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MULTI-OBJECTIVE OPTIMIZATION ALGORITHMS FOR WIRELESS SENSOR NETWORKS: A COMPREHENSIVE SURVEY

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ABSTRACT

In recent years, wireless sensor networks (WSNs) topics took advantages as it integrated in internet of things (IoT) applications, there are massive acceleration in using WSNs in monitoring, and tracing applications indoor, and outdoor, such as disaster managing, wildlife tracking, home, health, military, and industry monitoring. Several researchers worked on improving or optimizing one objective, to optimize (reduce) WSNs energy consumption, increase network coverage, or reliability. Since 2004, some researchers have optimized multiple parameters using multi-objective optimization algorithms such as evolutionary algorithms and particle swarm algorithm, some tend to reduce multi-objectives to single one by using weighted sum methods, others tend to make a tradeoff between multi-objectives and give number of solutions so that the decision maker can take a proper decision.

In this comprehensive survey, we reviewed most of the researches that addressed multi-objective optimization methods for WSNs during the years 2004 to 2019. Some of these researches use existing algorithms to solve multi-objective optimization problem; others proposed new methods or modified existing algorithms, either with Quality of Service (QoS) or without QoS considerations. In addition, we analyzed these papers to extract the robust and weak points from them. Next, we analyzed the problems that these researches tried to solve, the multi-objectives that optimized, the technical tasks, the mechanisms, and algorithm that these research papers used. Our focus in this survey is to help the researchers finding the available approaches in order to motivate future researches go further.

Keywords: *Wireless Sensor Network, Multi-objective, Optimization Algorithms*, *QoS.*

1. INTRODUCTION

Wireless Sensor Networks (WSNs) have been used to monitor many kinds of conditions including temperature, humidity, pressure, vehicular movement, and soil makeup [1]. A WSN consists of a large number of low power wireless sensor nodes; these nodes have limited transmission range so they cannot send data directly to sink nodes that need multi-hop communication [2].

WSNs application can be classified to two types: monitoring as analyzing or supervising real-time system, and tracking the change of an event from person or animal [3].

Energy consumption problem occurs due to several reasons. The first one is that the nodes near the sink have to take heavier traffic load; this causes the node around the sink to deplete their energy faster; a problem that leads to energy hole or hotspot problem [4]. The second reason is due to multipath routing. Although multipath improves reliability by increasing redundancy, but this high redundancy also causes more translations, and hence the energy consumption becomes greater. The third reason is error correction; once error occurs at sink node, a request will be sent to the source node for retranslation, so this leads to some problems such as doubling the energy consumption [5].

Routing protocols for WSNs are a very challenging problem because such protocols should be simple, scalable, energy efficient and robust to deal with very large number of nodes [1]. Two nodes can communicate directly to forward messages from the source node to the neighbor nodes until the messages reach the destination nodes so the nodes acts as both host and router at the constant time [7].

As energy efficiency is known to be a hot research topic, many routing protocols or algorithms have been proposed to deal with limited battery of sensors in order to improve energy efficiency and load balancing between sensor nodes thus reducing energy consumption, and prolonging the lifetime of WSNs [8][9].

Many researchers in WSNs routing field use optimization methods not only to achieve an optimal energy efficiency but also to enhance the performance of WSNs [10]. As routing is a crucial process to be considered in WSNs especially when dealing with the performance of multiple QoS routing metrics [11], we found optimization problems are divided into two types: Single–Objective Problems (SOP), and Multi-Objective Problems (MOP).

SOP type solved by single-objective optimization algorithms where the main aim of the optimizer is to minimize or maximize one objective under various constrains. It chooses the most salient performance metric to be optimized, so it may be unfair and unreasonable in real WSNs applications. Also, this approach may be biased in real-world applications because it assumes the importance of only one metric to the other dominate ones [3][6][12][13].

In the MOP type, however, the objects often conflict and the solution describes the best trade-off between conflicting objects, it can be solved using two approaches; the first approach is based on classical method such as weight sum that aggregates weight sums of all objectives. These objectives are secularized into single objective by pre-multiplying each objective with a user-supplied weight [3][6][12-15].

Other approach uses evolutionary multi-objective optimization algorithms; it is further sub-divided into three types: Aggregating functions, Population-based approaches, and Pareto-based approaches. In the aggregating functions, we use the concept of combining all the objectives in a single objective by any arithmetical operation. But in the Population-based approaches, we use EA's population to diversify the search, In which at each generation sub-populations are generated by proportional selection. While In the Pareto approach, multiple objects are simultaneously optimized to find the non-dominated points Pareto Front (FP). Therefore, it will be more realistic because it satisfies multiple objectives [3][6][12-15].

The rest of this paper is organized as following: section 2 illustrates our procedure and statistics to represent the multi-objectives of WSN topic where stumble, and where it deepened. The related work about using multi-objectives in WSNs presented in section 3. In sections 4, 5, and 6, we present WSNs technical tasks, mechanisms, and objectives respectively. Multi-objectives algorithms are explained in section 7. Section 8 summarizes and concludes our findings and introduces future possible work.

2. Procedure and Statistics

2.1 Statistics of Multi-Objectives Articles for Wireless Sensor Network by Year

To complete this survey, articles were retrieved from several well-known online databases such as IEEE Explore Digital Library, Science Direct, ACM Digital Library, some of it Scopus, or ISI, or both. These databases queried to obtain articles related to multi-objective algorithms for wireless sensor network field. The procedure followed to identify and filter the papers in this field between the years 2004 and 2019, by using the following search keywords: "Multi-objective + Non-dominated + Routing + WSN", using Google scholar web search engine, which index includes most peer-reviewed online academic journals, books, conference papers, thesis and dissertations.

Some statistical information about the articles is presented in table 1, and figure 1. The information presents the progression of the number of articles with respect to their publication years. In table 1, articles are sorted by publication years, and then it shows if this article is published in conference, journal, thesis, or book chapter. About 156 articles related to multi-objective algorithms in WSNs field are found. As represented, our interest is in the most recent articles; about 6 years ago; i.e. between the years 2014 and 2019 which formed about 79 articles; a 51% from the total summation of articles that focused on multi-objectives algorithms in WSNs.

Figure 2, represents the percentage of articles that published by well know publishers in the field of multi-objectives in WSNs; it illustrates the importance and robustness of this topic, and the increased pace of work in this area.

TABLE 1: Number of Articles by Year

Year	N. of Articles	Journal	Conference	Others
2019	23	17	5	1
2018	8	7	1	0
2017	10	7	2	1
2016	13	12	1	0
2015	15	10	5	0
2014	10	8	2	0
2013	6	4	2	0
2012	13	7	6	0
2011	10	5	5	0
2010	14	5	9	0
2009	14	6	8	0
2008	6	1	5	0
2007	7	2	4	1
2006	4	4	0	0
2005	1	1	0	0
2004	2	0	2	0
Total	**156**	**96**	**57**	**3**

2.2 Statistics about Fields of WSN Articles that Used Multi-Objective Algorithms

In table 2, we analyze twelve fields that we consider in our proposed approach, to represent all of previous studies where are focused.

As an example 48% of previous studies use exist algorithm to solve a multi-objective problems such as [78][88][90][105]. While papers that proposed new method or modified on existing one are 41% without QoS such as [104][106][109][117], and 11% with QoS such as [21][44][150].

In field of technical task there are 55% research that work in routing stage [54][82][93][95], other research papers take about 45% that work in wireless sensor deployment stage[80][98][132], we consider placement, layout, localization research papers all related to deployment. In [140] they are developing a clustering algorithm that used in deployment and routing stage.

In area of multi-objectives optimization algorithm that are used in previous researches Non-dominated Sorting Genetic Algorithm NSGA-II got highest percentage 21% as in [148][167], the second is genetic algorithm with 14% as in [102][156][163].

The third is Particle Swarm Optimization PSO with 9% as in [134] and Multi-Objective Evolutionary Algorithm Based on Decomposition MOEA/D with 7% as in [148]. Most of these researches methods are compared with LEACH so its used with 4% percent as in [115][139].

Other important fields that we analyze such as objective type, and number of optimization fitness value. In field of object type, we found that the most important object in WSN is energy preservation, we consider terms as energy consumption, energy efficiency, energy conservation, residual energy, and network lifetime have the same aim so energy object have used in 30% of this researches as in [158][166].

WSN coverage take the second rank in term of importance with 14% percent as in [142], in the third ranking there is equality between delay [118], and number of sensor nodes with 9% percent as in [115] [133], or number of sink nodes as in [143], reliability comes fourth with 6% percent as in [98]. Most of previous researches work on two objectives as we found 54% of these researches. While other work on three objectives with 35% percent. Few researches works on four objectives with 5.5% percent, the same as five or more objectives.

In terms of mechanism that are used to improve optimization methods we found clustering got highest percent with 55.5% [77][100], some of these researches work on solving optimal number of clusters as a research problem[111]. While researches without clustering got 45.5% percent. On the other hand, some researches depended on tradeoff between parameters using Pareto Front theory outperform weighted sum and got 83% percent [102][138], while weighted sum methods such as linear, dynamic, and average procedure got 17% [59][78][164].

In order to determine the multi-objectives Perto front solutions excellence, some research papers used performance evaluation indicators such as hypervolume (HV) (IA), unary epsilon (Iε), (Iε+), and non-dominated solution (NDS) [130]. So 14% of researches use performance indicator as in [25][36][79] these indicators gave robust to their researches, while 86% of papers don't use these indicators we can consider these as weakness point.

Finally, we found some of multi-objective methods are applies using synthetic dataset [12], real dataset [38], smart building [22], monitoring [30], and indoor activities [125].

We proposed our approach that we followed it, in analyzing the previous research papers in figure 3, this approach consider the strategy that we follow based on finding the technical methods, technical task, applications, optimization algorithm, mechanism, and object type.

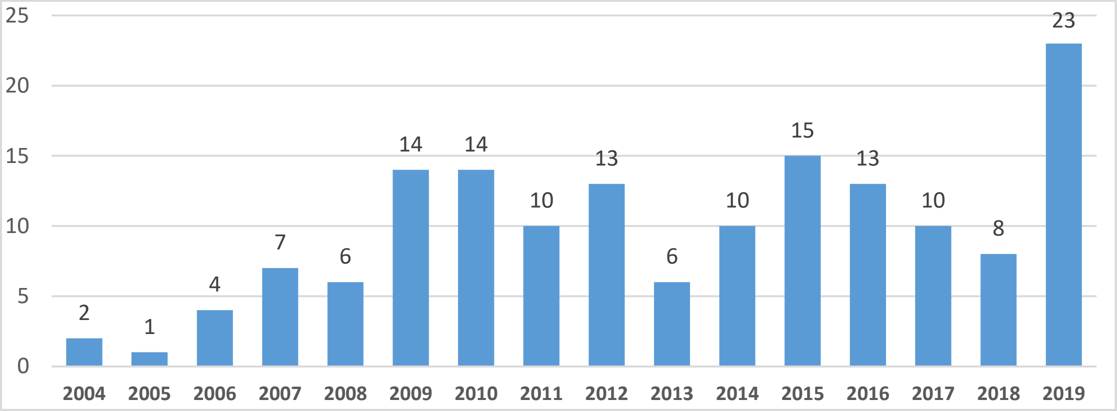


Figure 1: Number of Articles by Year

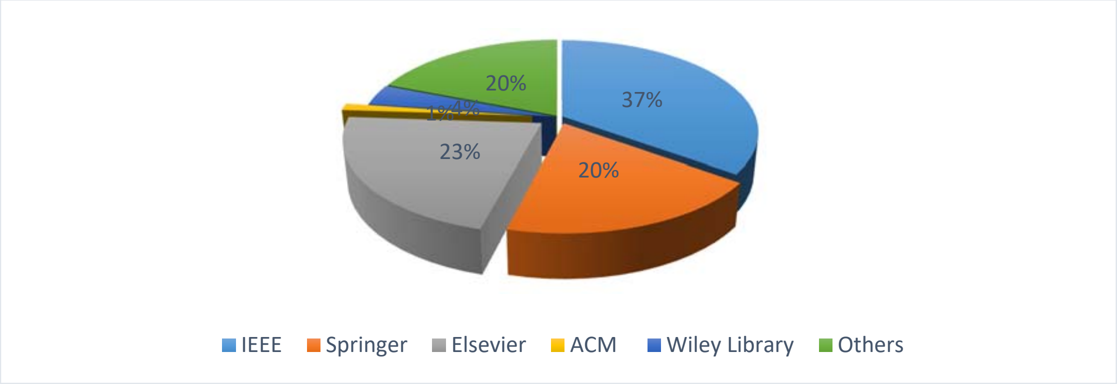


Figure 2: Percentage of Articles by Publisher

Table 2: Analyzed Field, Category, and Percentage

#	Field	Category	N. Article	Percentage %
1	Paper Type	Survey Paper	7	5%
		Technical Paper	146	95%
2	Technical Method that used	Exist Algorithm	69	48%
		New without QoS	60	41%
		New with QoS	16	11%
3	Technical Task	Routing	81	55%
		Deployment	67	45%
4	Used in Application	Application	37	26%
		Not	108	74%
5	Optimization Algorithm	NSGA-II	65	21%
		PSO	31	10%
		GA	42	13.5%
		SPEA-II	13	4%
		MOEA/D	22	7%
		ABC	7	2%
		ACO	9	3%
		LEACH	12	4%
		DE	11	3.5%
		Tabu Search	3	1%

		HAS	3	1%
		Other	91	30%
6	Mechanism (1)	Clustering	79	55.5%
		Not clustering	66	45.5%
	Mechanism (2)	Use relay node	27	19%
		Don't use relay	118	81%
7	Obtaining Fitness Value	Weighted Sum	24	17%
		Pareto Front	119	83%
8	Number of Objectives	Two	78	54%
		Three	52	35%
		Four	8	5.5%
		Five or More	8	5.5%
9	Objective Type	Energy Consumption	117	30%
		Coverage	55	14%
		# of Node	35	9%
		Reliability	21	6%
		Load Balance	10	3%
		Connectivity	13	3%
		Delay	35	9%
		Packet Ratio	14	4%
		# of Hop	8	2%
		Other	76	20%
10	Mobility	Static Node	106	73%
		Mobile Node	39	27%
11	Heterogeneity	Homogeneous	97	67%
		Heterogeneous	48	33%
12	Topology	Flat	68	47%
		Two-tier	77	53%
14	Using Performance Indicators	Use Indicators	20	14%
		Not used	125	86%

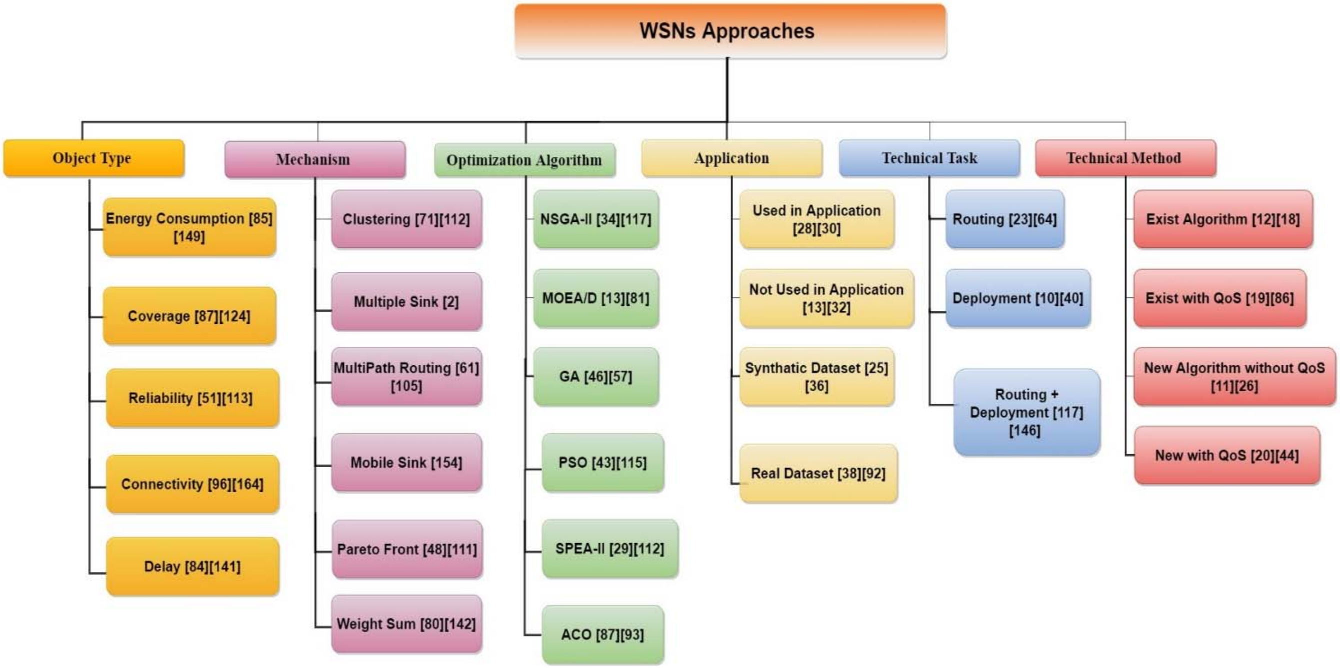


Figure 3: The Proposed Analyzing Approach

3. RELATED WORK

Several research papers have been advocating in Multi-objectives optimization methods for WSNs, therefore several surveys are related to this field in the period (2004 - 2019). Some of these surveys attended in QoS for WSNs, a systematic review for QoS mechanisms that employed by routing protocols introduced by [145], these survey presents comparative analysis of computational intelligence based QoS-aware routing protocols weather strength and limitations. Moreover, in [103] present the state of the art hybrid routing algorithms for WSNs based in multiple quality of service (QoS) metrics, such as power usage, aggregation, scalability, delay, and security. They proposed a novel hybrid routing algorithm called Multi-objective Hybrid Routing Algorithm (MOHRA) for WSN. The main goal of (MOHRA) is to select optimal routing up to sink based on multi-objective metrics in order to prolong the lifetime of WSN. Analyzing the literature articles based on the simulation environment and experimental setup studied by [159], the authors discuss features that are related to energy, security, and reliability problems, take in aware QoS and the deployment against various applications, in additional to this the authors studied the optimization of the routing methods using meta-heuristic algorithms.

A comprehensive review presented by [151] for different power saving and energy optimization techniques available for WSN, they consider researches that use the nature inspired metaheuristic techniques. While contemporary review for multi-objective optimization techniques are used to solve different problems relating to design, operation, placement, deployment, and management, of WSNs was presented in details by [19].

In [154], highlight the properties of WSNs applications that determine the placement problem, then provides an overview and concentrates on multi-objective strategies, their assumptions, optimization problems, formulation and results. A tutorial and survey of recent research and development efforts to addressing multi-objective problems by using multi-objective techniques provided in details by [3], which gives an overview of the main optimization objectives used in WSNs. Then, elaborate on various prevalent approaches produced for MOO, and a summarization for a range of recent studies of MOO in the context of WSNs presented in this survey.

Our survey aims to present a comprehensive study about articles that used multi-objective techniques to solve multi-objective problems in WSNs, it illustrates optimization problems, objectives that are optimized, related tasks, mechanisms that are used to achieve these tasks, and if it used in application or not. Otherwise, if these researches use exist algorithms to solve the Multi-objective problem, or if they proposed new methods, this may lead to if these methods used QoS parameters such as delay, reliability, packet ratio, and overhead, or if it isn't based on QoS.

We will introduce this survey paper to the readers in a way different from previous surveys; however, in our work, we give statistics that represent where the previous technical researches are centered, and what fields that these paper had covered. Therefore, our work gives a comprehensive view on most of these articles so it allows the reader to select the appropriate field that they are interested in it.

We found that there is a little interest in some multi-objectives algorithms such as NSGA-III (whereas, there is one research that used it at deployment stage [10]). A weakness point in this field there is a little of previous papers have a consideration for QoS, and it's metrics such as coverage, reliability, delay and packet delivery. Other weakness is the most of previous researches depended on two, or three objectives, while small number of researches that consider four or more objectives. On the other hand, another weakness in these researches was in employing performance indicators to evaluate Pareto front solutions for multi-objectives algorithms. Therefore, in our future work we will handle these weakness points, to overcome over these Obstacles.

4. WIRELESS SENSOR NETWORK OBJECTIVES AND RELATIONSHIPS

In WSNs, there are three type of relationships between desirable objectives; figure 4 shows these relations [6]:
1- The conflicting relationship: such as maximizing the coverage that conflicts with the energy consumption, and Network/Battery lifetime.
2- The supporting relationship between the two objectives (coverage and energy consumption): such as minimizing Network/Battery (energy consumption) will support maximizing energy efficiency, or maximizing network coverage that will support maximizing connectivity.

3- No direct relationship: such as maximizing the coverage, has no direct relationship on energy efficiency, and QoS (Reliability).

In table 3, we present the relationship between the objectives that researchers used it in their research as conflict, support, and no direct relation:

TABLE 3: RELATIONSHIP BETWEEN MULTIPLE OBJECTIVES PARAMETERS IN WSNS

	EC	**Cov**	**Con**	**RE**
EC		Conflict	Conflict	Conflict
Cov	Conflict		Support	No direct
Con	Conflict	Support		No direct
RE	Conflict	No direct	No direct	

EC. = Energy Consumption, Cov. = Coverage, Con. = Connectivity, RE. = Reliability.

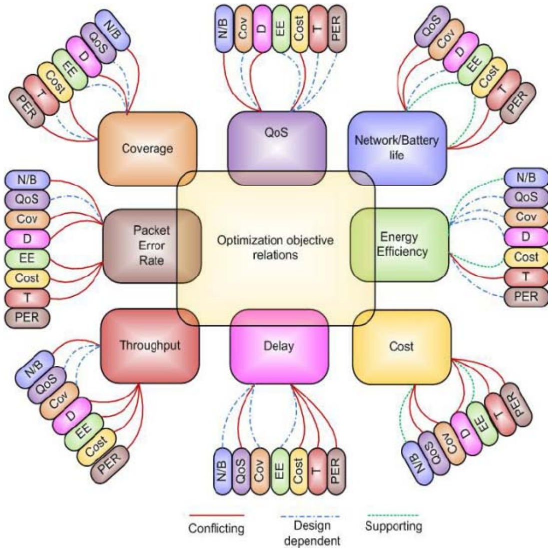


Figure 4: Relation between desirable objectives in wireless sensor networks (WSNs), where "N/B" = network/battery life; "QoS" = quality of service; "Cov" = coverage; "D" = delay; "Cost"=total cost of the system; "T"= throughput of the system; "EE"=energy efficiency; "PER" = packet error rate [6]

There are several shortcomings, which affect WSNs as latency, coverage, energy efficiency, computing capacity, security, and network lifetime, also these factors important in maintaining the QoS, which is critical for many real-world applications [12].

4.1 Energy Consumption

In our research paper, we summarize all terms that are related to energy as energy consumption, energy efficiency, residual energy, ect. In one term considering it as energy consumption.

Energy efficiency considered as the most predominant in WSNs [145]. Radio communications considered the main cause for energy consumption, besides other factors that affect energy as the weather, and the temperature [51][68], authors in [68] proposed data compression to reduce amount of translation reception by sensor node and extend WSN lifetime.

To minimize energy consumption it is required to transmit the sensing data over reduced distance in each hop [3], so there are several mechanisms employed to save energy such as clustering, multipath routing, and multiple sink [145]. In [40] the authors proposed online density control-based sleep-scheduling method for minimizing energy and prolong lifetime of WSN.

❖ Energy Consumption Model

Several researches use the following energy model such as in [13], these model represented in figure 5:

$$\boldsymbol{E(I) = \left(\sum_{i=1}^{nc} \sum_{s \in c_i} E_{TX_{S,CH_i}} + E_{RX} + E_{DA}\right) + \sum_{i+1}^{nc} E_{TX_{CH_i,BS}} + AEv} \quad (1)$$

Where nc is the total number of active CHs, s ∈ c_i is an active non-CHs associated to the $_i$th active CH node, $E_{TX,\ s1;\ s2}$ is the energy dissipated for transmitting data from node S_1 to node S_2, and E_{RX} and E_{DA} are the energy dissipated for receiving and aggregating data computed, respectively,

$$\boldsymbol{E_{TX_{s_i,s_j}} = \begin{cases} E_{elec} \times l + E_{fs} \times l \times d(s_i, s_j)^2 & if\ d < d_0 \\ E_{elec} \times l + E_{mp} \times l \times d(s_i, s_j)^4 & if\ d \geq d_0 \end{cases}} \quad \dots (2)$$

To receive an L–bit message the radio expends

$$\boldsymbol{E_{RX} = E_{elec} \times l} \quad (3)$$

Where:

E*elec* is the energy dissipated per bit to run the transmitter or the receiver circuit, $\boldsymbol{E_{fs}}$and $\boldsymbol{E_{mp}}$ depend on the transmitter amplifier model we use, and ***d*** is the distance between the sender and the receiver. By equating the two expressions at ***d*** = ***d0***, we have

$$\boldsymbol{d0} = \sqrt{\frac{\boldsymbol{E_{fs}}}{\boldsymbol{E_{mp}}}} \tag{4}$$

$$\boldsymbol{AE = \textstyle\sum_{i=1}^{nc} Activation\ energy\ \times a_i + \sum_{s \in c_i} Activation\ energy\ \times a_s} \tag{5}$$

$$\boldsymbol{a_j = \begin{cases} 1\ if\ sensor_j is\ activated \\ 0 \qquad\qquad\qquad otherwise \end{cases}} \tag{6}$$

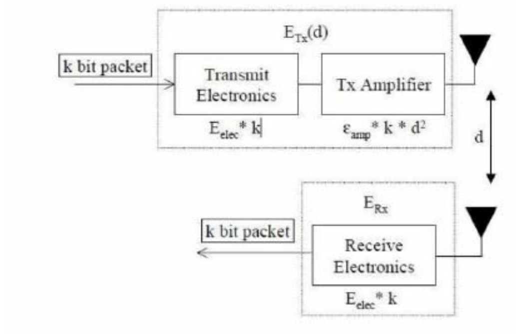


Figure 5: First-order radio mode [31]

4.2 Coverage

Coverage and connectivity considered as important and proper functional issue in WSNs. In many applications QoS measured by coverage, and connectivity [60]. The problem of maintaining sensing coverage can solved by keeping a small number of active nodes, and a small amount of energy consumption [13]. However, to solve coverage problem we must increase coverage rate, in which more sensor work needed, and reduce the working sensor will lead to lower coverage rate [94].
In [60] classify coverage into 1- Area coverage: the main objective in this case is to cover the region of interest, as in [63], they proposed a coverage aware load-balanced clustering protocol which takes care in the area coverage and load-balance. 2- Point coverage: it used to cover specific points of interest area. 3- Barrier Coverage: nodes deployed in such a manner to form a barrier in a specific path.

- **Coverage Model**

Several researches use the following coverage model such as in [13]:

NC is defined as minimizing the number of uncovered target points: M is the number of target points.

$$\boldsymbol{NC(I) = \textstyle\sum_{i=1}^{M} Uncoverd(S_t)} \tag{7}$$

Where:

$$\boldsymbol{Uncovared(S_t) = \begin{cases} 0 \quad if\ \exists S_i \in active\ sensors\ and\ d(S_i, S_t) \le r_i \\ 1 \qquad\qquad\qquad\qquad\qquad\qquad otherwise \end{cases}} \quad \dots (8)$$

$\boldsymbol{Uncovared(S_t)}$: is used to determine whether the target point S_t is covered or not.

4.3 Reliability

Reliability defined based on the number of disjoint paths between a given sensor and sink node, or it may defined as a probability of communication failure [12][98]. Measuring reliability marks the network robustness [18]. Sensing reliability may be affected by several parameters like strength of generated signal, environmental condition, sensor's hardware, interference, and noise [47][104].
Cluster- based approach perform better than the multi-hop approach from the reliability perspective to achieve an efficient traffic management [82].
Reliability is important to avoid losing packet route, when the loss of data packet increase in busy network. In other words, if subsets of nodes in a room used to detect temperature change, increase or decrease rapidly, the probability of losing data packet increases since sensing nodes are busy [83].

Reliability Model

Several researches use the following coverage model such as in [31]:

$$\boldsymbol{Signal(S_i, d_i) = \begin{cases} 0\ if\ r + r_u \le dis(s_i, d_j) \\ e^{-\lambda a^{\beta}}\ if\ r - r_u < dis(s_i, d_i) < r + r_u \\ 1\ if\ r - r_u \ge dis(s_i, d_j) \end{cases}} \quad \dots (9)$$

Where:
- r_u is the measure of the uncertainty.
- $\boldsymbol{dis(s_i, d_j)}$ is the Euclidean distance

$$\sqrt{\boldsymbol{(x_{si} - x_{dj})^2 + (y_{si} - y_{dj})^2}} \tag{10}$$

Between, n the source node s_i and destination node d_j.

- a =dis (s_i, d_j)– (r –r_u).
- λ and β: are probabilistic parameters to measure signal strength. When the distance between source and destination is within the interval r –r_u.
- r + r_u, signal strength exponentially decreases as the distance increases.

The nodes that positioned with in the distance r–r_u from the source are considered to be fully connected with signal strength of 1 (100%). On the other side, all nodes beyond the distance r+r_u are considered disconnected and signal strength is 0 (0%).

let N_i denote the set of all sensor node adjacent to cluster head CH_i where 1 < $_i$ < |CH|, and let S_{Ni}→CH_i denote the total signals sent from sensor node in N_i to cluster head CH_i. Then, the average of signals received by CH_i is expressed as:

$$\boldsymbol{AVG_{S_{N_i \to CH_i}} = S_{N_i \to CH_i}/N_i} \qquad (11)$$

This way, sensor node reliability denoted by N_R, it could formally calculated as:

$$\boldsymbol{N_R(I) = \left(\sum_{i=1}^{|CH|} AVG_{S_{N_i \to CH_i}}\right)/|CH|} \qquad (12)$$

In addition, cluster head reliability denoted by CH_R can formally calculated as:

$$\boldsymbol{CH_R(I) = \sum_{i=1}^{|CH|} AVG_{S_{CH_i \to BS}}} \qquad (13)$$

We find the unreliability for solution I:

$$\boldsymbol{U_R(I) = (1 - ((N_R + CH_R))} \qquad (14)$$

4.4 Connectivity

Two sensor nodes can be connected if they are within the same communication range, and there must be a path from each node to the base station [60].

Connectivity (network sustainability) is important to those applications that need to keep all nodes alive as long as possible to avoid partitioning such in military applications [83].

❖ Connectivity Model

Several researches use the following coverage model such as in [14]:

$$\boldsymbol{Connectivity = \frac{avilable\ links}{\frac{n(n-1)}{2}}} \qquad (15)$$

$\frac{n(n-1)}{2}$ It is the number of possible links in the group (G) considering it as an undirected graph.

4.5 Delay

Reducing delay is an important issue in QoS real-time applications such as multimedia. These applications need guaranteed delay, and bandwidth [69].

Packets should be delivered with minimum end-to-end delay, while delays are important in applications that need little latency. For example, security applications need to detect movements in a specific area [83].

❖ Delay Model

In computer networks, delays are known when the time that the packet take from source node to the destination node passes through intermediate node [99].

Each node suffer from several type of delay as [99]:
1- Processing delay: D_{proc}.
2- Queuing delay: D_{queue}
3- Transmission delay: D_{trans}
4- Propagation delay: D_{prop}

Therefore, the overall delay defined as:

$$\boldsymbol{D_{node} = D_{proc} + D_{trans} + D_{queue} + D_{prop}} \qquad (16)$$

These for one node, if we have k nodes, then the total delay are:

$$\boldsymbol{D_{total} = \sum_{i=1}^{k} D_i} \qquad (17)$$

5. WIRELESS SENSOR NETWORK TECHNICAL TASKS

5.1 Routing

Routing in WSNs plays a significant role in the field of environment monitoring; routing techniques are wanted for sending the data between the sensor nodes and the base station to establish communication [159].

Nevertheless, there are number of challenges that faces routing operations. First is sensor nodes have limited memory, second sensor nodes are unexpected to operate for a long time while it have run on batteries, third sensor nodes have short communication range, fourth the network efficiency, and intelligently should be high, and fifth the objectives and strategies, that routing protocols have built-in [54].

There are several types of routing problems: in [70] solving a mobile agent routing problem, and handle faulty sensor node by data fusion technique.

Routing protocols categorized based on the nodes participation, clustering, functioning mode, and network structure [159]. In [99] present that routing protocols are divided into flat-based routing, hierarchical-based routing, and location-based routing, which is used to route data in the network according to the protocol operations.

In [13] proposed new routing approach based on energy conservation, and coverage preservation using clustering mechanism.

In QoS routing many factors must take in consideration such as the energy status of nodes in the network, the delay, the bandwidth, and the reliability requirements to transmit the data [19]. Such approach must give guarantee bandwidth, reliability, and delay through the duration of data transmission [21].

5.2 Deployment

The deployment strategies can be classified into three criteria, the first can be random placement (nondeterministic), where large number of sensor node are scattered from plane, or grid-based placement (deterministic placement), and there are some applications where it is possible to select the site where to place the sensor node. The second is the optimization of performance metrics as coverage, connectivity, and energy consumption. The third depends on the role of deployed node, which can be regular, relayed, cluster head, or base station [22][24]. An efficient node deployment strategy would reduce cost while provide a high degree of coverage and maintain global connectivity in WSNs [60].

Node placement and deployment are important task in WSNs design [10][71], when deploy the optimal number of sensor nodes with providing optimal coverage and connectivity. This approach is considered a necessary issue, and this depends on whether the placement technique is static (performed at deployment time), or dynamic (performed at network working) [24][60].

Several deployment problems are tackled in previous works by estimating the sensing overlapping area between sensor nodes [14], WSNs designing requires high quality location assignment, and energy efficient power assignment for maximizing the network coverage and lifetime [72].

6. WIRELESS SENSOR NETWORK MECHANISMS

6.1 Clustering

Clustering sensor nodes into groups is an efficient topology control approach for achieving long-term operations of WSNs; it is observed that network constructions that depend on clustering are the most effective method in term of power utilization [38] [115].

Clustering techniques can classified in to homogeneous, or heterogeneous in term of initial energy, based on the type of WSN. Therefore, an efficient clustering allows equalization of load between clusters heads (CHs) [63]. While in [61] classify clustering techniques into partition clustering (Fuzzy-based clustering), optimized-based clustering, and LEACH-based clustering. Finding best possible CH considered as critical issue in clustering methods, selecting these node by using optimization algorithm and K-means are used to create clusters in the nodes, as selecting appropriate CH with largest energy, will reduce consumed energy and prolong network’s lifetime [13][44][62][141].

CHs treated as gateways, these gateways perform the multiple activates, such as data gathering, aggregation, and transmission, the most important objective in these mechanism is to minimize the distance between gateways (CH) and base station [64]. Sensor nodes correspond for selecting the CH, sensor nodes communicate with their CH, or with other sensors in the same cluster, while CH communicate with the sink node, or base station [44].

6.2 Multiple Routing Metrics

Routing metric are used to select the best optimal path towards the sink node, multiple routing metrics are vital to reduce energy consumption, these metrics as energy efficiency, delay, reliability, and hop count [145]. In [13], they add coverage to routing metrics to make trade-offs between multiple conflicting optimization objectives such as coverage preservation and energy conservation [13].

As we present several research papers that use multi-objective algorithms to solve MOP with clustering, or without clustering. In some work, they use weight sum by convert multi-objectives to single objective, while most of recent works use pareto front solutions, then the trade-off between metrics happen, so the decision maker can select the optimal solution.

However, the disadvantage that any researcher tumbles upon is when the number of routing metrics increase the complexity of route computation increase [145].

6.3 Mobile Sink

Mobility may apply to all nodes within a network or only to subsets of nodes; there are three cases for WSN, static nodes, mobile nodes, and mobile sink [154]. The mobile sink mechanism in WSNs introduced to maximize the network lifetime. The hotspots around the sink change, while the sink moving, energy consumption will be reduced, and so that prolonging the network lifetime [145].

Two type of mobile sink used: controlled mobile sink, which improves network connectivity, coverage, and reliability of data. On the other hand, uncontrolled mobile sink, which introduces significant communication overheads in terms of energy and delay [145].

Data collection through mobile sink node in WSNs is an effective solution to hotspot or sinkhole problems caused by multi-hop routing while using static sink node [112].

In [107], they use a mobile sink to address the problem of data collection with the objective of minimizing the energy consumption and the delay of data collection. They propose a Multi-objective Linear Programming (MLP) framework that allows to optimality place the gateways and minimize jointly the energy spent in the WSN and the route of the mobile sink.

In [112], they propose an MOPSO-based optimal path design algorithm for the mobile sink in WSN; this algorithm finds the rendezvous points (RPs), with a trade-off between transmission distance and intermediate data forwarding.

6.4 Multiple Sink

Deploying multiple sinks in an area of interest would decrease multi-hop routing, when the message passes from source to the closest sink [2].

Using multiple sinks will make data transmission faster and more successful with data delivery, and will decrease end-to-end delay (speed), traffic be will shared among multiple sinks so WSN will consume low energy, and large scale of networks can be divided into small sub networks, this will increase scalability [2][145]. However, the Difficult things about this mechanism is to locate the optimal number and the position of the multiple sinks [145].

6.5 Multipath Routing

An efficient multipath routing is required between sensor nodes to tolerance from fault and intrusion, and improve packet delivery and reliability, it grants additional robustness against link failure [61][105]. The number of optimal multipath can grow exponentially with respects to the network size [99].

Multipath routing distributes the network traffic along the multiple paths towered destination, it maintains reliability and load balance, but it requires fragmentation strategies in some applications as multimedia and video streaming [145].

7. MULTI-OBJECTIVE ALGORITHMS

The main goal of multi-objective optimization algorithms is to discover a set of non-comparable solutions called the Pareto-front considered as optimal, which represent the tradeoff between multiple objectives [70].

7.1 MOPSO Algorithm

Particle Swarm Optimization (PSO) has been established in 1995 and became a very mature and most popular domain in SI. Multi- Objective PSO (MOPSO) established in 1999.

PSO based on the hypothesis that members of a population (swarm) can profit from their experiences and the experiences of other individuals (particles). So it access to two pieces of information: the best potential solution (PS), and the best PS encountered by its neighborhood. The value, χ_i, represents the fitness assigned to x_i by the objective function. The p-vector contains the best PS discovered by a particle. The value, ρ_i,is the fitness assigned to the p-vector. Finally, the v-vector, known as the velocity as in figure 6 [136].

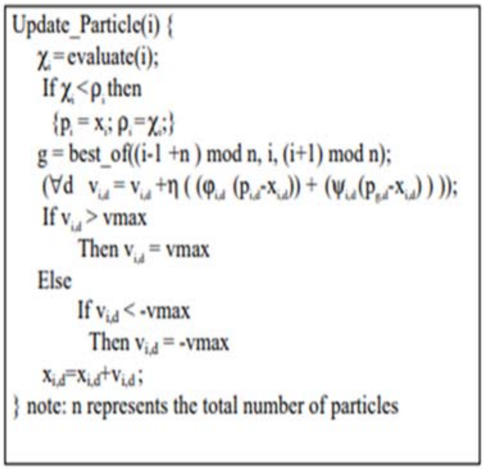
However, as we now in multi-objective algorithms try to maximize or minimize the optimal solution for MOPs such as these equations:

$$\boldsymbol{mix/\min f_n(x)}, \quad \mathbf{n = 1, 2, \ldots, N;} \qquad (18)$$

Where in [15] represent PSO Equations as following:

$$\boldsymbol{v_i^{t+1} = wv_i^t + c_1 r_1\left(x_{pbest} - X_i^t\right) + c_2 r_2\left(x_{gbest} - X_i^t\right)} \qquad (19)$$

$$\boldsymbol{X_i^{t+1} = X_i^t + V_i^{t+1}} \qquad (20)$$



```
Update_Particle(i) {
    $\chi_i$ = evaluate(i);
    If $\chi_i < \rho_i$ then
      {$p_i = x_i$; $\rho_i = \chi_i$;}
    g = best_of((i-1 +n ) mod n, i, (i+1) mod n);
    ($\forall d$  $v_{i,d} = v_{i,d} + \eta ( (\varphi_{i,d} (p_{i,d} - x_{i,d})) + (\psi_{i,d} (p_{g,d} - x_{i,d}) ) )$);
    If $v_{i,d}$ > vmax
        Then $v_{i,d}$ = vmax
    Else
        If $v_{i,d}$ < -vmax
          Then $v_{i,d}$ = -vmax
    $x_{i,d} = x_{i,d} + v_{i,d}$;
} note: n represents the total number of particles
```

Figure 6: PSO algorithm pseudo code [136]

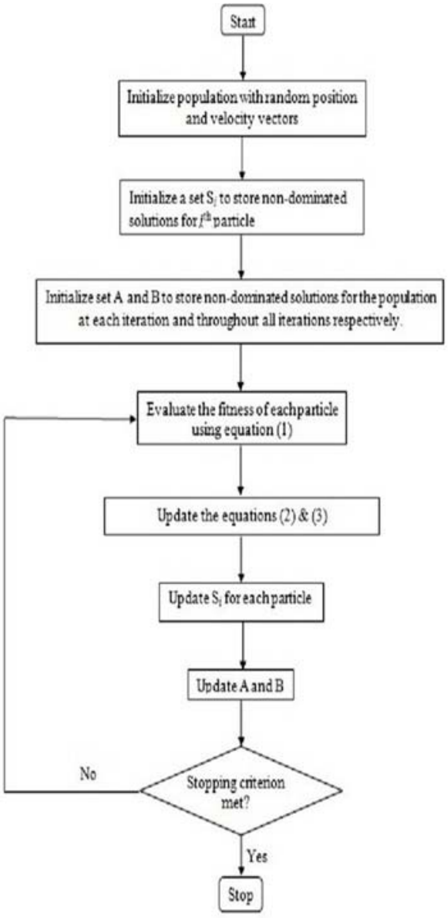


Figure 7: Flowchart for MOPSO Algorithm [15]

In MOPSO velocity update and position update equations remain the same as the equation in PSO. All parameters are declared the same as PSO except for the objective function [15]. The objective function contains multiple objectives as represented in figure 7. Where one type of preferences that has been widely used by multi-objective optimizers known as Pareto preference. When using Pareto preference, the set of non-dominated PSs discovered, and referred to users as the Pareto set [136].

7.2 MOEA/D Algorithm

Multi–objective evolutionary algorithm based on decomposition (MOEA/D) decomposes a multi-objective optimization problem into a number of scalar sub problems and optimizes them simultaneously; it has lower computation complexity at each generation than (NSGA- II) [37].

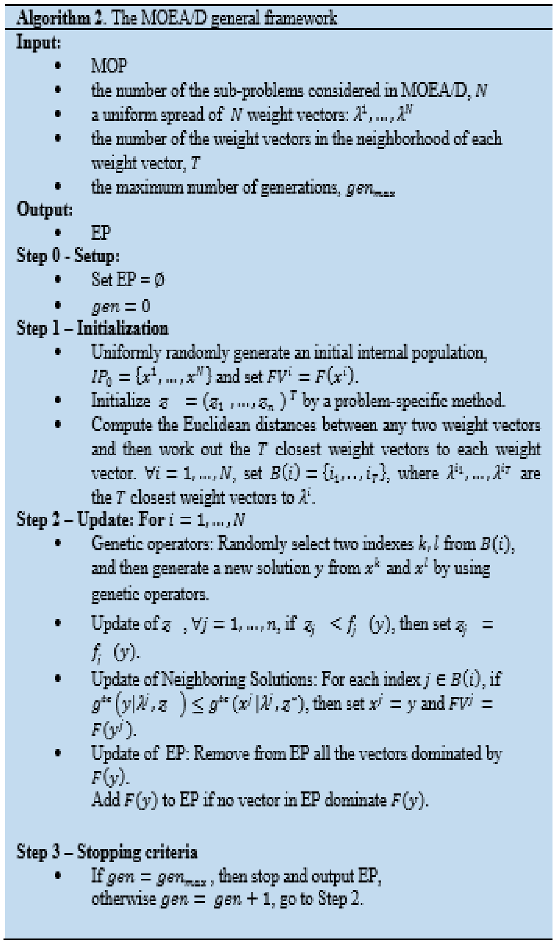
The main drawback of the generic evolutionary multi-objective techniques is that it treats a MOP as a “black box”, i.e. without using problem-specific knowledge, which may have undesirable effects, such as forcing the evolutionary process into unnecessary searches and destructive mating, negatively affecting their overall performance [13].

In [37], the authors introduce this algorithm in 2007 so we will discuss features and general framework for MOEA/D algorithm:

1- MOEA/D introduces a simple efficient decompose-approach to multi-objective evolution evolutionary computation.
2- MOEA/D has optimal N scalar optimization problems rather than solving it as all.
3- MOEA/D has lower computational complexity at each generation than NSGA-II. Moreover, in general exhibit a higher convergence rate [56].

Three approaches are used to solve problems to make decomposition and convert the whole problem to scalar sub problem, these approaches as weighted sum approaches, Tchebycheff approach, and boundary intersection (BI) approach.

In general, the framework for MOEA/D can be as, decompose the problem of approximation Pareto Front (FP) in to (N) scalar sub problems using Tchebycheff approach. As represented in figure 8, in [29].



```
Algorithm 2. The MOEA/D general framework
Input:
    • MOP
    • the number of the sub-problems considered in MOEA/D, $N$
    • a uniform spread of $N$ weight vectors: $\lambda^1, \dots, \lambda^N$
    • the number of the weight vectors in the neighborhood of each
      weight vector, $T$
    • the maximum number of generations, $gen_{max}$
Output:
    • EP
Step 0 - Setup:
    • Set EP = $\emptyset$
    • $gen = 0$
Step 1 – Initialization
    • Uniformly randomly generate an initial internal population,
      $IP_0 = \{x^1, \dots, x^N\}$ and set $FV^i = F(x^i)$.
    • Initialize $z = (z_1, \dots, z_n)^T$ by a problem-specific method.
    • Compute the Euclidean distances between any two weight vectors
      and then work out the $T$ closest weight vectors to each weight
      vector. $\forall i = 1, \dots, N$, set $B(i) = \{i_1, \dots, i_T\}$, where $\lambda^{i_1}, \dots, \lambda^{i_T}$ are
      the $T$ closest weight vectors to $\lambda^i$.
Step 2 – Update: For $i = 1, \dots, N$
    • Genetic operators: Randomly select two indexes $k, l$ from $B(i)$,
      and then generate a new solution $y$ from $x^k$ and $x^l$ by using
      genetic operators.
    • Update of $z$, $\forall j = 1, \dots, n$, if $z_j < f_j(y)$, then set $z_j =$
      $f_j(y)$.
    • Update of Neighboring Solutions: For each index $j \in B(i)$, if
      $g^{te}(y|\lambda^j, z) \le g^{te}(x^j|\lambda^j, z^*)$, then set $x^j = y$ and $FV^j =$
      $F(y^j)$.
    • Update of EP: Remove from EP all the vectors dominated by
      $F(y)$.
      Add $F(y)$ to EP if no vector in EP dominate $F(y)$.

Step 3 – Stopping criteria
    • If $gen = gen_{max}$, then stop and output EP,
      otherwise $gen = gen + 1$, go to Step 2.
```

Figure 8: MOEA/D algorithm pseudo code [29]

7.3 NSGA-II, and NSGA-III Algorithms

Many multi-objective optimization algorithms use evolutionary methods that involve mostly two and three objectives. Evolutionary multi-objective optimization (EMO) finds a set of well-converged and well-diversified non-dominated solutions for two or three objectives.

NSGA-III used to optimize many objectives, four or more; up to 15 objectives, it uses NSGA-II framework procedure but works with a set of supplied or predefined reference points and demonstrate its efficiency in solving two to 15 objectives. However, NSGA-III called many objectives NSGA-II algorithm, the changes in the selection mechanism, and maintenance of diversity among population added by supplying reference points [42].

The key features of NSGA-II summarized as follows by [41]:

- ❖ Emphasizes non- dominated sorting based on optimal Pareto fronts as shown in figure 9 [168], which represents number of optimal solutions in each front set between two objectives. It works to get number of Pareto optimal solutions in the evaluation generation [13].
- ❖ Uses diversity-preserving mechanism.
- ❖ Does crowding comparison: for solutions in last level member (last front F_L), chose the solution with lager crowding distance value.
- ❖ Uses elitist principle: some of parents go directly to the next generation based on the previous conditions.
- ❖ Most of previous optimization algorithms have computational complexity of $O(mN^3)$, where m is the number of objectives and N is the size of populations. While NSGA-II have computational complexity $O(mN^2)$ [17].

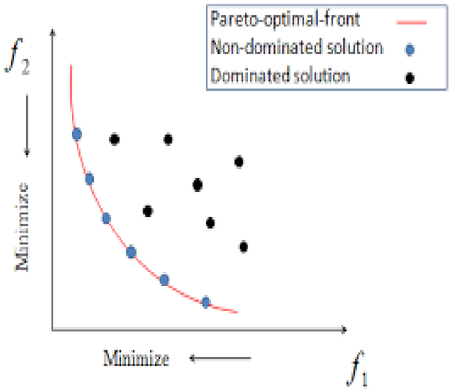
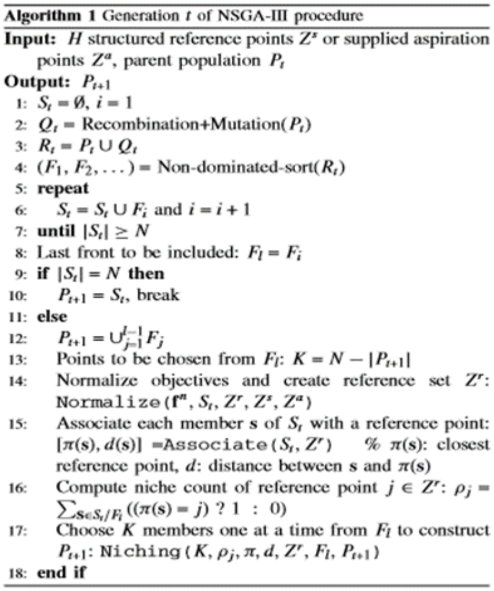


Figure 9: Non-dominated sorting of a population based on Pareto Front [168]

In NSGA-III, replace the crowding distance operation by the following operations, in figure 10 pseudo code for NSGA-III with these operations [42]:



```
Algorithm 1 Generation $t$ of NSGA-III procedure
Input: $H$ structured reference points $Z^s$ or supplied aspiration points $Z^a$, parent population $P_t$
Output: $P_{t+1}$
$S_t = \emptyset$, $i = 1$
$Q_t$ = Recombination+Mutation($P_t$)
$R_t = P_t \cup Q_t$
$(F_1, F_2, \dots)$ = Non-dominated-sort($R_t$)
repeat
    $S_t = S_t \cup F_i$ and $i = i + 1$
until $|S_t| \geq N$
Last front to be included: $F_l = F_i$
if $|S_t| = N$ then
    $P_{t+1} = S_t$, break
else
    $P_{t+1} = \cup_{j=1}^{l-1} F_j$
    Points to be chosen from $F_l$: $K = N - |P_{t+1}|$
    Normalize objectives and create reference set $Z^r$:
        Normalize($\mathbf{f}^n, S_t, Z^r, Z^s, Z^a$)
    Associate each member s of $S_t$ with a reference point:
        $[\pi(s), d(s)]$ =Associate($S_t, Z^r$)    % $\pi(s)$: closest reference point, $d$: distance between s and $\pi(s)$
    Compute niche count of reference point $j \in Z^r$: $\rho_j = \sum_{s \in S_t/F_l}((\pi(s) = j)\ ?\ 1\ :\ 0)$
    Choose $K$ members one at a time from $F_l$ to construct
        $P_{t+1}$: Niching($K, \rho_j, \pi, d, Z^r, F_l, P_{t+1}$)
end if
```

Figure 10: NSGA-III algorithm pseudo code [42]

7.3.1 Classify of population into non- dominated level

a) Population for all front without last front

$$P_{l+1} = \cup_{i=1}^{l-1} F_i \qquad (21)$$

b) Population members that chosen from the last front F_L.

$$K = N - |P_{i+1}| \qquad (22)$$

7.3.2 Determination of reference points on a hyper-plane:

NSGA-III considered a reference point method and it have reference point uniformly distributed throughout the objective space [169]. As in figure 11.

a) Chooses predefined set of reference points and places it on a normalized hyper-plane as represented in figure 11.

b) It assume if we have (P) division along each objective, an (M) objective problems then the reference points (H) is:

$$H = \binom{M+P-1}{P} \qquad (23)$$

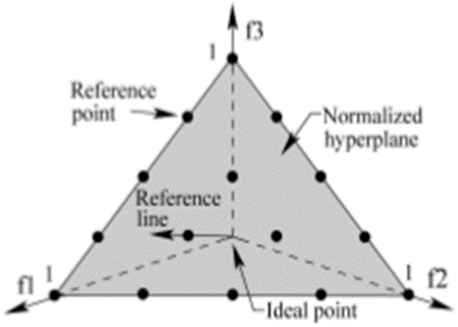


Figure 11: Fifteen structured reference points are shown on a normalized reference plane for a three-objective problem with p = 4 [42]

7.3.3 Adaptive normalization of population member:

a) Determine the ideal point of the population S_t, which is Z_i^{min}, for each objective function as figure 12, represent normalization pseudo code.

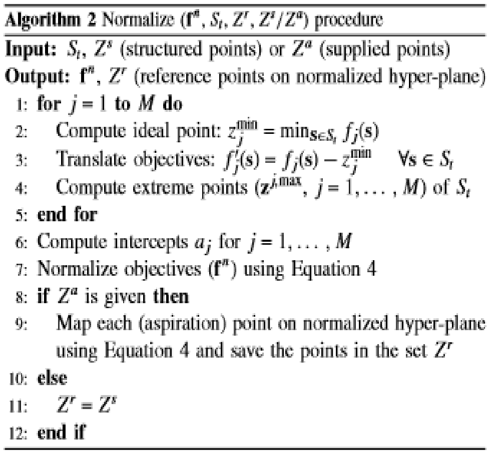
b) Each objective value S_t, translated by subtracting $F_i - Z_i^{min}$

$$\acute{f}_i(x) = F_i - Z_i^{min} \qquad (24)$$

c) Normalized objective function by:

$$f_i^n = \frac{\acute{f}_i(x)}{a_i} \quad \textbf{for i=1, 2,.....M} \qquad (25)$$

Where a_i, the intercept of i^{th}, objectives axis on the linear hyper-plane (supplied points).



```
Algorithm 2 Normalize ($\mathbf{f}^n, S_t, Z^r, Z^s/Z^a$) procedure
Input: $S_t$, $Z^s$ (structured points) or $Z^a$ (supplied points)
Output: $\mathbf{f}^n$, $Z^r$ (reference points on normalized hyper-plane)
for $j = 1$ to $M$ do
    Compute ideal point: $z_j^{min} = \min_{s \in S_t} f_j(s)$
    Translate objectives: $f'_j(s) = f_j(s) - z_j^{min}$   $\forall s \in S_t$
    Compute extreme points ($\mathbf{z}^{j,max}$, $j = 1, \dots, M$) of $S_t$
end for
Compute intercepts $a_j$ for $j = 1, \dots, M$
Normalize objectives ($\mathbf{f}^n$) using Equation 4
if $Z^a$ is given then
    Map each (aspiration) point on normalized hyper-plane
        using Equation 4 and save the points in the set $Z^r$
else
    $Z^r = Z^s$
end if
```

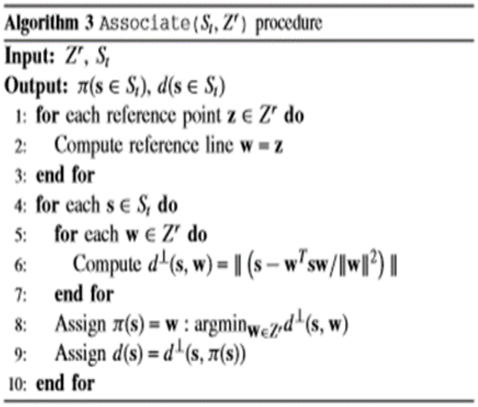
Figure 12: Normalization Operation pseudo code [42]

7.3.4 Association operation

a) Find a reference line corresponding to each reference point on the hyperplane by joining the point with the origin.

b) Calculate the perpendicular distance for each population member S_t from each of the reference lines.

c) The reference point whose reference line closest to a population member is associated with the population member as pseudo code in figure 13.



```
Algorithm 3 Associate($S_t, Z^r$) procedure
Input: $Z^r, S_t$
Output: $\pi(\mathbf{s} \in S_t), d(\mathbf{s} \in S_t)$
for each reference point $\mathbf{z} \in Z^r$ do
    Compute reference line $\mathbf{w} = \mathbf{z}$
end for
for each $\mathbf{s} \in S_t$ do
    for each $\mathbf{w} \in Z^r$ do
        Compute $d^{\perp}(\mathbf{s}, \mathbf{w}) = \| (\mathbf{s} - \mathbf{w}^T \mathbf{s} \mathbf{w} / \|\mathbf{w}\|^2) \|$
    end for
    Assign $\pi(\mathbf{s}) = \mathbf{w} : \text{argmin}_{\mathbf{w} \in Z^r} d^{\perp}(\mathbf{s}, \mathbf{w})$
    Assign $d(\mathbf{s}) = d^{\perp}(\mathbf{s}, \pi(\mathbf{s}))$
end for
```

Figure 13: Association Operation pseudo code [42]

7.3.5 Niche – preservation Operation:

a) Count the number of population member that is associated with reference point.

$$\boldsymbol{P_{t+1} = S_i/F_l} \qquad (26)$$

Denote this niche count ρ_j for j^{th} reference point

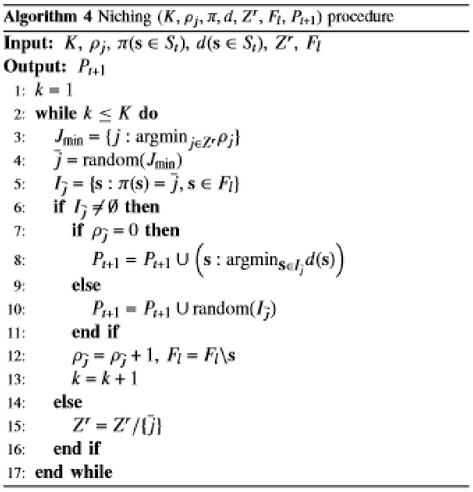
b) Identify reference point set $J_{min} = \{j: argminj\ \rho_j\}$ having minimum ρ_j, if there are multiple reference points. $\grave{j} \in J_{min}$ is chosen at random

c) If $\grave{\rho}_j = 0$ there are two scenario with *J* in set F_l, there exists one or more member in F_l, that associated with $\acute{j}$ then choose one with shortest perpendicular distance from the reference point $\acute{j}$.

The second scenario is F_l not have any member associated with the reference point $\acute{j}$.

d) $\grave{\rho}_j \geq 1$ already one member associated with reference point, choose it randomly from F_l and add in to P_{t+1}.

e) Incremented $\grave{\rho}_j$ count by one and repeat the process for total of K times to fill all population slot of P_{t+1} as in figure 14.



```
Algorithm 4 Niching ($K, \rho_j, \pi, d, Z^r, F_l, P_{t+1}$) procedure
Input: $K, \rho_j, \pi(\mathbf{s} \in S_t), d(\mathbf{s} \in S_t), Z^r, F_l$
Output: $P_{t+1}$
$k = 1$
while $k \leq K$ do
    $J_{\min} = \{j : \text{argmin}_{j \in Z^r} \rho_j\}$
    $\bar{j} = \text{random}(J_{\min})$
    $I_{\bar{j}} = \{\mathbf{s} : \pi(\mathbf{s}) = \bar{j}, \mathbf{s} \in F_l\}$
    if $I_{\bar{j}} \neq \emptyset$ then
        if $\rho_{\bar{j}} = 0$ then
            $P_{t+1} = P_{t+1} \cup \left(\mathbf{s} : \text{argmin}_{\mathbf{s} \in I_{\bar{j}}} d(\mathbf{s})\right)$
        else
            $P_{t+1} = P_{t+1} \cup \text{random}(I_{\bar{j}})$
        end if
        $\rho_{\bar{j}} = \rho_{\bar{j}} + 1,\ F_l = F_l \backslash \mathbf{s}$
        $k = k + 1$
    else
        $Z^r = Z^r / \{\bar{j}\}$
    end if
end while
```

Figure 14: Niching operation pseudo code [42]

7.2 Weight Sum Vs Pareto Front

Weighted sum combine the two or more objectives into a single objective, it solves the problem as a single objective optimization problem, and it does not guarantee an optimum solution because choosing the weight vector can allow weight, which is not an easy problem. Because small changes in the weight vector can yield very different solutions, it is simple but it not suitable for all multi-objectives problems (MOP) [95][144].

In this method, all objectives goals need to be converted into the same kind, which are all objectives are minimized or maximized. There are three types of weighted sum linear, dynamic, and average procedures. In linear weighted sum, the processing method normalized to [144]:

$$f = \sum_{i=1}^{m} w_i * f_i \qquad (27)$$

Where:

$$\sum_{i=1}^{m} w_i = 1 \qquad \textit{And} \qquad w_i > 0 \qquad (28)$$

M: number of objectives.

Pareto Front (PF) generated by specific set of solutions, where none of multiple objectives can be improved without scarifying the other objectives [3]. Pareto front approach has goals [149]:

1- Convergence: find a set of pareto optimal solutions.
2- Diversity: find a set of diverse solutions in order to prevent premature convergence and achieve a well-distributed trade-off pareto front. Diversity in two-dimensional space (two objectives) is symmetric, while in three-dimensional space (three objectives) is more difficult to obtained [46].

Table 3, represents our survey analyzing approach based on criteria as reference, the optimization problem that they want solve, the multi-objectives that they based on , technical task or stage that they work on, the mechanism that employed to solve the problem, the optimization algorithm that they use and compare with, and the application scope that this protocol applied on. While table 4 show new multi-objectives approaches that, the researchers proposed in some research papers, the algorithms that these approaches based on, the multi-objectives that these approaches take on consideration, and the number of these objectives. In table 5, we present the new approaches that the researchers have proposed but these approaches consider the QoS, and their metrics as reliability, delay, packet delivery ratio, and bandwidth.

Finally, in table 6 we compiled some research papers that based on WSNs properties as mobility, heterogeneity, and topology.

TABLE 3: Survey analyzing Approach in Using Multi-objectives for WSNs

Ref	Opt. Problem	Optimized Objectives	Technical Task	Mechanism	Opt. Algorithm	App. Scope
[16], [85]	Maintaining coverage by minimize active nodes and a small amount of energy consumption	Maximum Coverage [16][85], minimize financial cost [16][85], & minimize energy consumption[16]	Deployment	Multi Deployment metrics tradeoff & with clustering, & Scheduling	NSGA-II, compared with OGDC [16][85], Heuristic Algorithm [85]	No
[12], [25], [28], [36], [135]	Solving the relay node placement problem	Minimize energy cost, maximize average sensitivity area, & maximize network reliability	Deployment	Multi Deployment Matrices tradeoff to Relay node placement, & clustering	Compare between NSGA-II [12][25][28][36][135] , SPEA2 [12][25][28][36][135] , MOEA/D [31], MO-ABC [28][36], MO-FA[36], MO-GSA [12], MO-VNS [36][135], MO-VNS* [12]	Yes, using synthetic dataset
[14]	Control overlapping of sensing area	Maximization of coverage, & connectivity	Deployment	Multi Deployment metrics with weighted sum	NSGA-II, compared with TASCC	No
[19]	Cope with battery constraints, while providing QoS	Maximize reliability, minimize delay, & energy consumption	Routing	Multi Routing metrics tradeoff, with cluster-based	NSGA-II, compared with SPEED, & SAR	No
[18]	Deployment of a heterogeneous WSN optimizing some factors	Maximize reliability, maximize coverage, & minimize average number of hops	Deployment	Multi Deployment metrics tradeoff	NSGA-II compared with SPEA-II	Yes, using synthetic dataset

[22]	The coverage holes problem in 3D deployment	Maximizing the coverage area, & maximizing the precision localization	Deployment & Localization	Multi Deployment metrics tradeoff, using Mobile node	NSGA-II	Yes, WSN in smart buildings
[13], &[32]	WSN design problem which considers energy conservation and coverage preservation	Maximizing the coverage area, & minimize energy consumption	Design Routing	Multi Routing metrics tradeoff, with cluster-based	MOEA/D[13][32], Compared with LEACH [13], SEP [13], NSGA-II [13][32]	No
[17]	Improve performance of the cluster routing.	Minimize energy consumption, & Maximizing throughput	Routing	Multi Routing metrics tradeoff, with cluster-based	Compare NSGA-II, with LEACH-ME	No
[24], & [152]	Finding the coordinates of the sensor nodes in a two- dimensional sensing area	Minimize energy consumption, maximize coverage, & maintaining connectivity constraints	Deployment	Multi Deployment metrics tradeoff	MOFPA [24][152], compared with PSO [24][152], & NSGA-II [152]	No
[29]	Relocation of mobile nodes in a WSN with maximum coverage area	Maximize coverage, & minimize travelled distance	Deployment	Multi Deployment metrics tradeoff for mobile node	MOEA/D	No
[30]	Solving clustering problem using multi-objective way	Maximize cluster head energy, maximize number of nodes, & minimize energy consumption	Routing	Multi Routing metrics tradeoff, with cluster-based	NSGA-II compared with LEACH	Yes, environmental monitoring application
[34]	Present the modeling of a multi-objective problem by using multi-objective algorithms	Maximize coverage, maximize lifetime, & minimize sensor number	Deployment	Multi Deployment metrics tradeoff	NSGA-II compared with SPEA-II, & MOACO	No
[38]	Electing an optimal set of cluster heads	Maximize energy efficiency, & link quality	Routing	Multi Routing metrics tradeoff, with cluster-based	Compare between GA, DE, & PSO	Yes, tested under a realistic communication, energy consumption model
[47]	The transition of non-critical data involves use of excessive battery and network bandwidth	Minimize energy consumption, minimize path loss, maximize total detection signal energy	Routing	Multi Routing metrics tradeoff, Mobile agent, & Clustering	Compare EMOCA, with NSGA-II	No
[48]	Single and multipath routing problems	Minimize energy cost, & minimize the number of hops (latency).	Routing	Multi Routing metrics tradeoff	Using MODE, & D-MODE	Yes, underwater networks using both static and mobile nodes
[52]	Find optimal mobile agent routes to minimizing the transmission of non-critical data	Minimize energy consumption, minimize path loss, & maximize accuracy	Routing	Multi Routing metrics tradeoff, Mobile agent, & Clustering	sMOEA/D compared with MOEA/D, & EMOCA	No

[56]	Finding optimal routes from a given source to a given destination	Minimize energy consumption, & end to end delay	Routing	Multi Routing metrics tradeoff	NSGA-II, compared with MODE	No
[61]	Find out the optimal cluster head node iteratively in the IoT network model	Minimize distance, &delay, maximize energy efficiency, & link lifetime	Routing	Dynamic Weighted Sum, with cluster-based	MOFGSA, compared with ABC, GSA, & MPICA	Yes, in IoT networks to extend life time of
[64]	conserve gateways energy for prolonging the WSNs lifetime	Minimize distance from gateways to the base station, minimize relay node count, minimize Relay Load Factor	Routing	Dynamic Weighted Sum based on gateway	PSO, compared with, GA, GLBCA	No
[67], & [162]	Providing a good coverage of the facility without detecting sensor in hostile area	Maximize coverage [67] [162], maximize lifetime [67] minimize sensor number [162]	Deployment	Multi Deployment metrics tradeoff	MOGA	Yes, monitor a critical facility in a hostile region
[68], & [92]	Extending lifetime by compress amount of data transmitted/ received by sensor node	Entropy of quantized sequence, number of level in quantization, & signal to noise ratio (SNR)	Routing	Multi Routing metrics tradeoff	NSGA-II, compared with LTC	Yes, using three datasets collected by real WSNs
[70]	Addresses the problem of routing a mobile agent in a sensor network for fusing data from multiple sensors	Minimize energy consumption, minimize path loss, & maximize total detected signal energy	Routing	Multi Routing metrics tradeoff, based on Mobile agent	EMOCA coma red with Combinatorial optimization, NSGA-II, & WGA	Yes, The applications of mobile agents such as target detection
[74], & [81]	Solving deployment and power assignment problem (DPAP)	Maximize coverage, & lifetime, maintain connectivity as constrains	Deployment	Multi Deployment metrics tradeoff	Compare MOAE/D, with NSGA-II	No
[76]	build up the high level-energy paths to a base station	Minimize energy cost, & maximize utilization of network recourse	Routing `	Using ant-like agent, & linear weighted sum	ACO	No
[79]	Selecting the geographical positions of the nodes, to solve WSN layout problem	Minimize energy consumption, & number of node, with coverage constrained	Deployment	Multi Deployment metrics tradeoff	NSGA-II, compare with MOEA, IBEAε, & IBEAH D	No
[83]	Balance the requirements of multiple applications and the resource constrained sensor network nodes	Maximize reliability, minimize energy cost, & delay	Routing	Dynamic weighted sum	Multi-Objective Cross-Layer Algorithm	Yes, in Healthcare Monitoring, & Security

[86]	Solving design-space exploration problem (DSE), based on QoS	Maximize reliability, minimize energy cost, & latency	Deployment (design)	Multi Deployment metrics tradeoff	SPEA2	Yes, in the temperature mapping application
[96], & [164]	Solving an optimal design problem by find the optimal operation mode of each sensor	Minimize energy consumption, maximize connectivity, maintains application specific	Deployment (design)	Dynamic weighted sum, & clustering	GA	Yes, in precision agriculture application
[101], & [146]	Set coverage problem for mobile node [101], Set coverage problem [146]	Maximize coverage, & lifetime	Deployment & Routing	Multi parameters tradeoff	Compare NSGA-II [101][146], MOAE/D [101][146], MOPSO [146], & NOPSO [146]	No
[149]	Selecting the optimal set of CHs and finding the optimal inter-cluster routing tree	Minimize energy consumption, maximize scalability, & reliability	Routing	Multi Routing tradeoff, with Clustering	NSGA-II, compared with SMPSO	Yes, tested under a realistic communication, energy consumption model
[110]	Find multiple paths between the source sensors and sink node	Minimize energy consumption, hop count, & free space loss	Routing	Multi Routing tradeoff	SPEA2	No
[114]	Solving constrained relay nodes deployment problem (CRNDP)	Minimize energy consumption, & maximize reliability	Deployment	Multi Deployment metrics tradeoff	NSGA-II, compare with MOPSO, & AbYSS	No
[124]	Solving deployment problem for indoor sensor, and sink node	Minimize cost, maximize coverage, & connectivity	Deployment	Multi Deployment metrics tradeoff	Compare NSGA-II, with GA	Yes, indoor applications
[137]	Solving deployment problem based on minimum number of sensor nodes	Maximize coverage, & connectivity	Deployment	Multi Deployment metrics tradeoff	Compare NSGA-II, with GA	No
[157]	Determine the best conflicting objectives which are security, energy consumption, and QoS	Maximize security, throughput, packet delivery ratio, minimize delay, & energy consumption	Routing	Multi Routing tradeoff	NSGA-II	No
[126], & [161]	Solving monitoring and diagnostic problem	Maximize coverage, life time, minimize energy consumption, & satellites Number	Deployment	Multi Deployment metrics tradeoff, with clustering	NSGA-II	Yes, space-based security application

TABLE 4: The New Multi-objectives Approaches don't Consider QoS

Protocol Name	**Int. Algorithm**	**Alg. Type**	**Metrics (Objectives)**								**# of Obj.**
			#.Node	**E. Con. (L.T)**	**Reliability**	**Connectivity**	**Coverage**	**E2E delay**	**Packet rate**	**Load balance**	
M2NGA [8]	GA + SPEA	EA	X	√	X	X	X	√	X	X	2
QACMOR [11]	MOACO	SIA	X	√	X	X	X	√	X	√	3
MOR4WSN[17],[35]	NSGA-II	EA	√	√	X	X	X	X	X	X	2
MOEA/D-GSH [26],w/RH, w/RH+ [108]	MOEA/D	EA	X	√	X	X	√	X	X	X	2
MGoDA [27]	NSGA-II	EA	X	√	X	X	√	X	X	X	2
MO-RSCDS [31]	NSGA-II	EA	X	√	√	X	X	X	X	X	2
CPMEA [33]	CPMEA	EA	X	√	X	X	√	X	X	X	2
MODA [39]	MODA	(NSA, EA)	√	√	X	X	X	X	√	√	5(1)
MOEA/DFD [40], &MOEA/DFA[160]	MOEA/D	EA	X	√	X	X	√	X	X	X	2(2)
HybridMOEA/D-I, & Hybrid-MOEA/D-II [43]	MOEA/D+ GA+ DE MOEA/D-I + DBPSO	EA	X	√	X	X	√	X	X	X	3(3)
DyMORA [45]	HRA	DWP	X	X	√	X	X	√	X	X	2
MONSOON [50], & [84]	GA	EA	X	√	X	X	X	√	√	X	3
MOFCA [53]	Fuzzy logic	Heuristic	√	√	X	X	X	X	X	X	2
MOFPL [55]	FT + PSO + LOA	SIA	√	√	X	X	X	√	√	X	5(1)
RAMGA-DV-Hop [57]	GA+ NSGA-II	EA	X	X	X	X	X	X	X	X	2(4)
LEACH-AHP [59]	LEACH	linear weighted-sum	X	√	X	X	X	X	X	X	3(5)
MOMHR [62]	K-means + MO-ABC	SIA+ linear weighted-sum	X	√ √	X	X	X	X	X	X	2
MH-CACA [63]	HSA	HA+ weighted uniformly	X	X	X	X	√	X	X	√	2(6)
DECSA [65]	CSA + DE	SIA+ linear weighted-sum	X	√ √	X	X	X	√	X	X	6(7)
FCR [66]	FA	SIA	X	√	X	X	X	√	X	X	3(1)

NSEA [71], [121], & [123]	NSGA-II+ ES [71] MOPSO [121] ABCMO [123]	EA SIA	X	√	X	√	√	X	X	X	3
MOEA/D-LS [72]	MOEA/D	EA	X	√	X	X	√	X	X	X	2
PAPSO [73], & ELR [131]	PSO [73], CS + MOGA [131]	SIA [73] EA [131]	X	√	X	X	X	√	X	X	2
EMOGA [87]	MOGA	EA	√	X	X	X	√	X	X	X	2
PMOTS [89]	Tabu Search	DA	X	√	X	X	X	√	X	X	3(8)
ToCAIA [94]	AIA	Heuristic	X	√	X	√	X	X	X	X	2
EACO [97]	ACO	SIA	√	√	X	X	√	X	X	X	3
MLP [107]	LP	Heuristic	X	√	X	X	X	√	X	X	2
MOOCTC [120], & TASCC [129]	NSGA-II +LA [120] NSGA-II [129]	EA	√	X	X	X	√	X	X	√	3
NSHS [122]	HS+ Local Search	HA+APM	X	X	X	√	X	X	X	X	2(1)
MOICA [127]	ICA	EA	√	X	X	X	√	X	X	X	2
MLBC [128]	MOPSO	EA	X	√	√	X	X	X	X	X	2
Tabu-PSO [141]	Tabu Search + PSO	DA +SIA	√	X	X	X	X	√	√	X	3
IFPA, & NSMOFPA [144]	FPA	PA	√	√	X	X	√	X	X	X	3
LMOJPSO [147]	PSO	SIA	X	X	X	√	√	X	X	X	2
SMPSO-CR [149]	PSO	SIA	√	√	√	X	X	X	X	X	3
Me-NSGA-II [153]	NSGA-II	EA	X	√ √	X	X	X	X	X	X	2
MGEBDA [155]	NSGA-II	EA	√	X	X	X	√	X	X	X	2
ECCA [165]	MOGA	EA	√	X	X	X	√	X	X	X	2

(1)Other objectives such as distance between sensors.

(2)Maintain connectivity as constrains.

(3)Other objective as equilibrium of energy consumption.

(4)Objectives such as estimated distance, & real average distance.

(5)Other objectives such as node degree, & node centrality.

(6)Consider Load gateway, distance between sensor and gateway, sensors assigned with gateways as constrains.

(7)Other objectives such as inter-cluster distance, intra-cluster distance, & mobility.

(8)Transmission robustness as a third objective.

TABLE 5: The New Multi-objectives Approaches Consider QoS

Protocol Name	Intel. Algorithm	ALG. Type	QoS (Objectives)									# of Obj.
			# of Hop	Energy Con. (L.T)	E2E delay	Bandwidth	Packet ratio	Delay jitter	Load balance	Reliability	ETX	
MMOHRA [20], Q-MOHRA [44]	MHA	WAM	X	√	X	X	√	√	√	X	X	4
QG-QoS [21]	QGA	EA	X	√	√	√	X	X	X	X	X	3
AGA [46]	GA	EA	√	X	√	√	X	X	X	X	X	3
MQoSR [49]	PSM	Heuristic	X	√	√	X	X	X	X	√	X	3
FRMOO [51]	GA	EA	X	√	√	X	X	√	√	√	X	6
K-means++, & MCASO [58]	CASO	SIA	X	√	X	X	√	X	X	X	X	2
QuESt [69], & [75]	MOGA	EA	X	√	√	√	X	X	X	X	X	3
BFS-SPEA [99]	SPEA	EA	X	X	√	X	X	X	X	X	√	2
MOREA [91]	MOREA	SIA	X	√	√	X	X	X	X	X	X	2
POCTP [113]	CTP	Heuristic	X	X	√	X	√	X	X	√	X	3
ISPEA2 [116]	SPEA2	EA	X	√	√	X	X	X	X	X	X	2
MOBDEHS [117]	DE+HSA	EA +HA	√	X	√	X	√	X	X	√	X	4
MNSGA-II [119]	NSGA-II+ LA	EA	X	X	√	X	X	X	X	X	√	2

TABLE 6: WSNs Properties

Ref	WSN Properties					
	Mobility		Heterogeneity		Topology	
	Static	Mobile	Homo	Hetero	Flat	Two- tier
[10]	√	X	X	√	X	√
[11]	X	√	X	√	X	X
[16]	√	X	X	√	√	X
[19]	√	X	X	X	√	X
[23]	X	√	X	X	√	X
[26]	√	X	X	√	X	√
[27]	√	X	X	√	X	√
[31]	√	X	X	√	X	X

[52]	√	X	X	X	√	X
[59]	√	X	X	√	X	X
[67]	X	√	X	√	X	√
[72]	√	X	X	√	X	√
[101]	X	√	X	√	X	X
[112]	√	X	√	√	X	√
[148]	√	X	X	X	√	X

TABLE7: ABBREVIATION, &TERMS

Abbreviation	**Term**	**Abbreviation**	**Term**
AbYSS	*Archive-Based hYbrid Scatter Search*	*MOEA/D*	*Multi-Objective Evolutionary Algorithm Based on Decomposition*
AGA	*Adaptive Genetic Algorithm*	*MOEA/D w/RH*	*Multi-Objective Evolutionary Algorithm Based on Decomposition with Repair Heuristic*
APM	*Adaptive Partitioning Method*	*MOEA/DFD*	*Multi-objective Evolutionary Algorithm with Decomposition and Fuzzy Dominance*
BDF	*Breadth First Search*	*MOEA/D-GSH*	*Multi-Objective Evolutionary Algorithm Based on Decomposition-Generalized Sub problem-dependent Heuristic*
CPMEA	*Constrained Pareto-based Multi-objective Evolutionary Approach*	*MOEA/D-LS*	*Multi-Objective Evolutionary Algorithm Based on Decomposition-Local Search*
CSA	*Crow Search Algorithm*	*MO-FA*	*Multi-Objective Firefly Algorithm*
CSA	*Cuckoo Search Algorithm*	*MOFCA*	*Multi-objective Fuzzy Clustering Algorithm*
DA	*Deterministic Algorithm*	*MOFGSA*	*Multi-Objective Fractional Gravitational Search Algorithm*
DBPSO	*Discrete Binary Particle Swarm Optimization Algorithm*	*MOFPA*	*Multi-Objective Flower Pollination Algorithm*
DE	*Differential Evolution*	*MOGA*	*Multi-Objective Genetic Algorithm*
DE	*Dolphin Echolocation-based*	*MOGA*	*Multi-objective Genetic Algorithm*
DECSA	*Dolphin Echolocation-based Crow Search Algorithm*	*MO-GSA*	*Multi-Objective Gravitational Search Algorithm*
D-MODE	*Discrete Multi-objective Differential Evolution*	*MOHA*	*Multi-Objective Hybrid Algorithm*
DPAP	*Deterministic Deployment and power Assignment Problem*	*MOICA*	*Multi-Objective Imperialist Competitive Algorithm*
DWP	*Dynamic Weighting Procedure*	*MOMHR*	*Multi-Objective Multi-Hop Routing*
DyMORA	*Dynamic Multi-objective Routing Algorithm*	*MONSOON*	*Multi-objective Optimization for Network of Sensors using a cOevOlutionary mechaNism*
EA	*Evolutionary Algorithm*	*MOOCTC*	*Multi-Objective Optimization Coverage and Topology Control*
EACO	*Energy efficient Ant Colony Optimization*	*MOR4WSN*	*Multi-Objective Routing for WSN*
ECCA	*Energy-efficient Coverage Control Algorithm*	*MOREA*	*Multi-Objective Routing Evolutionary Algorithm*
ELR	*Egg Laying Radius*	*MO-RSCDS*	*Multi-objective reliable and stable Connected Dominating Sets*
EMOCA	*Evolutionary Multi-Objective Crowding Algorithm*	*MO-VNS*	*Multi-Objective Variable Neighborhood Search*
ETX	*Expected Transmission Cout*	*MPICA*	*Multi-Particle-swarm Immune Cooperative Algorithm*

FA	*Firefly algorithms*	*MQoSR*	*Multi-objective QoS Routing Protocol*
FCR	*Firefly algorithm with Cyclic Randomization*	*NSA*	*Neighborhood Search Algorithm*
FRMOO	*Fuzzy Random Multi-objective Optimization*	*NSEA*	*Non-dominated Sorting Evolution Algorithm*
FT	*Fractional Theory*	*NSGA-II*	*Non-dominated Sorting Genetic Algorithm*
GA	*Genetic Algorithms*	*NSHS*	*Non-dominated Sorting Harmony Search*
GLBCA	*Greedy Load Balancing Clustering Algorithm*	*NSMOFPA*	*Non-dominated Sorting Multi-Objective Flower Pollination Algorithm*
HA	*Human-based Algorithm*	*OGDC*	*Optimal Geographical Density Control*
HRA	*Hierarchical Routing Algorithm*	*PA*	*Physics-based Algorithm*
HSA	*Harmony Search Algorithm*	*PAPSO*	*Pareto optimality Particle Swarm Optimization*
IBEA$_{HD}$	*Indicator-Based Evolutionary Algorithm with Hypervolume Indicator*	*POCTP*	*Pareto Optimal Collection Tree Protocol*
IBEAε	*Indicator-Based Evolutionary Algorithm with Epsilon Indicator*	*PSM*	*Path Selection Mechanism*
IFPA	*Improved Flower Pollination Algorithm*	*PSO*	*Particle Swarm Optimization*
IFPA	*Improved Flower Pollination Algorithm*	*QACMOR*	*Quantum Ant Colony Multi-Objective Routing Algorithm*
LA	*Learning Automata*	*QGA*	*Quantum Genetic Algorithm*
LEACH	*Low Energy Adaptive Clustering Hierarchy*	*Q-MOHRA*	*QoS Assured Multi-Objective Hybrid Routing Algorithm*
LEACH-AHP	*Low Energy Adaptive Clustering Hierarchy- Analytic Hierarchy Process*	*QuESt*	*QoS-based Energy-efficient Sensor routing*
LEACH-ME	*Low Energy Adaptive Clustering Hierarchy Mobile Enhanced*	*RAMGADVHop*	*Real Average distance Multi-objective NSGA-II Distance Vector-Hop*
LMOJPSO	*Lagged Multi-Objective Jumping Particle Swarm Optimization*	*SEP*	*Stable Election Protocol*
LOA	*Lion Optimization Algorithm*	*SIA*	*Swarm Intelligence Algorithms*
LTC	*Lightweight Temporal Compression*	*sMOEA/D*	*specialized Multi-Objective Evolutionary Algorithm Based on Decomposition*
M2NGA	*multi-objective two-nested genetic algorithm*	*SMPSO*	*Speed-constrained Multi-objective Particle Swarm Optimization*
MCASO	*Multi-objective Chaotic Ant Swarm Optimization*	*SMPSO-CR*	*Speed-constrained Multi-objective Particle Swarm Optimization for Clustering and Routing*
MGEBDA	*Multi-Objective Genetic Evidence-Based Deployment Algorithm*	*SPEA2*	*Strength Pareto Evolutionary Algorithm 2*
MGoDA	*Multi-objectives Global on-Demand Algorithm*	*TASCC*	*Transmission range Adjustment Scheduling Coverage and Connectivity*
MH-CACA	*Multi-objective tournament Harmony search-based Coverage Aware load-balanced Clustering Algorithm*	*ToCAIA*	*Topology Control based on Artificial Immune Algorithm*
MLP	*Multi-objective Linear Programming*	*TR*	*Tree Routing*
MO-ABC	*Multi-Objective Artificial Bee Colony*	*WAM*	*Weighted Average Method*
MOBDEHS	*Multi-Objective Binary Differential Evolution Harmony Search*	*WGA*	*Weight based Genetic Algorithm*
MODA	*Multi-Objective Deployment Algorithm*	*MOEA/D*	*Multi-Objective Evolutionary Algorithm Based on Decomposition*
MODE	*Multi-objective Differential Evolution*	*MOEA/D w/RH*	*Multi-Objective Evolutionary Algorithm Based on Decomposition with Repair Heuristic*

8. CONCLUCION:

In this research, we aim to analyze the work of previous researches in multi-objectives optimization problems in WSNs, whereas reliance on multi-objectives better than considering single objective, while these problems considered as NP hard problems. In addition to this, they could not find a parameter that dominates another, so the researches use multi-objectives algorithms, which can solve these problems using pareto front theory, which makes trade-off between parameters and find number of optimal solutions, so the decision maker can select the best solution.

We found few survey papers that compile the previous technical papers, to analyze these papers, we searched using search engines as google scholar, and we found about 156 paper that work in this field between years 2004 to 2019.

We analyzed these papers based on the year of publication, and whether it published in conference, or journal, or thesis.

We divided our work to fields and categories, and found out the percentage of each category to display the strengths, and weakness in multi-objectives of WSNs.

After that we proposed our approach to analyze these papers based on criteria as optimization problems, objectives parameters, technical task, mechanisms that employed to solve the problem, the algorithms that are used in these papers, and if the approach presence in the application.

We found that there are little researches interested in NSGA-III algorithm in WSNs; few of previous papers have a consideration for QoS using multi-objective algorithms, and small number of researches that consider four or more objectives. On the other hand, small number of these researches depend on performance indicators to evaluate pareto front solutions for multi-objectives algorithms. Therefore, in our future’s work we will handle these weakness points on hope to overcome these Obstacles.

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