A Systematic Literature Review on Metaheuristic Optimization Techniques in WSNs

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Abstract—**Metaheuristic algorithms are recognized for developing new algorithms and optimizing various aspects in Wireless Sensor Networks (WSNs). Evaluating a multitude of possible modes is required, in most complicated problems, to obtain an exact solution. Metaheuristic algorithms can obtain solutions in acceptable time constraints. These algorithms play an operational role in solving such problems by optimizing the different metrics such as coverage rate and energy consumption of the networks. These metrics have valuable impact on network lifetime as well. This systematic review focuses on the published work from 2010 to 2020 in metaheuristic optimization in WSN. Furthermore, the systematic review will answer multiple questions that will be discussed in the methodology section.**

Index Terms—**Optimization, Systematic Literature Review (SLR), Wireless Sensor Network (WSN), Metaheuristic, Network lifetime, Node Localization, Clustering, Routing, Coverage.**

I. Introduction

Wireless Sensor Network consists of a sensor field that composes of sensor nodes, base stations, radio receivers for the various multipurpose functions and applications. Each node comprises of memory, sensors, analog to digital converter, micro-controller transmitter all this enable to work in one unit as single node when power is supply to them. The purpose of this is for tracking, detecting, monitoring of various real-life application [1].

Although they are having many issues and limitations regarding their limited battery life because whole architecture is working using power only. If power supply is limited it is affected the performance of network that results into increase in the number of dead nodes. As the dead nodes increase, the performance of the network is affected and degraded the lifetime of network [2].

To serve the same objective many researchers provided efficient models for better performance of WSN. The applications of WSN are available in different fields such as in military, health sector, aviation sector and telecommunication sector. Therefore, it is necessary to analyze and study the performance of WSN on various different optimization algorithms [3].

Metaheuristic methods are an important class of solution methods for practical optimization problems in WSN exhibiting high computational complexity. These methods are intended to quickly provide near-optimal solutions to complex optimization problems that cannot be solved exactly. Their advantages include easy implementation, rapidly-obtained so-

lutions and robustness to variations in problem characteristics [4].

The rest of this paper is comprised as follows: Related work is discussed in Section 2. Problem formulation and technical background are presented in Sections 3 and 4 respectively. Section 5 presents the methodology followed in this Systematic Literature Review (SLR). Finally, we conclude our research with results and discussions in Section 6 and conclusion in Section 7.

II. Related Work

Some SLRs have been conducted in the area of optimization of WSN. Mahapatra et al [5] presented a review of WSN and its Quality of Service (QoS) parameters using Nature-Inspired (NA) Optimization Algorithms. The SLR focused on papers that are concerned with optimizing the parameters of QoS of the WSN. In addition, the paper specified the difference between the application specific QoS and network specific QoS. As the application specific takes factors particular to an application e.g. (area of coverage and number of active sensor nodes). On the other hand, the network specific QoS implies the efficient use of network resources like power usage. Also, the paper presented a brief review on the NA algorithms. The review did not follow any of the popular SLR structures. The overall summary of the review discussed the algorithms used, the impacted factors and the main focus of each paper. The review concluded with some challenges and future scope of for further research work.

Shafiq et al [6] conducted a review on energy efficient routing schemes in WSN. The paper followed the Kitchenham SLR scheme [7]. Furthermore, the review has categorized the algorithms into 8 categories, all concerned with energy efficient routing. Some of these categories are (Power efficient gathering, Energy efficient distributing and clustering and Secure energy efficient routing algorithms). The overall summary of the review had different criteria suitable for each category. This SLR is different from the above as it is based on the guidelines in PRISMA [8] and the key contribution are as follows:

1) A Systematic Literature Review is performed to analyze the existing latest schemes addressing several challenges in WSN.

2) A number of related energy efficient schemes during 2010 to 2020 are searched as per research question and thoroughly studied.

3) Presents an overall review of four challenges in WSNs.

4) The different types of algorithms (hybrid, Modified or Standard) are showcased in this review.

III. PROBLEM FORMULATION

In WSN, network resources are very limited and should be used effectively and efficiently. WSN characteristics were designed while having this limitation in mind like clustering. But this was not enough to prolong the lifetime or the high energy consumption of the nodes. Thus, these characteristics and challenges had to be solved or optimized. In this section, the characteristics and challenges addressed by this literature review will be explained and form the optimization problem [9].

A. Clustering

A cluster is a group of sensor nodes where one of the sensor nodes works as Cluster Head (CH) and other nodes are called Cluster Members (CMs). The main responsibility of the CH is to collect the data from its CMs and transmit the aggregated data to the Base Station (BS) either directly or using multi-hop routing. CH near to the sink not only collects the data from its CMs but also works as a relay node for forwarding the packets of the other CHs towards sink node [10].

Each method used their own objective function, but generally the objective were minimizing the intra-cluster distance and energy of cluster head [11].

B. Routing

To achieve an energy efficient routing, most of the publications chose to minimize the number of nodes as well as minimizing the distance between the active nodes:

The $D(s_i, \rho)$ is the Euclidian Distance between the node si and point ρ shown in eq. (1).

$$min[D(s_i, \rho) = \sqrt{(x_i - x)^2 + (y_i - y)^2}] \quad (1)$$

$$min[\frac{R}{C}] \quad (2)$$

Where R is the total number of relay nodes in the network. C is the total number of cluster head candidates that act as relay nodes.

C. Coverage

To measures how much area of Region of Interest (RoI) has been covered the concept of coverage ratio can be used. Coverage ratio is a measure of what percentage of area of RoI has been covered by nodes. The formula of coverage has been given in eq. (3).

$$C_R = \frac{m}{n} \quad (3)$$

Here, m is the unique number of grid points insides the RoI which have been covered by the sensors and n is the total number of grid points inside the RoI [12].

D. Node Localization

To localize the node accurately, most of the methods try to minimize the location error [13]. Thus, mean squared error (MSE) is used as objective function between the actual and estimated distances of computed node coordinates and the actual node coordinates:

$$MSE = \frac{1}{M} \sum_{i=1}^{M} (d_i - \hat{d})^2 \quad (4)$$

Where d_i is actual distance and $\hat{d}$ is estimated distance (the value d_i obtained from noisy range measurements) and $M \geq 3$ (location of the sensor node needs a minimum of three anchors within transmission range R).

IV. TECHNICAL BACKGROUND

Both old and new metaheuristic algorithms are still being used in several research areas. WSN had its share of these algorithms. Thus, a background about some of these algorithms is discussed in this section.

A. Ant Colony Optimization (ACO)

Ant Colony Optimization is a bio-inspired algorithm based on the behavior of real ants. It has been observed that a group of ants can cooperatively figure out the shortest route between their nest and their food. The communication between ants happens through volatile chemical substances known as pheromones [14].

B. Artificial Bee Colony (ABC)

It is an important bio-inspired algorithm inspired by the collective foraging behavior of honey bees [15]. Like ACO it also searches for an optimal numerical solution among large data sets. Through the social cooperation of three types of bees namely employed bees, onlooker bees, and scout bees they can complete their task. The employed bees take the responsibility of searching food around the food source and share the information with the onlooker bees and finally these types of bees select good food sources from those discovered by the employed bees. ABC can address the multi-dimensional numeric problem [16].

C. Whale Optimization Algorithm (WOA)

In recent days more and more modern metaheuristic algorithms are emerging. The Whale optimization algorithm is one of the most recently proposed metaheuristic optimization algorithms introduced by Mirjalili, S. and Lewis, A. in 2016 [17]. WOA mimics the hunting mechanism of humpback whales in nature. In this short period due to its easy implementation, this algorithm has been used in a wide range of problems in several domains including WSNs [18]

D. Grey Wolf Optimization (GWO)

A new metaheuristic called Grey Wolf Optimizer (GWO) inspired by grey wolves have been proposed by Mirjalili et al. in [19]. The GWO algorithm mimics the leadership hierarchy and hunting mechanism of grey wolves in nature [20].

V. METHODOLOGY

SLR is a type of literature reviews that helps to discover, categorize, and examining the existing literature for any specific research question. The main purpose of SLR is to evaluate the existing literature as per research question and find the gap. This SLR is following the guidelines provided by PRISMA [8].

A. Research Questions

The main goal of this systematic review is to identify and examine research papers that optimize WSN in different areas . Based on that, the following research questions are identified:

RQ1 What are the different types of papers that are included in the study?

RQ2 What are the optimization algorithms commonly used to solve each challenge?

RQ3 What are the most common challenge solved using the metaheuristic or hybrid algorithms?

RQ4 What are the algorithms used to solve each challenge?

RQ5 What are the objectives used for each proposed method?

RQ6 What are the other metaheuristic algorithms that are compared with each proposed method?

RQ7 What is the type of each algorithm (Hybrid, Modified or Standard)?

RQ8 What are the advantages/drawbacks of each method?
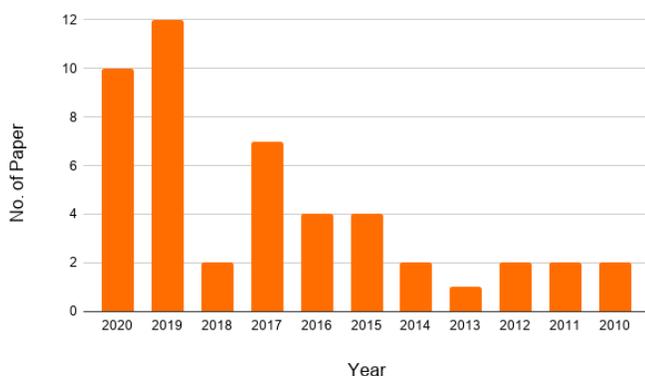
Fig. 1: Papers distribution over the years.

B. Search Strategy

1) Search Keywords: After defining research questions, the second most important step is to design strings and phases that help in searching. In order to have a quality research multiple steps are followed in this paper as mentioned below:

i Identifying the focal words and the complete understanding of the research question.

ii Use different replacements of phrases and words that can be used for literature searching

iii Combine different words to produce meaningful phrases.

iv Keywords used for researching: "Optimization, WSN, metaheuristic, Wireless Sensor Network, PSO, ACO, ABC"

2) Research Resources: The following digital libraries were used to search for the needed research papers:
get real sources

- Google Scholar
- IEEE Xplore
- Science Direct
- ResearchGate
- Springer

C. Screening and Selection

Originally, 80 papers were collected which were obtained from the mentioned resources using the search keywords. Further filtration was done by the authors to ensure only the valid and relevant papers were included as show in Fig. 2. The filtration included:

1) Obtain the date of publish and remove any paper before 2010.

2) Read Abstract and conclusion of each paper and remove the irrelevant and duplicates

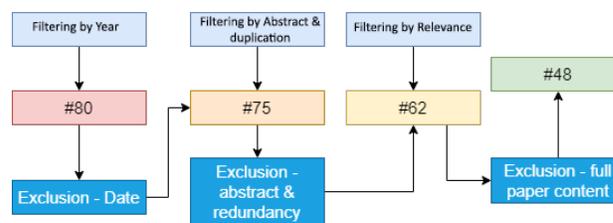3) Read the full research paper and choose the relevant papers to the topic.

Fig. 2: Screening and Selection stages.

D. Data Extraction Strategy

In this stage, the finalized list of papers was used to extract needed information to answer the set of research questions. Paper title, Ref ID, publication year, publication type and answers for research questions 1 to 8. It is also important to note that not all papers answered all research questions.

E. Synthesis Extracted Data

The extracted information obtained from answering RQ5-RQ8 in tabulated form and presented as comparison. while the other research questions were put as graphs and presented in results section.

VI. RESULTS AND DISCUSSIONS

A. Papers distribution (RQ1)

The total papers that were included in this review are 48 papers. These papers fall in 2 main categories, conference papers and journal papers. The majority of these papers fall into the journal papers at 77%. The rest 23% are conference papers. As shown in figure 1, most of the papers included were published in the past 5 years with 81% of the total number of papers.

TABLE I: Analysis of collected papers for questions (4-8)

Citation	Algorithm	Type	Challenge	Algorithms compared	Objective Func.	Other Advantages
[21],2020	EHMO	Hybrid	Routing	PSO,ACO,DE,SA	Energy/Lifetime	Lifetime
[22],2020	WOA-SA	Hybrid	Clustering	ABC,GA,AGSA,WOA	Intra-cluster/Energy	Energy reduction
[23],2020	TLBO	Modified	Clustering	PSO-C,GA-based,PSO-SD	Delay and Energy	Lifetime
[9],2020	DA-FF	Hybrid	Clustering	GA,GWO,WOA,FF,DA	Energy	Lifetime
[24],2020	ABO	Standard	Routing	-	Energy	Energy reduction
[25],2020	LEACH-ACO	Hybrid	Routing	-	Intra-cluster/energy	Lifetime
[26],2020	HAGOA	Hybrid	Routing/Clustering	LEACH,PSO,ACO,ABC	Intra-cluster /hop count	Lifetime
[11],2020	DEABC	Hybrid	Clustering	PSO-BSP,LEACH	Intra-cluster	Lifetime
[10],2020	Memtic	Modified	Clustering	GA,LEACH	Node Degree/Intra-cluster	Energy reduction
[27],2020	PSO	Modified	Coverage	PSO	Energy	-
[28],2019	KHO	Modified	Routing	-	Distance/Delay	Energy reduction
[29],2019	ACO	Standard	Clustering	-	Intra-cluster/energy	Energy reduction
[30],2019	PSO	Modified	Coverage	GA,PSO	Coverage	-
[31],2019	CSO	Standard	Routing	GWO,A3	Intra-cluster/Energy	Energy reduction
[32],2019	OB-CWO	Modified	Clustering	WOA,GSA,PSO	No. of cluster heads	Lifetime
[33],2019	SKFO	Standard	Coverage	PSO,GA	energy/throughput	-
[34],2019	DEA	Standard	Routing	GWO,BAT,ACO	Error in localization	Energy reduction
[35],2019	WOA	Standard	Node localization	PSO,DE,GWO,MFOA	Error in localization	-
[36],2019	EHO	Standard	Node localization	BBO,PSO, FFO	Error in localization	-
[37],2019	FPO	Modified	Node localization	PSO, FPA, pFPA	Node energy/Node degree/Intra clustering/Coverage	-
[38],2019	ACO-PSO	Hybrid	Clustering	GSTEB, ACO	Node power/Lifetime	Lifetime
[39],2019	ABC	Modified	Clustering	-	Region Of Interest/No. of nodes	Lifetime
[40],2018	ACO-PSO	Hybrid	Clustering	GA,ABC	Error in localization	Lifetime
[13],2018	EHO	Standard	Node localization	PSO MSPSO ABC MSABC	Intra-cluster/Energy	-
[41],2017	ABC	Modified	Clustering	EEBC,aABC	Active nodes	Lifetime
[42],2017	GA	Standard	Routing	-	Region Of Interest	Energy reduction
[43],2017	CS-HS	Hybrid	Routing/Clustering	LEACH, PSO-ECHS	Error in localization	Energy reduction
[44],2017	GWO	Standard	Node localization	PSO MBA	Maximize coverage	-
[45],2017	PSO-SA	Hybrid	Clustering	CSA, LEACH-C	Residual energy	Energy reduction
[46],2017	TLBO	Standard	Routing	PSO, ACO and HS	Distance Between nodes,	Lifetime
[47],2017	BOA	Standard	Node localization	PSO,FA	Region Of Interest/No. of nodes	-
[48],2016	FWA	Modified	Coverage	PSO	Intra-cluster/Energy	-
[49],2016	HS-Kmean	Hybrid	Clustering	K-means, HSA ,LEACH ,EAERP	Dissipated energy	Energy reduction
[50],2016	ABC	Standard	Clustering	PSO-HC,PSO-C,LEACH-C,LEACH	distance between nodes	Energy reduction
[51],2016	GWO	Standard	Routing/Clustering	SEP, DEEC, LEACH	stability period	Energy reduction
[52],2015	FOA-MAP	Hybrid	Node localization	BOAMAP,MCS-MAP	Intra-cluster/Energy	-
[53],2015	ACO	Standard	Routing	-	Intra-cluster	Lifetime
[54],2015	TCO	Standard	Coverage		Error in localization	-
[55],2015	PSO	Modified	Routing/Clustering	LEACH,PSO-C,GA-C,LEACH-C	No. of relay nodes/Worst quality branch	Energy reduction
[56],2014	HS	Standard	Clustering	LEACH-C, FCM	Error in localization	Lifetime
[64],2014	ACO	Modified	Routing	ACO	Error in localization	Energy reduction
[57],2013	ACO	Modified	Routing	LEACH	Region Of Interest	Lifetime
[58],2012	PSO	Modified	Node localization	GA,SA, PSO	Intra-cluster/Energy	-
[59],2012	BAT	Standard	Clustering	LEACH	No. of relay nodes/Worst quality branch	Energy reduction
[60],2011	EAERP	Hybrid	Routing	LEACH,SEP,HCR	Error in localization	Lifetime
[61],2011	ACO	Standard	Coverage	SA, CHC	No. of nodes	-
[62],2010	SA	Standard	Node localization	GA,PSO	Intra-cluster	-
[63],2010	ACO	Standard	Routing	EEABR	distance between nodes	Lifetime

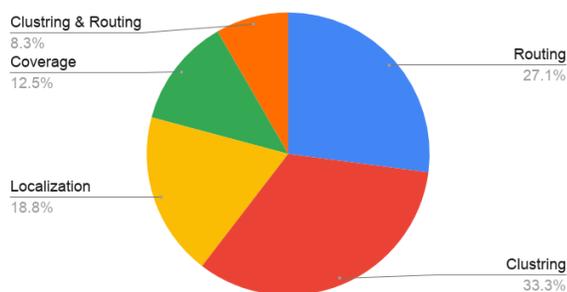Fig. 3: Most common metaheuristic algorithms used to solve WSN Challenges.

Fig. 4: Most common challenge solved using metaheuristic methods.

B. Frequently used Algorithms (RQ2)

Around 23 methods out of 48 were using new metaheuristic algorithms like BAT, BOA and TLBO algorithms. Followed by 12 papers using hybrid algorithms which combines the traditional metaheuristic logarithms together or with new methods as well. The rest 13 papers were using either the standard version of the traditional metaheuristic algorithms or with some modifications and improvements. These results can be seen in figure 3. and table I.

C. Commonly Addressed Challenges (RQ3)

Clustering had the largest number of paper trying to optimize it with 33.3% followed by Routing with 27.1%. The rest 39.6% are distributed over localization with 18.8% and coverage 12.5% and 8.3% for optimizing both clustering and routing with the same method. As shown in figure 4.

D. Research Question 4-8

As shown in table I, the research paper were ordered descendingly based on the publication year. In this table, each research paper was identified with their algorithm used, type of algorithm, addressed challenge, objective function, algorithms compared and other advantages. This table helps in answering multiple research questions, more specifically research questions 4 to 8.

VII. CONCLUSION

WSN is getting more and more common, since the technology is increasing very quickly, and therefore sensors are being used in multiple environment. Even though sensor are commonly being used, they are considered to be very complex due to the limited amount of energy and memory they are able to use. This research is done on the exiting data. This survey discuss SLR performed in order to build research question and literature review. Many steps are performed in order to select research papers related to research question. A trend can be noticed from this review as many researches are using the same objective function with no significant contribution overall. Also, more challenges of WSN can still be explored using optimization. Most of the WSN challenges were not addressed using the met-heuristic nor optimization algorithms in general.

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AUTHORS CONTRIBUTIONS

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