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Machiwa, Erick

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Review

A comprehensive survey on linear programming and energy optimization methods for maximizing lifetime of wireless sensor network

Erick J. Machiwa[1,2] · **Verdiana G. Masanja**[1,2] · **Michael F. Kisangiri**[1,2] · **Joseph W. Matiko**[2]

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Abstract

The wireless sensor network (WSN) is considered as a network, encompassing small-embedded devices named sensors that are wirelessly connected to one another for data forwarding within the network. These sensor nodes (SNs) follow an ad-hoc configuration and are connected with the Base Station (BS) through the internet for data sharing. When more amounts of data are shared from several SNs, traffic arises within the network, and controlling and balancing the traffic loads (TLs) are significant. The TLs are the amount of data shared by the network in a given time. Balancing these loads will extend the network's lifetime and reduce the energy consumption (EC) rate of SNs. Thus, the Load Balancing (LB) within the network is very efficient for the network's energy optimization (EO). However, this EO is the major challenging part of WSN. Several existing research concentrated and worked on energy-efficient LB optimization to prolong the lifetime of the WSN. Therefore, this review collectively presents a detailed survey of the linear programming (LP)-based optimization models and alternative optimization models for energy-efficient LB in WSN. LP is a technique used to maximize or minimize the linear function, which is subjected to linear constraints. The LP methods are utilized for modeling the features, deploying, and locating the sensors in WSN. The analysis proved the efficacy of the developed model based on its fault tolerance rate, latency, topological changes, and EC rates. Thus, this survey briefly explained the pros and cons of the developed load-balancing schemes for EO in WSN.

Keywords Wireless sensor network (WSN) · Linear programming (LP) · Energy optimization (EO) · Load balancing (LB) · Maximizing lifetime · Routing protocols · Sensor nodes (SNs) · Energy consumptions (EC) · Traffic loads (TL) · Comprehensive survey

1 Introduction

In the past few years, wireless sensor networks have enormously grown due to their automation applicability in many sectors [1]. WSN is a combination of electronics and networking and consists of small embedded sensor devices. The sensor devices are connected and communicate with each other in an ad-hoc manner for exchanging data and information [2].

Verdiana G. Masanja, Michael F. Kisangiri and Joseph W. Matiko contributed equally to this work

✉ Erick J. Machiwa, machiwae@nm-aist.ac.tz; Verdiana G. Masanja, verdiana.masanja@nm-aist.ac.tz; Michael F. Kisangiri, kisangiri.michael@nm-aist.ac.tz; Joseph W. Matiko, jwmatiko@dit.ac.tz | [1]The School of Computational and Communication Sciences and Engineering, The Nelson Mandela African Institution of Science and Technology, Arusha, Tanzania. [2]Electronics and Telecommunications, Dar es Salaam Institute of Technology (DIT), Dar es Salaam, Tanzania.

The WSN is utilized for various sensing applications, and the architecture of the WSN is designed based on the requirements of the particular application [3]. The sensors in the WSN are transducers that convert physical phenomena, such as light, heat, motion, and sound into electrical or any other signals used by some other apparatus [4]. Thus, the WSN is utilized in environmental monitoring, health care, industrial, military, agriculture, security surveillance, entertainment sectors, smart buildings, and traffic control [5].

The loads in WSN are the amount of collected and forwarded data through the sensor nodes to reach the destination at a particular time. The data is transmitted by creating a connection among the sensor nodes and generating routes within the network [6]. Thus, the sensor nodes have the capacity to transmit the data to a particular range within the network [7]. So, the sensor nodes within the network are connected for transmitting the data from the source to the destination point [8]. When the loads are transmitted and received over a particular node then the lifespan and energy of the nodes are quickly drained out; also, more amount of data shared from several sensor nodes creates traffic within the network [9]. This caused increased data packet loss, an imbalance in energy consumption, and a reduced packet delivery rate. So, effective traffic load balancing is very important for the WSN in data transmission. The traffic load balancing extended the lifetime of the network by reducing the energy consumption rate of the sensor nodes [10]. Figure1 represents the routing based load balancing process in WSN.

As exhibited in Fig. 1, many Sensor Nodes (SNs) are initialized within the network. These SNs are clustered as per their Energy Consumption (EC) level, and a cluster head is chosen among the node clusters. Also, the cluster heads are linked with each other through the routing path, by which the sensed data are transmitted to the Base Stations (BS). The load received at the BS is balanced using a load balancer for balancing the EC of data packets and reducing the data loss. Further, the balanced load of data packets is transmitted over the WSN to the target users.

Several existing works like [11, 14, 15], and [18] concentrated on energy optimization-based load balancing in WSN. The developed works utilize the linear programming-based optimization models for an energy-efficient traffic load balancing in the WSN. Along with that several alternative energy optimization models are also developed in [68, 71, 73, 74], and [77] for the traffic load balancing in WSN. Thus, this survey briefly analyzed the merits, demerits, purpose, process, and applications of the developed load-balancing optimization models. The organization of the survey is represented as; Section 2 describes the research question and article selection strategy for the survey, Section 3 presents the survey on related works based on energy optimization in WSN, Section 4 indicates the overall analysis and the review summary, and Section 5 concludes the survey with future recommendations.

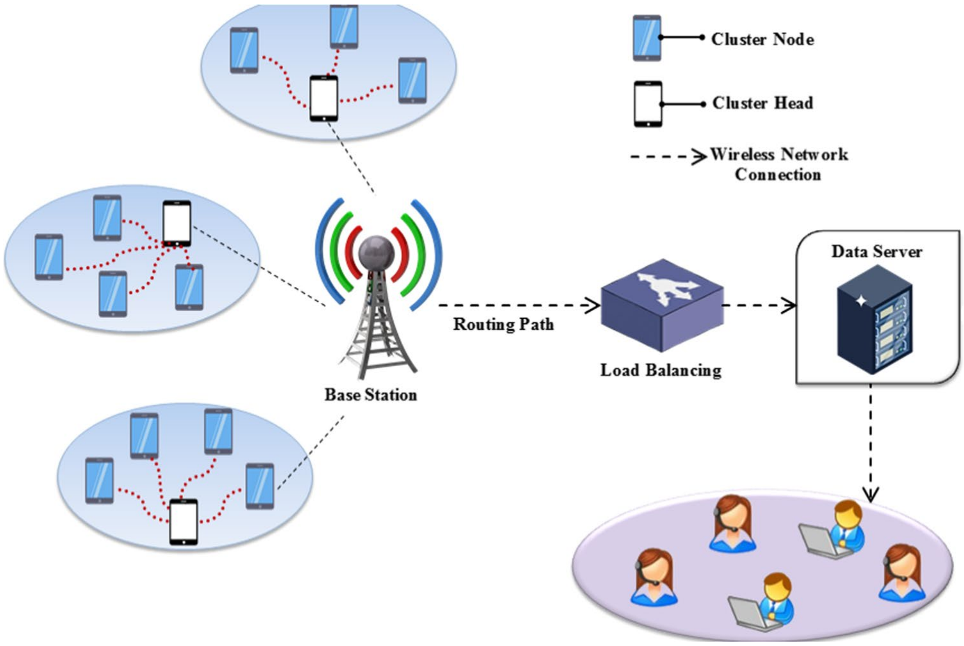

Fig. 1 Routing-based load balancing in WSN

1.1 Study motivation

As the usage of wireless communication systems rapidly increases in every field, reliable data transmission between source and destination becomes significant. However, the enormous data transferred through the wireless network system causes data traffic, resulting in information loss, communication delay, and eventually energy depletion of the sensor nodes being used frequently for traffic data transmissions . Energy consumptions by sensor nodes in the network is minimized by balancing the load, as balancing traffic load is equivalent to prolonging the lifetime of the sensor nodes. Moreover, enhanced load balancing is achieved by focusing on the energy consumption of the sensor nodes, which further improves network performance and the delivery rate of data packets. Considering its significance, energy-efficient load balancing approaches along with energy optimization (EO) methods are reviewed in this survey to provide ideas for future researchers to enhance the lifespan and performance of wireless sensor networks (WSN).

2 Research questions and article selection strategy for the survey

This survey proceeded in a way to understand the pros and cons of different load-balancing optimization models based on LP and other optimization algorithms. The research questions are also chosen to fulfill the objective of the review. The articles used for the analysis are also related to the review objective and utilized in a way to answer the research questions. The selection strategy describes the various criteria for choosing the articles for the review.

2.1 Research questions

In the realm of Wireless Sensor Networks (WSNs), effective management of energy consumption and load balancing is crucial for maintaining network performance and longevity. Energy Optimization (EO) is a key aspect that focuses on minimizing the energy consumption of sensor nodes, thereby extending the network's operational life. This involves the use of various routing protocols and Linear Programming (LP) optimization models designed to reduce energy consumption rates and balance traffic loads. Furthermore, exploring alternative optimization techniques can provide new insights and approaches for enhancing load balancing. To delve deeper into these aspects, the following research questions are posed.

1. What is Energy Optimization in WSN?
2. What are the different routing protocols utilized in reducing the Energy Consumption rate of Sensor Nodes in WSN?.
3. What are the different LP optimization models used in WSN for balancing the Traffic Loads?
4. What are the alternatives of optimization techniques for balancing the load of WSN? .
5. How to declare the best LP optimization approach for balancing the Traffic Loads in WSN?

2.2 Article selection strategy

The materials for the review are selected based on the keywords and appropriate synonyms of the keywords that are related to the objective of the review. The articles are collected from reputed search engines, such as Elsevier, Springer, IEEE, DOAJ, and PubMed article sources. From these sources, 80 related articles are chosen and surveyed to find out the energy-efficient load balancing optimization models. The articles published between the time period of 2017 and 2023 are only selected for the analysis. Only the English language articles and the materials based upon the objective of the review are taken for the survey. The following are the excluded parts of this review. The articles other than English language are not selected for the analysis. The articles published before 2017 are neglected, and the articles without the objective of energy optimization-based load balancing are also omitted. The exclusion criteria for the survey are described in Fig. 2.

The graphical representation of the article selection strategy for the review is presented in Fig. 3.

Figures 2 and 3 illustrate the exclusion and selection strategy of the articles for the survey. As expressed in Fig. 2, 150 articles were identified from the standard search engines. Among them, the article language, titles, duplication, and publication year are analyzed. Finally, 80 articles that are related to the research title in the English language and published in the time period from 2017 to 2023 are chosen for the survey. Figure 3 exhibits that more articles are chosen from the Scopus and IEEE journals and articles published before 2017 are not included for the survey.

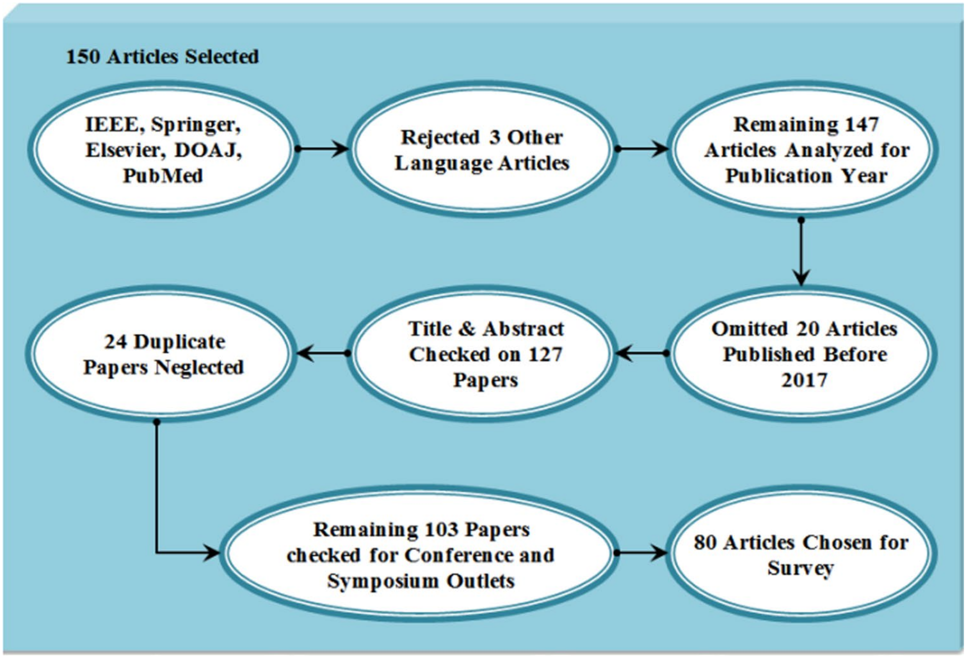

Fig. 2 Exclusion criteria of the survey

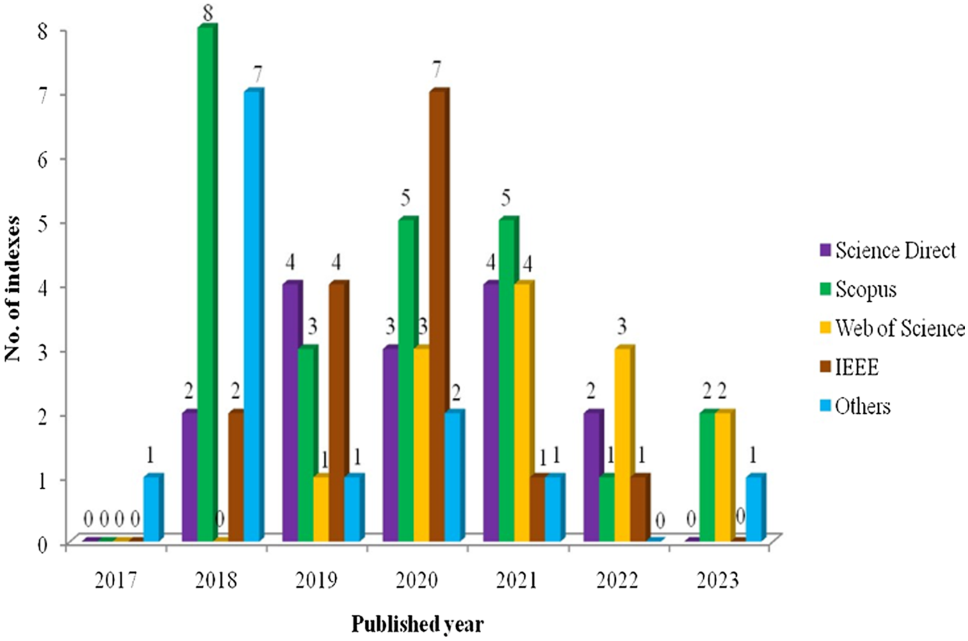

Fig. 3 Graphical representation of article selection strategy

3 Literature survey

Several works were developed in the existing research for maximizing the lifetime of WSNs with energy optimization based on effective load-balancing methods. This segment briefly described the different routing protocols, load balancing with LP-based optimization models, and some other optimization models for the energy optimization of WSNs. Sec 3.1 describes the basis of energy optimization in WSN; Sec 3.2 gives the analysis of various routing protocols used for load balancing in WSN; Sec 3.3 evaluates the different LP-based optimization models used in WSN for load balancing; Sec 3.4 surveys alternative load balancing optimization models; Sec 3.5 presents the performance and comparison analysis of different load balancing optimization models.

3.1 Energy optimization in WSN

The optimization of the WSN is necessary for reducing the redundancy and energy consumption rates of the network [11]. The energy optimization of the WSN is an efficient part of prolonging the lifespan of the network. The energy consumption rate of a network is determined as the total energy consumed by the sensor nodes while communicating [12]. The energy consumed by the sensor nodes within the network increased with the process of data forwarding from the source to the destination [13]. Balanced data transmission using efficient routing protocols can optimize the energy of the WSN [14].

Ezhilarasi et al [15] developed an optimal solution for energy minimization in the WSN. The Data Aggregation (DA) with an LB scheme was utilized for the EO in the network. The developed model concentrated on the EC by the SNs based on the grid network with the shortest path approach.The performance was evaluated in the Simulator-2 platform by using 250 nodes, an Omni antenna setup, and nodes'initial energy of 100J. The simulation analysis proved the effectiveness of the developed model based on an energy savings rate of 8% per node and a throughput rate of 18.2% However, the processing time of the developed model was high, which decreased the Packet Delivery Ratio (PDR).

Shailendra Mishra and Mayank Singh [16] presented an Improved Energy Efficient Communication Protocol (IECCP) based on the tree topology for WSN. In the developed work, the fixed sink was considered as the root, whereas the moving sink node and the SNs were considered as the branches and leaves, respectively. Non-orthogonal variable spreading factor code was utilized by the root for the identification of the information regarding the sender. The performance was assessed through the MATLAB software tool. For analysis, the network topologies of a 500 m region with 65 sensor nodes were utilized. The analysis results stated that the developed IECCP consumed less power of 12J than the conventional protocols in finding paths and transmitting data. Despite the IECCP saving 18J energy in WSN, it became complicated to handle with the large network because the hierarchy of the network became complex and the distance between the nodes was also increased.

Sunil Kr. Jha and Egbe Michael Eyong [17] employed different variations of Genetic Algorithms (GAs) for EO in WSN. Uniform mutation function, stochastic uniform-based selection process, and two-point crossovers were utilized in the developed model for EC evaluation. The performance analysis was conducted by using a single channel modulation and a packet size of 1000 bits. The performance analysis stated that the developed model obtained the minimum EC rate with the minimum distance betwixt the Cluster Head (CH) and BS. However, the developed model had an increased communication distance betwixt the CH and the BS, which affected the energy efficiency and inter-CH communication in the developed model.

Qian et al [18] introduced a Cluster-centric EO with a Mobile Sink (CEOMS) model in WSN. The CEOMS developed an Energy Density Function (EDF) of WSN and a directivity motion performance function of the mobile sink for enhancing the probability of the remote SN. Centered on the Low Energy Adaptive Clustering Hierarchy Protocol (LEACH) architecture, the EDF and motion function selected the CH. The performance of the nodes clustering and motion of mobile sinks were assessed by using 100 sensor nodes with predefined initial energy levels. The probability of choosing optimal CH was set to 0.1 and 4000 bits length of monitoring data was utilized for evaluation. The experimental analysis showed that the CEOMS extended the network lifetime with a balanced load and decreased the data delay. However, the developed CEOMS was inapplicable to time-constrained applications because it did not handle the time-varying quality of WSN.

Table 1 explains the Energy Optimization models' performance analysis in WSN based on the EC rate, delay, throughput, and PDR. The EC rate is achieved by analyzing the whole energy consumed during the data transmission. The delay is the time needed to transmit the data packet from one node to another node, and the throughput is the amount of data packets moved successfully from one node to another in a given time period. The PDR is the ratio of data packets received at the destination point to the total data packets originating from the source point.

Mohammed Almazaideh and Janos Levendovszky [29] developed an energy-aware and reliable routing protocol to maximize the lifespan of WSNs. A multi-hop routing scheme with predefined reliability constraints was employed in the developed work for generating a path, where the source node forwarded the data packets to the Base Station. The energy efficiency was achieved by maximizing the path's residual energy for fulfilling the predefined constraints. Here, the analysis was carried out by developing the simulated network with 100 sensor nodes and a predefined data loss rate of 0.05. The experimental analysis demonstrated the developed model's efficacy. But, the established model ignored the energy level of the nodes, which reduced the developed model's reliability.

Table 1 Performance analysis of energy optimization models in WSN

Authors	Aim	Energy Consumption (J/s)	Delay (ms)	Throughput (bps)	PDR (%)	Limitations
Meysam Yari et al [19]	To improve WSN lifetime with energy-efficient topology	175	55.43	NA	85	High complexity
Chirihane Gherbi et al [20]	Load balancing scheduling algorithm for energy savings in WSN	50	NA	200	NA	Large redundant data processing
S. Govindaraj et al [21]	Energy Optimization in WSN using capsule neural network learning model	NA	42.73	NA	NA	Increased packet loss rate
Samaneh Torkzadeh et al [22]	Energy-aware routing in WSN based on ant-colony optimization	800	NA	NA	NA	Scalability Issues
Muhammad Adil et al [23]	To maximize network lifetime by an energy-efficient load balancing scheme	150	NA	15	10K	Risk of congestion
Rachit Manchanda et al [24]	Energy-efficient compressive data gathering in WSN	NA	NA	325		Inappropriate performance due to irregular sink mobility
Nader Ajmi et al [25]	Multi-weight chicken swarm algorithm for energy-efficient WSN	NA	75	650	89	Energy hole problem
Jian Zhang et al [26]	Cooperative relay selection for load balancing in WSN	25	NA	NA	NA	Doesn't notify the dead nodes
Kalpna Guleria et al [27]	Energy-proficient clustering algorithm for relay selection in WSN	680	30	45850	98.86	Early death of CH near the BS due to higher network traffic
Sukhchandan et al [24]	Multi-objective load balancing clustering technique in WSN	90	NA	NA	NA	Link failure issue in a dynamic environment

Sukhchandan Randhawa and Sushma Jain [30] presented an energy-efficient load-balancing scheme in WSN for 2-tier communication. In tier 1, the EC by the communication between the BS and the CH was reduced based on the space-time block coding over M-ary quadrature amplitude modulation and binary phase-shift keying modulation. In tier 2, the energy consumed during the communication between the SN and CH was decreased by the feedback control system's concept. The assessment was done by developing the simulated environment with multi-hop packet transmission. The analysis stated that the developed model effectively balanced the network traffic in real-time. But, the lifetime of the network dropped with more SNs included in the communication.

As EC impacts the network performance while transmitting data, it plays an essential role in determining the network lifetime. Hence, optimizing the EC led to the enhancement of the network performance. As discussed above, many authors explored different optimization mechanisms for developing the energy-efficient WSN. It is interpreted that developing complex techniques, such as tree-like structures, grid-like networks, motion function, and multi-hop routing further complicates the load-balancing process. Additionally, it is also necessary to focus on the distance betwixt the cluster heads and the BS and the application suitability on the inconsistent WSN. Also, the EC of every node is required to be examined in order to ensure its longevity. Along with energy efficiency, the network capacity is a required criterion, which aids in balancing the respective data packets.

3.2 Routing protocols for traffic load balancing in WSN

Routing was considered as the process of path selection within the network. The routing protocols were defined as a set of predefined rules used by the routers in the network to maintain reliable communication between the source and destination [31]. The routing protocols selected an efficient path for the data transmission from the source point to the destination point [32]. The routing protocols effectively clustered the sensor nodes for the data transmission, and the data transmission by the sensor node through the generated path consumed less energy and was determined as an optimal path [33]. The routing in the network faced more difficulties while selecting an optimal path that depended on the network type, channel characteristics, and performance metrics [34].

Elham Hajian et al [35] developed a mechanism of LB OpenFlow routing protocol in the Software Defined-WSN (SDWSN) for the load distribution reduction and prolonged the network lifetime. With the direct monitoring of the link load information and also the network running status, the protocol determined the LB routing in every flow of the network. The performance was assessed by designing the simulated network with one controller, 100 nodes, and 5 base stations. As per the simulation results, the developed model considerably enhanced the network's lifetime with balanced load distribution over the network. However, the developed protocol didn't consider the distance between the CH and BS, which increased the network's packet loss rate.

Muhammad Adil et al [36] presented a hybrid energy-proficient LB routing scheme in WSN networking for maximizing the lifespan of the network. The Dynamic Cluster-Based Static Routing Protocol (DCBSRP), Leveraging Ad-hoc On-demand Distance Vector (AODV) routing protocol, and Low-Energy Adaptive Clustering Hierarchy (LEACH) protocol were the utilized hybrid routing protocols for effective LB. The developed model employed a communication mechanism that used a dynamic CH node with a static route configuration for exchanging information within WSN. The performance analysis was made by declaring the simulation parameters, including 128 bytes of data packets, a transmission range of 120 M, and 10Mbps of channel bandwidth. The simulation analysis proved the significance of the established model in enhancing the network's lifetime. However, the developed model's complexity minimized its applicability to real-time employment in WSN. The following table 2 presents an evaluation of different routing protocols based on EC used for balancing the TLs in WSN.

Vahid Rahmati [45] introduced a near-optimum Random Routing Algorithm (RndRtA) for uniformly balancing the network loads in WSN centered on the connectivity matrix. The developed RndRtA algorithm was processed with a fixed transmission power over communication. The frequent update of the connectivity matrix and the rerouting of the network using RndRtA resulted in near-optimum routing paths in a few rounds. The experiments were done by defining the fixed connectivity coefficient between nodes and the number of nodes. The simulation results stated that the efficiency of the developed scheme improved with the update of the connectivity scores. But, the efficiency was only determined based on the optimal routing and neglected the physical position of the nodes, which also affected the efficiency of the developed scheme.

Table 2 Evaluation of routing protocols for traffic load balancing models in WSN

Reference	Purpose	Routing	Energy	Challenges
Murat Dener [37]	Load balancing, data merge process, and network mapping	Hierarchical routing protocol	2	High probability of data packet collision
Chuhang Wang et al [38]	Minimize energy consumption and load balancing using a chaotic genetic algorithm	Multi-hop clustering routing protocol	11.7	Slow convergence
Omar Adil Mahdi et al [39]	Data aggregation, energy, and load balancing	Energy-aware and load balancing routing scheme	11.65	High packet drop rate
S. Sivakumar et al [40]	Reduced latency, delay, and energy consumption with balanced loads and high PDR	Efficient fault-tolerant routing	29	Cannot ensure efficacy when a single link failed
Nadjet Khoulalene et al [41]	Prolong network lifetime with the network's traffic load balancing	Improved gossiping routing protocol	25	The delay was so long
Regonda Nagaraju et al [42]	Load balancing and data storage capacity improvement	Threshold sensitive energy efficient sensor network routing protocol	43	Limited processing and memory capabilities
Rahim Khan et al [43]	Determined sensor node criticality factor, residual energy, and optimized load balancing strategy	Criticality-aware routing technique	20	Ineffective results with the throughput and lifespan
Eyman Fathelrhman et al [44]	To extend the network lifespan in terms of load balancing and energy efficiency	Energy efficient scalable routing algorithm	10	The routes found were longer than necessary which increased the network overhead

Maryam Farahbakhsh and Meisam Nesary Moghadam [46] developed a Multi-class multipath Routing Protocol for Low power and lossy networks (MRPL). The developed approach generated a braided multipath routing graph based on the MRPL. An Energy Balanced Optimal Rate Assignment (EBORA) mechanism was employed to solve the TL optimization problem. The framework also tried to enhance the lifespan of the network by equalizing the energy dissipation rates of the nodes. For analyzing the network performance, the simulated environment was formulated with a 250kbps data rate, 120J of nodes'initial energy, and about 80 sensor nodes. The simulation results showed the developed model's efficiency in increasing the network lifetime along with improving the reliability of the network. But, the developed approach delivered a high amount of redundant packets to the destination point, which gradually increased the EC rate of the network.

From the above discussions, it is known that the selection of an optimal path greatly contributes to reliable data communication. Different routing protocols like software-defined, OpenFlow routing, DCBSRP, AODV routing protocol, LEACH protocol, RndRtA, and MRPL were designed by many authors for balancing the TL and enhancing the network performance. These prevailing techniques monitor the link node and communication path and compensate for the energy dissipation. But, the path that depends on the channel characteristics and network type is difficult to estimate for routing. Furthermore, the position of the nodes and the distance between CH and BS is important for selecting the optimal path with reduced packet loss, which was not concentrated in the existing works. By analyzing the suggested factors, the real-time applicability of the protocol is improved for LB and reliable data transmission. Hence, the different routing protocols designed by the existing works are surveyed and it addresses the second research question.

3.3 Linear programming optimization techniques in WSN

Linear Programming (LP) is a technique used for optimizing a particular scenario in order to get optimal results [47]. LP, which is otherwise known as linear optimization, deals with finding efficient solutions with linear equalities and inequalities. That solution is obtained by maximizing and minimizing specific values [48]. In this phase, how the LP is utilized in the WSN for balancing the network traffic loads is briefly analyzed.

Harmanpreet Singh and Damanpreet Singh [49] developed a Multi-Level Clustering Protocol (MLCP) for energy-efficient LB on large-scale WSNs. A hierarchical clustering architecture and LP formulation were employed in MLCP for solving problems like latency in the clustering and routing process. A hybrid dragonfly algorithm-centric Particle Swarm Optimization (PSO) technique was utilized for an effective CH selection. The experimental results were obtained by deploying various network sizes and six different node densities during the simulation. As per the simulation outcomes, the developed protocol significantly increased the lifetime of the network along with improvement in the energy conservation of the network. But, the nodes'energy levels were not focused while clustering, which resulted in an unnecessary hop in the routing path.

Amar Kaswan et al [50] presented a Multi-Objective PSO (MOPSO) based energy-efficient path design for the mobile sink in WSN. First, LP formulation was presented for the sink-hole problem in WSN, and then, the developed MOPSO created an energy-efficient trajectory for the mobile sink. Pareto dominance was utilized in MOPSO for obtaining both local and global best paths. The simulation parameters include 500 sensor nodes, 120J of initial energy, and 120 m of communication range. The simulation results proved the superiority of the developed model in the minimum EC rate of the network. However, the moving nature of the mobile sinks caused the buffer overflow issue within the network.

Ademola P. Abidoye [51] introduced an Energy-Efficient Routing Protocol (EERP) for maximizing the lifespan of WSNs. The approach determined the energy level of the SNs in three parameters, such as initial energy, energy consumed for data transmission, and remaining energy. The developed algorithm was utilized for the maximization of the lifetime and coverage of the SN within the network. LP model formulation was also employed for solving the issue related to faults. The performance evaluation was performed by utilizing 4000 bits of packet size, 100–500 sensor nodes, and 65 random network topologies. The analysis showed the developed model's better performance in extending the network's lifetime. But, there was a high delay in collecting the data packets from the BS that affected the PDR of the network. The following table 3 presents the studies related to LP optimization models for energy-efficient WSNs.

Santosh Kumar Das and Sachin Tripathi [62] developed an adaptive and intelligent energy-effectual routing centered on the fusion of game theory and LP in heterogeneous wireless networking. The fusion of these two approaches was used for the analysis of the multi-person decision-making in the network that reduced the utility of each decision-maker. Here, the simulation was made by modeling a non-cooperative game theory with 26K of memory usage in the range of four iterations. The evaluation outcomes stated the developed fusion approach's effectiveness concerning effective

Table 3 Studies related to LP optimization for energy-efficient WSN

Reference	Process	LP techniques	Topology	Constraints	Achievements	Drawbacks
Saurabh Kumar et al [52]	Energy-efficient scheduling in WSN	Integer-LP (ILP)	Automatic metering infrastructure	Routing constraint, Half duplex single radio constraint and Maximum radio frequency channels constraint	Minimizing energy consumption each timeslot and reducing computational time	Obtained with local optimal solution
Subash et al [53]	Enhanced coverage and energy-efficient scheduling in WSN	ILP	NA	Energy constraints	Effectively find out the unused activated sensor nodes and deactivate them without breaking the communication connections	Mobility of the sensor node was not considered
S. Kokilavani et al [54]	Improve data aggregation accuracy and reduce energy consumption	Energy-aware decision stump-LP boosting model	Simple tree structure	Power constraints	Significantly reduced the energy consumption, delay, and data aggregation time	Poor data-gathering performance
Khadidja Fellah et al [55]	Extending the lifespan of the network with minimum energy consumption	ILP	Grid topology	Fault tolerance and location constraints	Significantly saved the energy level of the network	Higher delay rate
Rohit Kumar et al [56]	Reduce network congestion with effective network flow management	Mixed-ILP (MILP)	NA	Fault tolerance limited coverage and low transmission speed	Better efficiency with effective Packet Delivery Ratio (PDR) and reduced delay	Ineffective CH selection
Srijit Chowdhury et al [57]	Minimizing energy consumption to extend network lifetime	Mixed-ILP (MILP)	Hierarchical structure	Energy and delay constraints	Achieved dynamic load balancing efficiency with minimum energy consumed	A large number of death nodes
Raj Anwit et al [58]	Efficient tour planning in mobile sink nodes	ILP	Flat topology	Time and space constraints	Robustness mechanism generating optimal paths over the other state-of-arts models	Insignificant performance
Fatma H. El-Fouly et al [59]	Improve reliability of the network and data by balancing energy consumption	ILP	Block-shaped network	Reliability, energy, and latency constraints	Achieved dynamic energy balancing and consumption rate	Time complexity
Shirin Tahmasebi et al [60]	Energy-efficient topology control of the network based on fault tolerance and scalability	ILP	Grid topology	Fault tolerance, reliability, latency, and synchronization constraints	More scalable and applicable in large-scale WSN operations	Not capable of performing resource-intensive operations
Sahar Kouroshnezhad et al [61]	Mobile anchor path planning for increasing mobile anchor lifetime and reliability	MILP	NA	Energy constraint	Attained minimum localization error with less energy consumption	Scalability issues

routing within the network. However, the efficacy of the developed approach was insignificant as it optimized all the constraints of the network.

Farzad Kiani [63] presented an LP method for maximizing the lifetime of WSNs. A uniform distribution was used in the approach for the SN distribution over a circular area in the network. Two hubs were utilized in the model, such as essential hubs and optional hubs. The streamlined structure in the model sends the essential hubs with the goal of prolonging the network lifetime, and the optional hubs confirm the connectivity of the network nodes. The experiment was done by utilizing 10 sensor nodes with 1J of initial energy and with random channel distribution. The analysis proved that the developed model significantly maximized the lifetime of the network. However, the disconnections among the nodes were high in the developed model, which gradually reduced the performance efficiency of the system.

Kumar Nitesh et al [64] employed a delay-efficient trajectory design for a mobile sink in WSN based on the Voronoi diagram. The developed approach employed an efficient discovery scheme for fault tolerance of the network by recovering the cluster members at the time of CH failure. The LP formulation was utilized for finding the trajectory based on the minimum distance for the mobile sinks. Here, the performance was analyzed through the MATLAB platform by adopting 30–110 CHs with 2J initial energy, 40–100 m of communication range, and 4000 bits of packet size. The simulation analysis results stated that the developed model proved its efficacy in energy balancing and network lifetime improvement. But, the developed approach was inefficient for large-scale networks that resulted in long path generation for data collection.

As effective solutions were produced through linear relativity of the LP optimization techniques, it is highly utilized for the LB purpose. Also, the LP method assisted in tackling the sinkhole problems and determining the EC of the WSN. But, the nodes' connectivity and their energy levels are essential to analyze while clustering the nodes and proceeds the data communication. It helps in handling a large amount of data and balancing the load based on the EC level. Hence, the efficiency of LP techniques is entirely utilized for LB when deeply analyzing DA, path selection, and node connectivity among the node clusters.

3.4 Alternative optimization techniques for traffic balancing in WSN

The traffic load balancing in WSN is an efficient approach for balancing the workloads of the network and for extending the lifespan of the network. An effective load balancing reduced the energy consumption rates of the sensor nodes utilized for the data forwarding process [65]. Several optimization techniques other than LP optimization techniques were also employed for the traffic balancing within the WSN. The goals of the traffic load balancing optimization algorithm were increasing throughput, reducing response time and delay, and optimizing energy and traffic within the network to extend the network lifetime [66, 67].

Veena Anand and Sudhakar Pandey [68] developed GA-based clustering and PSO-based routing in WSN for enhancing the lifetime of the network. The GA effectively chose the CH centered on the distance and energy parameters for gathering data from the SNs. The PSO generated an optimal path for the routing that was chosen by the relay node to forward the data to the BS. The experimental analysis was performed by establishing the simulated environment with a predefined quantity and quality of parameters, such as sensor nodes, packet size, and energy levels. As per the simulation analysis, the developed model significantly improved the network's lifetime with a reduced EC rate. However, the model easily falls to the local optimal solutions in the high-dimensional network.

Piyush Rawat and Siddhartha Chauhan [69] presented a PSO-based energy-efficient clustering protocol in WSN. The CH and relay nodes were selected by using the PSO based on the energy ratio of the nodes, the distance between CH and nodes, and the node degree. The data transferred to the BS was based on the developed model's fitness values like residual energy and distance. For performance evaluation, the number of CHs, network energy, and the quantity of power nodes were defined. The simulation analysis stated that the framework had an effective stability period than the other existing models. However, the performance of the developed model was insignificant with the high-dimensional problems.

Ramy et al [70] developed an Evolutionary Multi-Objective Crowding Algorithm (EMOCA) for maximizing the fault tolerance rate and minimizing the communication delay in WSN. The EMOCA approach utilized a non-domination ranking scheme and a probabilistic technique II in evolving population for the optimization problem. The experiments were done by developing the simulated network with 100–2000 nodes based on Poisson distribution, initial energy level, and sensing energy level. The simulation analysis results demonstrated that the developed model effectively optimized the fault tolerance and delay in WSN. However, the crowded comparisons restricted the convergence of the network. The following table 4 describes the different developed optimization models for energy-efficient LB in WSN.

From the above discussion, it is understood that many alternative optimization techniques are prevalent for balancing the traffic of WSNs. Alternative optimization algorithms, namely GA, PSO, and EMOCA were used for clustering the energy-efficient nodes, improving the fault tolerance, and suppressing the communication delay. These alternate optimization approaches also aid in forwarding data via the optimal path and grouping the nodes regarding their EC rate. However, the premature convergence of these optimization algorithms resulted in a sub-optimal solution for balancing load, especially on a high-dimensional network. Therefore, the relevant techniques that improve the convergence rate of these algorithms are needed for obtaining a more efficient balancing of the load in WSN.

3.5 Performance evaluation and camparison analysis

Some of the best energy-efficient load balancing optimization models using LP in WSN are explored in this section and their performances are tabulated in Table 5.

Table 5 describes the performance evaluation of the prevailing works based on the EC rate of the developed load-balancing optimization models. Various load-balancing mechanisms are developed in the existing research. Among that, the five best models are chosen for the performance analysis. The state-of-the-art techniques were analyzed based on their EC rate, as it impacts the network lifespan and communication efficiency. The techniques used for the evaluations are Time Division Multiple Access (TDMA) with ILP [52], GA with LP [53], Decision Stump Linear Programming Boosting Node Classification (DSLPBC) [54], Optimal Generation of Clusters (OGENCL) with MILP [57] and shark smell optimization (SSO) with ILP [58]. In the above analysis, the OGENCL with MILP [57] attained the minimum EC rate of 19J, whereas the SSO with ILP [58] obtained the second minimum EC rate of 24J. Then, the DSLPBC [54] attained with 25J EC. Next, the GA with LP [53] and TDMA with ILP [52] were obtained with the 30J and 45J consumed energy respectively. These models were evaluated by predefining the number of sensor nodes, number of CHs, average relay hop, number of iterations, and the energy level. From the analysis, it is clear that the OGENCL with MILP [57] is the best energy-efficient LP optimization approach. The graphical representation of the comparison evaluation of the existing works is presented in Fig. 4.

Figure 4 compares the performance of the five different studies related to the LB mechanism in terms of EC. Among these existing studies, [52] consumed more energy of 45J for balancing the load. But, the minimum EC of 19J was attained by [57] and so, it is considered as the best approach for balancing load in WSN among the other compared approaches.

From Table 5 and Fig. 4, it is comprehended that the LB performance was evaluated by comparing the five studies, that utilized the LP-based optimization models. The analysis implicated that the model named OGENCL with MILP is declared as the efficient one that consumed minimum energy among the other chosen models for LB. Such minimal EC led to better network performance by expanding its lifespan and throughput. Hence, the model that attained lesser EC is considered as the most efficient technique for balancing the load in WSN. Thus, the fifth research question is addressed.

4 Overall analysis

It is determined from the above discussions that many techniques and attempts were presented by the authors to optimize the EC during LB in WSN. The techniques, including LP-based optimization and other alternate optimization algorithms, namely GA, PSO, and EMOCA attained supreme outcomes in EO. However, the convergence problem restricted the effectiveness of EO. Meanwhile, the LP techniques failed to consider the node connectivity between the clusters based on energy level, which remains as a notable drawback of LP-based optimization approaches. To develop energy-efficient LB for data communication, the appropriate routing protocols were also developed by the existing works. Some surveyed protocols are Software-defined, Openflow, DCBSRP, AODV, LEACH, RndRtA, and MRPL. These routing protocols aid in establishing a reliable communication path with minimum EC. Yet, the packet delivery rate is not efficient due to the lack of a longer distance between the CHs and BS. Hence, it is affirmed that the network and communication performance is further enhanced when resolving the analyzed limitations in the prevailing works.

4.1 Review summary

The WSN is a fusion of electronics and networking infrastructure consisting of small embedded devices named sensor devices. These sensor devices are represented as the nodes of the WSN that are used for data communication within the network. These SNs are connected with each other in an ad-hoc configuration and communicate with the BS through the internet. The total amount of data shared within the network for a particular process in a given time is represented as network loads. These loads are transmitted through the generated paths, which are created by using routing algorithms. But, more loads shared within the network at the same time increased the possibility of network traffic. This traffic resulted in an imbalance in EC, packet loss, less PDR, and reduced the network's lifetime. Thus, an energy-efficient LB mechanism is used for optimizing the lifespan of the WSN by reducing the EC rate of the SNs [55].

The LP optimization mechanisms are one of the efficient schemes used for energy-efficient LB in WSN and are formulated for solving optimization problems [56]. Some other alternative optimization approaches were also employed in the existing works for optimizing LB within WSN. Based on this objective, five research questions were taken and surveyed under different phases using several articles related to the objective of the review. The first research question is used to understand an overview of EO in WSN. Then, different routing protocols were studied based on the second research question, and the knowledge about LP optimization models occurred in the third research question. Under the LP optimization models, the EERP determined the energy level of sensor nodes through three different energy parameters. Further, the network lifespan was improved using the LP-based optimization by defining the essential hubs and the optimal hubs.

The LP models also tackled the communication delay by designing the mobile sink node using the Voronoi diagram. Next, some alternative optimization approaches like PSO [68], ACO [76], glowworm swarm optimization [71], dynamic firefly mating optimization [74], gray wolf optimization [67], Boolean spider monkey optimization [79], and genetic chicken swarm optimization [25] are studied under the fourth research question. Here, the PSO effectively selected the optimal CHs, and the significant path for data routing was produced by using the ACO and Glowwarm optimization algorithms. Also, the CH was chosen based on the distance among the nodes and their energy levels through the GA. Moreover, the fault tolerance of the network was improved along with the suppression of communication delay by utilizing the non-domination ranking technique. But, the LP-based models faced difficulty in regulating and balancing the large amount of data and the nodes' connectivity.

On the other hand, the premature convergence issue of the alternate optimization techniques delivered less efficient LB on the higher network space. Finally, the overall performance of the energy-efficient optimization models utilized in WSN is evaluated to estimate the superior EO model. The performance evaluation was based on the EC rate and resulted in the OGENCL with MILP [57] attaining the minimum EC rate of 19J, whereas the SSO with ILP [58] obtained the second minimum EC rate of 24J. Then, the DSLPBC [54] attained with 25J EC. Next, the GA with LP [53] and TDMA with ILP [52] were obtained with the 30J and 45J consumed energy, respectively. Hence, this comprehensive survey briefly described various prevailing models to prove the efficacy of different EO mechanisms in WSN.

5 Conclusion and future recommendations

An energy-efficient load-balancing optimization model in WSN is briefly surveyed in this review. This review described several routing protocols, LP-based optimization models, and alternative optimization algorithms for energy-efficient LB in WSN. The LP-based optimization models were developed with the mathematical formulation for giving solutions to the optimization problems. The developed models were analyzed to state the effective load-balancing approach for WSN. The evaluations were implemented in simulations like Simulink MATLAB, SensorSim, and OneSim for testing the developed model's efficacy. As per the simulation results, the developed model effectively balanced the TLs within the WSN and optimized the EC rate of the network, resulting in the lifetime enhancement of the network. The overall results stated that the developed models attained a minimum EC rate of 2J, a 15ms delay in packet transmission, and 98% PDR. The review briefly explains the merits and demerits of the developed models based on various constraints like fault tolerance, latency, topological condition, and EC. Thus, this review concluded that the ILP optimization models and ACO approaches are effective energy-efficient load-balancing optimization models. But, the random deployment of the SNs within the network is also a cause of the EC rate of the network. It was not concentrated in the developed works. So, future work will focus on the sensor deployment within the network for an energy-efficient WSN.

Table 4 Performance Evaluation of the Optimization Mechanism Used in WSN

Reference	Purpose	Techniques	Simulation Parameters - Values	Demerits
A. Sampathkumar et al [71]	LB and routing in WSN	Glowworm swarm optimization	Total nodes - 1000 Sink region - 100*100 Transmission range-100m Packets - 2000bits Nodes energy - 3J	Lower throughput
Xinlu Li et al [72]	LB in WSN	Ant colony optimization (ACO) based routing algorithm	Number of nodes-100 Topology dimension-1000 Initial energy -1000J Mobility - Random	Does not consider the energy balance of the whole network
Vishal Kumar Arora et al [73]	Energy-aware routing in WSN	ACO	Electronics Energy - 50 nJ/bit Initial energy - 0.25 J Number of SNs -100 Sensing area - 100*100	The topology information of the network is not equally spread
Muhammad Faheem et al [74]	Energy efficient routing protocol for internet of underwater WSN	Dynamic Firefly Mating Optimization	Deployed area - 1000*1000*500 Packet size - 30bytes Initial energy - 100kJ Transmission range - 120m	Significantly low PDR
Surjit Singh et al [75]	Load-balanced clustering for sustainable WSNs	Gray Wolf Optimization	Packet size - 4000bits Area - 500*500 Sink location - 500*250 Initial energy - 12J	Suitable only for small WSN
Noureddine Moussa et al [76]	Energy-efficient and reliable routing protocol for WSN	ACO	Number of nodes - 49 Target area - 10000	Not applicable to real-time applications and limited reliability
Anis Jari and Avid Avokh et al [77]	Sink placement and load-balanced anycast routing in multi-sink WSN	PSO	Number of particles - 50 Initial inertia weight - 0.4 Final weight - 0.9 Acceleration coefficient - 2 Maximum iterations - 100	High latency
A. Jameer Basha et al [78]	Minimizing energy in WSN	Genetic-Chicken Swarm Optimization Algorithm	Packet size - 4500bits Number of nodes - 150 Initial energy - 0.3J Coverage area - 1100*1100 Simulation period - 90ms	More computation issues
Nitin Mittal et al [79]	Energy efficient clustering approach for WSN	Boolean spider monkey optimization	Number of nodes - 100 Network size - 100*100 Initial energy - 1J DA energy - 5nJ/bit	Insignificant with large-scale WSN
Kai-Chun Chu et al [80]	Numerical optimization of the EC for WSN	ACO	Sensing radius - 3m Communication radius - 5m Initial energy - 5J Simulation time - 1000s Data transfer rate - 2Mbps	Low fault tolerance rate

Table 5 Performance evaluation of existing literature

Techniques	Energy consumption (J)
TDMA with ILP [52]	45J
GA with LP [53]	30J
DSLPBC [54]	25J
OGENCL with MILP [57]	19J
SSO with ILP [58]	24J

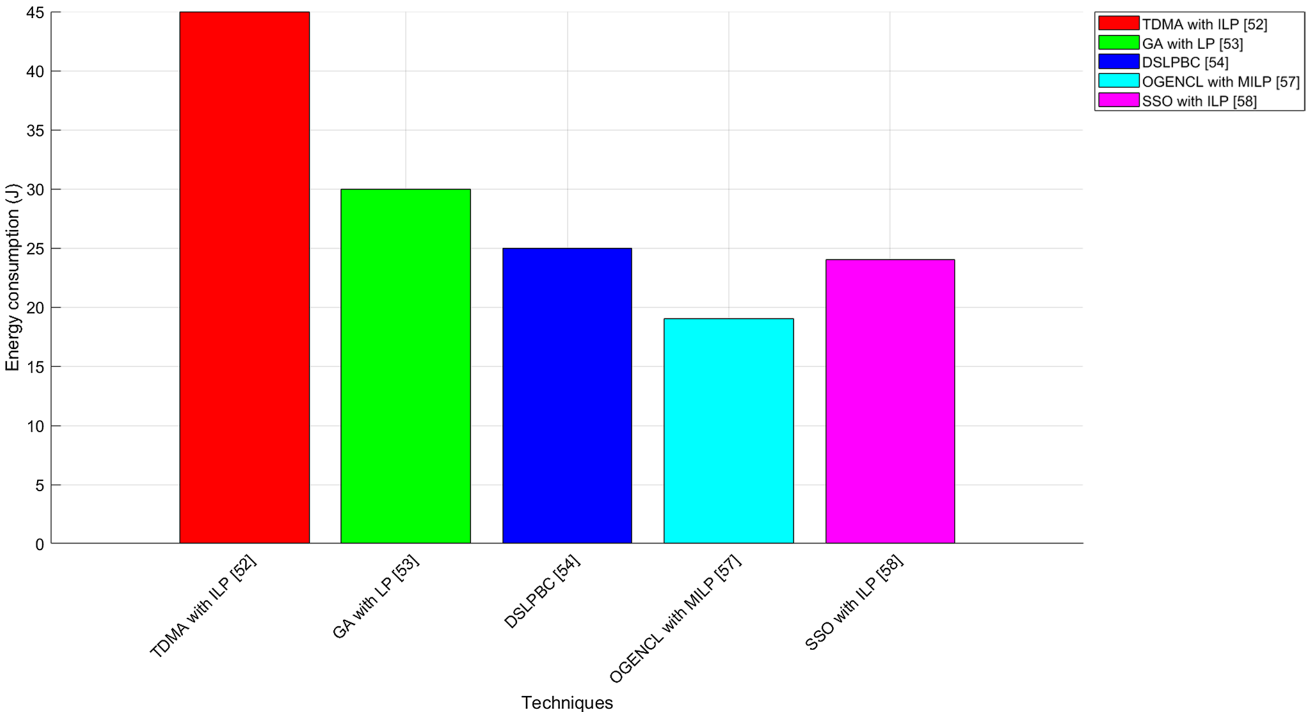

Fig. 4 Graphical representation of the comparison evaluation

Data availibility The authors have no data availability to declare since there was no datasets which were generated or analyzed during the current study ((No/Not applicable (this manuscript does not report data generation or analysis)).

Declarations

Competing interests The authors have no relevant financial or non-financial interests to disclose.The authors have no Conflict of interest to declare that are relevant to the content of this article. All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript. The authors have no financial or proprietary interests in any material discussed in this article.

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