Neural Computing and Applications (2022) 34:5283–5319
https://doi.org/10.1007/s00521-022-06941-y

REVIEW

Nodes placement in wireless mesh networks using optimization approaches: a survey

Sylia Mekhmoukh Taleb[1] · Yassine Meraihi[1] · Asma Benmessaoud Gabis[2] · Seyedali Mirjalili[3,4] · Amar Ramdane-Cherif[5]

Received: 10 May 2021 / Accepted: 4 January 2022 / Published online: 17 February 2022

Abstract

Wireless mesh networks (WMNs) have grown substantially and instigated numerous deployments during the previous decade thanks to their simple implementation, easy network maintenance, and reliable service coverage. Despite these proprieties, the nodes placement of such networks presents many challenges for network operators. In this paper, we present a survey of optimization approaches implemented to address the WMNs nodes placement problem. These approaches are classified into four main categories: exact approaches, heuristic approaches, meta-heuristic approaches, and hybrid approaches. For each category, a critical analysis is drawn according to targeted objectives, considered constraints, type of positioned nodes (Mesh Router and Mesh Gateway), location (discrete or continuous), and environment (static or dynamic). In the end, several new key search areas for WMNs nodes placement are suggested.

Keywords WMNs planning · Nodes placement in WMNs · Optimization · Artificial intelligence

1 Introduction

Wireless mesh network (WMN) is a promising communication technology that has received a lot of attention from the community of researchers and academics due to its easy implementation, dynamic self-organization, self-configuration, and self-adaptive nature [1–3]. It is currently used in many applications such as broadband home networking, education, healthcare, corporate networks, industrial automation, disaster management, military, and rescue operations [4, 5]. The WMN consists of three kinds of nodes including Mesh Router (MR), Mesh Gateway (MG), and Mesh Client (MC). It provides connectivity to various types of networks such as Wi-Fi, Cellular, WiMax, and Sensor (see Fig. 1). MC can be a desktop, mobile, laptop, PDA, Pocket PC, and many other devises. It connects to the internet through MR, MR relays traffic to and from MG which is connected to internet infrastructure.

The performance of WMNs mainly depends on the bad positioning of mesh nodes (MR and/or MG) [6]. Consequently, many interferences and congestion are resulted causing low throughput, considerable packet loss, and high delays. To cope with these drawbacks, network operators must adopt efficient optimization methods for WMNs

✉ Sylia Mekhmoukh Taleb
s.mekhmoukh@univ-boumerdes.dz

Yassine Meraihi
y.meraihi@univ-boumerdes.dz

Asma Benmessaoud Gabis
a_benmessaoud@esi.dz

Seyedali Mirjalili
ali.mirjalili@gmail.com

Amar Ramdane-Cherif
rca@lisv.uvsq.fr

1 LIST Laboratory, University of M'Hamed Bougara Boumerdes, Avenue of Independence, 35000 Boumerdes, Algeria

2 Ecole nationale Superieure d'Informatique, Laboratoire des Methodes de Conception des Systemes, BP 68M, 16309 Oued-Smar, Alger, Algerie

3 Centre for Artificial Intelligence Research and Optimisation, Torrens University Australia, Fortitude Valley, Brisbane 4006 QLD, Australia

4 Yonsei Frontier Lab, Yonsei University, Seoul, Korea

5 LISV Laboratory, University of Versailles St-Quentin-en-Yvelines, 10-12 Avenue of Europe, 78140 Velizy, France

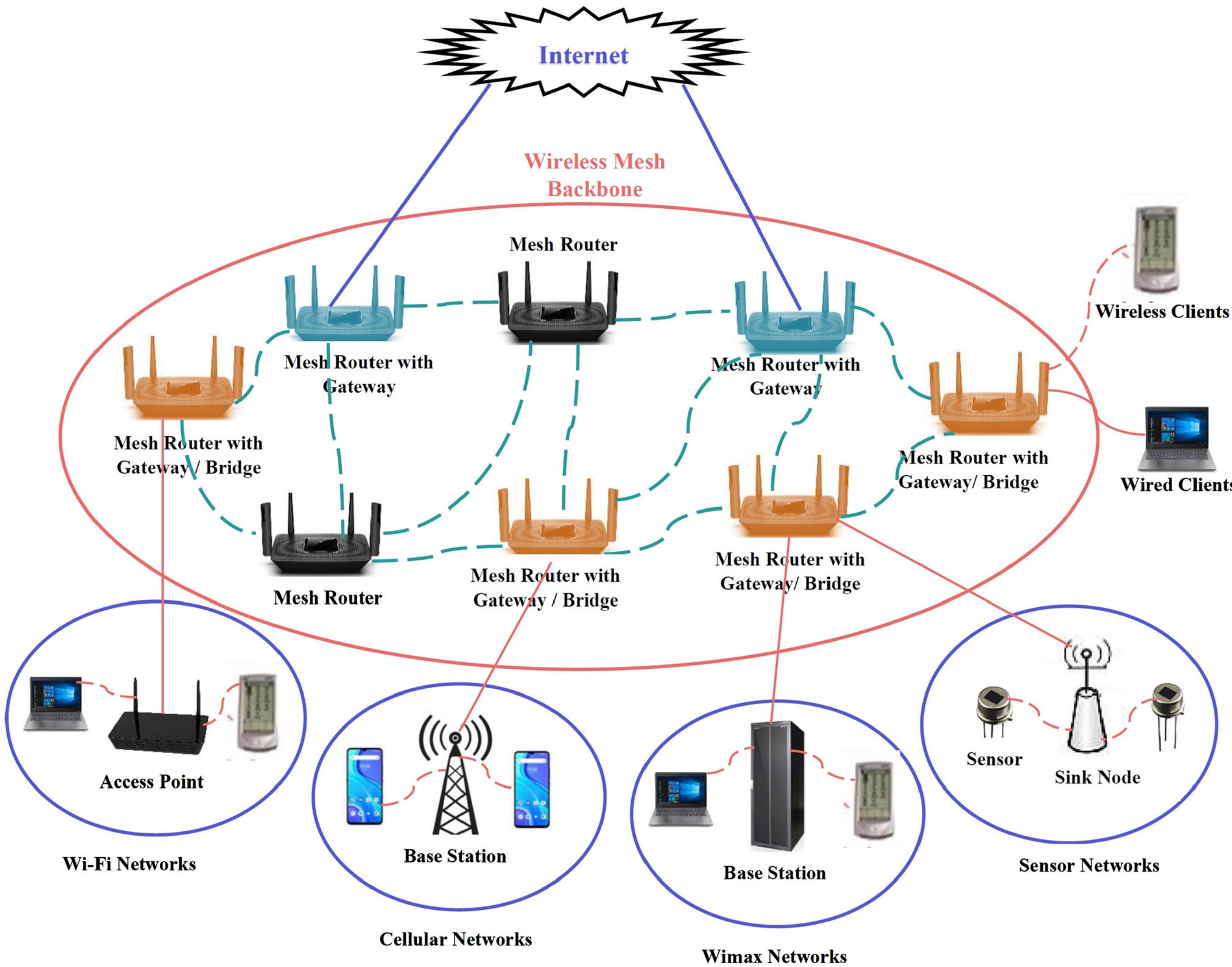

Fig. 1 Wireless Mesh Network architecture

nodes placement. WMNs nodes placement is known to be an NP-hard problem [7]. Indeed, a problem is said to be NP-hard if the computation of optimal solutions with polynomial-time algorithm becomes intractable in case of complicated real-size instances [8, 9]. The computational time grows exponentially with increasing the problem size. Most of complex and NP-hard problems can be defined as optimization problems [10]. So approximate optimization algorithms (i.e., heuristic, meta-heuristic, and hybrid algorithms) have been presented as successful optimization algorithms to obtain ideal solutions within reasonable time.

Several research works have been presented to solve the WMNs node placement problem using exact techniques, heuristics, meta-heuristics, and hybrid approaches. It can be solved in continuous and discrete spaces for static and dynamic environments as shown in Fig. 2. In the last decade, some surveys overview the different approaches. Each of them brings a contribution as it is summarized in Table 1. In the work of Benyamina et al. [11], the authors

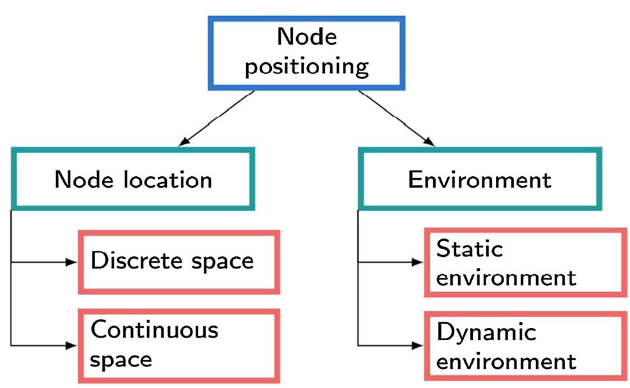

Fig. 2 Nodes positioning space and environment

surveyed different aspects of WMNs design and examined various methods that have been proposed categorized into fixed topology and unfixed topology-based approaches. Sanni et al. [12] introduced the modeling and formulation of the MG placement problem and surveyed some

Table 1 Summary of surveys on WMNs nodes placement

Authors (Ref)	Year	Nodes type	Summary
Benyamina et al. [11]	2011	MR and MG	-Fixed topology and unfixed topology-based approaches for WMNs design.
			- Future points that need to be properly addressed for WMNs nodes placement.
Sanni et al. [12]	2012	MG	- Modeling and formulation of MG placement problem.
			- Some heuristics and meta-heuristics for gateway placement optimization in WMNs
			- Gateway optimization objectives and constraints.
Ahmed and Hachim [13]	2014	MG	- Meta-heuristic approaches for MG placement optimization in WMNs.
			- Analysis based on MG placement objectives and constraints.
Govil and Rawat [14]	2016	MG	- Clustering techniques, throughput-based techniques, load-based techniques, and GPP-based approaches for MG placement in WMNs.
Mnguni et al. [15]	2019	MG	- Exact, heuristics and meta-heuristic approaches for MG placement in WMNs and Low Power Wire Area Networks LP-WAN.
			- Analysis based on network size, transmission range, link bandwidth, node capacity, network throughput, interference, and congestion.
Jahanshahi and Bozorgchenani [16]	2019	MG	- Operation research-based methods, Heuristics, and meta-heuristics for gateway placement in WMNs.
			- Analysis based on solutions techniques, channel assignment, and investigated parameters.
Seetha et al. [17]	2021	MR	- Heuristics, meta-heuristics, and multi-objective approaches for mesh routers Placement in WMNs.
			- Future research directions for mesh routers placement in WMNs.

heuristics and meta-heuristics applied to optimize the MG placement in WMNs. Ahmed and Hachim [13] reviewed the WMNs gateway placement optimization based on meta-heuristic approaches. In [14], Govil and Rawat focused on the MG Placement in WMNs using clustering techniques, throughput-based techniques, load-based techniques, and GPP-based approaches. Mnguni et al. [15] presented classical, heuristics, and meta-heuristic approaches for optimizing the gateway placement in WMNs and low power wire area networks. Jahanshahi and Bozorgchenani [16] presented MG placement techniques classified into three groups including operation research-based methods, heuristics, and meta-heuristics. Seetha et al. [17] surveyed the mesh routers placement optimization in WMNs based on heuristics, meta-heuristics, and multi-objective approaches. Despite that, to the best of our knowledge, no previous work categorized the nodes placement (MRs and MGs) approaches according to the techniques used. To address this, this paper presents a comprehensive survey on WMNs nodes placement by distinguishing four classes: exact approaches, heuristics, meta-heuristics, and hybrid approaches. This paper collects publications from several well-known databases such as IEEE, Elsevier, Springer, Inderscience, MDPI, and many others. Fig. 3 shows the number of related WMNs nodes placement publications by database where we can see that most papers are published in IEEE database. Figure 4 illustrates the number of WMNs node placement

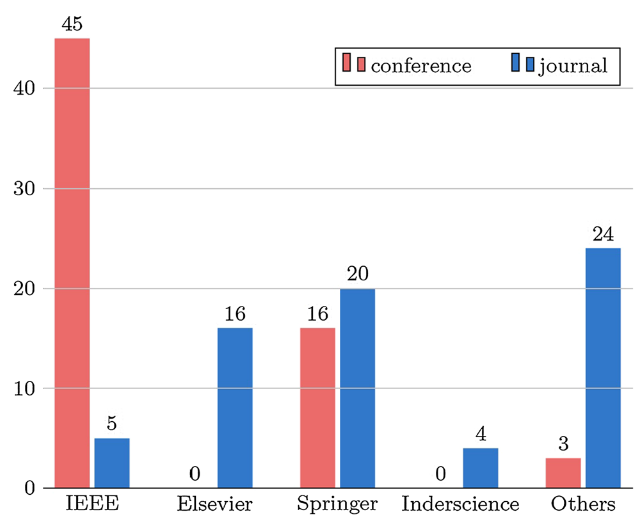

Fig. 3 Number of WMNs nodes placement related publications per Database

publications by year. We can see that this field recorded a great rise in 2010 and 2017.

The remainder of this paper is organized as shown in Fig. 5. In the second section, the process of research methodology is described. The third section presents parameters related to WMNs nodes placement problem. The fourth section summarizes and analyses previous techniques used for solving the WMNs nodes placement problem. In the fifth section, a case study based on WMNs

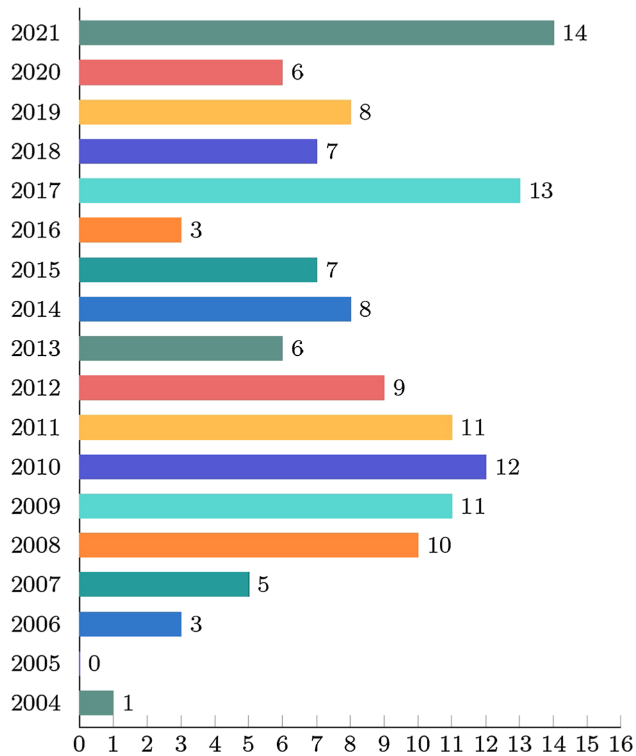

Fig. 4 Number of WMNs nodes placement publications per year

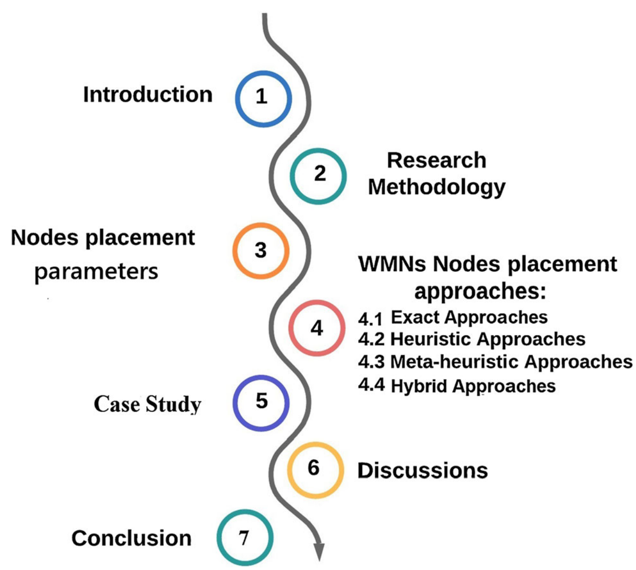

Fig. 5 The organization of the survey

nodes placement problem is illustrated. The sixth section presents the results analysis of WMNs nodes placement approaches. The last section concludes this survey.

2 Research methodology

This paper presents a survey of nodes placement in wireless mesh networks using optimization approaches. For this purpose, we adopt the systematic literature review methodology. Firstly, we start by collecting research papers providing a survey or a review on this area. We use Google Scholar by employing the following search strings (The most interesting surveys found from this research are given in Table 1):

– Wireless mesh networks topology planning: A survey, a review, an overview;
– Gateway placement approaches in wireless mesh network: A survey, a review, an overview;
– Mesh router placement approaches in wireless mesh network: A survey, a review, an overview;

Secondly, for finding new proposals and research articles in the context of nodes placement in WMNs, we use the following search terms in Google Scholar:

– Nodes placement in wireless mesh networks;
– Mesh routers placement in wireless mesh networks;
– Gateways placement in wireless mesh networks;
– Wireless mesh networks deployment;
– Wireless mesh networks planning;
– Wireless mesh networks design;
– Exact approaches for nodes placement optimization in wireless mesh networks;
– Classical approaches for nodes placement optimization in wireless mesh networks;
– Heuristic approaches for nodes placement optimization in wireless mesh networks;
– Meta-heuristic approaches for nodes placement optimization in wireless mesh networks;
– Gateways deployment optimization in wireless mesh networks;

Among the resulted articles, we do not consider those:

– Published by predatory publishers;
– Published in less than four pages;
– Written in non-English language;
– Which are incomplete, i.e., in the case where several versions of an article exist, only the most complete version is chosen;
– That do not address the location of the nodes in wireless mesh networks;

Finally, we give a set of research questions, which are helpful to identify the lack of research in this area. Therefore, the present paper tries to answer seven main questions described in Table 2.

Table 2 Research questions

Question	Purpose
What was the main approach used for WMNs nodes placement?	Identify the approach used for WMNs planning and its classification
What is the type of node used ?	Specify if authors have studied the placement of mesh routers, mesh gateways, or mesh routers and gateways at the same time
What are the objectives and constraints used in their studies ?	Determine the objective functions and constraints taken into account
What is the type of solution space?	Identify if the space solution is continuous or discrete
What is the type of the environment?	Identify if the positions of mesh nodes are statics or dynamics
Which simulator was applied to evaluate the performance of the studied approaches?	Identify the used simulators for testing the performance of the studied algorithms
Which algorithms were used in the comparison?	Validate the proposed approaches performance

3 Nodes placement parameters

WMNs nodes placement is an NP-hard optimization problem [7] that is characterized by various criteria, often contradictory and expressed either in terms of objectives to be optimized or constraints to be respected. In the following, we present the definitions of some of the parameters considered in solving the WMNs nodes placement problem.

3.1 Cost

Cost optimization is a fundamental objective when deploying WMNs. It represents the sum of multiple computation costs including the deployment cost, the number of deployed nodes, and the number of installed antennas in the network.

3.2 Coverage

Coverage is an important criterion guaranteeing access to users in the desired area. A test point is said covered if it receives a signal power higher than the minimum power threshold. As an objective, it can be treated by maximizing the number of clients covered by the network and minimizing the number of uncovered points.

3.3 Connectivity

Connectivity is a vital metric ensuring communication within a network. It often refers to the probability that nodes in a network can communicate with each other at any given time. This property is strongly related to the coverage. In fact, it depends on MRs, MGs, and MCs locations and channel conditions and can be determined by using proper propagation prediction tools [18].

3.4 Load-balancing

Load-balancing is an important parameter allowing the distribution of traffic among different paths. It ensures that each node has equal traffic to forward avoiding over-utilization of channels which is a source of congestion. This metric contributes in network performance enhancement in terms of throughput and delay optimization.

3.5 Throughput

Throughput is one of the most important metrics in WMNs. It is defined as the rate of the total number of received packets during a time unit. Throughput can be enhanced by minimizing traffic bottlenecks, minimizing the level of interference, and using multiple channels instead of a single channel.

3.6 Delay

Delay is one of the main requirements in WMNs design. It often refers to the accumulated number of communication hops between the MRs and their MGs [19]. For optimizing the network delay, the number of hops between any MR and MG should be lower than a MR-MG hops threshold.

3.7 Capacity

Capacity is a key parameter in WMNs Planning. It is measured by the number of MCs per MRs, MR relay load, number of MRs per MGs, link capacity, and radio access interface capacity. Capacity can be increased by minimizing the number of hops and reducing the level of interference.

3.8 Interference

Interference is a crucial issue in WMNs that degrades the network performance substantially (considerable packet losses and higher delays). Due to the nature of the transmission medium, nodes located in the same geographic area can interfere with each other when transmitting on the same channel. To deal with this issue, different models are used such as the protocol interference model (PrIM), physical interferences model (PhIM), and fixed protocol interferences model (FPrIM).

4 WMNs nodes placement approaches classification

In the literature, several WMNs nodes placement approaches were proposed. We give in the following a classification based on the type of the used method. As shown in Fig. 6, we distinguish four categories: methods based on exact approaches, methods using heuristics, methods using meta-heuristics, and those applying hybrid methods.

4.1 Exact approaches

Various exact methods were proposed for solving the WMNs planning problem as exhibited in Table 3. All these methods were applied under static environment and discrete locations for MR and/or MG nodes. Objectives and constraints they consider are given in Table 4, where we can see that connectivity and load-balancing objectives are never taken into account. However, some constraints such as capacity, interference, and cost are considered by most of these methods.

4.1.1 Branch and cut

Beljadid et al. [20] suggested a novel approach based on Branch & Cut algorithm for solving the WMNs design problem. Authors in their work aim to determine the topology and configuration of WMNs that minimize the cost of the network and satisfy the QoS requirements such as throughput, delay, and characteristics of nodes (number of channels and radios per node, power level/range, and channel assignment). Their results demonstrated that the proposed approach outperforms considerably existing solutions in terms of minimized cost.

Amaldi et al. [7] applied Branch & Cut technique for solving the WMN planning problem. Branch & Cut technique optimizes the deployment cost taking into account a set of constraints including full coverage, connectivity, traffic, capacity, interference, and rate adaptation. Numerical results showed that the Branch & Cut technique is able to capture the effect on the network configuration of all relevant parameters, providing a promising framework for WMNs.

Da Silva [21] proposed an improved model based on the integration of Monte Carlo strategy (MCs) into Branch & Cut algorithm for solving the WMNs planning problem. Branch & Cut method was used for optimizing the cost taking into account the requirements of full coverage and connectivity. Monte Carlo strategy was used to verify QoS parameters of packet loss and delay probabilities. Experimental results showed that the improved model is able to find satisfactory solutions with a short computation time.

4.1.2 Branch and bound

Lee and Murey [22] applied Branch & Bound method for solving the node placement problem in WMNs. Branch & Bound was used to optimize coverage and computational complexity metrics taking into account a set of constraints such as cost and connectivity. Simulation results demonstrated the effectiveness of the Branch & Bound method in achieving maximal coverage and survivable network design.

Branch & Bound technique was used in the work of Shilington and Tong [23] for solving the WMN topology planning-maximum coverage (WMNTP-MC) problem. Branch & Bound technique was used to optimize the coverage and computational time taking into account three constraints including the cost, connectivity, and capacity. Experimental results demonstrated the effectiveness of Branch & Bound for solving the WMN topology planning problem.

4.1.3 Dual simplex

Targon et al. [24] used the dual simplex technique for solving the gateway placement and spatial reuse problem in WMNs. The main objective was to optimize the cost and computational time taking into account four constraints including traffic, channel capacity, rate adaptation, and interference. Simulation results demonstrated the effectiveness of the proposed method on WMNs gateway placement.

Martingon et al. [25] used the dual simplex method for solving the nodes placement problem in WMMs. The dual simplex method was used to optimize delay using different threshold schemes for both random and grid networks. Numerical results showed that the dual simplex method increases the responsiveness of distributed security architectures with a short computing time.

Fig. 6 Nodes placement approaches classification

Table 3 Summary of exact approaches for nodes placement in WMNs

Algorithm	Authors (Ref)	Year	Type of node	Results
Branch & Cut	Beljadid et al. [20]	2007	MR MG	Better performance of Branch & Cut algorithm when compared with WMNs planning solutions found in the literature.
Branch & Cut	Amaldi et al. [7]	2008	MR MG	The effectiveness of the Branch & Cut method under various network conditions.
Improved Branch & Cut	Da Silva [21]	2012	MR MG	The improved Branch & Cut is able to find satisfactory solutions.
Branch & Bound	Lee and Murey [22]	2010	MR MG	The effectiveness of the Branch & Bound method in achieving maximal covering and survivable network design.
Branch & Bound	Shilington and Tàng [23]	2011	MR MG	The effectiveness of the Branch & Bound for solving the WMNs planning problem.
Dual Simplex	Targon et al. [24]	2011	MG	The effectiveness of the Dual Simplex model on Gateway Placement Problem in WMNs.
Dual Simplex	Martingon et al. [25]	2011	MG	Dual Simplex model represents a very effective tool to plan efficient and secure wireless networks.
Improved Bender's Decomposition	So and Liang [26]	2009	MR	The performance of the improved Bender' Decomposition when compared with the original Bender's Decomposition in terms of deployment cost and convergence.
Brute Force	Li et al. [27]	2008	MG	The Brute Force approach achieves better throughput when compared to random and fixed deployment models.
Brute Force	Liu et al. [28]	2013	MG	The effectiveness and efficiency of the Brute Force technique to optimize throughput for WMNs planning.

4.1.4 Bender's decomposition

An improved bender's decomposition model was proposed in the work of So and Liang [26] for solving the nodes placement problem in heterogeneous WMNs. The improved decomposition model was validated in terms of cost and running time taking into account three constraints including traffic, capacity, and interference. The results demonstrated the performance of the improved decomposition when compared with simulated annealing and original decomposition in terms of cost and convergence.

4.1.5 Brute force search

Li et al. [27] applied a brute force approach for solving the gateway placement problem in WMNs. The brute force approach was validated based on various scenarios having different network sizes taking into account the deployment cost and throughput metrics. Simulation results showed that the brute force approach achieves better performance when compared with random and fixed deployments models.

Liu et al. [28] proposed a brute force approach for solving the WMNs gateway placement problem. The objective is to select optimal MRs and adjust the appropriate traffic for nodes in order to optimize network throughput capacity. Simulation results demonstrated the effectiveness and efficiency of the brute force approach in terms of throughput.

4.2 Heuristic approaches

In the literature, a wide range of heuristics have been proposed for tackling the WMNs nodes placement problem under static environment and discrete nodes location. Table 5 provides a summary of these methods. Table 6 presents the objectives and constraints taken into account in heuristic approaches, where we can see that cost and delay objectives are applied by most of these approaches. It is also shown that the connectivity is never considered as an objective. Regarding constraints, we can see that coverage, capacity, delay, and interference are mostly considered by heuristic methods.

4.2.1 Greedy algorithm

Chandra et al. [29] proposed a greedy approach for solving the gateway placement problem in wireless neighborhood networks. This approach was validated in terms of cost under various scenarios. Simulation results demonstrated the performance of the proposed approach when compared

Table 4 The objectives and constraints considered in exact approaches

Authors(ref)	Objectives						Constraints						
	Cost	Coverage	Connectivity	Load Balancing	Throughput	Delay	Cost	Coverage	Connectivity	Traffic	Capacity	Delay	Interference
Beljadid et al. [20]	✔								✔		✔	✔	✔
Amaldi et al. [7]	✔							✔	✔	✔	✔		✔
Da Silva [21]	✔							✔	✔		✔	✔	
Lee and Murey [22]		✔					✔		✔				
Shilington and Tong [23]		✔					✔		✔		✔	✔	
Targon et al. [24]	✔									✔	✔		✔
Martingon et al. [25]						✔	✔					✔	
So and Liang [26]	✔									✔	✔		✔
Li et al. [27]					✔		✔				✔		✔
Liu et al. [28]					✔	✔	✔				✔		✔

Table 5 Summary of heuristic approaches for nodes placement in WMNs

Algorithm	Authors (Ref)	Year	Type of node	Results
Greedy approach	Chandra et al. [29]	2004	MG	The performance of Greedy approach when compared to others existing algorithms in the literature
Greedy approach	Aoun et al. [19]	2006	MG	Better performance of Greedy approach when compared with basic iterative, iterative greedy dominating set, and augmenting placement models.
Improved greedy approach	Prasad and Wu [30]	2006	MG	The performance of the improved greedy algorithm when compared with classical greedy approach.
D-GCP,W-GCP, and C-GCP	He et al. [31]	2008	MG	The superiority of D-GCP, W-GCP, and C-GCP methods compared to augmenting cluster partitioning algorithm (A-CP) in terms of cost and MR-MG hops.
SMS approach	Drabu and peyravi [32]	2008	MG	The performance of SMS algorithm compared to iterative, recursive, and greedy algorithms.
Degree-based GDTSP and weighted-based GDTSP	He et al. [33]	2008	MG	The effectiveness of degree based GDTSP and weighted based GDTSP when compared with other WMNs design algorithms found in the literature.
HA-LBPG	Zeng and Cheng [34]	2008	MG	The efficiency of HA-LGPG when compared to GA-LBC and recursive DS in terms of cost and load balancing.
Greedy approach	Peng and Zhou [35]	2009	MG	Greedy heuristic outperforms recursive algorithm in terms of connectivity, coverage, and throughput.
CSLBA and GGPA	Zeng and Chen [36]	2009	MG	The effectiveness of CSLBA and GGPA when compared with recursive-DS and OPEN/CLOSE in terms of cost, load variance, and CPU time execution.
WMB-LDS and GA-LDS	Chen and Zeng [37]	2010	MG	The robustness of WMB-LDS and GA-LDS in terms of cost and execution CPU time.
IKGPA	Luo et al. [38]	2010	MG	IKGPA achieves better results when compared to iterative greedy, weighted recursive and weighted based GDTSP algorithms.
Improved greedy heuristic	Tajima et al. [39]	2010	MG	Improved greedy approach provides larger throughput by 24%-80% for any instance when compared to open/close method.
MTWP	Zhou et al. [40]	2010	MG	The performance of MTWP when compared to random, regular busiest router placement methods in terms of throughput.
MTFW	Kemal et al. [41]	2016	MG	Effectiveness of MTFW algorithm in finding the optimal positions of gateways when compared to Random Placement Algorithm (RDP) and Busiest Router Placement (BRP).
CMRP	Chung et al. [42]	2011	MR	CMRP outperforms existing WMNs design schemes in terms of cost performance ratio and potential implementation feasibility.
Zero degree algorithm	Sayedzadegan et al. [43]	2013	MG	The performance of zero degree algorithm compared to Link Shaped Graph Algorithm and Degree Based GDTSP Algorithm in terms of deployment cost.
GSP	Wang et al. [44]	2015	MR MG	GSP can achieve good performance with significantly reduced computation when compared to exhaustive search method.
RTGS	Bozorgcheni et al. [45]	2017	MG	The effectiveness of RTSG model compared to IGS technique and Zero Degree algorithm in terms of throughput, delay, and network energy consumption.
GD-H	Fetng et al. [46]	2018	MG	GD-H outperforms zero degree and incremental algorithms in terms of load balancing and time transmission.
Algorithm-SH, algorithm-LR, and algorithm-BSHLR	Chen et al. [47]	2019	MR	The effectiveness of the proposed algorithms by obtaining high reliability and low latency.
Clustering algorithm	Lin et al. [48]	2006	MG	The efficiency of the clustering algorithm in in solving the WiMAX access network deployment problem.
Incremental clustering algorithm	Tang et al. [49]	2009	MG	The performance of the incremental clustering algorithm compared to recursive weighted, iterative greedy, augmenting algorithms.
NGLA	Komba et al. [50]	2014	MG	The effectiveness of NGLA when compared to iterative, augmenting, and weight recursive algorithms.

Table 5 (continued)

Algorithm	Authors (Ref)	Year	Type of node	Results
Clustering algorithm	Yang et al. [51]	2021	MR	The clustering algorithm is more effective compared to other well-regarded WMNS design models.
Two-stage LBGPA	Wu et al. [52]	2009	MG	Two-stage LBGPA achieves better performance in terms of cost, load balance, and average MR-GW hop count when compared with other WMNs design algorithms.
Two-stage heuristic	Saputro and Akkaya [53]	2017	MG	The two-stage heuristic gives good results when compared to V1-average hop and V1-COLA approaches.
DPF1, and DPF2	Nahle and Malouch [54]	2008	MR	The performance of DPF1, and DPF2 compared to the intuitive bottom-up approach (BU).
Minimize-Node and Measure-and-PLace	Robinson et al. [55]	2010	MR	The proposed algorithms provide good performance when compared with geometric covering algorithm.
Distributed heuristic	Xu et al. [56]	2010	MG	The distributed heuristic provides better performance in terms of deployment cost and coverage.
OPT	Sajjadi et al. [57]	2017	MG	The effectiveness of the OPT algorithm in terms of throughput and flow routing for different scenarios.
Improved RTT	Wzorek et al. [58]	20121	MR MG	The effectiveness of improved RTT in finding the optimal placement of mesh routers and gateways for real-world scenarios.
MST-CM-MSPB	Bagona and Fendji [59]	2021	MR	The efficiency of MST-CM-MSPB when compared with modified version of MST-MSP.

with other WMNs planning algorithms found in the literature.

Aoun et al. [19] used a greedy algorithm for solving the gateway placement problem in WMNs. This algorithm was validated in terms of the number of gateways taking into account 3 constraints including relay load, cluster radius, and cluster size. Simulation results showed that the greedy algorithm places up to 50% fewer gateways when compared with other WMNs planning methods found in the literature.

In the work of Prasad and Wu [30], an improved greedy algorithm based on the incorporation of open and close operations into greedy algorithm was proposed for solving the WMNs gateway placement problem. The improved greedy algorithm was evaluated in terms of deployment cost taking into account the impact of various parameters such as the user bandwidth, the number of candidate cites, and the number of nodes. Simulation results demonstrated the performance of the improved greedy algorithm when compared with the classical greedy approach.

He et al. [31] developed three variants of the greedy algorithm, namely degree-based greedy cluster partitioning (D-GCP), weighted-based greedy cluster partitioning (W-GCP), and capacity-based greedy cluster partitioning (C-GCP), for solving the gateway deployment problem in WMNs. These algorithms were validated taking into account 2 performance metrics such as the number of gateways and average MR-MG hops. Simulation results demonstrated the effectiveness of the developed algorithms when compared with augmenting cluster partitioning algorithm (A-CP).

Drabu and peyravi [32] developed an enhanced greedy algorithm, called SMS algorithm, based on the integration of split, merge, and shift operations into the greedy algorithm for solving the gateway placement problem in WMNs. SMS was assessed taking into account 2 metrics such number of gateways and cluster size variation. Simulation results demonstrated the performance of the SMS algorithm compared to iterative, recursive, and greedy algorithms.

He et al. [33] developed two greedy algorithms (i.e., degree-based Greedy Dominating Tree Set Partitioning (degree-based GDTSP) and weighted-based GDTSP) for solving the gateway deployment problem in WMNs. These algorithms were validated based on two factors such as the number of gateways and the average number of MR-MG hops under different network conditions. Simulation results demonstrated the effectiveness of the proposed algorithms when compared with other WMNs design algorithms found in the literature.

Peng and Zhou [35] considered a greedy heuristic algorithm for solving the gateway placement problem in

Table 6 The objectives and constraints considered in heuristic approaches

Authors(ref)	Objectives						Constraints						
	Cost	Coverage	Connectivity	Load Balancing	Throughput	Delay	Cost	Coverage	Connectivity	Traffic	Capacity	Delay	Interference
Chandra et al. [29]	✔							✔		✔	✔		✔
Aoun et al. [19]	✔							✔			✔	✔	
Prasad and Wu [30]	✔							✔			✔	✔	
He et al. [31]	✔					✔		✔		✔	✔	✔	✔
Drabu and peyravi [32]	✔					✔		✔		✔	✔	✔	✔
He et al. [33]	✔					✔		✔			✔	✔	✔
Zeng and Cheng [34]	✔			✔				✔			✔	✔	
Peng and Zhou [35]	✔					✔		✔			✔	✔	✔
Zeng and Chen [36]	✔			✔				✔			✔	✔	
Chen and Zeng [37]	✔							✔			✔	✔	
Luo et al. [38]	✔					✔		✔	✔		✔	✔	
Tajima et al. [39]	✔					✔		✔	✔		✔	✔	
Zhou [40]				✔			✔				✔		✔
Kemal et al. [41]					✔		✔				✔		✔
Chung et al. [42]		✔			✔		✔		✔		✔		✔
Sayedzadegan et al. [43]	✔					✔		✔			✔	✔	
Wang et al. [44]	✔									✔	✔		
Bozorgcheni et al. [45]					✔	✔	✔				✔	✔	✔
Fetng et al. [46]				✔		✔	✔				✔	✔	
Chen et al. [47]	✔					✔			✔				
Lin et al. [48]		✔					✔				✔		
Tang et al. [49]	✔							✔			✔	✔	
Komba et al. [50]	✔							✔			✔	✔	
Yang et al. [51]	✔							✔			✔	✔	
Wu et al. [52]	✔			✔		✔		✔			✔	✔	
Saputro and Akkaya [53]						✔	✔						
Nahle and Malouch [54]	✔							✔					
Robinson et al. [55]	✔								✔		✔		
Xu et al. [56]	✔							✔					
Sajjadi et al. [57]					✔		✔			✔	✔		✔
Wzorek et al. [58]	✔	✔					✔	✔	✔		✔		
Bagona and Fendji [59]	✔								✔				

WMNs. The main objective of their work is to optimize the cost, MR-MG hops, and computational complexity under the coverage, throughput capacity, and interference constraints. Simulation results showed that the greedy algorithm gives better performance when compared with the recursive algorithm.

Luo et al. [38] proposed a novel model based on a greedy approach, called Interference-aware and K-coverage Gateway Placement Algorithm (IKGPA), for solving the gateway placement problem in WMNs. IKGPA was assessed taking into account 3 performance metrics including cost, average MR-MG hop count, and gateway interference index. Simulation results showed that IKGPA achieves better solutions when compared with other well-regarded WMNs design algorithms.

Tajima et al. [39] proposed an efficient algorithm based on the integration of variable depth search (VDS) method into the greedy heuristic for solving the WMNs planning problem. The proposed algorithm was validated based on various scenarios taking into account the deployment cost and throughput parameters. Simulation results showed that the proposed algorithm provides larger throughput by 24%-80% for any instance when compared to the open/close method.

Zhou et al. [40] proposed an iterative greedy algorithm, called multi-traffic weight placement (MTWP) for solving the gateway placement problem in WMNs. MTWP was validated taking into account six factors (i.e., number of mesh routers, number of mesh clients, number of gateways, traffic demand, locations of gateways, and interference) impacting the throughput. Simulation results proved the performance of the proposed MTWP in terms of throughput when compared to random placement, busiest router placement, and regular placement approaches.

Maximum traffic flow weight algorithm (MTFW) based on greedy approach was implemented in the work of Kemal et al. [41] for solving the gateway placement problem in WMNs. MTFW was implemented based on geographical data taken from Rebild municipality in Denmark taking into account the deployment cost and throughput metrics. Simulation results demonstrated the performance of the MTFW algorithm when compared with random placement algorithm (RDP) and busiest router placement (BRP).

Chung et al. [42] proposed a novel approach based on a greedy approach, called cross-layer mesh router placement (CMRP), for solving the WMNs deployment problem. CMRP was used principally to minimize the network deployment cost. Simulation results demonstrated that CMRP outperforms existing WMNs design schemes in terms of deployment cost, coverage, and throughput.

Seyedzadegan et al. [43] proposed a modified greedy algorithm called zero degree algorithm for solving the mesh gateway placement problem in backbone WMNs. The zero degree algorithm was validated in terms of the number of gateways and the total number of IGW-MR hops for different scenarios. Simulation results demonstrated the superiority of the zero degree algorithm when compared with other WMNs planning techniques found in the literature.

Wang et al. [44] proposed a greedy search-based placement (GSP) algorithm for solving the hybrid placement of gateways and rechargeable routers in WMNs. GSP was evaluated bases on different scenarios with various system parameters including traffic demands, available candidate locations, electricity power unit cost, and solar panel charging capabilities. Simulation results showed that GSP can achieve good performance with significantly reduced computation time when compared to other WMNs design models found in the literature.

A novel scheme based on a greedy approach, called reliability and traffic aware gateway selection algorithm (RTSG), was proposed in the work of Bozorgcheni et al. [45] for solving the WMNs planning problem. RTSG was validated taking into account the network throughput, network energy consumption, and average delay parameters. Simulation results demonstrated the effectiveness of the RTSG model compared to IGS technique and zero degree algorithms.

Fetng et al. [46] proposed a novel approach (GD-H) based on a greedy algorithm for solving the WMNs planning problem. The main objective of their work is to balance load among gateways and reduce time transmission while satisfying 3 QoS requirements such as relay load, MG capacity, and delay. Simulation results showed that the load-balancing and transmission time can be enhanced significantly by the GD-H as compared to zero degree and incremental algorithms.

Chen et al. [47] proposed three methods based on greedy heuristic (i.e., algorithm-SH, algorithm-LR, and algorithm-BSHLR) for solving the WMNs planning problem. These algorithms were evaluated using 11 instances with different numbers of field devices, taking into account 3 metrics such as required number of routers, average hop per route, and average rank per router. Simulation results demonstrated the effectiveness of the proposed algorithms by obtaining high reliability and low latency.

4.2.2 Clustering algorithm

Lin et al. [48] proposed a heuristic clustering algorithm for solving the wireless broadband overlay network deployment problem. This algorithm was evaluated and compared in terms of cost and coverage in different network topologies with various demand densities, transmission ranges, and capacities. Simulation results demonstrated the efficiency of the proposed algorithm in solving the WiMAX access network deployment problem.

An incremental clustering algorithm was proposed in the work of Tang et al. [49] for solving the WMNs gateway placement problem. The incremental clustering algorithm was used to optimize the cost under the constraints of relay load, gateway capacity, and delay. Simulation results showed that the incremental clustering heuristic outperforms some well-regarded WMNs design models.

Komba et al. [50] proposed an incremental clustering algorithm, called new gateway location algorithm (NGLA) for solving the gateway location problem in WMNs. NGLA was validated in terms of deployment cost taking into account the constraints of coverage, capacity, and delay. Simulation results showed the effectiveness of NGLA when compared to iterative, augmenting, and weight recursive algorithms.

4.2.3 Two-stage heuristic

Wu et al. [52] proposed a novel method based on a two-stage heuristic, called a two-stage load-balancing gateway placement algorithm (two-stage LBGPA), for solving the gateway placement problem in WMNs. The two-stage LBGPA was validated taken into account the number of gateways, average MR-GW hop count, and variance of gateway load. Simulation results showed that the two-stage LBGPA achieves better performance in terms of cost, load balance, and average MR-GW hop count when compared with other WMNs planning algorithms.

In the work of Saputro and Akkaya [53], a two-stage heuristic was proposed for solving the gateway placement in WMNs. The two-stage heuristic was validated under different network sizes and different data sizes taking into account the delay and packet delivery ratio (PDR) metrics. Simulation results showed that the two-stage heuristic gives good results when compared with V1-average hop and V1-COLA approaches.

4.2.4 Others

Nahle and Malouch [54] proposed two variants of distant point first (DPF) heuristic, called DPF1 and DPF2, for solving the nodes placement problem in WMNs. The objective is to minimize the number of MRs needed to cover a certain trajectory while ensuring a required data rate along this trajectory. Simulation results demonstrated the performance of DPF1 and DPF2 in finding the smallest number of MRs and guarantying a required data rate compared to the intuitive bottom-up approach.

Robinson et al. [55] presented two approaches, called Minimize-Node and Measure-and-Place, for solving the WMNs nodes deployment problem. The proposed approaches were validated taking into account the deployment cost, coverage, and connectivity metrics. Simulation results revealed that the proposed algorithms provide good performance when compared with the geometric covering algorithm.

Xu et al. [56] proposed a distributed heuristic for solving the gateway placement problem in WMNs. The main objective of their work is to minimize the number of gateways with minimum overall cost. Simulation results showed that the distributed heuristic provides better performance in terms of deployment cost and coverage.

In the work of Wzorek et al. [58], an improved rapidly exploring tree (improved RTT) was proposed for solving the nodes placement problem in WMNs. The improved RTT is based on the integration of the graph clustering mechanism into RTT. The improved RTT was evaluated using real models of different sizes and complexity. Simulation results demonstrated the effectiveness of the improved RTT in finding the optimal placement of mesh routers and gateways for real-world scenarios.

To tackle the problem of nodes placement in WMNs, an enhanced minimum Steiner tree algorithm, called MST-CM-MSPB, was proposed in the work of Bagona and Fendji [59]. MST-CM-MSPB was validated over dense and spare randomly generated networks. The results obtained demonstrated the efficiency of MST-CM-MSPB when compared with modified version of MST-MSP.

4.3 Meta-heuristic approaches

Several meta-heuristic approaches were used for solving the WMNs planning problem as summarized in Table 7. These approaches categorized into single-based and population-based [60–63] were applied under static/dynamic environment and discrete/continuous locations for MR and/or MG nodes. The objectives and constraints considered in meta-heuristic approaches are given in Table 8. Coverage, connectivity, and cost objectives are mostly considered by these approaches, while the most commonly used constraints are cost, capacity, delay, and interference.

4.3.1 Single based approaches

A) Local Search

A local search algorithm was proposed by Franklin and Murthy [64] for solving the nodes placement problem in WMNs. The main idea of their work is to optimize the coverage and connectivity simultaneously under the constraint of the limited budget. Simulation results showed that the local search algorithm provides good performance with low time complexity.

Table 7 Summary of meta-heuristic approaches for nodes placement in WMNs

Algorithm	Authors (Ref)	Year	Type of node	Locations	Environ	Results
Local search algorithm	Franklin and Murthy [64]	2007	MR	Discrete	Static	Local search algorithm provides good performance with low time complexity.
ILSearch	Wang et al. [65]	2009	MR	Discrete	Static	The effectiveness of ILSearch when compared with other well-regarded algorithms in terms of cost and network capacity.
Neighborhood search	Xhafa et al. [66]	2009	MR	Discrete	Static	The good performance of the neighborhood search method compared to ad-hoc placement method in terms of optimality of the solutions.
SA	xhafa et al. [67]	2011	MR	Discrete	Static	The performance of SA compared to hill climbing in terms of user coverage and network connectivity.
SAP and GSP	Huan et al. [68]	2014	MR	Discrete	Static	GSP and SAP can achieve good performance with greatly reduced computation complexity when compared to exhaustive search model.
Improved SA	Lin et al. [69]	2014	MR	Discrete	Static	The performance of the improved SA when compared to the original SA.
SA and hill climbing	Nawaf et al. [70]	2015	MG	Discrete	Static	SA produces better results than hill climbing, but it takes slightly longer to run.
SA	Nawaf et al. [71]	2017	MG	Discrete	Static	SA algorithm produces a set of effective optimization solutions.
Enhanced SA	Ebongue Kedieng Fendji et al. [72]	2015	MR	Discrete	Static	The efficiency of the Enhanced SA algorithm to solve mesh router nodes in WMNs.
SA	Sayad et al. [73]	2018	MR	Continuous	Dynamic	Effectiveness of SA when compared with PSO.
MSA, MCM, And MSAC	Fendji and Förster [74]	2021	MR	Continuous	Dynamic	MSAC gives better performance in terms of robustness and quality of solutions.
Hill climbing	Xhafa et al [75]	2012	MR	Discrete	Static	The performance of hill climbing algorithm for optimizing mesh router placement problem in WMNs
Hill climbing, GA, and SA	Barolli et al. [76]	2012	MR	Discrete	Static	The performance of GA compared to SA and hill climbing in terms of connectivity. Hill climbing and SA achieved better results in terms of coverage.
Hill climbing	Katayama [77]	2020	MR	Discrete	Static	The superiority of hill climbing when compared with TS.
Improved hill climbing	Hirata et al. [78]	2021	MR	Discrete	Static	The performance of the improved hill climbing when compared with CCM method.
TS	xhafa et al. [79]	2015	MR	Discrete	Static	The effectiveness of TS compared to SA method.
Improved TS	Wang et al. [80]	2019	MR	Discrete	Static	The effectiveness of the improved TS in terms of coverage, cost, and quality of service.
Pattern search	Ivanov et al. [81]	2010	MR	Discrete	Static	Pattern search produces correct results, in limited number of iterations and in acceptable time.
GA	Hsu et al. [82]	2008	MR	Discrete	Static	The efficiency of GA when compared to WMNs design models.
MOGAMESH	De marco [83]	2009	MR	Discrete	Static	Good performance of MOGAMESH in terms of deployment cost, coverage, and user density for realistic instances.
GA	Xhafa et al. [84]	2010	MR	Discrete	Static	Efficiency of GA for computing high quality solutions of mesh router nodes placement in WMNs.
Improved GA	Mahani et al. [85]	2011	MR	Discrete	Static	The effectiveness of the improved GA algorithm in terms of cost and delay transmission.
QIEA	Ali et al. [86]	2011	MR	Discrete	Static	The efficiency of QIEA compared to GA for different scenarios of the network planning
GA-CL and GA-DEFFINED	Lee et al. [87]	2011	MR	Discrete	Static	GA-CL and GA-DEFFINED improve the performance by 30-40% compared to the random selection scheme.

Table 7 (continued)

Algorithm	Authors (Ref)	Year	Type of node	Locations	Environ	Results
GA	Oda et al. [88]	2012	MR	Discrete	Static	GA has better performance in terms of network connectivity and user coverage.
EA	Le et al. [89]	2012	MG	Discrete	Static	The superiority of EA when compared to MTW based gateway placement scheme.
GA	Oda et al. [90]	2013	MR	Discrete	Dynamic	The performance of GA in terms of coverage and connectivity when mesh clients are mobile.
GA and TS	Girgis et al. [91]	2014	MG	Discrete	Static	GA is better than TS when the link capacity is high, however TS is better when the link capacity is low.
GA and SA	Girgis et al. [92]	2014	MG	Discrete	Static	GA was better than SA in a small size network however SA was better in a large size network.
GA	Ahmed et al. [93]	2015	MG	Discrete	Static	The robustness of the GA approach in terms of deployment cost, and convergence rate.
EGA-GP	Lazrag et al. [94]	2017	MG	Discrete	Static	The performance of EGA-GP when compared with greedy algorithm and GA.
RGA	Tang and Chen [95]	2017	MG	Discrete	Static	The satisfactory performance of RGA when compared with incremental clustering algorithm in terms of cost and computational time.
MOGA and NSGAII	Bello et al. [96]	2017	MR MG	Discrete	Static	The proposed algorithms are able to improve the coverage and reliability when designing WMNs.
Improved GA, improved AIA, and improved K-means	Huang et al. [97]	2017	MG	Discrete	Static	The effectiveness of the improved algorithms when compared with AIA, GA, and k-means algorithms.
NSGAII	Nawaf et al. [98]	2018	MG	Discrete	Static	The effectiveness and good performance of NSGA-II when compared with the weighted sum approach in terms of diversity and solution quality.
MTMG	Liu et al. [99]	2019	MG	Discrete	Static	The effectiveness of MTMG compared to ICLB-GPS algorithm and weighted recursive algorithm in term of throughput, cost, and coverage.
Improved GA	Tang et al. [100]	2019	MG	Discrete	Static	The effectiveness and feasibility of the improved GA for various scenarios.
MOPSO	Benyamina et al. [101]	2008	MR MG	Discrete	Static	MOPSO approach provides good results compared to other WMNs design models existing in the literature.
PSO	Le et al. [102]	2011	MG	Discrete	Static	The superiority of PSO algorithm in terms of throughput when compared with MTW based gateway placement algorithm.
VMOPSO	Benyamina et al. [103]	2011	MR MG	Discrete	Static	VMOPSO generates from 10% less expensive solutions when compared to AML generated solutions.
MOPSO	Mountassir et al. [104]	2012	MR MG	Discrete	Static	The MOPSO approach is a promising solution for solving WMNs planning problem.
Enhanced MOPSO	Mountassir et al. [105]	2012	MR	Discrete	Static	The enhanced MOPSO provides good performances with a low cost.
Enhanced PSO	Lin [106]	2013	MR	Continuous	Dynamic	The efficiency of the enhanced PSO compared to the original PSO to cope with dynamic node placement problem in WMNs
Improved MOPSO	Mountassir et al. [107]	2012	MR MG	Discrete	Static	The improved MOPSO is a promising solution for solving WMNs planning problem.
ACO	le et al. [108]	2013	MG	Discrete	Static	The performance of ACO compared to MTW scheme and and PSO algorithm in terms of throughput.
PSO, GA, and ACO	Le [109]	2013	MG	Discrete	Static	The superiority of PSO, GA, ACO when compared to MTW scheme in terms of cost and throughput. PSO and ACO has better properties compared to GA algorithm.

Table 7 (continued)

Algorithm	Authors (Ref)	Year	Type of node	Locations	Environ	Results
Improved BA	Lin et al. [110]	2014	MR	Continuous	Dynamic	The improved BA can obtain better solutions compared to PSO and original BA.
PSO	Sakamoto et al. [111]	2015	MR	Discrete	Static	The performance of PSO in terms of user coverage and network connectivity.
Improved PSO	Hamdi and Mhiri [112]	2015	MR	Continuous	Dynamic	The improved PSO provides better results when compared to PSO approach.
Social based-PSO	Lin et al. [113]	2016	MR	Continuous	Dynamic	The effectiveness of the social-based PSO approach when compared with the original PSO approach.
Adaptive PSO	Lin et al. [114]	2016	MR	Continuous	Dynamic	The performance of the adaptive PSO when compared to legacy PSO in terms of coverage, connectivity, and stability.
RPSO	Li et al. [115]	2017	MG	discrete	static	RPSO provides an optimal gateway deployment with a smaller coverage radius and faster convergence rate when compared with other optimization techniques.
Adaptive binary MOPSO	Wang et al. [116]	2017	MR MG	Discrete	Static	The performance of the adaptive binary MOPSO in finding a robust WMNs design.
APSO	Wang [117]	2020	MG	Discrete	static	The performance of APSO when compared with GA and K-mean algorithms.
APSO	Nouri et al. [118]	2021	MR	Continuous	Static	Simulation results confirmed the superiority of APSO when compared to LDWPSO.
FA	Sayad et al. [119]	2018	MR	Continuous	Static	Efficiency of FA compared to GA in terms of coverage and connectivity.
FA	Zhang et al. [120]	2021	MR	Discrete	Static	Robustness and effectiveness of FA compared to GA.
VFPlace	Wang et al. [121]	2008	MR	Continuous	Static	The effectiveness of VFPlace approach compared to random placement in terms of coverage and connectivity.
EM	Sayad et al. [122]	2019	MR	Continuous	Static	The efficiency of EFO compared to GA in terms of coverage and connectivity.
RCO	Sayad et al. [123]	2017	MR	Discrete	Static	Superiority and robustness of RCO compared to GA and SA.

Wang et al. [65] proposed an efficient method based on a local search algorithm, called incremental local search (ILSearch), for solving the mesh routers placement problem in WMNs. The ILSearch method was validated in realistic instances, increasing the number of clients and traffic density per client. Simulation results demonstrated the effectiveness of the ILSearch method in terms of cost and network capacity when compared with other well-regarded WMNs design algorithms.

Neighborhood search method and ad-hoc placement algorithms were considered in the work of Xhafa et al. [66] for solving mesh routers placement problem in WMNs. The proposed methods were validated based on 2 scenarios with different distributions of mesh clients, taking into account the coverage and connectivity metrics. Simulation results demonstrated the good performance of the neighborhood search method compared to the ad-hoc placement method in terms of optimality of the solutions.

B) Simulated Annealing

Simulated annealing (SA) algorithm was proposed by Xhafa et al. [67] for solving the mesh router placement problem in WMNs. SA was validated using 48 instances having different sizes of grid area with four distribution of mesh clients, taking into account user coverage and network connectivity metrics. Simulation results demonstrated the effectiveness and good performance of SA when compared with the hill climbing algorithm in terms of connectivity and coverage.

Huan et al. [68] designed two placement algorithms namely simulated annealing-based placement (SAP) and greedy search-based placement (GSP) for solving the mesh routers placement problem in WMNs. These algorithms

Table 8 The objectives and constraints considered in meta-heuristic approaches

Authors(ref)	Objectives						Constraints						
	Cost	Coverage	Connectivity	Load Balancing	Throughput	Delay	Cost	Coverage	Connectivity	Traffic	Capacity	Delay	Interference
Franklin and Murthy [64]		✔	✔				✔						
Wang et al. [65]	✔							✔	✔	✔	✔		✔
Xhafa et al. [66]		✔	✔				✔						
xhafa et al. [67]		✔	✔				✔						
Huan et al. [68]	✔									✔	✔		
Lin et al. [69]		✔	✔				✔						
Nawaf et al. [70]	✔				✔						✔		✔
Ebongue Kedieng Fendji et al. [72]		✔					✔		✔				
Nawaf et al [71]	✔	✔			✔						✔		✔
Sayad et al. [73]		✔	✔				✔						
Fendji and Förster [74]		✔	✔				✔						
Xhafa et al [75]		✔	✔				✔						
Barolli et al. [76]		✔	✔				✔						
Katayama [77]		✔	✔				✔						
Hirata et al. [78]		✔	✔				✔						
Xhafa et al. [79]		✔	✔				✔						
Wang et al. [80]	✔	✔				✔						✔	
Ivanov et al. [81]	✔	✔				✔			✔			✔	
Hsu et al. [82]	✔								✔	✔	✔	✔	
De marco [83]	✔	✔					✔		✔		✔		✔
Xhafa et al. [84]		✔	✔				✔						
Mahani et al. [85]	✔	✔				✔			✔			✔	
Ali et al. [86]	✔	✔									✔		
Lee et al. [87]		✔					✔						
Oda et al. [88]		✔	✔				✔						
Le et al. [89]					✔		✔				✔		✔
Oda et al. [90]		✔	✔				✔						
Girgis et al. [91]	✔							✔	✔	✔	✔	✔	
Girgis et al. [92]	✔							✔	✔	✔	✔	✔	
Ahmed et al. [93]						✔	✔					✔	
Lazrag et al. [94]	✔					✔						✔	
Tang and Chen [95]	✔							✔			✔	✔	
Bello et al. [96]	✔							✔			✔	✔	
Huang et al. [97]	✔							✔			✔	✔	
Nawaf et al. [98]	✔				✔						✔		

Table 8 (continued)

Authors(ref)	Objectives						Constraints						
	Cost	Coverage	Connectivity	Load Balancing	Throughput	Delay	Cost	Coverage	Connectivity	Traffic	Capacity	Delay	Interference
Liu et al. [99]	✔				✔			✔			✔	✔	✔
Tang et al. [100]	✔				✔			✔			✔	✔	✔
Benyamina et al. [101]	✔				✔			✔	✔		✔		
Le et al. [102]					✔		✔				✔		✔
Benyamina et al. [103]					✔		✔				✔		✔
Mountassir et al. [104]	✔	✔		✔					✔		✔	✔	✔
Mountassir et al. [105]	✔			✔					✔		✔		✔
Lin [106]		✔	✔				✔						
le et al. [108]					✔		✔				✔		✔
Le [109]					✔		✔				✔		✔
Lin et al. [110]		✔	✔				✔						
Sakamoto et al. [111]		✔	✔				✔						
Hamdi and Mhiri [112]		✔	✔				✔						
Lin et al. [113]		✔	✔				✔				✔		
Lin et al. [114]		✔	✔				✔				✔	✔	
Li et al. [115]						✔	✔						
Wang et al. [116]				✔			✔		✔		✔		✔
Wang [117]						✔	✔						
Nouri et al. [118]		✔	✔				✔						
Sayad et al. [119]		✔	✔				✔						
Zhang et al. [120]		✔	✔				✔						
Wang et al. [121]		✔	✔				✔				✔		
Sayad et al. [122]		✔	✔				✔						
Sayad et al. [123]		✔	✔				✔						

were evaluated in different network topologies with various system parameters such as the number of mesh clients, average traffic demand of mesh clients, and maximum charging capability of mesh routers. Simulation results showed that GSP and SAP can achieve good performance with greatly reduced computation complexity when compared to the exhaustive search model.

Lin et al. [69] developed an improved SA based on the incorporation of momentum terms into SA for solving the mesh routers placement problem in WMNs. The improved SA was evaluated for different-size instances under various parameters such as coverage, connectivity, and convergence. Simulation results demonstrated the good performance of the improved SA when compared with the original SA.

SA and hill climbing were implemented in the work of Nawaf et al. [70] for solving the gateway placement problem in WMNs. These algorithms were evaluated and compared taking into account the parameters of cost, throughput, wireless link capacity, wireless range connectivity, and running time. Simulation results showed that SA produces better results than hill climbing, but it takes slightly longer to run.

Ebongue Kedieng Fendji et al. [72] proposed an enhanced method based on the incorporation of metropolis strategy into SA for solving the mesh routers placement problem in rural WMNs. The enhanced SA was validated based on 3 instances with different areas, taking into account 3 metrics such as cost, coverage, and connectivity. Experimental results showed that the enhanced SA achieves a coverage between 94% and 97% with an optimal number of routers. SA was used in the work of Nawaf et al. [71] for solving the gateway placement problem in WMNs. SA algorithm was validated based on 23 instances taking into account 3 metrics such as cost, coverage, and throughput. Simulation results showed that SA algorithm produces a set of effective optimization solutions.

Sayad et al. [73] used SA algorithm for solving the dynamic mesh routers placement problem in WMNs. SA was evaluated based on two network scenarios with low and high mobility respectively, taking into account the connectivity, coverage, and average distance parameters. Simulation results demonstrated the effectiveness of SA when compared with PSO approach.

Fendji and Förster [74] proposed three variants of SA, called multi-objective SA (MSA), multi-objective center of mass (MCM), and multi-objective SA-based CM (MSAC), for solving the WMNs design problem. The effectiveness of the proposed methods was evaluated taking into account the deployment cost, coverage, and min-max regret metrics. Simulation results demonstrated that MSAC gives better performance in terms of robustness and quality of solutions.

C) Hill climbing

Xhafa et al. [75] proposed hill climbing algorithm for solving the mesh routers placement in WMNs. Hill climbing was validated based on 48 benchmarks using different distributions of mesh clients with different grid sizes taking into account the coverage and connectivity metrics. Simulation results demonstrated the good performance of the hill climbing algorithm for optimizing the mesh routers placement in WMNs.

Barolli et al. [76] applied hill climbing, SA, and GA algorithms for solving the mesh routers placement problem in WMNs. These algorithms were evaluated based on 48 benchmarks using different distributions of mesh clients with different sizes of the grid area. The comparison is done in terms of coverage and connectivity. Simulation results showed that the three algorithms achieve full connectivity whereas hill climbing and SA give better results than GA in terms of coverage.

The hill climbing approach was proposed in the work of Katayama [77] for optimizing the placement of mesh routers in WMNs. The proposed approach was validated by considering the normal and uniform distribution of mesh clients. Simulation results confirmed the superiority of hill climbing when compared with TS.

Hirata et al. [78] proposed an improved hill climbing algorithm for solving the mesh routers placement problem in WMNs. The improved hill climbing algorithm was evaluated for different instances considering normal and uniform distribution of mesh clients. Simulation results demonstrated the effectiveness of the improved hill climbing algorithm when compared with coverage construction method (CCM).

D) Tabu Search

Tabu Search (TS) algorithm was proposed in the work of Xhafa et al. [79] for solving the mesh routers placement problem in WMNs. TS was validated based on 48 instances using 4 different distributions of mesh clients with different sizes of grid area taking into account the user coverage, network connectivity, and convergence metrics. Simulation results showed the effectiveness of TS when compared with SA method.

An improved TS was proposed in the work of Wang et al. [80] for optimizing the deployment of mesh-routers in WMNs. The improved TS was validated for the 3D mountain environment in the Wanglang national nature reserve of Sichuan province, taking into account the cost, coverage, and connectivity metrics. Simulation results showed that the mountain is almost completely covered (more than 90%) with only a small part of the not-covered region.

E) Pattern search

Ivanov et al. [81] proposed a novel algorithm based on pattern search, called base station planning algorithm for solving the fault-tolerant base station planning problem of WMN in dynamic industrial environments. The proposed algorithm was validated based on three performance metrics including fault-tolerance, termination, and minimality. Simulation results showed that the presented algorithm produces correct results, in a limited number of iterations and in an acceptable time. The provided fault-tolerance is sufficient in most practical situation.

4.3.2 Population based approaches

A) Evolutionary based

De marco [83] proposed a multi-objective genetic algorithm, called (MOGAMESH), for solving the nodes placement in WMNs. MOGAMESH algorithm optimizes WMN topology by maximizing the user coverage percentage and minimizing the nodes degree. Simulation results demonstrated the good performance of MOGAMESH in terms of deployment cost, coverage, and speed for realistic instances.

GA was applied in the work of Xhafa et al. [84] for solving the mesh routers placement problem in WMNs. GA was validated considering 48 instances having different network sizes with 4 clients distributions, taking into account the user coverage and network connectivity as metrics. Experimental results showed the efficiency of GA by obtaining high-quality solutions for mesh routers placement in WMNs.

Mahani et al. [85] proposed an improved GA based on the integration of real and binary encoding into GA for solving the WMNs design problem. The improved GA algorithm was evaluated in terms of cost, delay, and required connectivity metrics. Experimental results demonstrated the effectiveness of the improved GA algorithm.

A multi-objective approach based on a quantum-inspired evolutionary algorithm (QIEA) was proposed in the work of Ali et al. [86] for solving the WMNs planning problem. QIEA was used to maximize coverage and optimize the cost based on 6 scenarios. Computational experiments confirmed the performance of QIEA compared to GA.

To solve the mesh router placement problem in indoor WMNs, Lee et al. [87] proposed two GA variants, called GA-CL (GA with Cluster algorithm) and GA-DEFINED (GA with manually selected initial solutions). These two algorithms were validated based on 7 scenarios by investigating the impact of the number of MRs, coverage radius, threshold, and walls (obstacles). Simulation results showed that the proposed algorithms improve the performance by 30-40% compared to the random selection scheme.

Oda et al. [88] applied GA for solving the nodes placement problem in WMNs. GA was evaluated based on four scenarios taking into account the user coverage and network connectivity metrics. Simulation results showed that GA offers good performance in terms of network connectivity and user coverage.

An evolutionary algorithm (EA) was proposed in the work of Le et al. [89] for solving the gateways placement problem in WMNs. EA was validated based on two experiments taking into account the cost and throughput metrics. Numerical results showed the superiority of the proposed algorithm when compared with the MTW scheme.

Oda et al. [90] applied GA for solving the nodes placement problem in WMN considering client mobility. GA was evaluated in terms of coverage and connectivity using exponential and Weibull distributions of mobile mesh clients, considering 10 patterns for different client positions. Simulation results showed that GA has good performance in terms of coverage and connectivity when mesh clients are mobile.

GA and TS approaches were applied in the work of Girgis et al. [91] for solving the WMNs design problem. GA and TS were evaluated based on 2 scenarios: (i) small network size with low link capacity; (ii) large network size with high link capacity. They take into account cost and computational time metrics. Simulation results showed that GA and TS are able to minimize the cost. GA is better than TS when the link capacity is high, while TS is better when the link capacity is low.

Girgis et al. [92] used GA and SA approaches for solving the WMNs design problem. GA and SA were validated using a small network size with low link capacity and a large network size with high link capacity. Simulation results showed that GA outperforms SA in a small size network, whereas SA is better in a large size network.

Ahmed et al. [93] applied GA approach for solving the gateways placement problem in WMNs. GA approach was validated using many generated instances under different conditions (population size, tournament size, crossover type, and mutation type). Experimental results showed the robustness of the GA approach in terms of deployment cost, convergence rate, and scalability.

Lazrag et al. [94] proposed a multi-objective GA approach, called EGA-GP, for solving the gateways placement problem in WMNs. EGA-GP was assessed taking into account the deployment cost and delay metrics. Simulation results proved the performance of EGA-GP when compared with greedy algorithm and GA.

Tang and Chen [95] proposed a modified GA, called Repairing GA (RGA), for solving the gateways placement problem in WMNs. RGA was validated in terms of number of gateways and computational time using 10 test problems of different sizes. Experimental results demonstrated the satisfactory performance of RGA when compared with the incremental clustering algorithm.

Bello et al. [96] proposed an improved MOGA and an improved non-dominated sorting genetic algorithm II (NSGAII) for solving the nodes placement problem in WMNs. The proposed algorithms were validated based on 3 instances with different area sizes, taking into account deployment cost and coverage metrics. Simulation results showed that the proposed algorithms are able to improve the coverage and reliability when designing WMNs.

To tackle the gateways deployment problem in WMNs, Huang et al. [97] applied an improved GA, improved artificial immune (AIA), and improved K-means algorithms based on the integration of T-step substitution strategy into original algorithms. These algorithms were validated based on six instances with different network sizes. Simulation results demonstrated the effectiveness of the improved algorithms when compared with AIA, GA, and k-means algorithms.

NSGA-II algorithm was applied in the work of Nawaf et al. [98] for solving the gateways placement problem in WMNs. NSGA-II was assessed taking into account two metrics such as cost and coverage. Simulation results demonstrated the effectiveness and good performance of NSGA-II when compared with the weighted sum approach.

Liu et al. [99] proposed a modified GA, called MTMG, for solving the gateways deployment problem in WMNs. MTMG was validated based on 6 instances with different gateway deployment locations taking into account the cost and throughput metrics. Simulation results demonstrated the effectiveness of MTMG when compared with ICLB-GPS algorithm and weighted recursive algorithm.

Tang et al. [100] proposed an improved GA based on GA coupled with minimum spanning tree (MST) was proposed for solving the mesh routers deployment problem in WMNs. The improved GA was validated taking into account the deployment cost, coverage, and connectivity metrics. Simulation results demonstrated the effectiveness and feasibility of the improved GA for various scenarios.

B) Swarm Intelligence based

Benyamina et al. [101] proposed a multi-objective particle swarm optimization algorithm (MOPSO) for solving the WMNs planning problem. MOPSO algorithm was used to optimize two conflicting objectives (i.e., Network deployment cost and network channel interference) while satisfying the coverage and connectivity requirements. Simulation results showed that MOPSO provides good results compared to other WMNs design models existing in the literature.

Le et al. [102] applied PSO algorithm for solving the gateway placement problem in WMNs. PSO algorithm was validated based on two experiments taking into account the deployment cost and throughput metrics. Simulation results showed the superiority of PSO algorithm compared to other WMNs planning studies found in the literature.

Benyamina et al. [103] proposed a new variant of MOPSO based on crowding and mutation factor techniques, called VMOPSO, for solving the WMNs topology design problem. VMOPSO was validated based on three performance metrics namely cost, interferences, and congestion. Simulation results showed that VMOPSO generates 10% less expensive solutions when compared to AML generated solutions.

Mountassir et al. [104] applied MOPSO for solving the WMNs topology planning problem. The principal idea is to optimize three objectives namely deployment cost, coverage, and load-balancing with a set of constraints including connectivity, delay, and interference. Simulation results proved that MOPSO algorithm represents a promising solution for solving the WMNs planning problem.

Same authors [105] proposed an enhanced MOPSO based on the incorporation of crowding distance and mutation factor strategies into MOPSO for solving the nodes placement problem in WMNs. The enhanced MOPSO was used to optimize the cost, coverage, link load balancing, and gateway load-balancing while satisfying the and interference requirements. Simulation results showed that the improved MOPSO provides good performances with a low cost.

Lin [106] developed an enhanced PSO algorithm based on the integration of restriction coefficient into PSO for solving the dynamic mesh routers placement problem. The enhanced PSO algorithm was tested for 3 cases in static and dynamic scenarios, taking into account the user coverage and network connectivity metrics. Experimental results proved the efficiency of the enhanced PSO compared to the original PSO to cope with the dynamic mesh routers placement problem in WMNs.

In the work of Le et al. [108], ACO algorithm was proposed for solving the gateways placement problem in WMNs. ACO algorithm was validated based on two experiments taking into account the metrics of cost and throughput. Numerical results showed that ACO achieves much better performance when compared with multi-hop traffic-flow weight (MTW) scheme and PSO algorithm.

Le [109] presented a comparative study between PSO, GA, and ACO algorithms in the context of the gateways placement problem in WMNs. These three algorithms were evaluated and compared based on three scenarios in terms of throughput and cost. Numerical results demonstrated the superiority of PSO, GA, and ACO when compared to the

MTW scheme in terms of cost and throughput. PSO and ACO have better properties compared to GA algorithm.

In the work of Lin et al. [110], an improved bat algorithm (improved BA) based on the integration of dynamic search scheme into the original BA was proposed for solving the dynamic mesh routers placement problem in WMNs. The improved BA was validated based on 10 instances, taking into account the coverage and connectivity parameters. Simulation results showed that the improved BA can obtain better solutions when compared with PSO and the original BA.

Sakamoto et al. [111] proposed PSO algorithm for solving the nodes placement problem in WMNs. User coverage and network connectivity are considered as metrics to be optimized. Simulation results demonstrated the good performance of PSO in terms of coverage and connectivity.

Hamdi et mhiri [112] proposed an improved PSO for optimizing the placement of dynamic routers in WMNs. The improved PSO was evaluated in terms of user coverage and network connectivity considering static and dynamic scenarios (networks with high and low mobility). Simulation results showed that the improved PSO provides better fitness value and more stable topology in both static and dynamic scenarios when compared with PSO algorithm.

An enhanced PSO including a social-supporting vector, called a social-based-PSO, was proposed in the work of Lin et al. [113] for solving the mesh routers placement problem. The social-based-PSO was validated based on 3 dynamic scenarios with social community behavior, taking into account the coverage and connectivity parameters. Experimental results demonstrated the effectiveness of the social-based-PSO approach when compared with the original PSO approach.

Lin et al. [114] proposed an adaptive PSO approach based on the incorporation of three local search operators into PSO for solving the mesh routers placement problem in dynamic WMNs. Adaptive PSO was used to maximize the user coverage and network connectivity metrics taking into account three constraints such as relay load, gateway capacity, and delay hop. Simulations results proved the performance of the adaptive PSO when compared with legacy PSO for static and dynamic scenarios.

Li et al. [115] proposed an improved PSO algorithm (RPSO) based on the incorporation of maximum coupling sub-graph strategy into PSO algorithm for solving the gateways deployment problem in WMNs. RPSO was evaluated based on eight different scales random networks taking into account the cost, convergence, and coverage radius metrics. Simulation results showed that RPSO provides an optimal gateways deployment with a smaller coverage radius and faster convergence rate when compared with other optimization techniques.

In the work of Wang et al. [116], an adaptive binary MOPSO based on the integration of self-adaptive evolutionary learning strategy into MOPSO was proposed for solving the WMNs deployment problem. The proposed algorithm was validated taking into account the deployment cost, coverage, and load-balancing metric. Simulation results showed that the improved binary MOPSO is helpful for providing a robust WMNs design.

Wang [117] proposed an adaptive PSO (APSO) algorithm for solving the gateway deployment problem in WMNs. APSO was used to minimize the path length between the node and gateway. Simulation results demonstrated the good performance of APSO when compared with GA and K-mean algorithms.

An accelerated PSO (APSO) algorithm was considered in the work of Nouri et al. [118] for solving mesh routers placement problem. Accelerated PSO was validated in terms of coverage and connectivity using different generated benchmarks of multiple configurations. Simulation results confirmed the superiority of APSO when compared to linearly decreasing weight PSO.

Firefly algorithm (FA) was applied in the work of Sayad et al. [119] for solving the mesh routers placement problem in WMNs. FA was validated in a rectangular simulation area of $2Km^2$ taking into account the user coverage and network connectivity metrics. Simulation results demonstrated the efficiency of FA when compared with GA.

Zhang et al. [120] used FA for solving the mesh routers placement problem in WMNs. Client coverage and network connectivity are considered as objective functions to be optimized and the obtained results demonstrated the robustness and effectiveness of FA compared to GA.

C) Physical based

Wang et al. [121] proposed an enhanced virtual force algorithm, called virtual force placement (VFPlace) algorithm for solving the mesh routers placement problem in WMNs. VFPlace was validated based on three scenarios (prohibited regions, regular preferential regions, and virtual preferential regions) considering the metrics of coverage and connectivity. Simulation results showed the effectiveness of VFPlace when compared with random placement scheme in terms of coverage and connectivity.

Sayad et al. [122] applied electromagnetism-like mechanism (EM) meta-heuristic for solving the mesh routers placement problem in WMNs. EM was validated based on various scenarios taking into account the user coverage, network connectivity, and convergence metrics. Simulation results showed that the EM algorithm outperforms PSO and GA with regard to client coverage and network connectivity.

D) Chemical based

Sayad et al. [123] proposed chemical reaction optimization (RCO) algorithm for solving the mesh routers placement problem in WMNs. RCO was used for optimizing three objectives: user coverage, network connectivity, and execution time under the constraints of cost and coverage. Simulation results showed that RCO gives better results when compared with GA and SA algorithms in terms of improvement of network connectivity.

4.4 Hybrid approaches

Some approaches based on the hybridization of several algorithms aim to fill the limits of one technique with the advantages of another one. Generally, several ways of hybridization are possible. In WMNs nodes placement problem, however, we found five hybridization types: hybridizing two meta-heuristic methods, hybridizing meta-heuristics with heuristics, hybridizing two heuristics, hybridizing meta-heuristics with the fuzzy system, and hybridizing heuristics with exact approaches. All concerned approaches are applied for MR and/or MG nodes under static environment and discrete nodes location as summarized in Table 9. The objectives and constraints considered in hybrid approaches are given in Table 10, where it is shown that the most commonly used objectives are cost, coverage, and connectivity whereas, coverage, capacity, and delay constraints are considered by most of hybrid methods.

4.4.1 Meta-heuristics with meta-heuristics

Benyamina et al. [124] proposed a hybrid model (VMOPSO) based on the hybridization of MOPSO with GA for solving the WMNs design problem. VMOPSO was used to optimize the deployment cost and throughput objectives while satisfying the coverage and connectivity constraints. Simulation results showed that VMOPSO performs better in terms of deployment cost and throughput when compared to other optimization models.

Sakamoto et al. [125] proposed a hybrid model (PSOHC) based on the hybridization of PSO and hill climbing algorithm for solving the mesh routers placement problem in WMNs. User coverage, network connectivity, and convergence were considered as metrics to be optimized and results showed that PSOHC has better performance when compared with PSO approach.

Barolli et al. [126] proposed a hybrid algorithm based on the hybridization of PSO and distributed GA, called PSODGA, for solving the mesh routers placement problem in WMNs. PSODGA algorithm was evaluated taking into account 4 factors including the number of router nodes, number of mesh client nodes, coverage radius, and size of the deployment area. Simulation results showed that PSODGA has good performance for the WMNs planning.

Two-hybrid approaches were proposed in the work of Sakamoto et al. [127] for solving the mesh router placement problem in WMNs. The first approach (PSOHC) is based on combining PSO with hill climbing, while the second one (PSOSA) is based on PSO and SA. User coverage and network connectivity are considered as metrics to be optimized. Simulation results showed that PSOHC and PSOSA approaches have better performance when compared to PSO. It is also proved that PSOHC converges faster than PSOSA.

Sakamoto et al [128] implemented a combined model (PSO-HC-DGA) based on hybridizing PSO algorithm with hill climbing and DGA for solving the mesh routers placement problem in WMNs. PSO-HC-DGA aimed to find the best locations for mesh routers considering the user coverage and network connectivity metrics. Simulation results showed that PSO-HC-DGA has better performance when compared with PSO-DGA model.

To tackle the router nodes placement problem in WMNs, Sylejmani et al. [129] proposed two approaches, called improved GA and improved greedy randomized adaptive search procedure (improved GRASP), based on embedding hill climbing algorithm within their standard phases. These algorithms were evaluated and compared over a dataset of 4 large instances taking into account the cost and coverage metrics. Experimental results showed that the improved GA and the improved GRASP can obtain competitive results compared to some well-regarded WMNs planning methods found in the literature. The improved GA performs better than the improved GRASP for three of the considered instances.

Sakamoto et al. [130] proposed a hybrid algorithm based on the combination of PSO and SA, called PSO-SA, for solving the mesh routers placement problem in WMNs. PSO-SA was evaluated considering four replacement methods, which are given as follows: constriction method (CM), random inertia weight method (RIWM), linear decreasing inertia weight method (LDIWM), and rational of decrement of Vmax method (RDVM). They take into account the connectivity and coverage metrics. Simulation results showed that PSO-SA converges faster and has better performance using LDIWM and RDVM methods.

Ohara et al. [131] developed a hybrid algorithm (PSO-DGA) based on the hybridization of PSO with GA for solving the WMNs nodes placement problem. PSO-DGA was evaluated considering the coverage, connectivity, and load-balancing metrics and results showed that PSO-DGA has better performance when compared with other WMNs design techniques.

Table 9 Summary of hybrid approaches for nodes placement in WMNs

Algorithm	Authors (Ref)	Year	Type of node	Results
VMOPSO	Benyamina et al. [124]	2012	MR MG	VMOPSO performs better in terms of deployment cost and throughput when compared to other optimization models.
PSOHC	Sakamoto et al. [125]	2017	MR	The performance of PSOHC when compared with PSO approach in terms of coverage and connectivity.
PSODGA	Barolli et al. [126]	2018	MR	PSODGA has good performance for the WMNs planning
PSO-HC and PSO-SA	Sakamoto et al. [127]	2018	MR	The performance of PSO-HC and PSO-SA when compared to PSO in terms of coverage and connectivity.
PSO-HC-DGA	Sakamoto et al [128]	2018	MR	WMN-PSO-HC-DGA has better performance when compared with WMN-PSO-DGA model.
Improved GA and Improved GRASP	Sylejmani et al. [129]	2019	MR	The improved GA and the improved GRASP can obtain competitive results compared to WMNs planning methods found in the literature.
PSO-SA	Sakamoto et al. [130]	2019	MR	PSO-SA converges faster and has better performance using LDIWM and RDVM methods.
WMN-PSODGA	Ohara et al. [131]	2020	MR	PSODGA has better performance when compared with other WMNs design techniques.
PSO-HC	Sakamoto et al. [132]	2020	MR	Simulation results showed that PSO-HC achieves better results for CM when compared with the case of RDVM.
PSOSA-DGA	Barolli et al. [133]	2020	MR	Simulation results showed that PSOSA-DGA has better performance for CM compared with the case of RIWM.
PSOSA-DGA	Barolli et al. [134]	2021	MR	Simulation results showed that PSOSA-DGA achieves full coverage and full connectivity for a number of routers over 32.
PSO-DGA	Barolli and Takizawa [135]	2021	MR	The efficiency and robustness of PSODGA compared to other WMNs planning models found in the literature.
Hybrid greedy algorithm	Farag et al. [136]	2009	MG	The performance of the combined algorithm when compared to manual AP allocation method.
Improved VMOPSO	Benyamina et al. [137]	2011	MR MG	The effectiveness and scalability of the improved VMOPSO in designing robust cost-effective WMNs infrastructure.
Hybrid VMOPSO	Benyamina et al. [138]	2012	MR MG	The performance of the hybrid VMOPSO when compared to RGSB in terms of average bandwidth, packet loss, and delay.
PMRGLB	Aljober and thool [139]	2014	MR MG	The superiority of PMRGLB when compared with LIGDR and LGLB heuristics.
PRACA	Wong et al. [140]	2014	MR	The performance of PRACA when compared to greedy based placement (GBP) approach in terms of loss rate, delay, fairness, and throughput.
K-GA	Raithatha et al. [141]	2021	MG	K-GA provides better results compared to other WMNs design approaches.
FDE	Sheeba and Nachiappan [142]	2017	MG	FDE provides better performance compared to SA and DE algorithms.
Hybrid GA	caello et al. [143]	2019	MR	The feasibility of hybrid GA for positioning mesh routers in WMNs.
Hybrid greedy approach	Wang et al. [144]	2007	MR	the effectiveness of greedy hybrid algorithm compared to other WMNs planning approaches.
CeNP LSA	Wu et al. [145]	2010	MR MG	The effectiveness of CeNP LSA for placing mesh nodes in WMNs.
LMP	Souza and albuquerque [146]	2010	MR	LMP algorithm presents optimal solutions when compared with distance algorithm.
LIGDP	luo et al. [147]	2011	MG	LIGDP outperforms weighted recursive and weighted based GDTSP algorithms in terms of MR-GW path, load balancing, interference, and cost
GPSR	Chen and Chekuri [148]	2007	MG	GPSR provides optimal solutions when compared with other WMNS planning models.
GSR	Chen et al. [149]	2009	MR	GSR generates optimal solutions in terms of cost and number of covered users.

Table 9 (continued)

Algorithm	Authors (Ref)	Year	Type of node	Results
Hybrid non-uniform method	Fu et al. [150]	2009	MR	The effectiveness of hybrid method when compared with the uniform WMNS nodes placement method.

Sakamoto et al. [132] used a combined method, called PSO-HC, based on the combination of PSO and hill climbing algorithms for tackling the mesh router placement problem in WMNs. PSO-HC was validated considering two replacement methods (i.e., CM and RDVM), taking into account two metrics such as coverage and connectivity. Simulation results showed that PSO-HC achieves better results for CM when compared with the case of RDVM.

Barolli et. al. [133] proposed a hybrid algorithm, called PSOSA-DGA, based on combining PSO, SA, and DGA for solving the WMN router nodes placement problem. PSOSA-DGA was validated in terms of coverage and connectivity, considering chi-square distribution of mesh clients and two router replacement methods (CM and RIWM). Simulation results showed that PSOSA-DGA has better performance for CM compared with the case of RIWM.

Barolli and Takizawa [135] proposed a combined method, called PSO-DGA, based on PSO and GA for tackling the nodes placement problem in WMNs. PSO-DGA was validated by considering the Chi-square distribution of mesh clients and 5 router replacement methods. Experimental results showed that PSO-DGA gives better performance compared to other WMNs planning models found in the literature.

Barolli et al. [134] proposed a combined model, called PSOSA-DGA, based on combining PSO, SA, and DGA for solving the router WMN nodes placement problem. PSOSA-DGA was evaluated by considering Stadium Distribution of mesh clients and different numbers of mesh routers. Simulation results showed that PSOSA-DGA achieves full coverage and full connectivity for a number of routers over 32.

4.4.2 Meta-heuristics with heuristics

Farag et al. [136] combined local search algorithm with the greedy algorithm for solving the WMNs nodes allocation problem in an indoor environment. The combined algorithm was evaluated based on three networks with three gateway positions taking into account the cost, throughput, maximum AP-MG hop count, and average transmission power metrics. Simulation results demonstrated the performance of the combined algorithm when compared with the manual WMNs allocation method.

Benyamina et al. [137] developed a hybrid model based on combining VMOPSO with Bi-connected algorithm (BCN) for solving the reliable WMNs design problem. The principal idea is to optimize the deployment cost and load-balancing metrics while satisfying the coverage, connectivity, and interference requirements. Simulation results proved the effectiveness and scalability of the hybrid model in designing robust cost-effective WMNs infrastructure.

Benyamina et al. [138] coupled VMOPSO with clustering-based gateway placement algorithm (CBGPA) for solving the WMNs design problem. The objectives of deployment cost, throughput, and congestion were optimized simultaneously while satisfying the constraints of coverage and connectivity. Simulation results showed that the hybrid algorithm performs better when compared with VMOPSO hybridized with random gateway selection algorithm (RGSA) by obtaining cost-effective solutions.

Aljober and Thool [139] proposed a hybrid algorithm, called Path Mesh Router Gateway Load-Balancing (PMRGLB), based on the hybridization of MOPSO with gateway selection heuristic for solving the WMNs nodes placement problem. PMRGLB was validated for six instances with different network sizes, taking into account four factors such as number of gateways, standard derivation of gateway load, average path length, and average interference of active link. Simulation results demonstrated the superiority of PMRGLB when compared with LIGDR and LGLB heuristics.

Wong et al. [140] proposed an efficient algorithm, called PRACA, based on TS coupled with pruning algorithm for optimizing the nodes placement in WMNs. PRACA was validated taking into account the parameters of loss rate, delay, fairness, and throughput. Simulation results showed that PRACA gives better performance when compared with greedy based placement (GBP) approach.

Table 10 The objectives and constraints considered in hybrid approaches

Authors(ref)	Objectives						Constraints						
	Cost	Coverage	Connectivity	Load Balancing	Throughput	Delay	Cost	Coverage	Connectivity	Traffic	Capacity	Delay	Interference
Bnenyamina et al. [124]	✔				✔			✔	✔		✔		✔
Sakamoto et al. [125]		✔	✔				✔						
Barolli et al. [126]		✔	✔				✔						
Sakamoto et al. [127]		✔	✔				✔						
Sakamoto et al [128]		✔	✔				✔						
Sylejmani al. [129]		✔					✔						
Sakamoto et al. [130]		✔	✔				✔						
Ohara et al. [131]		✔	✔	✔			✔						
Sakamoto et al. [132]		✔	✔				✔						
Barolli et al. [133]		✔	✔				✔						
Barolli et al. [134]		✔	✔				✔						
Barolli and Takizawa [135]		✔	✔	✔			✔						
Farag et al. [136]	✔				✔	✔		✔	✔		✔		
Benyamina et al. [137]	✔			✔				✔	✔		✔		✔
Benyamina et al. [138]	✔			✔	✔			✔	✔		✔	✔	
Aljober and Thool [139]	✔			✔		✔			✔		✔		✔
Wong et al. [140]					✔	✔	✔		✔		✔		
Raithatha et al. [141]		✔	✔	✔			✔						
Sheeba and Nachiappan [142]	✔				✔						✔		✔
Caello et al. [143]	✔	✔						✔					
Wang et al. [144]	✔							✔	✔	✔	✔		
Wu et al. [145]	✔							✔	✔		✔	✔	
Souza and albuquerque [146]	✔							✔	✔				
Luo et al. [147]	✔			✔		✔		✔			✔	✔	
Chen and Chekuri [148]		✔					✔		✔		✔		
Chen et al. [149]		✔					✔		✔		✔		
Fu et al. [150]					✔		✔	✔	✔				

4.4.3 Meta-heuristics with fuzzy system

In the work of Sheeba and Nachiappan [142], a combined method (FDE) based on the hybridization of differential evolution with fuzzy system was proposed for solving the WMNs nodes placement problem. FDE was validated based on 7 performance metrics such as design cost, transmission cost, CPU time, throughput, PDR, failure rate, and delay for various instances. Simulation results showed that FDE provides better performance compared to SA and DE algorithms.

Two approaches were proposed in the work of Caello et al. [143] for solving the mesh routers placement problem in WMNs. The first approach is based on GA considering coverage as an objective function. The second one is based on the combination of GA and the fuzzy aggregation system for optimizing coverage area and cost under the localization constraint. Results indicated the feasibility of the proposed methods for positioning mesh routers in WMNs.

4.4.4 Heuristics with heuristics

Wang et al. [144] proposed an efficient algorithm based on a reversible greedy algorithm combined with the add-and-merge scheme for solving the mesh routers placement problem in WMNs. The proposed algorithm was validated by investigating the impact of network size and traffic density. Simulation results proved the effectiveness of the proposed algorithm compared to other WMNs planning approaches.

Wu et al. [145] proposed an efficient method, called CeNP LSA, that joints three heuristics (MSC-based coverage algorithm, weighted clustering algorithm, and GW-rooted pruning algorithm) for solving the mesh nodes placement problem in WMNs. CeNP LSA was validated in terms of cost and average length MAP-GW under different conditions and results showed that CeNP LSA is highly effective for strategically placing mesh nodes in WMNs.

Luo et al. [147] proposed an efficient approach (LIGDP) based on the combination of two greedy approaches namely MSC-based location algorithm (MLA) and load aware and interference aware association algorithm (LIAA), for solving the gateways deployment problem in WMNs. LIGDP was validated based on four parameters including the Number of gateways, the average length of MR-GW paths, the standard deviation of gateway load, and the average interference of active links. Simulation results demonstrated the performance of LIGDP when compared with the weighted recursive and weighted-based GDTSP algorithms.

4.4.5 Heuristics with exact approaches

Chen and Chekuri [148] proposed a hybrid algorithm, called GPSR, based on the greedy approach combined with the dual simplex method for solving the urban WMNs planning problem. GPSR was used to maximize the profit of deployment, minimize the deployment cost, and guarantee the connectivity and robustness of the system. Simulation results showed that GPSR provides optimal solutions when compared with other WMNS planning models.

Chen et al. [149] proposed an efficient approach (GSR) based on the hybridization of greedy algorithm with dual simplex method for solving the nodes placement problem in WMNs. The main objective is to optimize the deployment cost and user coverage. Simulation results showed that GSR generates a topology above 95% of the optimal in terms of number of covered users while never exceeding the budget by more than 15%.

Fu et al. [150] proposed a non-uniform method based on the combination of Voronoi approach with min-max algorithm for solving the mesh routers placement problem in WMNs. The hybrid method was used to optimize the coverage, connectivity, and energy consumption requirements. Simulation results demonstrated the effectiveness of the non-uniform method when compared with the uniform WMNS nodes placement method.

5 Case study

In this section, we study the performance of meta-heuristics in solving the WMNs router nodes placement problem. The main aim of this problem is to find the optimal location of a given number of routers which maximizes the network connectivity and user coverage simultaneously. We consider four well-known meta-heuristics such as GA, SA, PSO, and FA. In all experiments, the number of routers is varied from 5 to 40 for covering from 50 to 300 clients in a rectangular deployment area of $2000m \times 2000m$. The parameter values considered in our simulations are given in Table 11.

GA, SA, PSO, and FA approaches are evaluated by investigating the impact of varying the number of mesh clients, the number of mesh routers, and coverage radius values. The evaluation is done based on three performance metrics such as coverage, connectivity, and fitness value. The results are presented in Tables 12, 13 and 14 and their associated graphical representations can be seen in Fig. 7, 8 and 9.

Table 12 and Fig. 7 illustrate the effect of varying the number of mesh clients. It is shown that the fitness value decreases slightly when increasing the number of mesh

Table 11 Parameters values

Parameter	Description	Value	Default value
n	N° of mesh clients	[50 300]	100
m	N° of Mesh routers	[5 40]	20
CR	Coverage radius	[50 400]	200 m
W	Width	2000	2000 m
H	Height	2000	2000 m
λ	Control parameter	[0 1]	0.5
Pop	Population size	30	30
T	N° of iteration	1000	1000

clients. In general, the GA algorithm outperforms the other algorithms in terms of coverage and connectivity.

The impact of increasing the number of mesh routers on coverage, connectivity, and fitness value is shown in Table 13 and Fig. 8. It can be seen that the coverage, connectivity, and fitness value increase with the increase in the number of routers in the network. In fact, the more the number of routers is added to the network, the better is the mesh clients coverage. The results revealed that GA algorithm outperforms SA, PSO, and FA algorithms.

In Fig. 9 and Table 14, we measured the impact of varying the coverage radius. It is demonstrated that the

Table 12 Impact of varying number of mesh clients on the performance of GA, FA, PSO, and SA

Mesh	Coverage				Connectivity				Fitness			
clients	GA	FA	PSO	SA	GA	FA	PSO	SA	GA	FA	PSO	SA
50	41.33	39.73	40.33	44.33	60.96	57.76	60.33	63.53	0.84	0.8	0.83	0.9
100	81.26	79.1	76.03	84	101.26	98.26	95.86	100.7	0.82	0.8	0.77	0.84
150	115.16	119.43	112.46	108.76	135.16	137.26	132.46	125.2	0.78	0.8	0.76	0.73
200	151.6	148.36	148	152.36	171.6	165	167.6	171.2	0.76	0.74	0.75	0.77
250	186.1	183	179.5	179.5	206	201.03	198.76	196.26	0.75	0.73	0.72	0.72
300	225.73	225.3	211.93	214.76	245.73	245.3	231.5	231.76	0.76	0.75	0.71	0.72

Table 13 Impact of varying number of mesh routers on the performance of GA, FA, PSO, and SA

Mesh	Coverage				Connectivity				Fitness			
routers	GA	FA	PSO	SA	GA	FA	PSO	SA	GA	FA	PSO	SA
5	31.26	30.36	32.16	19.36	34.46	30.4	34.86	33.86	0.32	0.29	0.32	0.26
10	49.33	53.53	44.7	53.93	58.93	57.53	53.9	53.46	0.51	0.52	0.46	0.51
15	60.13	66.83	63.9	68.7	74.63	74.9	76.83	79.4	0.62	0.65	0.65	0.68
20	82.7	74.7	79.7	74.96	102.4	93.06	99.7	93.53	0.84	0.76	0.81	0.76
25	91.1	86.13	85.16	90.1	115.9	110.8	110.16	114.4	0.91	0.87	0.86	0.9
30	96	93	94.9	93.3	126.03	122.3	124.73	123.03	0.96	0.93	0.95	0.93
35	97	97.4	96.6	98.8	132	132.16	131.6	133.73	0.97	0.97	0.97	0.98
40	98.7	98.4	98.46	99.46	138.7	138.8	138.26	139.46	0.98	0.98	0.98	0.99

Table 14 Impact of varying coverage radius values on the performance of GA, FA, PSO, and SA

Coverage	Coverage				Connectivity				Fitness			
radius	GA	FA	PSO	SA	GA	FA	PSO	SA	GA	FA	PSO	SA
50	26	26.86	23.83	30.13	16.36	8.26	14.16	8.06	0.19	0.16	0.17	0.18
100	34.53	39.53	32.16	45	48.93	32.66	48.1	20.3	0.37	0.33	0.36	0.33
150	51.46	55.86	52.9	63.96	70.06	67.5	69.2	54.86	0.54	0.56	0.55	0.54
200	75.9	75.76	79.7	80.76	95.73	94.96	99.7	97.9	0.77	0.77	0.81	0.81
250	94.86	94.23	94.7	94.63	114.86	114.23	114.7	114.63	0.95	0.94	0.95	0.95
300	99.3	99.46	99.36	100	119.3	119.16	119.36	120	0.99	0.99	0.99	1
350	100	100	99.96	100	120	120	119.96	120	1	1	0.99	1
400	100	100	100	100	120	120	120	120	1	1	1	1

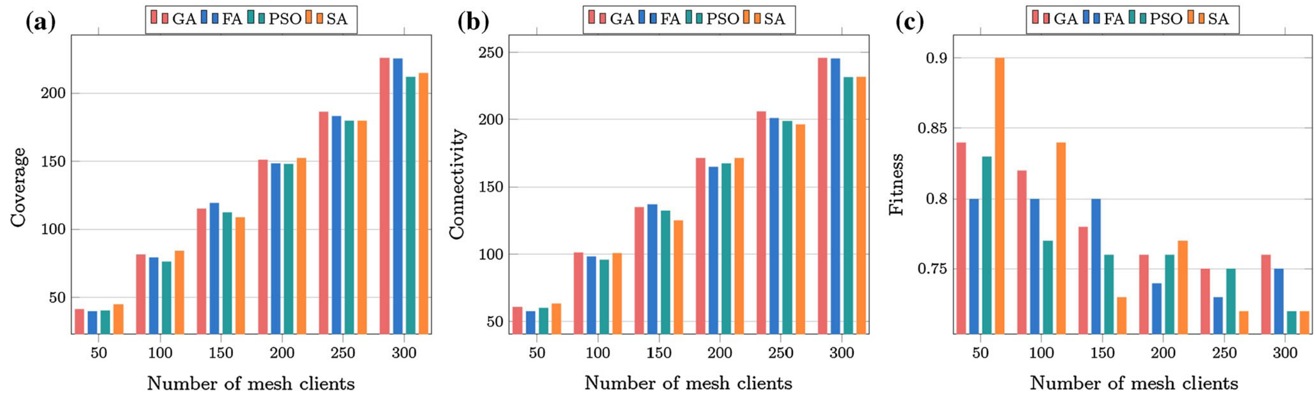

Fig. 7 Impact of varying the number of mesh clients on: (a) Coverage (b) Connectivity (c) Fitness

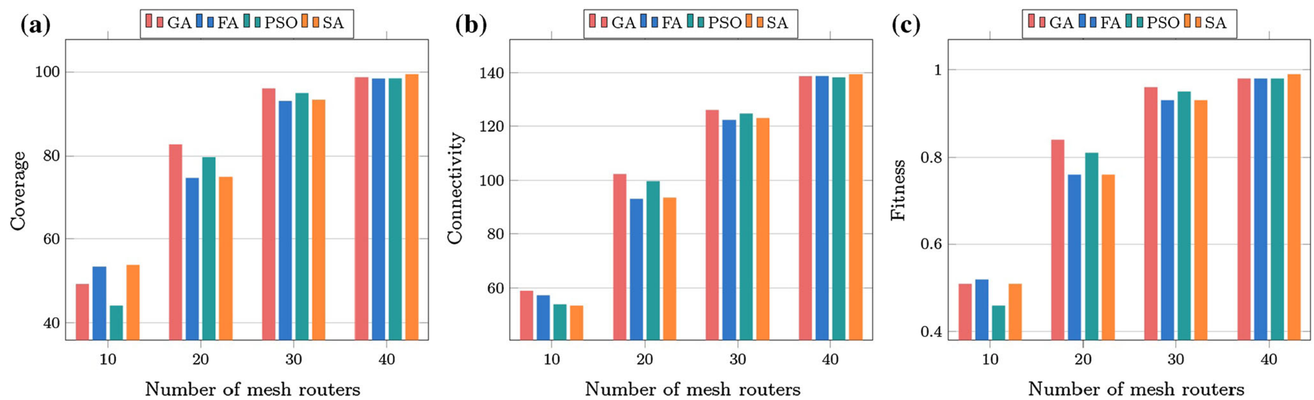

Fig. 8 Impact of varying the number of mesh routers on: (a) Coverage (b) Connectivity (c) Fitness

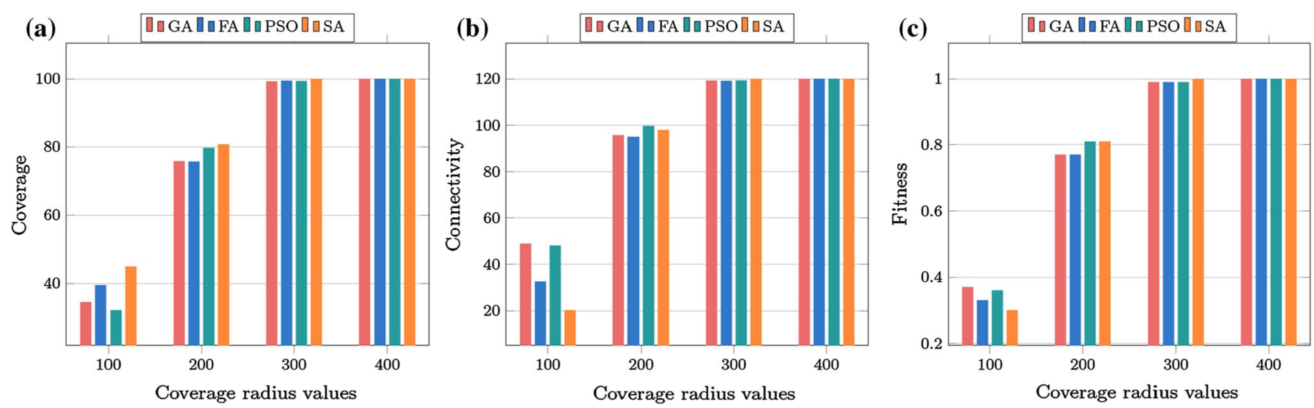

Fig. 9 Impact of varying coverage radius values on: (a) Coverage (b) Connectivity (c) Fitness

coverage, connectivity, and fitness are proportional to the coverage radius value. It is clearly shown that when the coverage radius is between 200 and 300, the performance of the four algorithms is almost the same. However, SA provides better results than other algorithms when the coverage radius exceeds 300.

6 Discussion

In this paper, we discussed several works on existing WMNs nodes placement approaches. In order to sum up the state of the art in regards to the WMNs nodes placement, we provide hereafter some statistics about the different parameters used in the proposed approaches.

As shown in Fig. 10, MRs placement is the most addressed case in the literature representing a proportion of

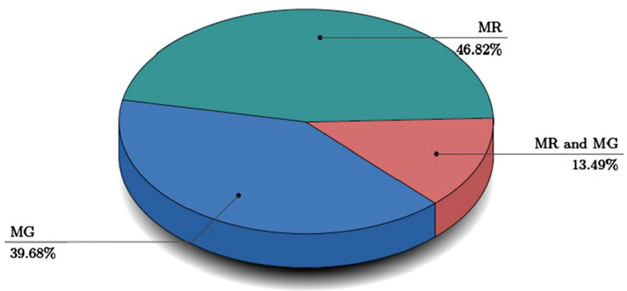

Fig. 10 Classification of related WMNs nodes placement articles per node type

46.82%. 39.68% of papers treated the MGs placement problem, whereas 13.49% of them treated the placement of both MRs and MGs.

The result given in Figure 11 shows the interest rate that each technique grants to each of nodes placement type. We can see that most of the WMNs heuristic-based propositions focus on MGs placement, while meta-heuristic-based approaches treat more the MRs placement case. However, considering the problem with both MRs and MGs placement at the same time represents a small proportion for the moment.

On the other hand, the analysis of the environment, where the proposed approaches were applied, revealed that the static environment is the most used one, as shown in Fig. 12. Nevertheless, the dynamic environment is used in few cases and only when the approach uses meta-heuristics in its resolution method.

From Fig. 13, we can see that most of the approaches treated the WMNs nodes placement problem in discrete space, whereas the continuous space is only used with some approaches based on meta-heuristics.

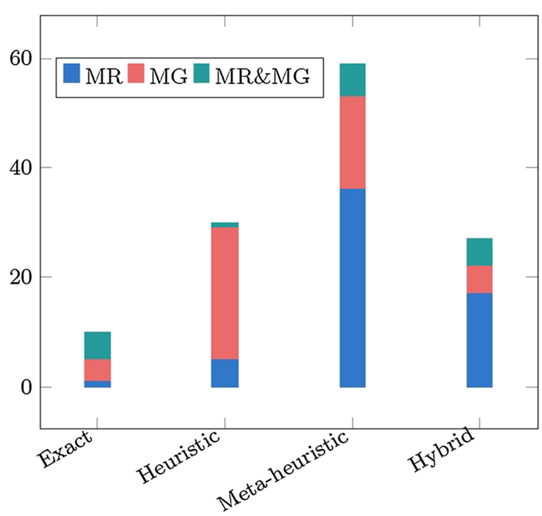

Fig. 11 Classification of related WMNs nodes placement articles per method and node type

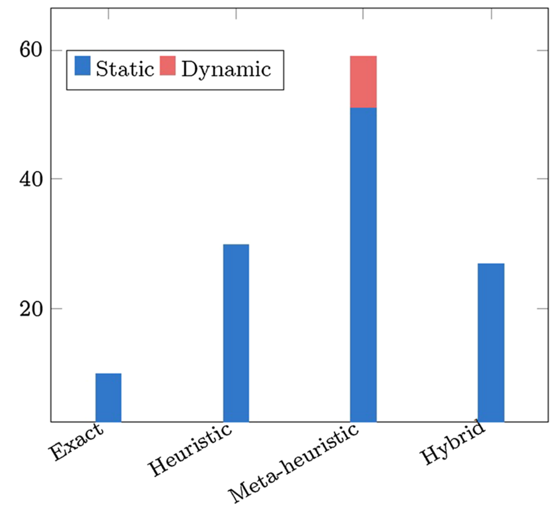

Fig. 12 Classification of related WMNs approaches per environment

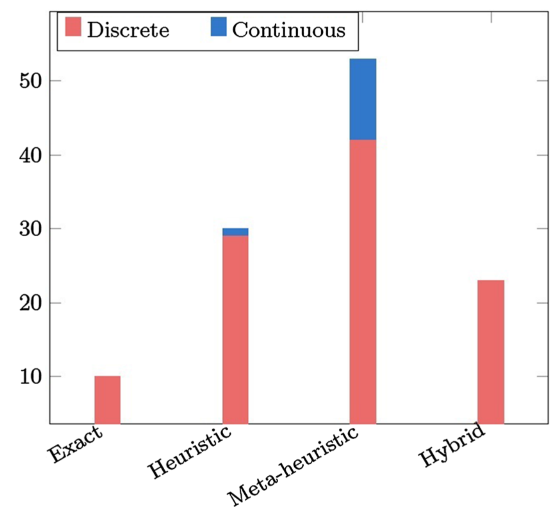

Fig. 13 Classification of related WMNs approaches per space type

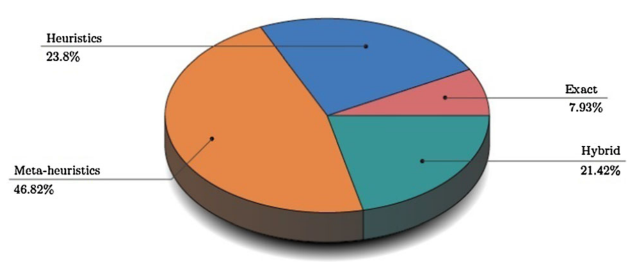

Fig. 14 Classification of related WMN node placement articles per method

Similarly, we illustrated in Fig. 14 the rate of reviewed articles in each technique class. Therefore, we can see that meta-heuristic, heuristic, and hybrid techniques are used in 46,82% 23,8%, and 21.42% of papers, respectively, but only 7.93% of them were based on exact approaches.

Table 15 Strengths and Weaknesses of WMNs nodes placement approaches

Method	Strength	Weakness
Exact	- Good solutions for WMNs planning in terms of deployment cost, coverage, and connectivity.	- Can not face to complex problems with high number of constraints
	- Appropriate for static environment and discrete space	- Not suitable for dynamic environment and continuous space
	- Get exact solutions	- High computation time
Heuristics	- Good results for WMNs nodes placement with mono-objective resolutions	- Bad results for WMNs nodes placement with multi-objective resolutions
	- Appropriate for static environment and discrete space	- Not suitable for dynamic environment and continuous space
	- Same implementation adapted for small, medium, and large instances	- Optimal solutions not guaranteed
	- Reasonable time response	- Stuck in local optimal
Meta-heuristics	- Good results for WMNs nodes placement problem with multi-objective resolutions	- Optimal results not guaranteed
	- Appropriate for dynamic and static environments	- Control parameters tuning
	- Suitable for continuous and discrete spaces	- No theoretical converging property and nature
	- Easy implementation for small, medium and large instances	- Premature convergence
	- Reduced execution time	- More resources requirements

Finally, we established in Table 15 a list of weaknesses and strengths of the surveyed approaches where we noticed the following results:

Exact approaches, such as branch & bound, branch & cut, can not face to complex problems with a high number of constraints. They are more appropriate for static environments and discrete spaces. Even if they require high computational time, exact approaches ensure exact solutions.

Heuristic algorithms appeared to overcome the weaknesses of exact approaches; they are solicited for their reasonable time response and for their constant implementation that could be adapted for small, medium, and large instances. However, heuristics are not suitable for dynamic environments as well and stuck in local optimal. Moreover, they return generally bad solutions for WMNs design in case of multi-objective resolutions.

To deal with the heuristic limits faced in multi-objective cases, meta-heuristics are the alternative which are considered as the trade-off in this kind of problem. In fact, they can provide good solutions in both mono and multi-objective situations. They can be adapted to dynamic environments and continuous spaces while reducing the execution time. Nevertheless, they require high resources, suffer from parameter convergence, and they do not guarantee optimal solutions.

Furthermore, choosing between one of these three techniques is not the only way to solve the WMNs nodes placement problem. In fact, mixing several techniques together can ensure that the shortcomings of one are filled by the advantages of the other and vice versa. In this review, we listed a plenty of approaches opting for this solution. Some of them hybridized two different meta-heuristics or two different heuristics, and some others hybridized heuristics with meta-heuristics or heuristics with exact techniques. As a result, more objectives are met while taking into account a higher number of constraints.

7 Conclusion

The WMNs nodes placement represents a very important issue in the field of wireless communication networks and has attracted great interest from researchers and scientists. This paper presents a comprehensive survey of more than 100 articles related to WMNs nodes placement techniques published from 2004 to the first half of 2021. These techniques are classified into four categories namely exact, heuristic, meta-heuristic, and hybrid techniques. For each category, we present a comparative analysis according to the cost, coverage, connectivity, load balancing, throughput, delay as objectives under a set of constraints including full coverage, connectivity, capacity, delay, and interference. We provide critical analysis to show the most used technique in each category. The results of this study allowed us to discover the lacks in the field of WMNs nodes placement and to define points of future research that we define below:

– Solving WMNs nodes placement for dynamic environment in continuous space;

– Considering the placement of mesh routers and gateways at the same time;
– Solving the WMNs nodes placement problem using multi-objective approaches considering all the parameters that influence the performance of WMNs;
– Parallel implementation of meta-heuristics for tackling the nodes placement problem;
– Using recent meta-heuristics for solving the WMNs nodes placement problem;
– Combining meta-heuristics with more exact approaches and/or heuristics algorithms for optimizing the WMNs nodes planning;
– Combining meta-heuristics with machine learning algorithms for optimizing WMNs nodes placement results.

Finally, we can conclude that the network performance is achieved at a higher level if an efficient method for WMNs planning is assessed by addressing all the fundamental objectives along with QoS requirements.

Declarations

Conflicts of interest The authors declare that there is no conflict of interest with any person(s) or Organization(s).

References

1. Akyildiz Ian F, Wang X, Wang W (2005) Wireless mesh networks: a survey. Comput Netw 47(4):445–487
2. Barolli A, Bylykbashi K, Qafzezi E, Sakamoto S, Barolli L, Takizawa M (2021) A comparison study of chi-square and uniform distributions of mesh clients for different router replacement methods using wmn-psodga hybrid intelligent simulation system. Journal of High Speed Networks, P. 1–16
3. Sakamoto S, Liu Yi, Barolli L, Okamoto S (2021) Performance evaluation of cm and riwm router replacement methods for wmns by wmn-psohc hybrid intelligent simulation system considering chi-square distribution of mesh clients. In: International Conference on Innovative Mobile and Internet Services in Ubiquitous Computing, Springer, p. 179–187
4. Karthika KC (2016) Wireless mesh network: A survey. 2016 International Conference on Wireless Communications. Signal Processing and Networking (WiSPNET), IEEE p, pp 1966–1970
5. Rao AN, Babu PR, Reddy AR (2021) Analysis of wireless mesh networks in machine learning approaches. In: Proceedings of International Conference on Advances in Computer Engineering and Communication Systems, Springer, p. 321–331
6. Lili Q, Paramvir B, Ananth R, Zhou L (2006) Troubleshooting wireless mesh networks. ACM SIGCOMM Comp Commun Rev 36(5):17–28
7. Edoardo A, Antonio C, Matteo C, Ilario F, Federico M (2008) Optimization models and methods for planning wireless mesh networks. Comput Netw 52(11):2159–2171
8. Youcef A, Abdelmadjid B (2021) Bio-inspired vanet routing optimization: an overview. Artif Intell Rev 54(2):1005–1062
9. Mohadese B, Akbari JMR, Erfan H (2020) Bi-objective optimization approaches to many-to-many hub location routing with distance balancing and hard time window. Neural Comput Appl 32(17):13267–13288
10. Soleimanian GF, Human S, Hojjat G (2020) A comprehensive survey on symbiotic organisms search algorithms. Artif Intell Rev 53(3):2265–2312
11. Djohara B, Abdelhakim H, Michel G (2011) Wireless mesh networks design-a survey. IEEE Commun surv tutor 14(2):299–310
12. Sanni Mistura L, Hashim Aisha-Hassan A, Anwar F, Naji Ahmed W, Ahmed Gharib SM (2012) Gateway placement optimisation problem for mobile multicast design in wireless mesh networks. In: 2012 International Conference on Computer and Communication Engineering (ICCCE), IEEE, p. 446–451
13. Ahmed AM, Aisha Hassan AH (2014) Metaheuristic approaches for gateway placement optimization in wireless mesh networks: a survey. Int J Comp Sci Net Sec (IJCSNS) 14(12):1
14. Govil S, Rawat P (2016) Comparative analysis of gateway placement approaches for wireless mesh network. Int J Comp Techn. 3(2)
15. Smangaliso M, Abu-Mahfouz Adnan M, Pragasen M, Adigun Matthew O (2019) A review of gateway placement algorithms on internet of things. 2019 International Conference on Advances in Big Data. Computing and Data Communication Systems (icABCD), IEEE, pp 1–6
16. Jahanshahi M, Bozorgchenani A (2019) Gateway placement and selection solutions in wmns: a survey. arXiv preprint arXiv:1906.06774
17. Seetha S, Francis SA, Kanaga EG (2021) Optimal placement techniques of mesh router nodes in wireless mesh networks. In: 2nd EAI International Conference on Big Data Innovation for Sustainable Cognitive Computing
18. El Saoud MA, Al Zubaidy H, Mahmoud S (2008) Connectivity model for wireless mesh networks. In: 2008 IEEE International Conference on Communications, IEEE, p. 2889–2894
19. Bassam A, Raouf B, Youssef I, Gary K (2006) Gateway placement optimization in wireless mesh networks with qos constraints. IEEE J Sel Areas Commun 24(11):2127–2136
20. Beljadid A, Hafid AS, Gendreau M (2007) Optimal design of broadband wireless mesh networks. In: IEEE GLOBECOM 2007-IEEE Global Telecommunications Conference, IEEE. p. 4840–4845
21. da Silva M, Senne Edson LF, Vijaykumar NL (2012) Wireless mesh networks planning based on parameters of quality of service. In: ICORES, p. 441–446
22. Lee G, Murray Alan T (2010) Maximal covering with network survivability requirements in wireless mesh networks. Comput Environ Urban Syst 34(1):49–57
23. Luke S, Daoqin T (2011) Maximizing wireless mesh network coverage. Int Reg Sci Rev 34(4):419–437
24. Valerio T, Brunilde S, Antonio C (2010) The joint gateway placement and spatial reuse problem in wireless mesh networks. Comput Netw 54(2):231–240
25. Martignon F, Paris S, Capone A (2011) Optimal node placement in distributed wireless security architectures. In *International Conference on Research in Networking*, Springer, p. 319–330
26. Aaron S, Ben L (2009) Optimal placement and channel assignment of relay stations in heterogeneous wireless mesh networks by modified benders decomposition. Ad Hoc Netw 7(1):118–135
27. Fan Li Yu, Li WX-Y, Ashraf N, Yanwei W (2008) Gateway placement for throughput optimization in wireless mesh networks. Mob Netw Appl 13(1–2):198–211
28. Wei L, Hiroki N, Nei K, Yoshitaka S, Tomoaki K (2013) A novel gateway selection technique for throughput optimization

in configurable wireless mesh networks. Int J Wireless Inf Netw 20(3):195–203
29. Chandra R, Qiu L, Jai K, Mahdian M (2004) Optimizing the placement of internet taps in wireless neighborhood networks. In *Proceedings of the 12th IEEE International Conference on Network Protocols, 2004. ICNP 2004.*, IEEE, p. 271–282
30. Rajesh P, Hongyi W (2006) Gateway deployment optimization in cellular wi-fi mesh networks. J Netw 1(3):31–39
31. He Bing, Xie Bin, Agrawal Dharma P (2008) Internet gateway deployment optimization in a multi-channel multi-radio wireless mesh network. In: 2008 IEEE Wireless Communications and Networking Conference, IEEE, p. 2259–2264
32. Drabu Y, Peyravi H (2008) Gateway placement with qos constraints in wireless mesh networks. In: Seventh International Conference on Networking (Icn 2008)
33. He B, Xie B, Agrawal DP (2008) Optimizing deployment of internet gateway in wireless mesh networks. Comp Commun 31(7):1259–1275
34. Zeng F, Chen Z (2008) Load balancing placement of gateways in wireless mesh networks with qos constraints. In: 2008 The 9th International Conference for Young Computer Scientists
35. Peng J, Zhou Q (2009) Gateways placement optimization in wireless mesh networks. In: 2009 International Conference on Networking and Digital Society. IEEE. 1 221–226
36. Feng Z, Zhi-Gang C (2009) Cost-sensitive and load-balancing gateway placement in wireless mesh networks with qos constraints. J Comp Sci Technol 24(4):775–785
37. Zhigang C, Feng Z (2010) Minimum-cost gateway placement in wireless mesh networks with qos constraints. Int J Commun Netw Distrib Syst 4(4):389–406
38. Luo Junzhou W, Wenjia YM (2010) Interference-aware gateway placement for wireless mesh networks with fault tolerance assurance. 2010 IEEE International Conference on Systems. Man and Cybernetics, IEEE, pp 2373–2380
39. Shigeto T, Nobuo F, Teruo H (2010) A wds clustering algorithm for wireless mesh networks. IEICE Trans Inf Syst 93(4):800–810
40. Ping Z, Xudong Wang BS, Manoj, and Ramesh R, (2010) On optimizing gateway placement for throughput in wireless mesh networks. EURASIP J Wirel Commun Netw 2010:1–12
41. Kemal Mohammed S, Alexandru C, Olsen Rasmus L (2016) Gateway placement for wirless mesh networks in smart grid network planning. In: 2016 10th International Conference on Compatibility. Power Electronics and Power Engineering (CPE-POWERENG), IEEE, pp 144–147
42. Tein-Yaw C, Hao-Chieh C (2011) Lee Hsiao-Chih George (2011) A novel cross-layer mesh router placement scheme for wireless mesh networks. EURASIP J Wirel Commun Netw 1:134
43. Mojtaba S, Mohamed O, Mohd AB, Shamala S (2013) Zero-degree algorithm for internet gateway placement in backbone wireless mesh networks. J Netw Comput Appl 36(6):1705–1723
44. Bang W, Xiaoli H, Yang Laurence T, Yijun M (2015) Hybrid placement of internet gateways and rechargeable routers with guaranteed qos for green wireless mesh networks. Mob Netw Appl 20(5):543–555
45. Arash B, Mohsen J (2017) A novel reliability and traffic aware gateway selection scheme in wireless mesh networks. Wireless Pers Commun 96(4):6111–6128
46. Fetng HW, Hung CC, Tseng Ying-Tsu (2018) Gateway deployment in a wireless mesh network for load balancing and transmission reduction. In: 2018 IEEE 7th Global Conference on Consumer Electronics (GCCE), IEEE, p. 109–113
47. Qian C, Juan ZX, Lih LW, Sam KY, Sumei S (2019) High reliability, low latency and cost effective network planning for industrial wireless mesh networks. IEEE/ACM Trans Netw 27(6):2354–2362
48. Lin P, Ngo H, Qiao C, Wang X, Wang T, Qian D (2006) Minimum cost wireless broadband overlay network planning. In: 2006 International Symposium on a World of Wireless, Mobile and Multimedia Networks (WoWMoM 06), IEEE, p. 7–pp
49. Tang M et al (2009) Gateways placement in backbone wireless mesh networks. Int J Commun, Netw Syst Sci 2(01):44
50. Komba Giresse M, Kogeda Okuthe P, Zuva T (2014) A new gateway location protocol for mesh networks. In Proc World Congr Eng Comp Sci 2:713–718
51. Yanjun Y, Aimin L, Hongwei X, Jianguo W, Xin Yu, Wen Z (2021) Deployment optimization of wireless mesh networks in wind turbine condition monitoring system. Wireless Netw 27(2):1459–1476
52. Wu W, Luo J, Yang M (2009) Gateway placement optimization for load balancing in wireless mesh networks. In: 2009 13th International Conference on Computer Supported Cooperative Work in Design, IEEE, p. 408–413
53. Nico S, Kemal A (2017) Investigation of smart meter data reporting strategies for optimized performance in smart grid ami networks. IEEE Internet Things J 4(4):894–904
54. Nahle S, Malouch N (2008) Placement algorithms for wimax mesh network. In: International Conference on Next Generation Wired/Wireless Networking, Springer, p. 37–48
55. Robinson J, Singh M, Swaminathan R, Knightly E (2010) Deploying mesh nodes under non-uniform propagation. In: 2010 Proceedings IEEE INFOCOM, IEEE, p. 1–9
56. Xu X, Tang S, Mao X, Li XY (2010) Distributed gateway placement for cost minimization in wireless mesh networks. In: 2010 IEEE 30th International Conference on Distributed Computing Systems, IEEE, p. 507–515
57. Dawood S, Rukhsana R, Maryam T, Jianping P (2017) Fine-grained access provisioning via joint gateway selection and flow routing on sdn-aware wi-fi mesh networks. 2017 IEEE 13th International Conference on Wireless and Mobile Computing. Networking and Communications (WiMob), IEEE, pp 1–10
58. Mariusz W, Cyrille B, Patrick D (2021) Router and gateway node placement in wireless mesh networks for emergency rescue scenarios. Autonom Intell Syst 1(1):1–30
59. Bagona PL, Fendji Jean Louis KE (2021) Fault-tolerant placement of additional mesh nodes in rural wireless mesh networks: A minimum steiner tree based centre of mass with bounded edge length
60. Boussaïd I, Lepagnot J, Siarry P (2013) A survey on optimization metaheuristics. Inf Sci 237:82–117
61. Jaddi NS, Abdullah S (2020) Global search in single-solution-based metaheuristics. *Data Technologies and Applications*
62. Elshaer R, Awad H (2020) A taxonomic review of metaheuristic algorithms for solving the vehicle routing problem and its variants. Comp Ind Eng 140:106242
63. Gabis AB, Meraihi Y, Mirjalili S, Ramdane-Cherif A (2021) A comprehensive survey of sine cosine algorithm: variants and applications. Artificial Intelligence Review, 1–72
64. Franklin AA, Murthy C Siva R (2007) Node placement algorithm for deployment of two-tier wireless mesh networks. In: IEEE GLOBECOM 2007-IEEE Global Telecommunications Conference, IEEE, p. 4823–4827
65. Wang J, Cai K, Agrawal DR (2009) A multi-rate based router placement scheme for wireless mesh networks. In: 2009 IEEE 6th International Conference on Mobile Adhoc and Sensor Systems, IEEE, p. 100–109
66. Xhafa F, Sanchez C, Barolli L (2009) Ad hoc and neighborhood search methods for placement of mesh routers in wireless mesh networks. In: 2009 29th IEEE International Conference on Distributed Computing Systems Workshops, IEEE, p. 400–405

67. Fatos X, Admir B, Christian S, Leonard B (2011) A simulated annealing algorithm for router nodes placement problem in wireless mesh networks. Simul Model Pract Theory 19(10):2276–2284
68. Huan X, Wang B, Mo Y (2014) Placement of rechargeable routers based on proportional fairness in green mesh networks. In: 2014 23rd International Conference on Computer Communication and Networks (ICCCN), IEEE, p. 1–8
69. Lin C-C, Shu L, Deng D-J (2014) Router node placement with service priority in wireless mesh networks using simulated annealing with momentum terms. IEEE Syst J 10(4):1402–1411
70. Nawaf L, Mumford C, Allen S (2015) Optimizing the placement of itaps in wireless mesh networks by implementing hc and sa algorithms. In: International Conference on Ad Hoc Networks, Springer, p. 29–41
71. Nawaf L, Allen Stuart M, Rana O (2017) Internet transit access point placement and bandwidth allocation in wireless mesh networks. In: 2017 IEEE 7th Annual Computing and Communication Workshop and Conference (CCWC), IEEE, p. 1–8
72. Kedieng Fendji Jean LE, Thron C, Nlong JM (2015) A metropolis approach for mesh router nodes placement in rural wireless mesh networks. arXiv, pages arXiv–1504
73. Lamri S, Louiza B-M, Djamil A (2018) A simulated annealing algorithm for the placement of dynamic mesh routers in a wireless mesh network with mobile clients. Internet Technol Lett 1(5):e35
74. Fendji Jean Louis EK, Forster A (2021) A multi-objective approach for wireless heterogeneous router placement in rural wireless mesh networks. In: Towards new e-Infrastructure and e-Services for Developing Countries: 12th EAI International Conference, AFRICOMM 2020, Ebene City, Mauritius, December 2-4, 2020, Proceedings 12, Springer International Publishing, p. 43–55
75. Fatos X, Christian S, Leonard B (2012) Local search methods for efficient router nodes placement in wireless mesh networks. J Intell Manuf 23(4):1293–1303
76. Admir B, Fatos X, Christian S, Makoto T (2012) A study on the performance of local search versus population-based methods for mesh router nodes placement problem. J Intell Manuf 23(6):2057–2067
77. Katayama K (2020) A coverage construction method based hill climbing approach for mesh router placement optimization. In: Advances on Broad-Band Wireless Computing, Communication and Applications: Proceedings of the 15th International Conference on Broad-Band and Wireless Computing, Communication and Applications (BWCCA-2020), Springer Nature, Vol:159, 355
78. Hirata A, Oda T, Saito N, Nagai Y, Hirota M, Katayama K, Barolli L (2021) A coverage construction and hill climbing approach for mesh router placement optimization: simulation results for different number of mesh routers and instances considering normal distribution of mesh clients. In: Conference on Complex, Intelligent, and Software Intensive Systems, Springer, p. 161–171
79. Fatos X, Christian S, Admir B, Makoto T (2015) Solving mesh router nodes placement problem in wireless mesh networks by tabu search algorithm. J Comput Syst Sci 81(8):1417–1428
80. Wang Q, Wang H, He M, Chen H, Zhang X (2019) Optimization deployment of wl-mesh network with base-station in nature environment. In: 2019 IEEE 9th Annual International Conference on CYBER Technology in Automation, Control, and Intelligent Systems (CYBER), IEEE, p. 107–112
81. Ivanov S, Nett E, Schumann R (2010) Fault-tolerant base station planning of wireless mesh networks in dynamic industrial environments. In: 2010 IEEE 15th Conference on Emerging Technologies & Factory Automation (ETFA 2010), IEEE, p. 1–8
82. Hsu Chun-Yen W, Jean-Lien C, Shun-Te W, Chi-Yao H (2008) Survivable and delay-guaranteed backbone wireless mesh network design. J Parall Distrib Comp 68(3):306–320
83. De Marco G (2009) Mogamesh: a multi-objective algorithm for node placement in wireless mesh networks based on genetic algorithms. In: 2009 6th International Symposium on Wireless Communication Systems, IEEE, p. 388–392
84. Fatos X, Christian S, Leonard B, Evjola S (2010) Evaluation of genetic algorithms for mesh router nodes placement in wireless mesh networks. J Ambient Intell Humaniz Comp 1(4):271–282
85. Mahani A, Tahmasby F, Nezamabadi-pour H (2011) Two tiers wireless mesh networks: optimal configuration. In: 2011 1st International eConference on Computer and Knowledge Engineering (ICCKE), IEEE. p. 303–307
86. Mostafa AH, Ashrafinia S, Liu J, Lee DC (2011) Wireless mesh network planning using quantum inspired evolutionary algorithm. In: 2011 IEEE Vehicular Technology Conference (VTC Fall), IEEE, p. 1–5
87. Lee S, Lee Y, Jeong MS, Sahu S (2011) Mesh router placement exploiting obstacles for mitigating interference. In: 2011 Proceedings of 20th International Conference on Computer Communications and Networks (ICCCN), IEEE, p. 1–6
88. Tetsuya O, Admir B, Evjola S, Fatos X, Leonard B, Makoto T (2012) Evaluation of wmn-ga for different mutation operators. Int J Space-Based Sit Comp 2(3):149–157
89. Dac-Nhuong L, Nhu GN (2012) A new evolutionary approach for gateway placement in wireless mesh networks. Int J Comp Networks Wireless Commun (IJCNWC) 2(5):550–555
90. Oda T, Sakamoto S, Spaho E, Ikeda M, Xhafa F, Barolli L (2013) Performance evaluation of wmn-ga for wireless mesh networks considering mobile mesh clients. In: 2013 5th International Conference on Intelligent Networking and Collaborative Systems, IEEE, p. 77–84
91. Girgis Moheb R, Mahmoud Tarek M, Abdullatif Bahgat A, Rabie Ahmed M (2014) Solving wireless mesh network design problem using genetic algorithm and tabu search optimization methods. Int. J. Comput. Netw. Wirel. Commun. 4(2)
92. Girgis Moheb R, Mahmoud Tarek M, Abdullatif Bahgat A, Rabie Ahmed M (2014) Solving the wireless mesh network design problem using genetic algorithm and simulated annealing optimization methods. Int J Comp Appl. 96(11)
93. Ahmed AM, Aisha Hassan AH (2015) A genetic approach for gateway placement in wireless mesh networks. Int J Comp Sci Netw Sec (IJCSNS) 15(7):11
94. Lazrag Z, Hamdi M, Zaied M (2017) Bi-objective ga for cost-effective and delay-aware gateway placement in wireless mesh networks. In: 2017 IEEE/ACS 14th International Conference on Computer Systems and Applications (AICCSA), IEEE, p. 103–108
95. Tang M, Chen CA (2017) Wireless network gateway placement by evolutionary graph clustering. In: International Conference on Neural Information Processing, Springer. p. 894–902
96. Oumarou M, Bello K, Dina T (2017) Mesh node placement in wireless mesh network based on multiobjective evolutionary metaheuristic. Int J Aut Comp 2(3):231–254
97. Shu-Qiang H, Zhen Z, Yang L, Zhu-Song L, Yong-Hui L (2017) Deployment optimization of multi-hop wireless networks based on substitution graph. Inf Sci 400:129–141
98. Nawaf Liqaa F, Allen Stuart M, Rana Omer (2018) Optimizing infrastructure placement in wireless mesh networks using nsga-ii. In: 2018 IEEE 20th International Conference on High Performance Computing and Communications; IEEE 16th International Conference on Smart City; IEEE 4th International

Conference on Data Science and Systems (HPCC/SmartCity/DSS), IEEE, p. 1669–1676
99. Liu Wei X, Chang TZ, Li Dong-Kun L, Guan-Zhong SW (2019) Research on gateway deployment for throughput optimization in wireless mesh networks. 2019 International Conference on Computer. Information and Telecommunication Systems (CITS), IEEE, pp 1–5
100. Liang T, Zhichao W, Jun H, Li B (2019) A general purpose deployment method for wireless mesh network. Int J Internet Protoc Technol 12(1):44–50
101. Benyamina D, Hafid A, Gendreau M (2008) A multi-objective optimization model for planning robust and least interfered wireless mesh networks. In: IEEE GLOBECOM 2008-2008 IEEE Global Telecommunications Conference, IEEE, p. 1–6
102. Le VT, Dinh NH, Nguyen NG (2011) A novel pso-based algorithm for gateway placement in wireless mesh networks. In: 2011 IEEE 3rd International Conference on Communication Software and Networks, IEEE, p. 41–45
103. Djohara B, Abdelhakim H, Michel G (2011) Throughput gateways-congestion trade-off in designing multi-radio wireless networks. Mob Networks Appl 16(1):109–121
104. Tarik M, Bouchaib N, Abdelkrim H, Samir B (2012) Wireless mesh networks topology auto planning. Int J Comp Appl 52(2):27–33
105. Tarik M, Bouchaib N, Abdelkrim H, Samir B (2012) Optimization model for relays placement in mutli-radio multichannel wireless mesh networks. J Electr Syst 2(3):109
106. Chun-Cheng L (2013) Dynamic router node placement in wireless mesh networks: a pso approach with constriction coefficient and its convergence analysis. Inf Sci 232:294–308
107. Mountassir T, Nassereddine B, Haqiq A, Mountassir Jamal (2012) On optimizing nodes deployment in multi-radio multichannel wireless mesh networks. In: 2012 IEEE 13th International Symposium on Computational Intelligence and Informatics (CINTI), IEEE, p. 91–95
108. Dac-Nhuong LH, Gia NN, Huu DN, Dang LN, Trong LV (2013) Optimizing gateway placement in wireless mesh networks based on aco algorithm. Int J Comp Commun Eng 2(2):143
109. Dac-Nhuong L (2013) A comparatives study of gateway placement optimization in wireless mesh network using ga, pso and aco. Int J Inform Netw Sec 2(4):292
110. Lin CC, Li YS, Deng DJ (2014) A bat-inspired algorithm for router node placement with weighted clients in wireless mesh networks. In: 9th International Conference on Communications and Networking in China, IEEE, p. 139–143
111. Sakamoto S, Oda T, Ikeda M, Barolli L (2015) Design and implementation of a simulation system based on particle swarm optimization for node placement problem in wireless mesh networks. In: 2015 International Conference on Intelligent Networking and Collaborative Systems, IEEE, p. 164–168
112. Hamdi M, Mhiri S (2015) Dynamic mesh router placement for connectivity maximization in wireless mesh networks. In: 2015 5th International Conference on Information Communication and Technology and Accessibility (ICTA), IEEE, p. 1–6
113. Chun-Cheng L, Pei-Tsung T, Ting-Yu W, Der-Jiunn D (2016) Social-aware dynamic router node placement in wireless mesh networks. Wireless Netw 22(4):1235–1250
114. Chun-Cheng L, Teng-Huei C, Hui-Hsin C (2016) Adaptive router node placement with gateway positions and qos constraints in dynamic wireless mesh networks. J Netw Comput Appl 74:149–164
115. Yang L, Shuqiang H, Rensheng F, Zhen Z, Yuyu Z (2017) Research on gateway deployment of wmn based on maximum coupling subgraph and pso algorithm. Soft Comput 21(4):923–933
116. Tao W, Jun L, Lianglun C, Hong X (2017) Robust collaborative mesh networking with large-scale distributed wireless heterogeneous terminals in industrial cyber-physical systems. Int J Distrib Sens Netw 13(9):1550147717729640
117. Weiqiang W (2020) Deployment and optimization of wireless network node deployment and optimization in smart cities. Comput Commun 155:117–124
118. Nouri NA, Aliouat Z, Naouri A, Hassak SA (2021) Accelerated pso algorithm applied to clients coverage and routers connectivity in wireless mesh networks. J Amb Intell Human Comp, 1–15
119. Sayad L, Aissani D, Bouallouche-Medjkoune L (2018) Placement optimization of wireless mesh routers using firefly optimization algorithm. In: 2018 International Conference on Smart Communications in Network Technologies (SaCoNeT), IEEE, p. 144–148
120. Zhang H, Wu S , Zhang C, Krishnamoorthy S (2021) Optimal distribution in wireless mesh network with enhanced connectivity and coverage. In: Proceedings of the 9th International Conference on Computer Engineering and Networks, Springer, p. 1117–1128
121. Wang J, Fu W, Agrawal DP (2008) An adaptive router placement scheme for wireless mesh networks. In: 2008 IEEE Globecom Workshops, IEEE, p. 1–5
122. Lamri S, Louiza B-M, Djamil A (2019) An electromagnetism-like mechanism algorithm for the router node placement in wireless mesh networks. Soft Comput 23(12):4407–4419
123. Sayad L, Bouallouche-Medjkoune L, Aissani D (2017) A chemical reaction algorithm to solve the router node placement in wireless mesh networks. Mob Netw Appl ,1–14
124. Djohara B, Abdelhakim H, Nasreddine H, Michel G, Maureira JC (2012) A hybrid nature-inspired optimizer for wireless mesh networks design. Comput Commun 35(10):1231–1246
125. Shinji S, Kosuke O, Tetsuya O, Makoto I, Leonard B (2017) Performance evaluation of wmn-psohc and wmn-pso simulation systems for node placement in wireless mesh networks: a comparison study. International Conference on Emerging Internetworking. Springer, Data and Web Technologies, pp 64–74
126. Admir B, Shinji S, Kosuke O, Leonard B, Elis K, Makoto T (2018) Design and implementation of a hybrid intelligent system based on particle swarm optimization and distributed genetic algorithm. International Conference on Emerging Internetworking. Springer, Data and Web Technologies, pp 79–93
127. Shinji S, Kosuke O, Makoto I, Leonard B (2018) Implementation of intelligent hybrid systems for node placement problem in wmns considering particle swarm optimization, hill climbing and simulated annealing. Mob Netw Appl 23(1):27–33
128. Sakamoto S, Barolli A, Barolli L, Takizawa M (2018) Design and implementation of a hybrid intelligent system based on particle swarm optimization, hill climbing and distributed genetic algorithm for node placement problem in wmns: a comparison study. In: 2018 IEEE 32nd International Conference on Advanced Information Networking and Applications (AINA), IEEE, p. 678–685
129. Kadri S, Admir K, Endrit I, Bujar K (2019) Genetic algorithms and greedy-randomized adaptive search procedure for router placement problem in wireless networks. Jf High Speed Netw 25(3):273–300
130. Shinji S, Kosuke O, Admir B, Makoto I, Leonard B, Makoto T (2019) Implementation of an intelligent hybrid simulation systems for wmns based on particle swarm optimization and simulated annealing: performance evaluation for different replacement methods. Soft Comput 23(9):3029–3035
131. Seiji O, Admir B, Phudit A, Shinji S, Keita M, Leonard B (2020) A hybrid intelligent simulation system for constructing iot

networks: Performance evaluation of wmn-psodga simulation system considering different router replacement methods. Internet of Things 11:100215

132. Shinji S, Leonard B, Shusuke O (2020) Performance comparison of cm and rdvm router replacement methods for wmns by wmn-psohc hybrid simulation system considering normal distribution of mesh clients. International Conference on P2P. Parallel, Grid, Cloud and Internet Computing, Springer, pp 9–17
133. Admir B, Shinji S, Phudit A, Seiji O, Leonard B, Makoto T (2020) A comparison study of constriction and random inertia weight router replacement methods for wmns by wmn-psosa-dga hybrid simulation system considering chi-square distribution of mesh clients. International Conference on Broadband and Wireless Computing. Springer, Communication and Applications, pp 11–21
134. Barolli A, Sakamoto S, Barolli L, Takizawa M (2021) Performance evaluation of wmns by wmn-psosa-dga hybrid simulation system considering stadium distribution of mesh clients and different number of mesh routers. In: Conference on Complex, Intelligent, and Software Intensive Systems, Springer, p. 100–109
135. Barolli L, Takizawa M (2021) A hybrid intelligent simulation system for node placement in wmns considering chi-square distribution of mesh clients and different router replacement methods. In: Advances in Internet, Data and Web Technologies: The 9th International Conference on Emerging Internet, Data and Web Technologies (EIDWT-2021), Springer Nature, vol:65, 10
136. Tamer F, Nobuo F, Toru N (2009) An access point allocation algorithm for indoor environments in wireless mesh networks. IEICE Trans Commun 92(3):784–793
137. Djohara B, Abdelhamid H, Michel G, Maureira JC et al (2011) On the design of reliable wireless mesh network infrastructure with qos constraints. Comput Netw 55(8):1631–1647
138. Djohara B, Abdelhakim H, Michel G (2012) Design of scalable and efficient multi-radio wireless networks. Wireless Netw 18(1):75–94
139. Nasser AM, Thool RC (2014) Multi-objective particle swarm optimization for multicast load balancing in wireless mesh networks. Int J Comp Sci Inform Technol 5(2):1958–1963
140. Wong W, Dzinamarira S, Gary CSH (2014) Optimizing router placement for wireless mesh deployment. In: 2014 IEEE International Conference on Communications (ICC), IEEE, p. 2797–2802
141. Mital R, Chaudhry Aizaz U, Hafez Roshdy HM, Chinneck John W (2021) A fast heuristic for gateway location in wireless backhaul of 5g ultra-dense networks. IEEE Acc 9:43653–43674
142. Merlin SG, Nachiappan A (2017) Performance evaluation of fuzzy de based node placement in wmn. Jf Eng Res. 5(4)
143. Coelho Pedro HG, do Amaral Jose FM, Guimaraes KP, Bentes Matheus C (2019) Layout of routers in mesh networks with evolutionary techniques. In: ICEIS (1):438–445
144. Wang J, Xie B, Cai K, Agrawal DP (2007) Efficient mesh router placement in wireless mesh networks. In: 2007 IEEE International Conference on Mobile Adhoc and Sensor Systems, IEEE, p. 1–9
145. Wu W, Luo J, Yang M (2010) Cost-effective placement of mesh nodes in wireless mesh networks. In: 5th International Conference on Pervasive Computing and Applications, IEEE, p. 261–266
146. Souza FR, Albuquerquece lio VN (2010) Linear wireless mesh network planning. In: Proc. of I2TS
147. Junzhou L, Wenjia W, Ming Y (2011) Optimization of gateway deployment with load balancing and interference minimization in wireless mesh networks. J. UCS 17(14):2064–2083
148. Chen CC, Chekuri C (2007) Urban wireless mesh network planning: The case of directional antennas. Technical report
149. Chen CC, Chekuri C, Klabjan D (2009) Topology formation for wireless mesh network planning. In: IEEE INFOCOM 2009, IEEE, p. 2671–2675
150. Fu W, Wang X, Agrawal DP (2009) Characterizing deployment and distribution of self-powered mesh routers in wireless mesh networks. In: 2009 IEEE 28th International Performance Computing and Communications Conference, IEEE, p. 185–192