other communication techniques, the routing power consumption has decreased, the network's overall lifetime has increased, and the network quality of service has increased.
- Due to the changeable topology in MANETs, most of the algorithms depend on different thresholds and parameters to accommodate topological changes. Those thresholds are regularly experimentally determined based on specific routing attributes and network configuration.
- We can't claim that a specific routing protocol or one algorithm provides the most proper performance.
- We can't also assume that a particular metric is the only metric that should be considered for network performance evaluation.
- We evaluate the routing performance in terms of multiple specific metrics.
- Trade-off analysis is essential to achieve the expected QoS. The trade-off process depends on network limitations and system operational requirements, as shown in Fig.3. More throughput involves more routing load, more routing cost, and more power consumption. Consequently, the more throughput, the more power consumption.
- Security requires more algorithms, more extra transmitted packets between nodes to ensure routing security, and requires more cryptographic algorithms. Therefore, the more security procedures, the more power consumption [57]. Also, the more practiced security schemes, the less throughput.
- MANET's QoS routing needs discovering a route from to a destination as well as determining the route that meets the QoS requirement. That route is usually given in terms of specific proposed metrics and parameters such as power consumption, throughput, bandwidth, loss probability, and security. Therefore, a trade-off between the correlated areas is a must.

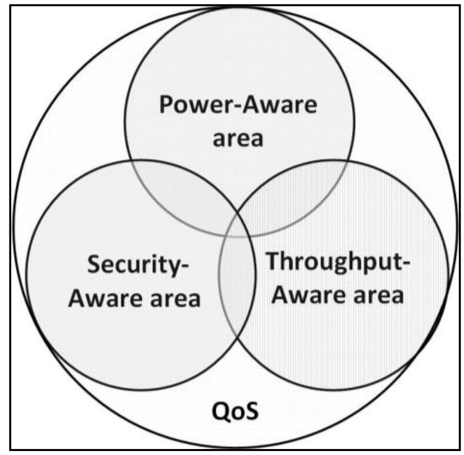

Figure 3. MANETs' trade-off

5. Conclusion

MANETs are infrastructure-less networks that confront several challenges. These challenges include limited node's battery energy, mobility of the nodes, network security, and dynamic topology as nodes can leave or join the network anytime. Conserving the node's energy implies increasing the network lifetime. Several innovative routing protocols are proposed to achieve network power optimization. These proposed protocols are based on both software or hardware design techniques. The software technique is either performed by enhancing the traditional routing protocols or by using bio-inspired techniques. We have analyzed these techniques individually by conducting several comparative analyses. The GA is a powerful class of bio-inspired approaches. GA can be used in high changing topology networks to determine the most appropriate route and provide the best alternative routes. Consequently, GA increases network reliability. Although several routing techniques seem promising, many challenges need more research endeavors to be settled. A trade-off between different performance metrics is required to achieve the most desirable QoS.

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