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OPTIMIZATION OF THE NUMBER AND PLACEMENT OF ROUTERS IN WIRELESS MESH NETWORKS

Mohammed Sadeq Ali ALI

Master`s Thesis

Supervisor

Asst. Prof. Dr. Mesut ÇEVİK

Istanbul, 2022

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The thesis titled OPTIMIZATION OF THE NUMBER AND PLACEMENT OF ROUTERS IN WIRELESS MESH NETWORKS prepared by MOHAMMED SADEQ ALİ ALI and submitted on 13 /12 /2022 has been **accepted unanimously** for the degree of Master of Science in Electrical and Computer Engineering.

____

Asst. Prof. Dr. Mesut ÇEVİK

Supervisor

Thesis Defense Jury Members:

Asst. Prof. Dr. Mesut ÇEVİK	Department of Electrical and Electronics Engineering, Altınbaş University	____________________
Asst. Prof. Dr.Timur İNAN	Department of Software Engineering, Altınbaş University	____________________
Assist. Prof. Dr. Merve TEMİZER ERSOY	Department of Software Engineering, Nişantaşı University	____________________

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Mohammed Sadeq Ali ALI

Signature

DEDICATION

I want to express my deepest appreciation and gratitude to my advisor Dr. Öğr. Üyesi Mesut ÇEVİK has been very supportive and generous at all times to complete my master's thesis. It was a pleasure to be his student.

I dedicate my thesis to those who brought me to this life and gave me all they could give to be here, to succeed, and to be a good person, my beloved father and mother.

My lovely brothers and sister, you have always respected what I wanted to do and have given me full support and encouragement throughout my life. I would like to express my great appreciation for your great love.

ABSTRACT

OPTIMIZATION OF THE NUMBER AND PLACEMENT OF ROUTERS IN WIRELESS MESH NETWORKS

ALI, Mohammed Sadeq Ali

M.Sc., Electrical and Computer Engineering, Altınbaş University,

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Wireless mesh networks are a new type of wireless network that has been growing in popularity. These networks consist of routers and clients. the routers are called mesh routers and the clients are called mesh clients. Wireless mesh networks have a number of advantages over traditional wireless networks, such as more reliable coverage and faster speeds. One of the disadvantages to these networks is that they require more router placement than traditional wireless networks. This is because each router needs to be within range of all other routers in the network. There are many different types of algorithms that can be used to determine the best placement for these routers, with some algorithms being better than others depending on the environment or situation. One algorithm is called a Genetic Algorithm which uses a process called genetic programming to find an optimal solution for router placement. (GA) genetic algorithm is used to find the best placement of the router so that it can provide the most coverage possible for a specific area. It uses a probabilistic approach and avoids placing too many nodes in one spot, which can lead to connectivity issues. The suggested method was implemented utilizing the C++ programming environment and the NS2 software suite. Using a benchmark of produced instances, the experimental outcomes have been analyzed. Variable sets of produced instances ranging in size from small to big have been explored. Consequently, several properties of WMNs, including the topological placement of mesh clients, have been recorded. In terms of network connection, coverage, and a number of routers, simulation results also indicate that superior performance is attainable with the suggested strategy.

Keywords: WMN, Wireless Mesh Network, GA Genetic Algorithm, Router Placement, Connectivity, Coverage

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ABBREVIATIONS

AP	:	Access point
BSS	:	Basic service sets
C&P	:	Cutting and Packing
CCP	:	Circle coverage problem
COV	:	Coverage
CPP	:	Circle packing problem
EC	:	Environment constraint
GA	:	Genetic algorithm
IGW	:	Internet gateway
NRP	:	Novel router placement
PP	:	Packing problem
SA	:	Simulated Annealing method
TC	:	Traffic constraint
WMN	:	Wireless mesh network

LIST OF SYMBOLS

P_r : Probability of reproducing

P_c : Probability of Crossover

P_m : Probability of mutation

$f1$: Connection Degree

$f2$: Coverage Percentage

R : Network Disk Radius

r : Transmission Radius of Each of The Routers

TL : Tree level

v_i : Aggregated Traffic

1. INTRODUCTION

In this chapter, first, an introduction to wireless mesh networks, their applications and characteristics will be presented, then the topic selected in this dissertation and its importance will be reviewed. At the end, the structure of the dissertation is determined.

1.1 WIRELESS MESH NETWORK (WMN)

The initial implementations of wireless networks based on the IEEE 802.11 standard consist of several Basic Service Sets (BSS). Within each BSS there is a station called the Access Point (AP), which is used to access the wired structure. BSSs are connected via Ethernet LANs (wired structure) or access the Internet. As shown in Figure 1.1, there are two base stations, each with an access point [1].

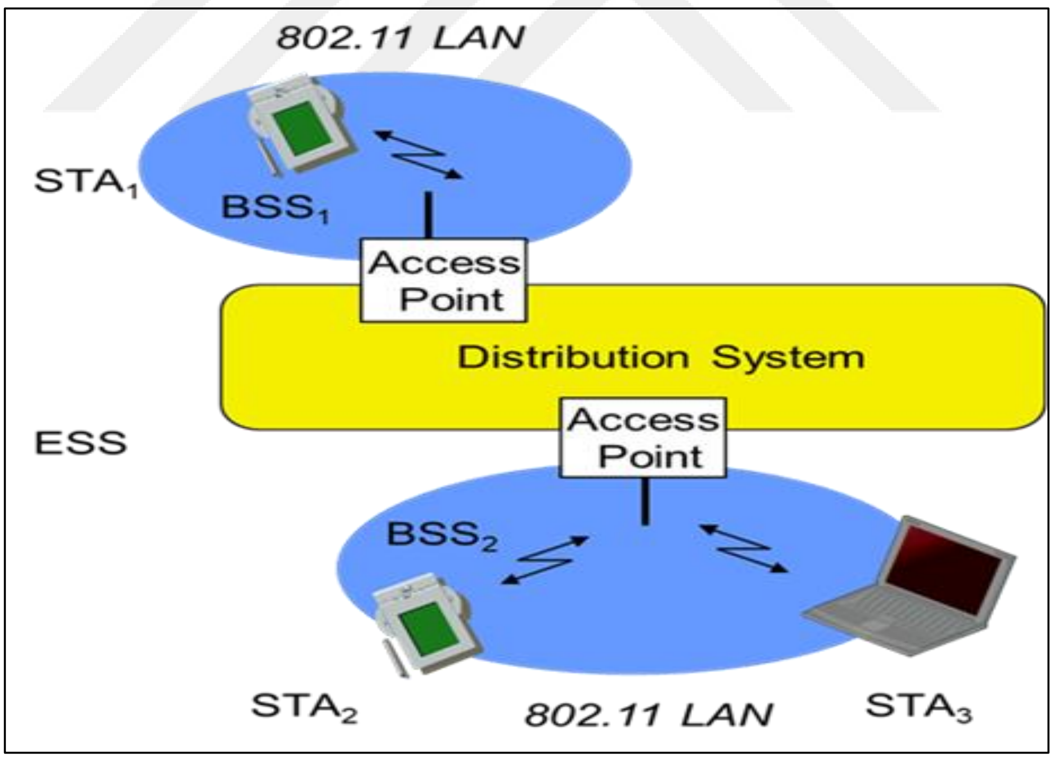

Figure 1.1: View of the wireless LAN [1].

The access points are connected to a wired network, which connects the two BSSs. Such networks are fixed-architecture single-hop networks with low flexibility and high implementation costs. Ad-hoc Networks were created to provide node mobility and network multi-hop, which is unstructured. In this case, the stations are connected without any central coordinator such as an access point or a distribution system (wired structure) and the nodes are completely autonomous (Figure 1.2) [2].

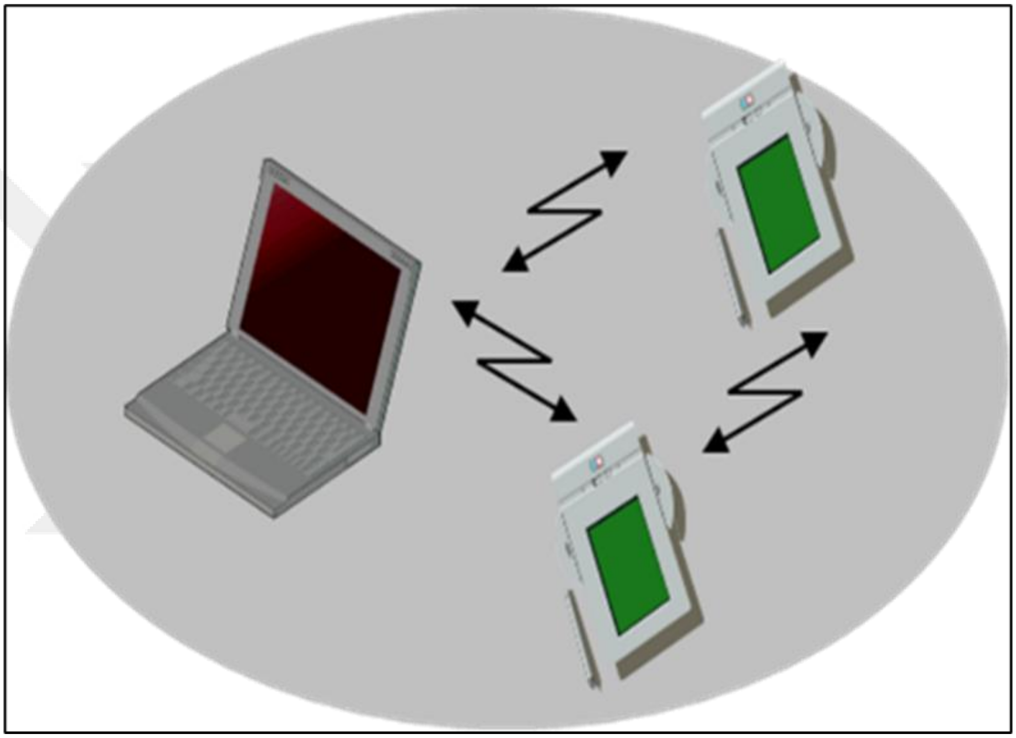

Figure 1.2: Networks of Ad-Hoc [2].

Ad-hoc Networks are not suitable for many applications because just as mobility and multi-hop are required, so is Internet access and integration with other networks. Thus, structured and unstructured modes have been combined to create a new type of multi-hop network called wireless mesh. A WMNs is a network of several nodes that are connected wirelessly, and as its name implies, there is a direct or indirect communication path between all nodes. Each node serves as both a host and a router, transmitting information to other nodes that may or may not be within the Communication Range of the target node [3]. Figure 1.3 shows an overview of the mesh network.

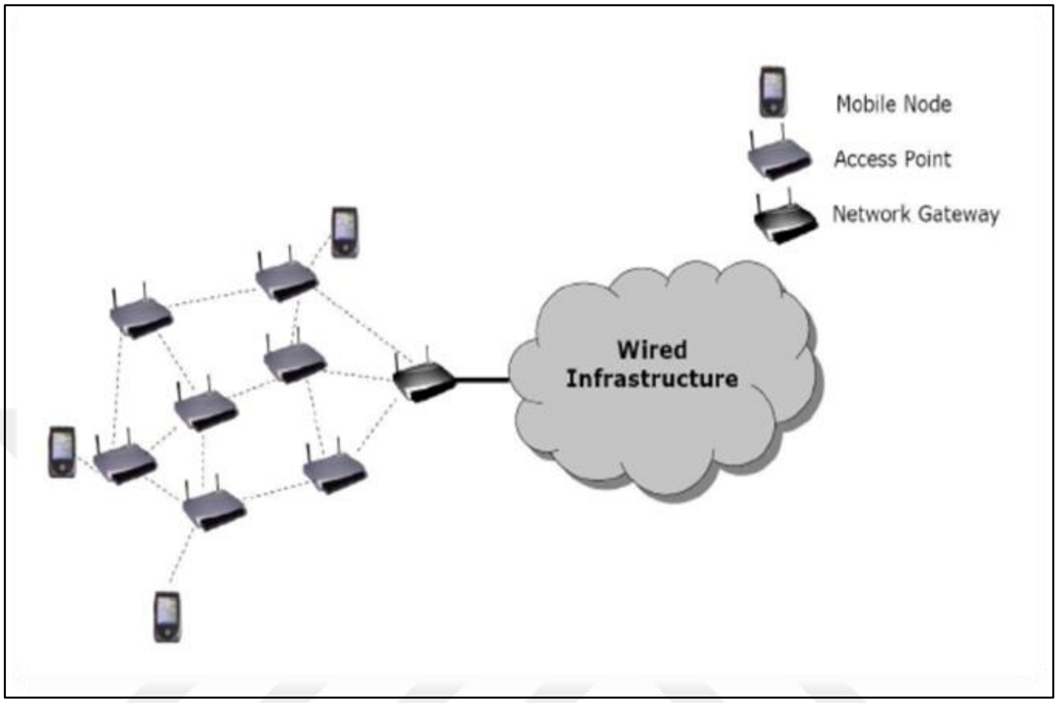

Figure 1.3: Mesh network [3].

In a WMNs, the nodes automatically establish and sustain contact with one another. This kind of network is self-organized and self-configurable. This improvement has brought forth a slew of benefits, including reduced costs, simplified network upkeep, increased network resilience, and dependable service in WMNs. Devices that function as nodes (pc, notebook, PDA, etc.) are linked to the mesh network using wireless network cards [1]. Users without wireless cards may still join the mesh network by connecting their computers to Ethernet-based mesh routers. As a result, wireless mesh networks allow people to be productive in any setting, at any time. In addition, the wireless mesh network may be combined with other wireless networks, including sensor networks, Wi-Fi networks, WI-MAX networks, Wi-Media networks, and more, thanks to the Gateway features included in mesh routers. Therefore, users on a mesh network that is also integrated may take use of services provided by other networks. There are many uses for wireless mesh networks beyond just home networking [4].

1.2 MESH NETWORK ARCHITECTURE

There are two distinct kinds of nodes in a wireless mesh network:

a. Router.

b. User.

In order to set up and provide mesh networking, wireless mesh routers have extra routing capabilities beyond those of traditional wireless networks. A mesh router's many wireless interfaces, which may use the same or different wireless access protocols, contribute to the overall performance of the mesh network. Because of its multi-step communications, a mesh router may provide the same level of coverage as older routers while using less transmission. However, the hardware basis upon which wireless mesh routers and traditional routers are built is same. Both embedded and general-purpose computer systems may be used as the foundation for mesh routers.

Users in a mesh network also have the resources necessary to act as a router in the network. Even though these nodes do not serve as gates or bridges. Another distinction is that mesh clients often only have a single interface. Users of mesh networks have it made easy for them in terms of hardware and software platforms compared to users of routers. Mesh applications, in contrast to routers, come in a wider range of form factors, such as desktop, laptop, personal digital assistant, etc. [5].

WMNs architecture is classified into three main groups:

Structured backbone network: Mesh routers are a key component of this wireless network architecture. Multiple radio standards, including IEEE 802.11 standard, are supported by this device. Routers in a mesh network are able to form and repair connections among themselves. Mesh routers are able to access the web because they may act as a gateway. It is because to this program that the wireless mesh network may be combined with preexisting wireless systems and serve as a backbone for conventional clients. Traditional clients with Ethernet interfaces may connect to mesh routers via Ethernet lines using the gateway functionality of mesh routers.

Users with similarly equipped radio clients may talk to mesh routers directly (Figure 1.4) [4]. Mesh is often used in these ways. This approach has a number of potential applications, such as neighborhood communication networks. Mesh routers are mounted on homes' rooftops and serve as an access point for those inside the home. There are two main kinds of radios used in routers:

i. For backbone communications.

ii. For user communications.

Mesh backbone communications can be established using a wide range of communication techniques, such as directional antennas [2].

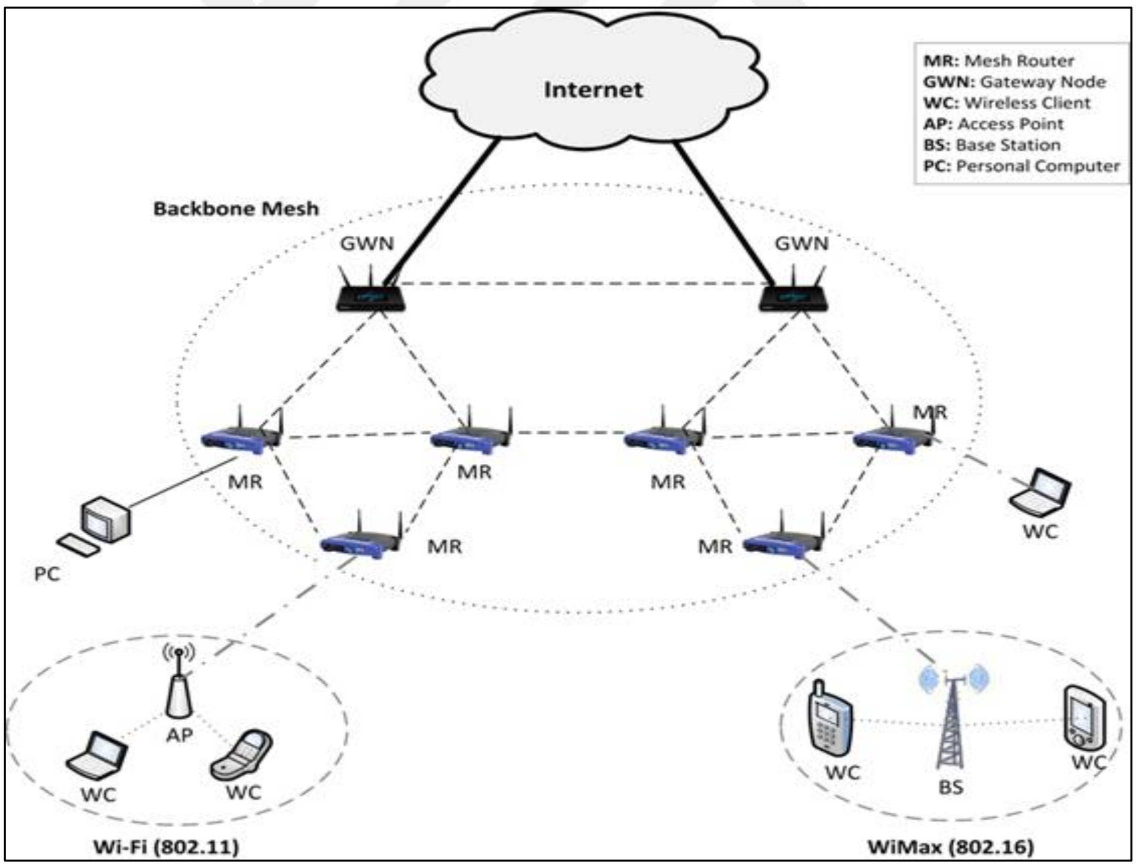

Figure 1.4: Backbone mesh network [4].

Client’s network: This method creates communication between user devices. In this type of architecture, client nodes form a real network to perform routing and configuration capabilities such as creating applications for customers, so the router does not have a mesh for this type of application (Figure 1.5). In this architecture, a packet goes through several steps (several nodes) to reach the destination node. This method usually uses a type of radio for the devices. In addition, the requirements for end-users increase compared to the first model because in some applications, end-users must perform additional functions such as routing and auto-tuning [6].

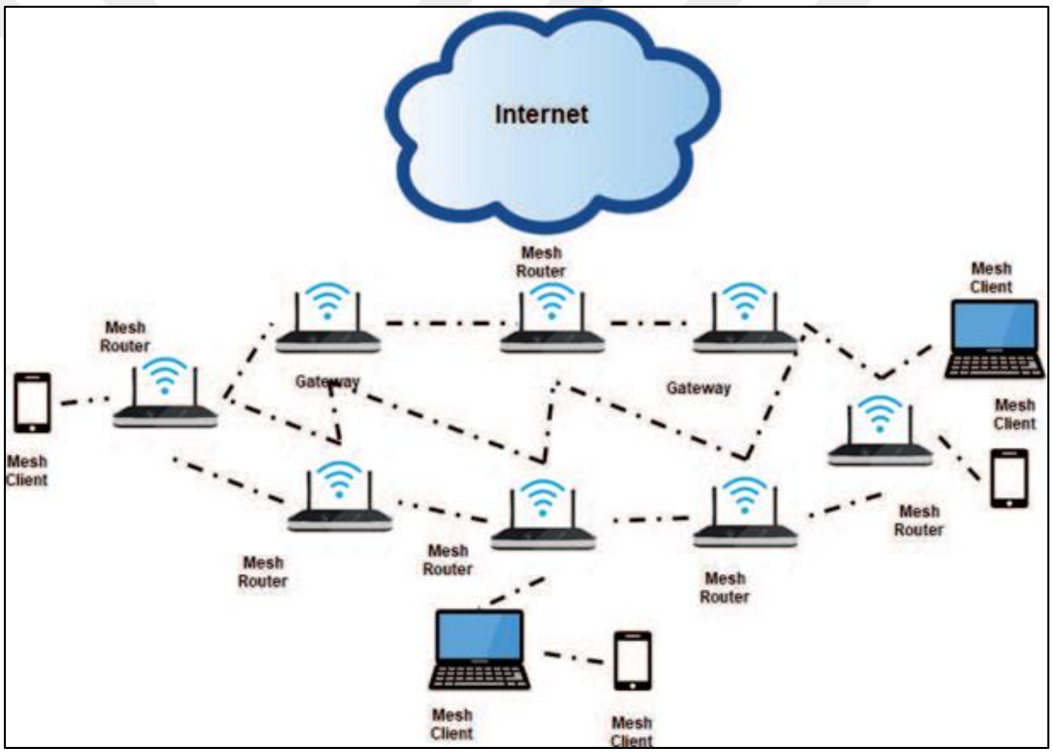

Figure 1.5: Client’s mesh network [4].

Hybrid network: This architecture is a combination of the previous two methods, as shown in Figure 1.6. Mesh users connect to the network through mesh routers. In addition, they communicate directly with other mesh users. While the network provides the infrastructure to connect to other networks such as Wi-Fi, WI-MAX, cellular, etc., it also improves the clients' routing capabilities, connectivity, and coverage in the network. This model is more practical than the previous two models [2].

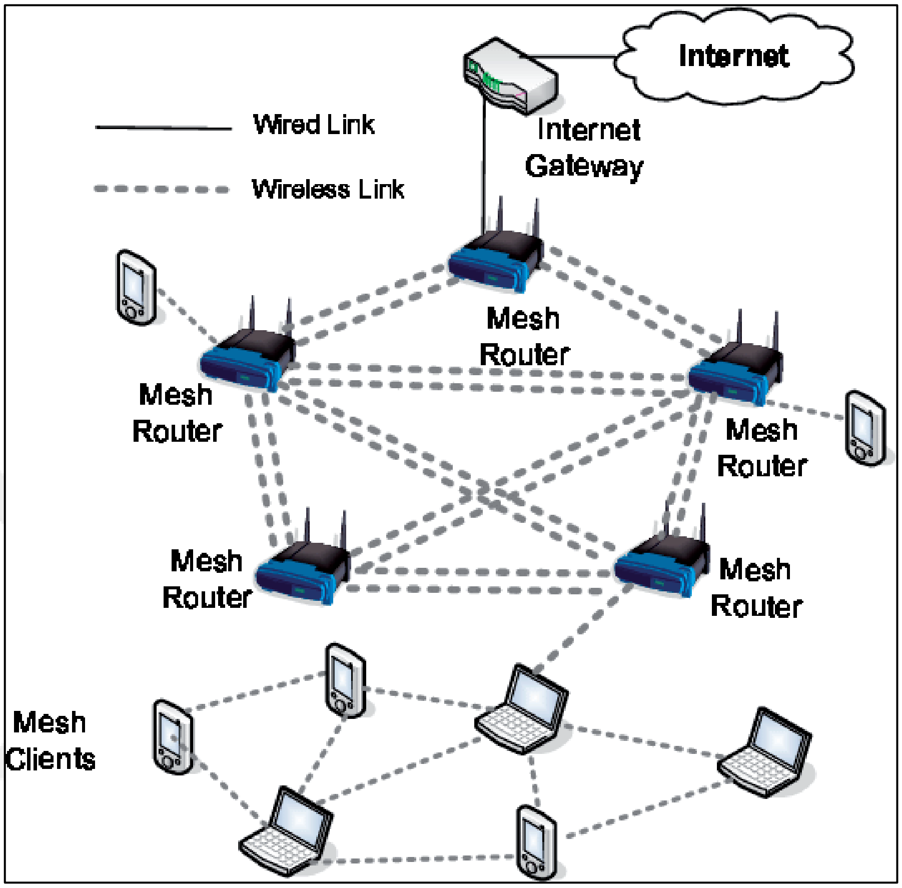

Figure 1.6: Hybrid mesh network [1].

1.3 WIRELESS MESH NETWORK CHARACTERISTICS

The characteristics of wireless mesh networks are as follows:

i. Multi-Hop: One goal of expanding mesh networks is to expand the coverage area of the mesh network without sacrificing or wasting channel capacity. Another goal is to create a connection outside the realm of direct visibility among users, without direct links. Multi-hop mesh networking is essential to meet these needs. In this network, it is possible to achieve a higher throughput without wasting useful radio bandwidth by using less link distance, less interference between nodes and taking advantage of frequency reuse [7].

ii. Support for Ad-Hoc Networking and the Ability to Self-adjust, Self-healing and Self-Governance: Wireless mesh networks enhance network performance due to flexible network architecture, scalability, easy configuration, and fault tolerance. Because of these features, these networks are low cost and the network can grow gradually whenever needed [8].

iii. Mobility depending on the type of node: Mesh routers usually have the least mobility while mesh users can be stationary or mobile [9].

iv. Several ways to access the network: Wireless mesh networks have both multi-step Internet access and peer-to-peer communication between users. In addition, wireless mesh networks can be integrated with other wireless networks and provide services to end users of these networks [9].

v. Energy Constraints Depending on the Type of Node: In most cases, mesh routers are not subject to any particular power consumption constraints, but mesh clients may need power efficiency methods. To function effectively, a mesh-capable sensor, for instance, requires its own set of communication protocols. As power economy is a primary consideration for wireless sensor networks, network layer and transmission layer protocols that are designed for mesh routers may not be suitable for mesh users, such as sensors [10].

vi. Adaptability to existing wireless networks: In order to accommodate both mesh capabilities and traditional Wi-Fi clients, IEEE 802.11-based mesh networks must be compliant with this standard. Connectivity to other wireless networks, such as Wi-MAX and cellular, is an important feature of wireless mesh networks [2].

vii. Extension of network flexibility: The wireless mesh network consists of interconnected routers, with the ability to operate in multiple modes. Routers can be a host, for aggregating data from related clients, and relays and packet routing from other routers. The area covered by the network can be expanded through additional interfaces, routers or additional gateways. Because routers have minimal dependence on the infrastructure, wired internet connection, WMNs can easily extend their coverage to a wider area [11].

viii. Cost-effective development: Components based on 802.11 they are very cheap, but the wireless community of WMNs with the Internet, compared to other wireless components such as base stations in cellular networks, depends on wired links that are expensive in hardware and connectivity, significantly reduces. Therefore, the cost of network development is reduced by the same amount.

In addition, among the applications of wireless mesh networks, which have been used in recent years, the following areas can be mentioned [2]:

i. High bandwidth home applications.
ii. Metropolitan.
iii. Enterprise.
iv. Medical systems and health diagnostics.
v. Automated building systems.
vi. Transfer systems.
vii. Security systems.

1.4 DIFFERENCES WITH OTHER MULTI-HOP NETWORKS

Due to the absence of infrastructure in cellular or Wi-Fi networks, wireless mesh networks are often classified as an Ad-Hoc network, as described above. Wireless mesh networks need Ad-Hoc networking approaches in addition to a number of more complex algorithms and other designs. That is, they don't aim to create a new category of Ad-Hoc network, but rather to expand the capabilities of existing ones; in fact, Ad-Hoc networks may be thought of as a special case of wireless mesh networks. The benefits of a wireless mesh network, as well as the ways in which this design differs from those of traditional wireless networks, are outlined in [6].

i. Structured Wireless Backbone Network: In wireless mesh networks, the routers, or "mesh nodes," are also wireless. Wireless backbones strengthen and extend the reach of wireless networks by connecting distant nodes and distributing traffic evenly. However, the Ad-Hoc network's connection is contingent on the end users' voluntary participation, which is not always stable [5].
ii. Integration: Previous clients using the same radio technology as the mesh router are supported by the mesh network. Due to the gateway functionality of mesh routers, wireless mesh networks may also interoperate with other networks, including Wi-Fi, the Internet,

cellular, and sensor networks. Because of this wireless setup, users on one network may access the resources of another. Integration of wireless networks via a wireless mesh network is analogous to the Internet's backbone [7].

iii. Designated Routing and Configuration: In Ad-Hoc networks, end users perform routing and configuration tasks for other nodes. But in wireless mesh networks, mesh routers do this. Therefore, the operational load on end users is reduced, and this reduces energy consumption and increases the capabilities of end users who have limited energy and are mobile. In addition, the requirements of end users are reduced and as a result, the cost of manufacturing the equipment used in the wireless mesh network is reduced [8].

iv. Multi-Radio: As we've already established, a mesh network's ability to isolate the two most common forms of wireless traffic is made possible by the routers' ability to have multiple routing radios. End users may access the network through a separate radio while routing and configuring between mesh routers is performed, thus expanding the network's capacity. Therefore, the efficiency of Ad-Hoc networks suffers since these tasks must be executed by a radio rather than a computer [3].

v. Mobility: Because the Ad Hack Network performs routing using end users, the network and connection topology depends on the movement of users. This imposes additional challenges and the problem of network configuration and its extension to routing protocols [3].

   a. To compare the mesh network with the sensor network, the following can be mentioned:
   b. The bandwidth of sensor networks is low but the bandwidth of mesh networks is high.
   c. In most applications, the sensor nodes are fixed, but in the mesh network, some nodes are fixed, and some are mobile.
   d. Because we have the problem of energy constraints in sensor networks, optimal energy consumption is a principle, but usually in mesh networks we do not have energy constraints because the router nodes that do the routing work are fixed.
   e. Sensor networks are limited in resources, while in mesh networks resources are not a concern.
   f. In sensor and mesh networks, traffic is often from the user to the gateway [3].

1.5 CHALLENGES IN WIRELESS MESH NETWORKS

i. Capacity: One of the problems in wireless mesh networks is the low capacity of these networks. Low network capacity is due to several factors, the most important of which is the interference between wireless links. Interference causes the amount of useful bandwidth of each wireless link to be much less than the actual amount of bandwidth of that link. The low capacity of wireless links reduces network throughput. This value decreases greatly as the number of nodes in the network increases. Mesh network protocols should be designed in such a way as to reduce network interference and thus increase throughput [4].

ii. Scalability: Multi-Hop communication is common in wireless networks. In all multi-Hop networks, communication protocols suffer from scalability. As network size increases, network performance decreases significantly. As the network grows, routing protocols will not be able to find a reliable route, transmission layer protocols will lose network connectivity, and transmission layer protocols will experience a large reduction in throughput. For example, the access control layer protocol with the current IEEE 802.11 standard cannot create an acceptable pass when the number of steps reaches 4 or more [4].

iii. Connection Policy: The advantages of wireless mesh networks are due to the network connection policy that should be considered in designing the access control and routing protocol. These networks require automatic tuning features and topology control algorithms. Topology-aware access control and routing protocols greatly improve network performance [6].

iv. Quality of service: Broadband services have unique requirements for network throughput and reliability compared to traditional Ad-Hoc and mesh network use cases. Because of this, it is important to take into account not only the latency and fairness of transmission from end to end, but also the latency and throughput of individual nodes, as well as the total throughput and packet loss rate [7].

v. Adaptability: Facilitating mesh users' and senior users' accessibility is a crucial component of wireless mesh networks. Therefore, it is important for wireless mesh networks to accommodate standard users. Extending a mesh network requires agreeable aims, to put it another way. Special mesh routers that are compatible with heterogeneous wireless networks [3] are required for integrating wireless mesh networks with other wireless networks.

vi. Security: These networks cannot be successful without convincing security solutions in mesh networks. Although there are many security plans for wireless networks, they are not applicable to wireless mesh networks. For example, due to the distributed architecture of this network, there is no secure and centralized authentication unit that distributes public keys in the network. The security plans used for Ad-Hoc networks are applicable to wireless mesh networks, but several points need to be considered [4]:

a. The solutions used for Ad-Hoc networks are not currently feasible.

b. The mesh network architecture is different from Ad-Hoc networks that create different security needs.

As a result, many security schemes, including encryption algorithms, distributed security keys, secure routing protocols, error detection, and security monitoring, need to be expanded.

vii. Ease of Use: Mesh network protocols should be designed to enable the network to automatically manage power, auto-tuning, dynamic topology control, link error resistance, and user authentication function. In addition, network management tools are required to monitor network performance, operational efficiency, and configure wireless mesh network parameters. These tools, in addition to automated mechanisms in protocols, cause the rapid expansion of the wireless mesh network [4].

viii. Placement of Nodes in the Mesh Network: The location of the nodes in the mesh network, including routers and Internet gateways, should be targeted. An important issue that also affects the network throughput is the purposeful location of routers in the mesh network, because the placement of MRs without purposeful planning and design, can itself cause the following problems [5]:

i. Intrinsic Interference: Interference in wireless networks reduces the accessibility of links and nodes. In the worst case, it could cause some links, part or all of the network to crash. Placing MRs without considering the general information of the network and neighbors can create an overlapping topology that is difficult to overcome due to the network infrastructure connection (wired connection to the Internet), which is not the case in large-scale WMNs, can be acceptable.

ii. Unexpected Hotspots: Hotspots are called Overloaded MR. Congestion in hotspots leads to more retransmissions, removal of packets and switches at lower transfer rates. All of these can significantly reduce network throughput and efficiency. Unplanned placement of MRs, independent of traffic demands, may result in fewer MRs being used than is required in some areas with heavy traffic. MRs in these areas become hotspots because they have to withstand the traffic overhead that has accumulated from connected clients or other MR. Although an all-self-organized WMN is able to partially eliminate the existence of these hotspots by directing traffic through the Internet to multiple routes, network performance is still limited by the inherent limitations of network resources. Has been. This can be significantly avoided through proper network design.

iii. Unreliable architecture: An acceptable network must be reliable with an appropriate degree of fault tolerance. Failure of part of the network should not cause the entire network to shut down. Unplanned placement of MRs cannot guarantee network reliability because this architecture is not able to have the necessary redundancy and will be very vulnerable to link or node failure. For example, if the WMN has only one gateway and is connected to only one MR, a malfunction of the MR or gateway will cause the network to crash.

1.6 THE PROBLEM AND NECESSITY OF RESEARCH

WMNs include MRs and mesh clients, with the least mobile mesh routers forming the backbone of the mesh network. Routers and clients on the mesh network access the Internet through gateways. These days, wireless mesh networks provide wireless services for a broad variety of uses, from the residential to the commercial to the institutional to the municipal. The placement of mesh routers is a significant obstacle when planning a wireless mesh network. In fact, locating MRs in building a WMNs is the first step in ensuring optimal network performance. The key to locating mesh routers is to find the number of routers that the mesh needs to meet the criteria required by the network. In this dissertation, an innovative method using genetic algorithm to find the number of routers and their optimal position is proposed. The proposed method can effectively meet the necessary criteria of this network.

1.7 RESEARCH OBJECTIVES

Given the challenges of node placement mentioned, and the resulting problems, unplanned mesh router (MR) placement is unsuitable for developing a large-scale wireless mesh network (WMN), and therefore targeted placement of routers on the network is the first and most important step in efficient design of wireless mesh network. Analyzes show that the maximum WMN capacity is achievable when the MRs are in the optimal position. This is because network capacity is greatly affected by the capacity of nodes and multi-step communications.

The goal of an efficient and effective placement strategy is to minimize the cost (the number of MRs) to service the area, while taking into account a number of limitations, including coverage, connectivity, environment, and traffic demand. This particular strategy should provide feedback on the following questions:

i. Exactly how many MRs are required for a WMN?

ii. Where should these MRs be located so that full coverage and full connection can be achieved in WMN?

1.8 RESEARCH METHOD

Inspired by the Packing Problem (PP) model, a GA was developed to solve the problem of locating routers. A special example of Packing Problem its Circle Packing Problem (CPP) was used and after customizing for the problem, it became Circle Coverage Problem (CCP). The CPP result was used as the initial state of the genetic algorithm. Using this model, by minimizing the number of routers, the placement is such that the maximum possible coverage at the network level results. The proposed method results in a placement in which the routers are spaced as far apart as possible to further cover the network surface, while overlapping to connect. The environmental and traffic constraints of the network were also taken into account in the placement, so that by forming a relay tree, for each of the routers, it calculates the amount of traffic that it must transmit, if it exceeds the capacity of the router, that area It is marked as a critical area, and that area is reinforced with additional or more powerful routers so that network traffic can be routed to the Internet gateway (IGW).

The (NRP) Novel Router Placement method, which is based on the proposed algorithm genetics, has the following characteristics:

i. The final network is created by n routers. Each router is in the center of the corresponding circle. Each router is surrounded by several other routers to completely encase the network disk.

ii. When the combined transmission range of two nodes is smaller than the gap between them, $r_i + r_j$ there is a path between each node, so a network connection is guaranteed.

iii. Geographical restrictions are considered.

iv. The number of routers required is ultimately determined by the constraints.

Therefore, it can be said that in the NRP method, while considering the necessary limitations of the mesh network, including environmental and traffic constraints, the number of routers required to achieve maximum coverage and network connection is determined and specified. The method compared to previous methods includes the following:

i. Put all the above together to place the routers, which was not done in the previous work.

ii. Router transmission range and network size should be considered while deciding on the optimal number of routers.

iii. Decrease the total number of routers required using the Circle Coverage Problem (CCP) pattern.

In general, the research method will be as follows:

i. Defining the exact problem and defining the steps to be taken.

ii. Optimization of the Number and Placement of Routers in Wireless Mesh Networks using Genetic Meta-Heuristic Algorithm.

iii. Simulation the Genetic Meta-Heuristic Algorithm and compare with other algorithms utilizing C++ programming environment in conjunction with NS2 software package.

iv. Performance analysis of the Genetic Meta-Heuristic Algorithm and Define its correct operation.

v. Prepare the final report of the proposed algorithm.

For information, search for available articles and reference books from available libraries, search in the web for resources such as Google Scholar and databases such as IEEE Springer, Elsevier, etc. used common Internet searches.

1.9 THESIS STRUCTURE

In this dissertation, in the second chapter, the methods used so far to examine the location of routers in the WMNs are reviewed. In the third chapter, the proposed algorithm and its features are introduced. In the fourth chapter, the evaluation of the methods used is done in the form of algorithmic comparison and implementation in the simulation environment. Finally, the fifth chapter concludes the work done in the dissertation and offers suggestions for future work that can be done in this field.

2. LITERATURE REVIEW

For the problem of determining the location of routers in mesh networks, different solutions have been provided so far, each of which has provided the required criteria to some extent. In this chapter, some of the previously used methods are introduced.

There have been two primary factors contributing to the sustained rise in popularity of Wi-Fi-based wireless mesh networks in recent years: First, WMNs have successfully used multi-radio and multi-channel technologies to get high bandwidth. They make it possible for people to access the web from their mobile devices whenever and wherever they choose. The absence of a need for physical connections between nodes in a WMN makes it possible for the network to be designed and developed at a lower cost than more conventional networks like WLANs. However, the topic of how to define a low-cost WMN connection that can provide a sufficient Internet throughput in a sizable community has emerged as a significant challenge in light of this growing popularity.

In most research, in the methods proposed to improve the performance of WLANs, it is assumed that the existing WMN is already built, that is, each of the mesh routers is placed in a given position and configured efficiently. Determining the effective location of MRs, as an important first step in ensuring satisfactory performance of a WMN, has been largely neglected. An improper deployment of MRs not only causes a lot of interference that could otherwise be avoided, but also creates undesirable hotspots that impose additional load on some routers while other MRs work with low resource efficiency [5].

The efficiency and good performance of WMN depends greatly on the placement of mesh routers in the geographical area to achieve network connectivity and stability. Therefore, finding the optimal or near-optimal location for mesh router nodes in these networks is vital and necessary. A practical scheme for locating MRs is a compromise between two key design constraints: cost and the requested traffic to be answered. The problem of determining the location of routers should be able to determine how many MRs are needed and where these MRs should be placed according to network constraints. Restrictions that include geographic and traffic restrictions. Since the location determination problem is one of the NP-hard problems, innovative methods are used to solve the problem. In the following, the methods that have been used to solve the problem so far, along with the review and analysis of the characteristics of each one, are given.

2.1 INTRODUCTION

This chapter discusses some prior research on using various machine learning algorithms to identify and categorize various network attacks in the field of information security using numerous network intrusion datasets, as shown in Table 2.1 and Table 2.2. Some examples of these datasets are CIDC-2017, NSL-KDD, UNSW-NB15, KDD99, and others. The aforementioned datasets can be used with a variety of machine learning methods to carry out the detection task, which results in the development of numerous models to defend the network from both internal and external threats.

2.2 AN OVERVIEW OF THE LITERATURE REVIEW

2.2.1 Methods Based on Heuristic Algorithms

In this part, the methods in which innovative algorithms are used for the router placement problem will be explained.

In [5], routers are placed in predetermined candidate positions. In this research, request traffic for the Internet is considered and peer-to-peer traffic is omitted. To estimate the traffic of each router, a density function has been used, in which the requested traffic of each node is equal to the sum of the traffic load of its clients and the traffic load it has to relay. Three steps are taken to reach the desired solution. In the first step, the network traffic is checked and a traffic density function is determined and determined to estimate the traffic. In the second step, the location of the Internet gateway is determined, assuming that there is only one Internet gateway in the network. This step is done as follows:

Initially, it is assumed that the IGW is placed at the coordinates (x0, y0) and the radius of the network perimeter is equal to R. For a very small area (a) whose center is the point (x, y), (a) is measured by dx*dy. The traffic density function μ (a) in (a) is calculated by μ (x, y). Therefore, the requested traffic in (a) is equal to μ (x, y) dxdy. It is assumed that the shortest path routing protocol is used, so the path length from (a) to IGW can be approximated by the Euclidean distance between (a) and IGW, which is equal to $\sqrt{(x-x_0)^2+\ (y-y_0)^2}$. Therefore, the traffic volume of area (a) should be defined as μ (x, y) dxdy *d. The total network disk traffic volume is equal to the sum of the traffic volume from all disk areas to the IGW, $\int_{x}^{x0}\int_{y}^{y0}\mu(x,y)\times d\ dx\,dy$. As a result, to minimize the total traffic volume, the following expression should be minimized:

$$\int_{-R}^{+R}\int_{-\sqrt{R^2-y^2}}^{+\sqrt{R^2-y^2}}\mu(x,y)\sqrt{(x-x_0)^2+\ (y-y_0)^2}\,dx\,dy \qquad (2\text{-}1)$$

If the IGW is placed in any other position, the overall communication path length will increase. As a result, the number of MRs must increase, as more traffic effort is required to transmit the same amount of data. Having μ (x, y), it is easy to find the location (x0, y0) where the minimum traffic effort is obtained in the heterogeneous traffic model. If none of the candidate nodes of V have coordinates (x0, y0), the closest candidate node to (x0, y0) in V is selected and considered as (x0, y0).

In the second step, the position of the routers is selected from among the candidate positions so that they can cover the network disk with the IGW. In this method, positioning of routers is modeled as a covering problem with hexagonal cells. As a result of using this model, a solution with the following features is obtained:

i. To provide a constant data connection, the router's transmission range must be greater than the distance between any two adjacent MR nodes (hexagon). In this approach, we suppose that all routers have the same range.

ii. If MRs can be placed anywhere on the disk, then $\left\lceil \frac{\pi R^2}{\sqrt{3}r_k^2}/2 \right\rceil$ number of MRs are required (if the disk boundary effect is neglected).

In the third step, a two-stage algorithm is used, disk coverage is achieved in the first stage by choosing a small group of nodes to test. In the second phase of the algorithm, a complete connection between the routers is established, so that, if the complete connection between the routers is not established with the above set, a merge-addition procedure is used to establish the connection.

The characteristics of this method include achieving complete network coverage and connectivity and determining the number of routers needed to cover the network, but instead, the same radius is considered for all routers, which is the case in the case that the traffic related to one router If it is more than its capacity, it will cause problems. In fact, stronger routers with greater transmission radius can be used to pass heavy traffic in a part of the network. In addition, the geographical limitations that the network may face in determining the location of the routers have not been considered in solving the problem. In addition, according to the model used, it is assumed that the hexagons are tangent to each other and do not overlap, while in reality, the routers must overlap each other to establish a complete connection with the gateway, and this overlap It causes a change in the number of routers needed in the network and increases their number compared to the ideal state.

In [6], the Simulated Annealing method (SA) is used to determine the location of routers in the mesh network. A feature of SA is its neighborhood exploration policy, which leads to promising regions in the solution space, which can lead to qualitative answers. The SA method is one of the possible meta-heuristic methods whose idea originates from the gradual cooling of metals for their greater strength. Like hill climbing and generalized hill climbing methods, in this method, the problem starts from a state like S in the problem state space and approaches the optimal solution of the problem by passing from one state to another. The selection of the starting state can be done randomly or we can choose the initial state of the problem based on a rule. Here, the objective function calculates the optimality of the current state and generates the neighbor of the neighbor state for the current state. In this method, different parts of the SA algorithm are customized to solve the problem of locating the routers, and use the evaluation function like the method [12]. The features of this method are similar to [12].

In [7], it used the placement methods that are used in previous mobile networks. In fact, it has used the output results of these methods as an initial value for use in evolutionary and heuristic methods. As an example, the neighborhood space search algorithm has been used, in which the neighborhood exploration of an initial solution is done with local moves and is repeated until the stopping condition of the algorithm is reached.

In [8], local search-based methods are used to optimally determine the location of routers in a wireless mesh network. The proposed methods have investigated and explored different local displacements, and have resulted in incremental improvements in the placement of routers.

In [9], the development area is divided into a square grid, which is used to count the number of users and measure the signal strength received from the mesh node. To measure and estimate the strength of the received signal in each position, the pathloss channel model has been used. The pathloss model estimates wireless signal attenuation as a function of distance. The amount of coverage and connection is formulated based on the calculation of the received signal strength in different parts of the network and used in comparison. In order to find the solutions, an heuristic algorithm is used which finds the final positions among the candidate positions, in which the evaluation function including the multiplication of the coverage and connection criteria is used. Since the two criteria of connection and coverage are calculated in the form of probability relations, the closer the value of this evaluation function is to one, the better the quality of the investigated solution will be.

In [10], an algorithm called VFPlace is used, which, having a certain number of mesh routers, determines the position of these routers in such a way that the traffic and geographic restrictions of a WMN are satisfied by maximizing the overall network coverage. In this network, three types of zones are defined and used: the forbidden zone, which includes areas where routers cannot be located, and is used to satisfy geographic restrictions. The front area is an area with heavy traffic, which exceeds the MR capacity, and it is used to consider the traffic limit, and to consider the non-uniform distribution of traffic. and the normal region which represents a normal region. By using a density function that measures the penetration or influence of each area, along with a virtual force model, it has been used to determine the location of each MR by measuring the defined forces. Although in this method, the range of all routers is considered the same, but in terms of considering geographic and traffic limitations, and including them in the problem, compared to the previously mentioned methods, for use in the real world, it seems more appropriate. In addition, in this method, the number of routers was predetermined, and this specific number has been used to cover the network. The criteria that have been investigated in this method are the network coverage rate and the connection rate, the results of which show that it was satisfactory in both criteria. But regarding the amount of routers used to cover the network, it seems that it can be improved, and by reducing this number, it is possible to save a good amount of the cost of setting up and developing the network.

In [11], a method for determining the location of routers is presented, based on which MRs have the ability to transmit at multiple rates, that is, they use radio interfaces that work at different transmission rates, in other words, multi-rate MRs. A rate has been used. The presented method has performed the location determination in a two-step process: in the first step, the coverage MRs are determined, in which the selected MRs are greedily used to cover the mesh clients. In the next step, a number of MRs are added to relay the traffic and connect the MRs to the IGWs, using a local algorithm, thus taking into account the network connectivity and traffic limitation conditions in this step. Routers with the same range, and different transmission rates are considered. The algorithm used is such that it selects or adds MRs based on the coverage of the clients and not on the coverage of the entire network environment. In other words, a client may enter or be added to the network that cannot be covered by any of the MRs at first, but it is done by adding an MR. In this study, the positions of clients are also predetermined, just like IGWs.

2.2.2 Methods Based on Evolutionary Algorithms

In [12], genetic algorithm is used to determine the location of routers. The area is considered as a cellular network, which routers and clients are distributed in these cells. According to different applications and different possible modes of traffic in the network, different distributions are used for clients, so that the traffic load of the network for different samples can be well estimated. Therefore, 4 normal, uniform, exponential and Weibull distributions have been used to distribute clients in network cells. And also, the range of routers is considered different.

The fitting function of the algorithm has examined and taken into account the two criteria of the connection rate of routers and the number of covered users for each individual. In this way, whichever solution is better in these two criteria, the value of its fitting function is higher. To check the solution, a benchmark set with networks of different sizes and different distributions has been used. The results show that in the routers connection criterion, a good result is obtained, but regarding the number of users covered by the routers, due to different distributions, there is a large deviation and not all users are covered. In this method, although the transmission board of the routers has been considered differently, and for the network traffic, it has used a different distribution, but it has done location determination without considering the geographical limitations. In addition, the number of routers used is predetermined, and in fact, their optimal number is not obtained by the algorithm.

In [13] he used a method based on genetic algorithm. Individuals or solutions are displayed using a network graph and an evaluation function is used to evaluate the optimality of the solutions, with the two objectives of installation cost and coverage probability. A two-stage evolutionary optimization algorithm has been used. In the first step, candidate topologies of the network are found and identified, which are related to satisfying the coverage objective. And in the second step, a link removal algorithm reduces the number of network links to reduce the cost.

2.2.3 Methods Based on the Optimization Model

In [14], a multi-objective optimization model was used for the WMN design problem. The mentioned method is designed with the aim of providing a model to minimize network development cost, maximize network throughput, and fully cover mesh clients. Two optimization models are presented, one of which aims to maximize capacity, and the other to reduce radio interference. Particle Swarm Optimization Algorithm has been used with several different objectives as optimization techniques to solve the mentioned two models. A Particle in the Swarm is like a position in the search space and includes information about users' connections, nodes' connections to each other, cost, and the number of routers.

The presented results show the impact of various factors on the number of MRs: the increase in the number of requests and the increase in the amount of traffic increases the number of required MRs, because it is not possible to provide service with the number of MRs available and beyond the capacity. is the network.

In [15], it formulates the mesh nodes problem as an optimization problem with the two objectives of maximizing the expected coverage in the case where the distribution of clients and their requests is variable, and minimizing the number of required mesh nodes. The network model is modeled using a graph, which includes vertices consisting of clients, mesh nodes and IGW. Graph edges will exist between two nodes only if two graph nodes are in the transmission range of each other. To take into account the variability of subscriber requests, a probability variable is defined, which determines the probability that a user is interested in receiving the service. Because in practice, individual users with a subset of users, based on the availability of services, and the state of the area in which they are (for example, in dormitory camps, the number of requests can be much higher than in an office environment), have possibilities They are different to apply.

In this way, a distinction is made between potential users and users with requests, and users who have requests are covered. A genetic algorithm has been used for optimization, which optimizes two goals: minimizes the network construction cost (the number of required mesh nodes), and maximizes the coverage. The mentioned method has been tested on three data sets, all three of which were randomly generated. As a result, the effect of changing the range of the mesh node on the required number has been investigated and presented, that is, by increasing the range of routers, although it causes additional cost, it reduces the number of required routers.

In [16], a number of optimization models have been proposed for WMN design, whose goal is to minimize the cost of network installation and operation (the number of required equipment) and provide full coverage of mesh clients. Using linear programming, the models lead to the selection of the number and location of mesh routers such that routing traffic, interference and channel allocation are also considered. Three models are used in this method, which include basic, interference, and multi-channel models. To model the constraints, each of them is applied parametrically in linear programming. To minimize the installation cost, the installation cost of MR and IGW is considered different. Traffic, connectivity and coverage are also considered to obtain a solution.

In the results, it is shown that, with the increase in the number of demands, the number of Internet gateways required to direct the traffic of mesh clients to the wired area increases, but if the capacity of the gateway is assumed to be infinite, with the increase in the amount of client demand, more MRs will be required. Another result is that, with the increase in the number of candidate positions, the probability that a mesh client can connect to the Internet gateway through a multi-step route increase, and this means that the number of MRs required to establish this multi-step connection is higher. The interesting point is that, considering that the proposed method finds the answer by considering the installation cost, if the cost of IGW is much higher than MR, the proposed model tends to use a smaller number of IGW and a greater number of MR. To serve the clients while minimizing the cost by creating a multipath which is routed by adding MR.

2.2.4 Other Methods

In [17], two algorithms are used to determine the location of mesh routers: 1- An approximate algorithm that finds an initial location design. 2- A heuristic algorithm to select a small number of nodes to minimize the number of mesh nodes and ensure connectivity in the network. In this method, the type of propagation of signals is considered non-uniform, which means that the network areas, according to the received signal, can have different shapes, unlike uniform propagation, which are circular coverage areas. In this way, each mesh node has an optional coverage area (with a different shape) and the network coverage is done with this specification.

The problem is modeled as a connection graph where the vertices are the corresponding nodes in discrete positions and its edges indicate the existence of usable links between the positions. Signal estimation techniques are used in the physical layer to determine potential links in the input connectivity graph. The input graph contains two sets of vertices: the set of physical coordinates representing the target areas in which the coverage of the clients is considered, and the second set contains the possible positions for the mesh nodes that are predetermined. The links in the input graph can be used if the estimated or measured signal strength exceeds a threshold.

The constraints related to the network are also applied to the network and used to form the final graph. The coverage constraint is formulated in such a way that, for all clients to be covered, there is at least one link between the client and one of the selected mesh nodes. The constraint of connectivity is applied in such a way that the resulting graph must be connected. Therefore, the answer to the problem consists of finding a tree that contains the following properties:

A spanning tree that spans all the mesh nodes, and has the connectivity property. This spanning tree must also include client nodes, these clients are connected to a mesh node as a leaf of the tree so that all clients are covered. The results show that in this method, compared to the uniform propagation mode, fewer routers are used.

[18] is presented with the aim of determining the optimal position of the relay node in a wireless mesh network when it is placed between two mesh routers. A simple transmitter-receiver model and another simple model with 3 plans have been used for the position of the relay node. The network capacity analysis shows that according to the operating area of the relay node, the maximum capacity is obtained when the relay node is located in the middle between the transmitter and the receiver.

In [19], a scenario is considered, in which a number of APs communicate with clients through an 802.11 network card, and communicate with mesh nodes through an 802.16 interface, so that the clients' requests be serviced Therefore, the problem is defined as, given the requests of each AP and the set of possible positions for the mesh nodes, to find the optimal number of mesh nodes plus a topology that satisfies the requested constraints. Two cost functions have been used, one function calculates the cost based on the transmission distance between nodes, and the other cost function considers the power required for transmission, and restrictions are applied:

First, the volume of requests on each potential link should not exceed the capacity of the link, secondly clients' requests must be satisfied, and the number of mesh node links is limited and its range must be considered. The algorithm used is the type that results in a different topology according to the requests in the network, so the feature of this research is the ability to change the topology based on the requests.

In [20], a method is presented in which the objective is to minimize the number of relay nodes or mesh nodes. The problem is formulated by defining a number of variables and finally their combination, which represents all the constraints that have been considered. Finally, it has been shown that the number of radio channels used in the mesh node has an effect on the number of required routers, so that increasing the number of channels reduces the number of required MRs.

In [21], a distributed algorithm is proposed to dynamically select a number of nodes among the available APs to form the backbone of the network. In this architecture, it is assumed that all candidate APs are connected to the Internet and the mesh links can be at most two steps away from the IGW.

In [22], he used 3 different types of optimization algorithms to find the minimum number of transceivers to provide adequate coverage (around 90%) of the desired area. A radio emission tool is used to determine and detect the exact location of the cover in the target area. Their results examine the effectiveness of greedy, genetic, and Darwinian algorithms in solving network design problems.

[23] presented a hybrid linear program for WMN design that considers location, capacity, and routing constraints while minimizing cost. Even without adding these complexities, Mixed Integer Linear Program (MIP) is an NP-hard problem and can only be solved for very small networks.

2.3 CONCLUSION

In this section, a number of methods are compared with each other in terms of the criteria required for the problem of determining the location of routers, which can be seen in Table 2-1. Table 2-1 shows the characteristics of each method and as can be seen, in none of the methods, all the necessary criteria are included together, that is, the method that takes into account the traffic and environmental restrictions to obtain Network coverage and connectivity, considering different routers, also determine the number of routers needed in the network.

Table 2.1: Comparison of Placement Methods of Mesh Routers.

Specification	TC	EC	Num	RT	Cove	Con	Method
Using probability distributions to estimate the distribution of clients in the network	Yes	No	Fixed	Different	Medium	Yes	Genetics [12]
Determine the number of routers	Yes	No	Changeable	Same	Medium	Yes	Heuristic [5]
Using the probability distribution	Yes	No	Fixed	Different	Good	Yes	Local search
Using probabilistic distribution, appropriate coverage of users	Yes	No	Fixed	Different	Good	Yes	Simulated Annealing
Using forward mobile placements as the initial state of evolutionary algorithms	Yes	No	Fixed	Different	Good	Yes	forward mobile placements
Very good coverage and not specifying the number of routers	Yes	Yes	Fixed	Same	Very Good	Yes	Virtual force model

Con (Connectivity): indicates the presence of connection in the network.

RT (Router-Type): It shows whether the router type is the same or different.

Cove (Coverage): Network coverage.

Num (Number of routers): determining or not determining the number of routers.

EC (Environment Constraint): indicates the consideration of environmental constraints.

TC (Traffic Constraint): indicating the consideration of traffic restrictions.

Specification: indicating the characteristics of each method.

3. PROPOSED METHODOLOGY

In this chapter, the prerequisites for defining the proposed algorithm will be introduced first, and then the proposed (GA) will be discussed in complete.

3.1 INTRODUCTION OF PACKING PROBLEM

Cutting and Packing (C&P) problems are a class of optimization problems that involve packing a set of items with known dimensions as far as possible into one or more larger objects, with the goal of minimizing parts Unused or wasted is a bigger object. In C&P problems, there are two types of objects: Container and goods. Container is an object in which smaller objects are placed, and goods are objects that must be placed inside the Container. C&P problems are one of the most challenging scientific problems with a wide range of applications and one of the interesting combined problems of NP-Hard optimization. They are used in a wide range of real-world applications, including manufacturing and packaging for automobiles, aerospace, and food industries. Objects and items can be rectangular, square, circular or irregular, that is, problems such as fitting a number of rectangles in a larger rectangle, a circle in a rectangle are among these problems. One of these examples is the problem of fitting a set of circular items into the smallest possible circle. An example of the applications of this problem is in the car wiring building, which connects the car sensors to the display board. The wires must be passed through a hole created in the car body. The hole should be large enough to pass all the wires and at the same time, as small as possible to avoid creating unnecessary space in the body. Another example is the tendency of electrical communication companies to run a series of cables of different types through cylindrical forms, across thousands of kilometers; The smaller diameter of the cylindrical mold reduces the cost [26, 27, 28].

3.2 CIRCLE PACKING PROBLEM

CPP consists of packing a set "N= {1, 2…, n}" of circles of equal or unequal radius Ci without overlapping into the smallest possible Container circle C. The radius of each Ci is determined by Ri. The goal of finding the best pattern is to fit all circles into C so that the best fitting pattern minimizes the junk space as much as possible. CPP means determining the coordinates (xi, yi), The center of each circle Ci, i ∈N, the radius of the Container circle is R and the coordinate (x, y) is the center of the Container C circle so that none of the circles overlap each other two by two. Formal definition of the problem: The problem can be in the form of finding the optimal level for the variables r, (x, y) and (xi, yi), i ∈N.

$$CCP = \begin{cases} \quad\quad\quad\quad\quad\quad Minimize\ r \\ Subject\ to \sqrt{(xi-x)2+(yi-y\,)2} \quad \leq r-r\,, i\ \in N \\ \sqrt{(xi-x)2+(yi-y\,)2} \quad \geq ri+rj\,,\quad i\ \in N*N, j<i \end{cases} \tag{3-1}$$

The first set of constraints states that each Ci must be contained within C. So, there are n number of constraints, one for each Ci. The second set expresses the absence of overlap between both pairs of distinct circles (Ci, Cj), that is, the Euclidean distance between the centers of Ci and Cj must be greater than or equal to (ri+rj). There is [n (n-1) / 2] overlapping constraints and a total of [n (n-1) / 2] constraints must be satisfied [29, 30, 31]. An example of the output of the CP problem is shown in Figure 3.1.

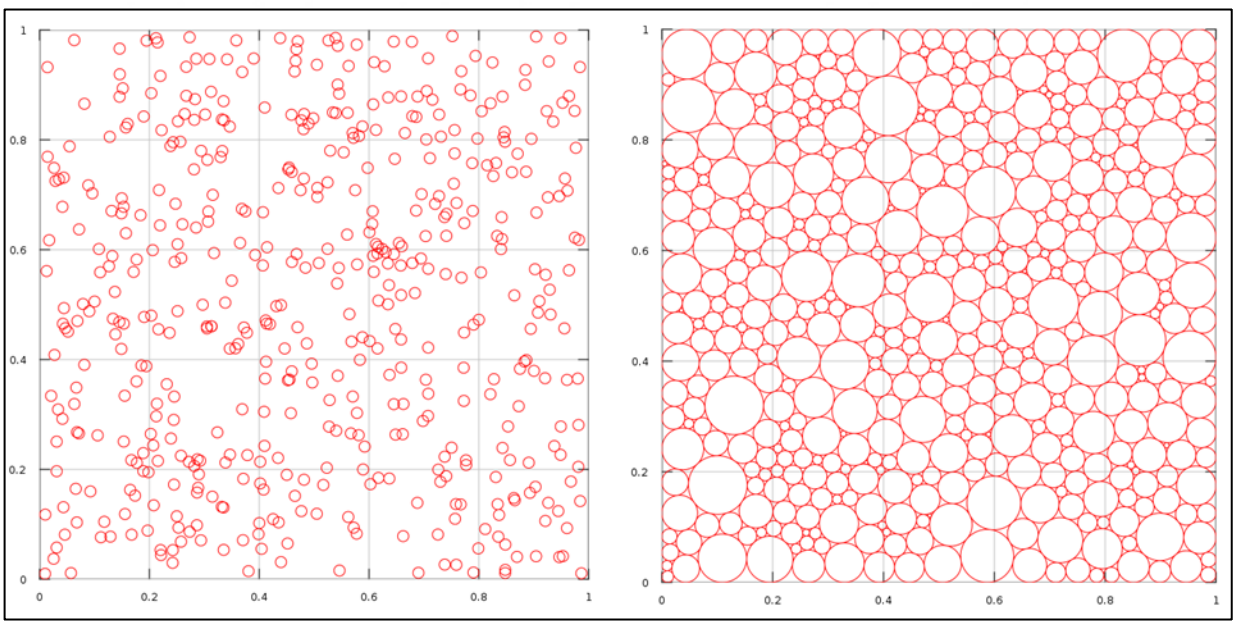

Figure 3.1: (CPP) Circle packing problem.

3.3 NETWORK MODEL

The problem of determining the location of routers in a wireless mesh network can be described as a method to determine the location of a number of MRs in the network environment, while satisfying the traffic and environmental constraints. The area to be covered by the WMN backbone is modeled as a 2D disk with radius (r) in the 2D coordinate plane. The center of the disc is located at the origin (0,0). First, a set of routers named RON = {“RO0, RO1…, RON-1”}, each element of which represents a router. Each of the routers is considered as a circle since they have a circular board. In order to be able to use this model, the presence of obstacles in the network environment that may cause the actual shape of the board to deviate from the circular shape has been ignored. The transmission range of each router is considered as the radius of the corresponding circle. A set named RVc= {RV1, RV2, …, RVc+1} it is defined to take into account geographical limitations. In such a way that each member of the set shows a circular environment whose center is (xc, yc) and none of the MRs can be placed inside these areas. For each MR, (xi, yi) represents where the MR is located, which is the center of the corresponding circle. In this model, an IGW Internet Gateway is considered to be located in the center of the disk.

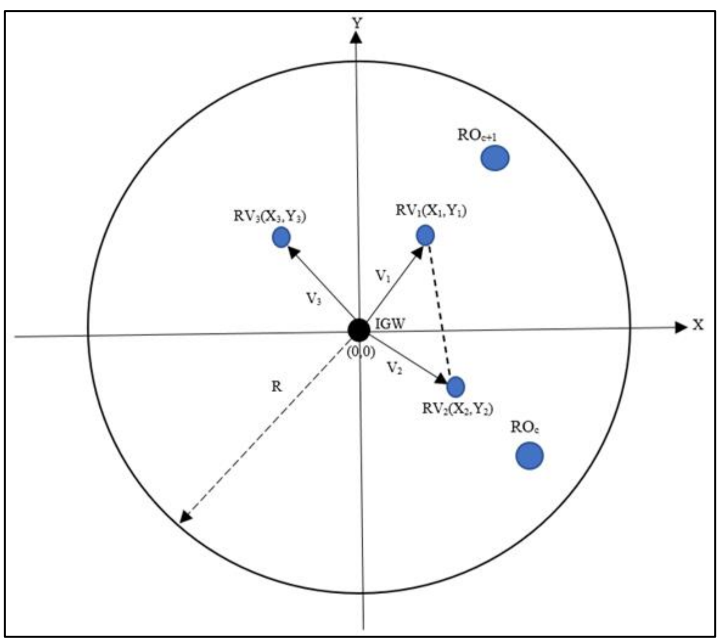

Figure 3.2: Network model.

In Figure 3.2, the network model is shown. Two mesh nodes are connected to each other if the Euclidean distance between them is not greater than the sum of their transmission range, in other words, if two routers overlap, they are connected to each other, $d_{ij} \leq r_i + r_j$.

In the used model, routers can have different radio range (transmission range) and routers with more radio range (longer transmission range) are considered stronger. In other words, according to the used model, circles with a larger radius have been used to show stronger routers.

3.4 PROBLEM DEFINITION

The plan for determining the placement of MR nodes should minimize the number of required MR nodes, while maximizing the coverage as much as possible and establishing a complete connection in the network. Due to geographical limitations, it is not practical to reach full coverage of the network, because the presence of these areas in the network area prevents the coverage of these areas, as a result, it is not possible to achieve 100% coverage. The traffic limit and how to apply it are explained in the section of presenting the proposed method. CPP algorithm [32, 33, 34] can be used to solve the router placement problem. In the genetic algorithm, the method of using this algorithm is stated that the output of the algorithm is used to generate a part of the initial population.

Preliminaries: If we consider each of the circles as a router that has a transmission range r_i, then the transmission range can be considered as the radius of the circle. (x_i,y_i) the center of circle C_i, where the router is located. Since the routers can be different transmission ranges, the problem becomes a solution to the Circle Coverage Problem (CCP) problem, a version of Circle Packing Problem (CPP) tailored to the router placement problem and its constraints. To solve the CCP problem, since it is NP-hard, an algorithm based on genetic algorithm is presented. In the following, the genetic algorithm and its different parts will be presented, followed by the structure of the proposed algorithm.

3.5 GENETIC ALGORITHM

Genetic algorithms or evolutionary algorithms are based on a biological theory known as Darwin's theory. In evolutionary algorithms, it is based on the fact that the information of the problem becomes chromosomes, and then the problem is solved by special problem-solving techniques in the evolutionary algorithm. The genetic algorithm consists of different parts, which are [35]:

i. Chromosome.
ii. Genetic population.
iii. Fitness function.
iv. Genetic operation.
v. Genetic algorithm parameters.

3.5.1 Chromosome

Chromosomes are a set of genes that are arranged in a certain order and shows a solution in the genetic algorithm. Gene is the smallest piece of information that is inside the chromosome [36]. A chromosome is shown in Figure 3.3:

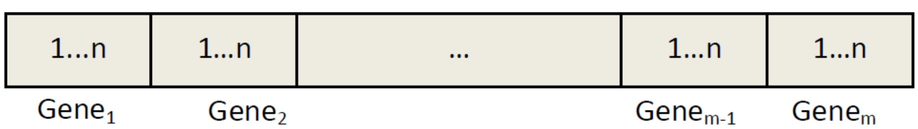

Figure 3.3 : Chromosome with n genes.

3.5.2 Genetic Population

A set of chromosomes in genetic algorithm is called genetic population. In fact, this population provides a set of answers to the genetic algorithm. The size of this population is usually fixed during the execution of the genetic algorithm, but the number of people in this population cannot exceed a maximum number, and as a result, due to competition, the chromosomes that provide a better answer to the problem remain in the population and the rest are removed [37].

3.5.3 Fitness Function

The survival of the chromosomes during the execution of the genetic algorithm depends on their ability to solve the problem, and the chromosomes that provide a better answer have a greater chance of survival, and on the contrary, those that provide an inappropriate answer have a lower chance, so there must be a model for determining the appropriate or there is inappropriateness of the answer provided by a chromosome, for which a function called the fitting function is used. This function returns a number as output for each chromosome, which indicates the degree of desirability of the solution to the problem [38].

3.5.4 Genetic Operations

Genetic operations are a set of operations that cause a new population to be formed from the current population, which is called a generation. For this purpose, the genetic algorithm uses operators to create a new generation of solutions that are improved compared to the previous generation. These operators include selection, intersection, Crossover, mutation, reproduction, etc. [39].

3.5.5 Genetic Algorithm Parameters

Genetic algorithm is a random method to reach the solution of a problem, and for this purpose, as mentioned, it uses operators to generate a new generation of solutions, therefore, these operators must be activated at certain times with a certain probability, and these probabilities are the parameters of the algorithm. They say genetics. Also, the size of the population and the number of generations are also parameters of the genetic algorithm. These parameters are [40]:

a. Probability of reproducing $P_{r.}$

b. Probability of intersection P_c (Crossover).

c. Probability of mutation $P_{m.}$

d. Population size.

e. Number of generations.

3.5.6 Coding Methods

The genetic algorithm needs a set of chromosomes to do its work, and each chromosome must be coded. Coding of chromosomes is the first step in the genetic algorithm and the type of coding depends on the problem. In this section, we introduce various coding methods [41].

3.5.6.1 Binary Coding

In binary coding, each chromosome is a string of 0 or 1. This coding is a common method in most genetic algorithms [42].

Chromosome A	0100010000010101001000000101111101111111
Chromosome B	0101010100010010101111110100100101111111

Figure 3.4: Binary Coding of network model.

3.5.6.2 Displacement Coding

In displacement coding, each chromosome is a string of integers. This coding is mostly used in issues where order is important [43].

Chromosome A	1483983247973247867435843658734653846345
Chromosome B	3453457489327483264873268726389563202493

Figure 3.5 : Displacement coding.

3.5.6.3 Quantitative Coding

In quantitative coding, each chromosome is a string of some values, which can be integers, real numbers, characters, etc. This coding is mostly used in problems that directly deal with problem values [44].

Chromosome A	AABBBCBCBCBABBCBABCBCBCBCABCB
Chromosome B	Back, Back, Forward, Forward, Up, Down, Up

Figure 3.6: Quantitative coding.

3.5.7 Genetic Operators

As mentioned, to create a new generation of improved solutions, we need operators that we call genetic operators. The most important of these operators are selection, intersection (Crossover) and mutation [45].

3.5.7.1 Selection Operator

In the implementation of the genetic algorithm, chromosomes from the population should be selected as parents so that the next generation chromosomes can be created through other operators and form the next genetic population. Some selection operators are roulette wheel selection, continuous mode selection, race selection, elite selection [40].

In the roulette wheel method, parents are selected based on their merit. We show this by means of a wheel in which the fitness level of each chromosome is specified. This wheel has a hand that we rotate and wherever it stops, we choose the corresponding chromosome as one of the parents, and we repeat the same thing to choose the next parent. Because parents with high competence occupy a larger area of the wheel, the probability of choosing them will be higher [42].

In the continuous selection method, a large part of the current population with the highest fitness is selected for the next generation, and new chromosomes replace the weak chromosomes of the current generation (if their fitness is higher than the fitness of the weak chromosomes of the current population).

In the competitive selection method (race selection), some chromosomes are randomly selected from the population and then the best chromosome from this group is selected for the next generation.

In the elite selection method, the best chromosomes are first selected and transferred to the next generation, and the rest of the next genetic population is obtained by conventional methods. This method increases the efficiency of the genetic algorithm and prevents the loss of the best answers [46].

3.5.7.2 Intersection Operator (Crossover)

To perform recombination, it is necessary to have an operator for this purpose. The crossover operator does this and the selected chromosomes are broken from a random point in the selection phase and the first part of one chromosome is linked with the second part of another chromosome. The operation of intersection depends on the type of coding. Three important types of intersection operators are one-point intersection, two-point intersection, and uniform intersection [47]. These three types of intersections are shown in figures 3-7, 3-8 and 3-9.

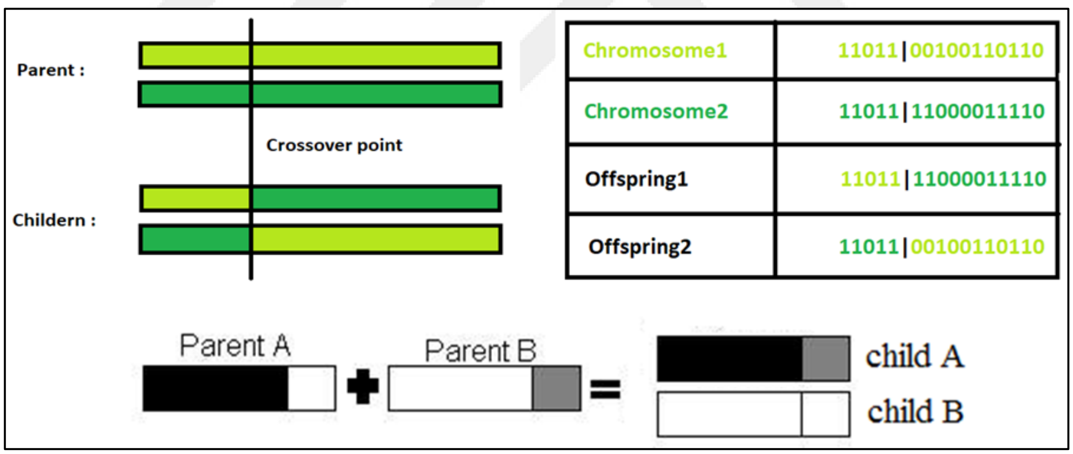

Figure 3.7: Intersection of one-point.

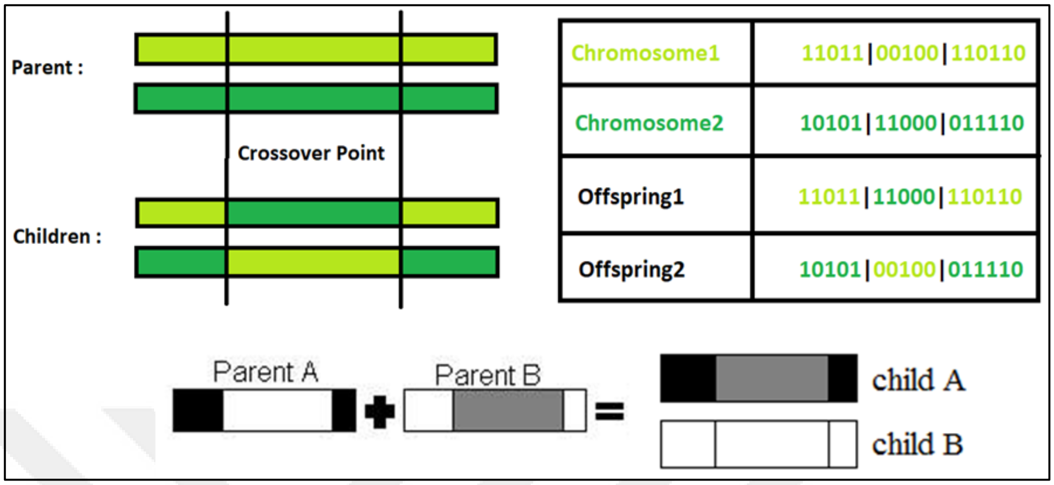

Figure 3.8: Intersection of two-point.

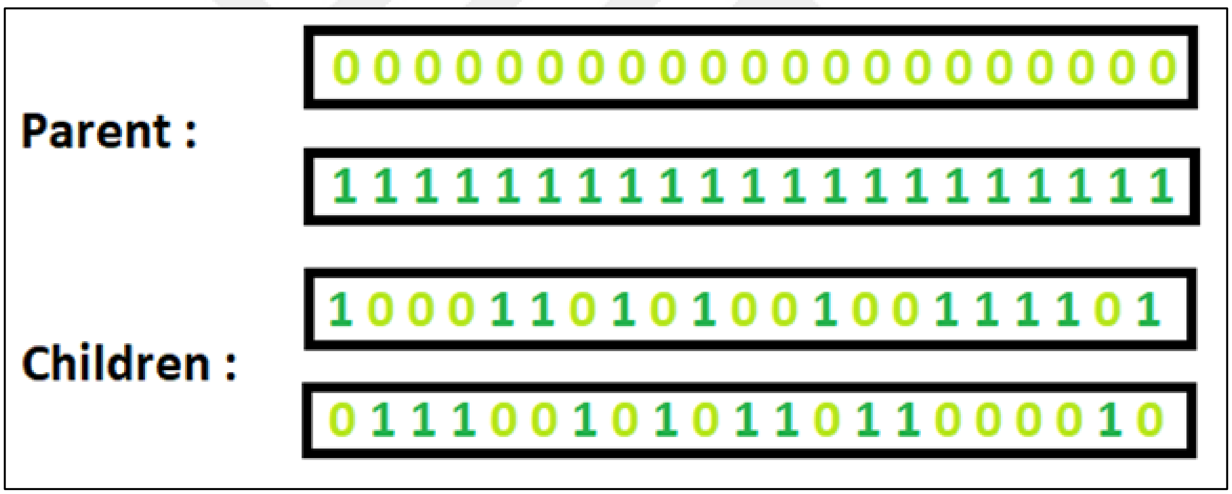

Figure 3.9: Intersection of uniform.

3.5.7.3 Mutation Operator

The mutation operator is another genetic operator that causes evolution in the chromosomes of a genetic population and increases exploration in the sample space and prevents uniformity in the genetic population. This action is also like the intersection depending on the type of encoding. In the mutation operator, a few genes of the chromosomes are changed to prevent the algorithm from getting trapped in the trap of local optima. The probability of mutation is equal to Pm. The mutation should not result in the production of an unauthorized chromosome [48].

3.5.7.4 Genetic Algorithm Termination Conditions

The optimization process in the genetic algorithm can end in different conditions. These conditions include [49]:

i. Creating a maximum of K generations after executing the genetic algorithm on the initial genetic population.
ii. The passage of time like T after the execution of the genetic algorithm.
iii. Creation of several successive generations so that no better chromosome is created.
iv. Greater than or equal to the fitness level of a chromosome than a threshold fitness value.
v. The similarity of the degree of fitness of chromosomes and the uniformity of chromosomes in a population (if the mutation operator is not used.)

In the above conditions, the first and second cases are definite and the other cases are indeterminate, that is, if we use the first or second cases, the algorithm will definitely end, but in the following cases, the algorithm may not end, that's why sometimes the combination The above conditions are used [44].

3.5.7.5 Features of Genetic Algorithm

The genetic algorithm has features and advantages that made us use it to obtain the placement of routers. Also, its disadvantages are such that it does not cause much problem to use the algorithm in this problem [37].

The characteristics of the genetic algorithm are:

i. The genetic algorithm deals with the coding of the set of parameters of the problem, not with them, therefore it is independent of the problem. In other words, it is enough to code the problem of placement of routers for the mesh network in such a way that it can be used in the problem, and the genetic algorithm does not need any information about the routers.

ii. Genetic algorithm searches for a set of points instead of searching for a single point. This feature is one of the most important features of this algorithm and the main reason for choosing it. Because when the search starts from several points of the sample space, the possibility of reaching the answer is also very high. This feature is very important in the placement of routers. Because due to the large number of possible positions and local optima, searching from one point will lead to getting stuck in local optima.

Also, this algorithm has disadvantages, which are [39]:

i. Uncertainty, that is, the answers that the algorithm returns as output may not be an optimal solution, that is, the use of the genetic algorithm may lead us to the neighborhood of an optimal solution, not the solution itself, which in case of using the complete sample space and properly, the probability of this situation will be very low.

ii. If the output of the algorithm is not the same for a specific input, this problem also comes back to the nature of probability and randomness of the genetic algorithm, that is, the execution of this algorithm several times on the same system will give different answers. Of course, this defect is not very important considering that the goal is only to find a placement that meets the desired conditions, and it is not very important that the answers are not the same.

3.5.8 Structure of the Proposed Algorithm

We call the proposed algorithm Novel Router Placement (NRP) and in the following we use this title to refer to the proposed method. To compare chromosomes, there must be an evaluation function to score chromosomes. The algorithm has two goals, which are defined as follows:

$$Connectivity\_Degree = \frac{Number\ of\ router\ have\ path\ to\ IGW}{Number\ of\ all\ router} \tag{3-2}$$

$$Coverage = \frac{Area\_Covered}{Total\ Area\_Network} \tag{3-3}$$

The first objective or Connectivity examines the connection criterion and shows the degree of connection of a placement. Binding states that there must be at least one path between each router and the IGW. For this purpose, the routers are connected to each other so that they can communicate with the IGW through multi-hop paths. When two routers are connected, they overlap, in other words, the distance between them is less than the total range of their transmissions, that is $d_{ij}<r_i+r_j$. To check the connection of routers in a placement, we use an (n+1×n+1) matrix, where n is the number of routers in the network, and one row is related to the only IGW that exists in the network. The entries in row i of the matrix indicate which routers i overlaps with and is connected to. If there is an overlap, it will be 1 and otherwise 0. For each placement, the connectivity matrix is calculated. After calculation, the connection degree of the embedding pattern is calculated. In this way, it is checked whether there is a path between router i and IGW or not, $1\leq i\leq n$. If there is a path with IGW for all nodes, the connection is complete. The degree of placement connection is calculated by equation (3-2).

The second goal of coverage shows the amount of network coverage achieved by placement. To calculate the coverage of each placement, we calculate the ratio of the space covered by the pattern to the total network space.

Since there are two objective functions, there is a need to prioritize between them to determine the individual utility. The degree of connection compared to coverage is considered more important and has higher priority in determining the value of an individual. Suppose we denote the connection degree by f_1 and the coverage percentage by f_2, so if M_1 and M_2 are two solutions with the evaluation function values f_1 and f_2 for M_1 and f_1' and f_2' for M_2, then M_2 is superior to M_1 It is taken if and only if the following conditions are met:

1. $f_1' > f_1$ (3-4)
2. $(f_1' = f_1)\ and\ (f_2' > f_2)$ (3-5)

Also, each chromosome consists of m genes, each gene (x or y) accepts a value between [-x, x], where x represents the maximum coordinate of the network in one dimension. Each of the genes or (x,y) indicates the location of a router. Figure 3.10 shows the structure of a chromosome. The number of genes of a chromosome is variable according to the size of the network and the transmission radius of the routers, and it is obtained based on the equation (3-6) below.

$$number\ of\ neede\ routers\ to\ coverage = \frac{R^2}{r^2} \tag{3-6}$$

where R is the network disk radius and r are the transmission radius of each of the routers.

(x_1,y_1)	(x_2,y_2)	……	(x_n,y_n)

Figure 3.10 : Chromosome structure.

The main part of the NRP algorithm is shown in Figure 3.13 and other parts of the algorithm are shown in Figures 3.14, 3.15, 3.16, and 3.17, respectively.

The NRP algorithm first calculates the size of the genes by using equation (3-6) and then by using the genetic algorithm and the functions that are described below, it locates each of the routers with the aim of maximizing the coverage and establishing the connection. determines Next, the traffic phase is applied to estimate the load of each of the routers and determine the bottleneck areas or critical areas, which are described in Section 3-7. After calculating and determining these areas, the necessary action (replacing routers or adding routers) is done and the final number of routers is calculated with equation (3-7).

$$Final\ number\ of\ routers = \frac{R^2}{r^2} + Router\_trafic\_num \tag{3-7}$$

Initial population generation function: 80% of the initial population is randomly generated. The remaining 20% are generated from the positions obtained from the CPP algorithm, thereby reducing the probability of being in the local optimum.

Intersection function (Crossover): By applying the intersection operator on a pair of parents, two children are produced. For the intersection operator, an intersection point is randomly generated, and the intersection operation is performed from this point. The intersection is done as follows:

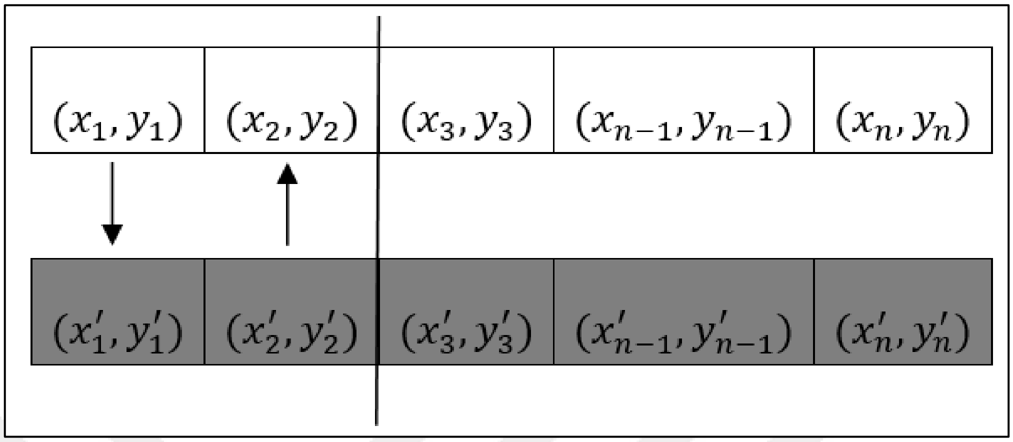

Figure 3.11 : Determining the point of intersection (crossing over).

After the intersection operation, the following two new children are produced.

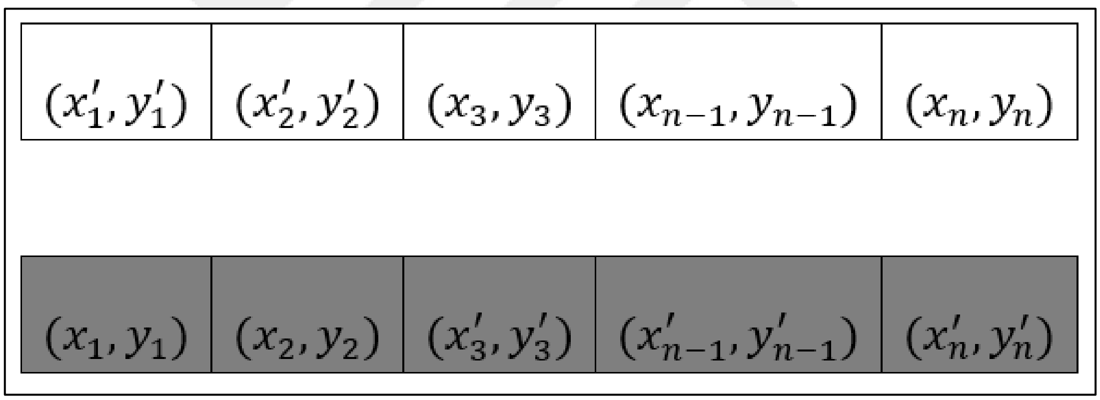

Figure 3.12 : Chromosomes after intersection (crossing over).

Mutation function: In this function, some genes of some chromosomes change randomly with a certain probability (Pm). When an individual is selected for mutation, one of its coordinate's changes with the probability Pm. New coordinates are randomly generated between [-x,x], where x represents the maximum coordinates of the grid.

Selection function: The selection function works by first sorting the children generated from the intersection step (Crossover), then replacing the best ones from the previous step with the worst ones. In this way, the best chromosomes are always taken to the next stage. Of course, the number of chromosomes that are taken to the next step is very small (about 2-3 chromosomes), because if the number is large, the algorithm quickly converges to the local optimum.

```
Function Placement_Plan_Optimizer
    Initialize chromosomes() ;
While not find appropriate plan do
        Sort all chromosomes according to their local score;
        Selection() ;
        Crossover() ;
        Mutation() ;
  End While
End Function
```

The main part of the algorithm.

```
Function Initialization Chromosome
   For 20% of population do
      Select chromosomes that their positions are
      selected from Circle packing problem positions
   End For
   For 80% of population do
      Select chromosomes that their positions
     are generated randomly.
   End For
End Function
```

Production function of the initial population.

Function Crossover Use of one point Crossover like below: Randomly select crossover point and exchange part after (before) crossover point in two chromosomes with each other. End Function

Intersection (Crossover) function.

Function Selection Replace N number of best chromosomes from previous step with N worst chromosomes of current step End Function

Selection function.

Function Mutation If an individual is selected for mutation, all of coordinates modified with with probability of $P_{m.}$ New Coordinates generate randomly in range$[-x, x]$. End Function

Mutation Function

3.6 TRAFFIC MODEL

One of the important characteristics of traffic in wireless mesh networks is that traffic is generally aggregated towards the IGW and this is for two reasons: first, all MRs depend on the IGW to send Internet traffic, if we ignore the peer-to-peer traffic within the network, which is generally negligible compared to the traffic sent to the Internet, all traffic is directed towards the IGW, or flows from the IGW into the network. Second, MRs use multi-step routes to reach the IGW. All MRs closer to the IGW must bear greater relay traffic than distant relays. When the combined volume of traffic from the relay and the MR is too high to handle, the MR will experience congestion, the area affected by the MR becomes a critical area.

In the design phase, establishing the existing traffic distribution of a WMN is difficult. It has been shown that calculating its theory requires knowledge of the channel allocation method and routing information, which is an NP-hard issue. Consequently, we must estimate network activity as follows. A relay tree is developed for estimating the traffic relayed by each node.

First, we assume that each MR node uses the shortest path routing to connect to the IGW in this way:

i. The number of nodes required for traffic transmission should be minimized.

ii. And as a result, the number of critical areas should be minimized.

Once the links between MRs and IGWs are determined, routers can be grouped into clusters. Each cluster has an IGW, and an MR node is connected to an IGW. In the investigated problem, as mentioned in the network model section, the network has only one IGW, so we have only one cluster. Figure 3.18 shows a cluster with 15 MRs. MRs within a cluster are stratified based on their step count distance from the IGW. Level L denoted by LV_1 ($1 \leq L \leq 8$), includes all nodes that are L steps away from the IGW. For example, in Figure 3.18, the nodes of level LV_1 $\{V_2, V_6, V_{14}, V_{15}\}$ and LV_2 $\{V_3, V_4, V_5, V_8, V_{10}, V_{11}, V_{12}, V_{13}\}$ are shown.

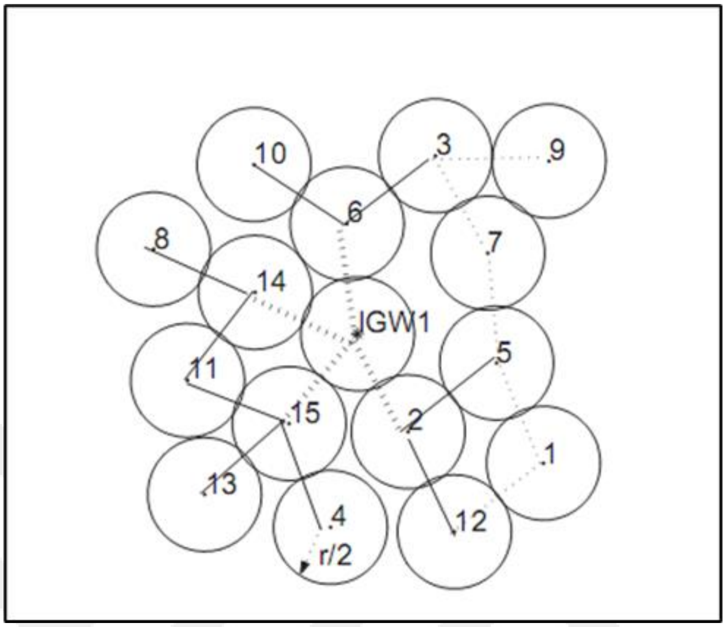

Figure 3.13: Cluster with gateway (IGW).

Therefore, having a node $v_i \in LV_l$, its relay tree $T(v_i)$ is obtained in this way: At the beginning, $T(v_i)$ includes the node v_i itself. First, all neighboring nodes at the $LV_{(i+1)}$ level are added as children, which are identified by $child(v_i)$. Then, for each of the level nodes of $LV_{(i+1)}$ in $T(v_i)$, adjacent nodes in $LV_{(i+2)}$ It did not appear in $T(v_i)$, They are added as children. In this method, each node is added to its appropriate set until the maximum level is reached (farthest).

Having a node $v_i \in LV_l$ and its relay tree $T(v_i)$, total traffic volume TL (v_i) consists of two parts:

i. The traffic that is MR from the affected area means x.

ii. Data from other MRs is sent via this node's traffic hierarchy. To calculate this, we have used a recursive method of the TL (v_i) of each node v_i in a cluster, which is specified by the following formula.

$$TL(v_i) = x + \sum_{v_j \in child(v_i)} TL(v_j)/dgr_L(v_j) \quad (3\text{-}8)$$

$dgr_L(v_j)$ equals the total number of neighbors that $\boldsymbol{v_j}$ has at the lower level. In Figure 17.3 $dgr_L(v_{11}) = 2$ and $dgr_L(v_{13}) = 1$. An MR distributes distributed its combined traffic across its MRs of progressively lesser status in a uniform manner, ($dgr_L(v_j)$). It means that each lower-level neighbor will receive $\frac{TL(v_j)}{dgr_L(v_j)}$traffic from this MR. Consider node V_6 in Figure 17.3, its relay traffic will be equal to the sum of $\frac{TL(v_3)}{dgr_L(v_3)} + \frac{TL(v_{10})}{dgr_L(v_{10})}$. $TL(v_3)$ is recursively dependent on both its aggregated traffic and the degree of its lower-level children.

$w(v_i)$ the rate between aggregated traffic v_i and MR Cap (capacity), can be calculated as follows:

$$w(v_i) = {}^{TL(v_i)}/_{Cap} \tag{3-9}$$

$w(v_i) > 1$ indicates that the provisioned capacity v_i is not sufficient to support the aggregated traffic load and additional or stronger MRs (with more capacity) are needed. Therefore, the area affected by v_i becomes a critical area. If this situation occurs, we will replace the desired router with a more powerful router so that it can relay the relevant traffic. Since the position of all the routers is determined, it is only necessary to replace the corresponding routers with its more powerful type, or to add a router to the mentioned area, because if the router is added in the area, the traffic load will be shared between the routers. and avoids traffic congestion.

3.7 DETERMINE THE NUMBER OF ROUTERS

If the range of the routers is considered the same and we assume that none of the routers overlap each other two by two, the minimum number of $\frac{\pi R^2}{\pi r^2} = \frac{R^2}{r^2}$ routers for the coverage area of the network is required, where R is the radius of the network disk and r is the transmission radius of each router. But it is clear that in this case, the network connection and full network coverage will not be achieved, because the routers do not overlap with each other and there is a gap in the network, the connection criterion is not satisfied. To find the number of routers, we use the following procedure:

```
Function Finding_number_routers
Start with R^2/r^2 number of routers to coverage network disk
While (coverage close to 100%)
    Add one by one router to network and calculate coverage placement
End While
Determine vital regions with traffic model
Apply need changes (add router or change routers with powerful router)
Number of need routers determine after two phases.
End Function
```

Function determines the number of routers.

The algorithm starts with the minimum number of $\frac{R^2}{r^2}$ routers and the number of routers is added one by one until adding routers has a negligible effect on increasing the network coverage, and is close to 100%. Due to the environmental limitations that the network faces, it is not possible to reach 100% coverage. After determining the number of routers in this phase, using the traffic model, the critical areas of the network are determined and the required change is applied, that is, the routers in these areas are replaced with stronger routers or a number of routers are added to These areas are added so that the requested traffic load can be passed. After this phase and its application, the final number of routers will be determined.

To apply geographic restrictions, means areas where routers cannot be located, we do as follow:

The center and radius of each of the prohibited circular areas are predetermined. To prevent the placement of routers in these areas, we calculate the overlap of each of the points that are produced in the initial population generation phase with these areas, and if there is an overlap, we generate a new point instead.

3.8 CONCLUSION

The NRP method, which is based on the proposed genetic algorithm, has the following features:

i. The final network is made of N routers. Each router is located in the center of the corresponding circle. Each router is surrounded by a number of other routers to completely cover the network disk.
ii. The combined transmission range of two nearby nodes is less than the distance between them $(r_i + r_j)$, there is a path between each two nodes, so the network connection is guaranteed.
iii. Geographical restrictions are included.
iv. The number of required routers is finally determined according to the existing limitations.

Therefore, it can be said that, in the NRP method, while taking into account the necessary limitations of the mesh network, including environmental and traffic limitations, the number of routers required to achieve maximum coverage and network connection is determined and determined. and the points of this method compared to the previous methods include the following:

i. Considering all the above items together to place the routers, which was not done in the previous works.
ii. The number of routers needed is calculated by taking into account both network size and router transmission range.
iii. Lessening the number of routers required by using the CCP method.

4. SIMULATION AND RESULT

Genetic algorithm is implemented in C++ programming language and NS2 software is used to evaluate the proposed method. Since each of the compared methods have different environmental parameters in terms of size, etc., therefore, an environment with the same characteristics has been presented to compare the results with each one. Therefore, the proposed method has been compared separately with these methods based on the following criteria.

In order to evaluate a placement plan, as mentioned before, the criteria of network coverage, the presence of complete connection in the network, the number of routers used in the network to cover and satisfy the traffic and environmental restrictions have been used in the comparisons [50].

The size of each gene of a chromosome in the genetic algorithm is calculated according to the size of the network and the routers used. The size of genes is calculated and used by equation 3-6 given in chapter 3. In the genetic algorithm, the initial population size is (20, 40, 60, 80, 100) chromosomes, the genetic algorithm is executed 100 times and the best results among these executions are considered.

4.1 COMPARISON WITH OTHER METHOD

The network environment is considered with a radius of 8 units and the transmission radius of each of the routers is 2 units. The network traffic is randomly generated, the capacity of each router is assumed to be 6 Mbps.

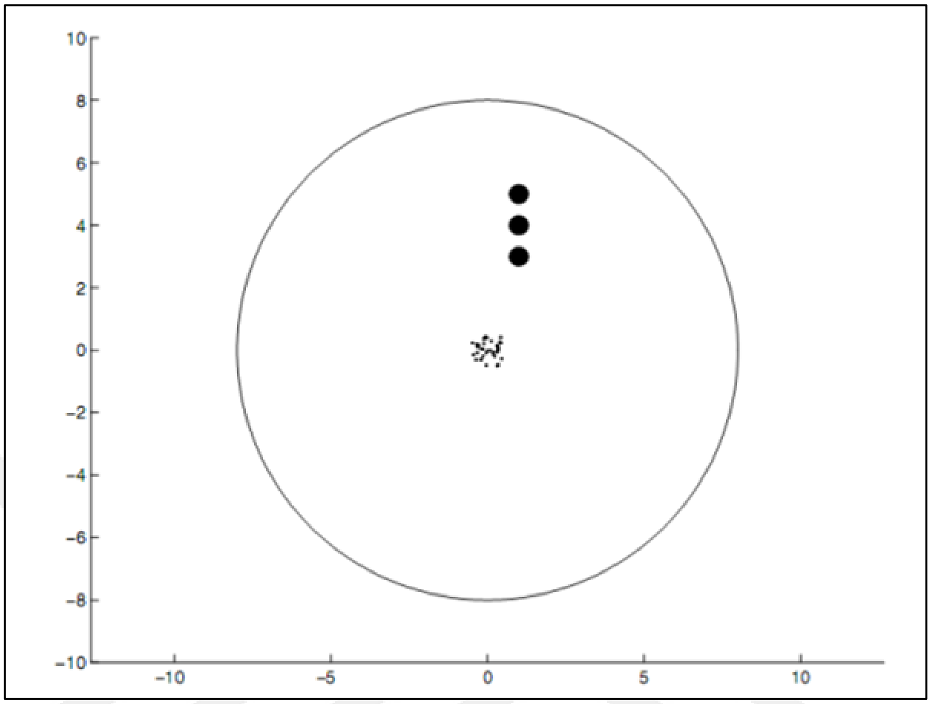

Figure 4.1: Basic network with environmental restriction.

In the network, there is only one IGW to send traffic to the Internet, it is situated at (0,0) at the disk's center. Figure (4.1) shows the network environment with environmental restrictions. If we assume that there are no environmental restrictions in the network, the placement obtained by the NRP algorithm is shown in Figure (4.2). Both in terms of the amount of coverage, the number of routers, and the connection criterion, compared to random placement, the NRP algorithm provides better results.

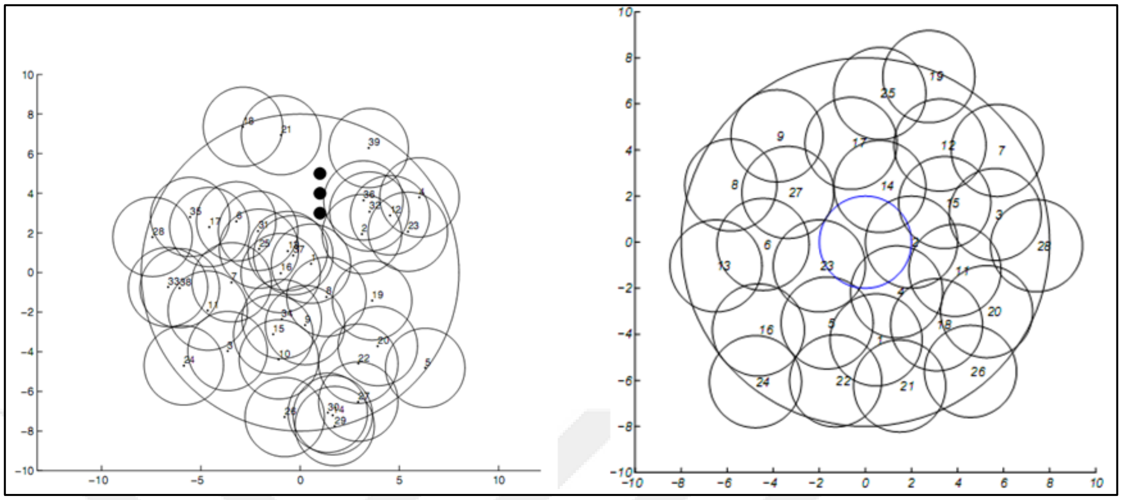

Figure 4.2: Random distribution and NRP distribution.

As it can be seen, compared to the random mode, the amount of coverage obtained is higher, the number of routers is less, and in the connection, unlike the random placement that produces a number of unusable nodes, such as nodes 5 and 24, the full type can be achieved. establish it the amount of coverage obtained in the proposed NRP method is more than 95%, while in the random placement of Figure 4.2, 92% of the network environment is covered. In terms of the number of routers, while 92% coverage has been achieved using 38 routers in Figure 4.2, the NRP method has been able to achieve more than 95% coverage using only 28 routers. the output of the NRP algorithm considering the environmental constraint, that is, in some places, routers cannot be located, and should be covered as much as possible. the number of routers used has decreased significantly, so that only 28 routers instead of 38 routers [50] is needed for network coverage and this means a 26% reduction in network development cost, Because the NRP algorithm determines the positions in such a way that the maximum network coverage is obtained. In terms of coverage, the results are close to each other, so that in simulations 95% coverage is obtained.

Figure 4.3 shows a situation where routers No. 6, 11, and 20 are overloaded due to the amount of traffic they have to relay, and the available capacity, and there is a need to strengthen the mentioned area. Therefore, these routers are replaced by a stronger router, indicated by a larger circle, as shown in Figure 4.4. If a stronger router is not available, by adding a new router to this area, the traffic is divided between them and the overhead is eliminated. Therefore, the results show that compared to the random mode, a better value is obtained in all criteria, and compared to the reference method [50], there is a significant reduction in terms of the number of routers used.

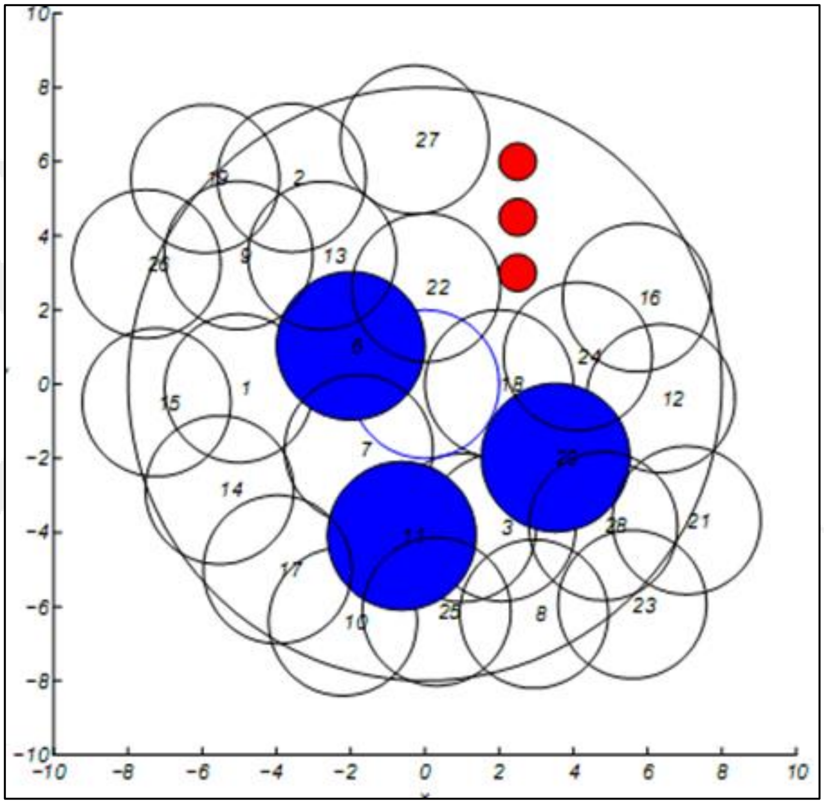

Figure 4.3: Determining critical areas in the NPR method.

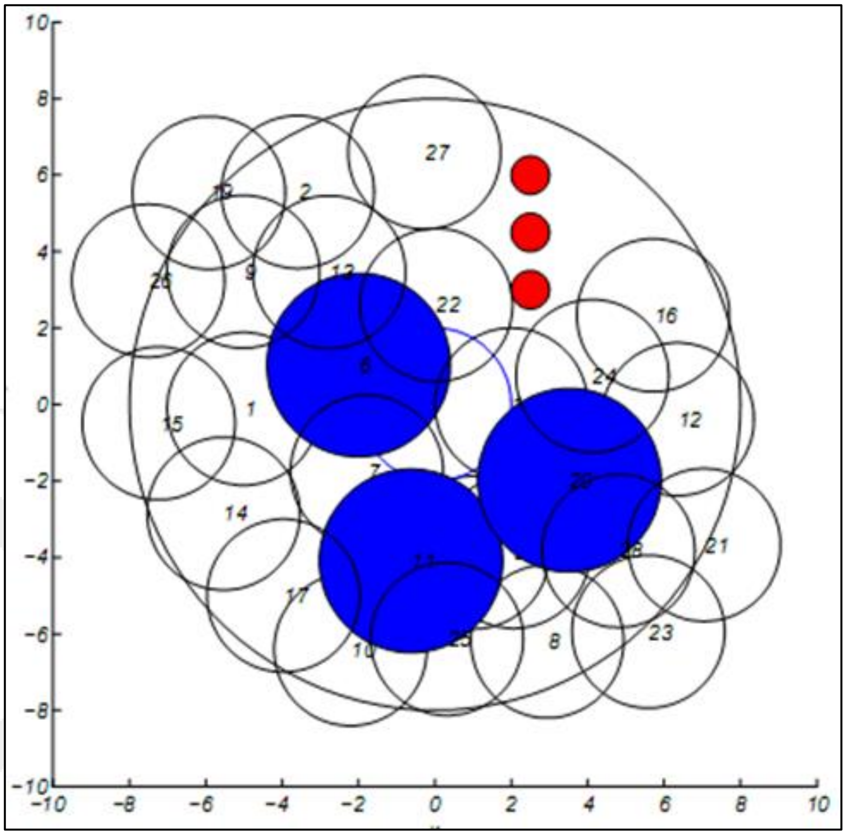

Figure 4.4: Routers replaced by a stronger router.

Below, the results obtained for networks of different sizes are compared with the R-SNGA. In each of the figures, the average number of clients included in the NRP method in the mentioned network sample was compared with the results of the same distribution related to reference [50].

The comparison was made in terms of delay, spread, number of nodes, and also Throughput. Here are the following results, according to our simulation:

Table 4.1: Comparison between our methods according to speed.

Speed	NRP	R-SNGA
5	0.064954	0.175186
10	0.076877	0.27933
15	0.07928	0.39411
20	0.119167	0.428473

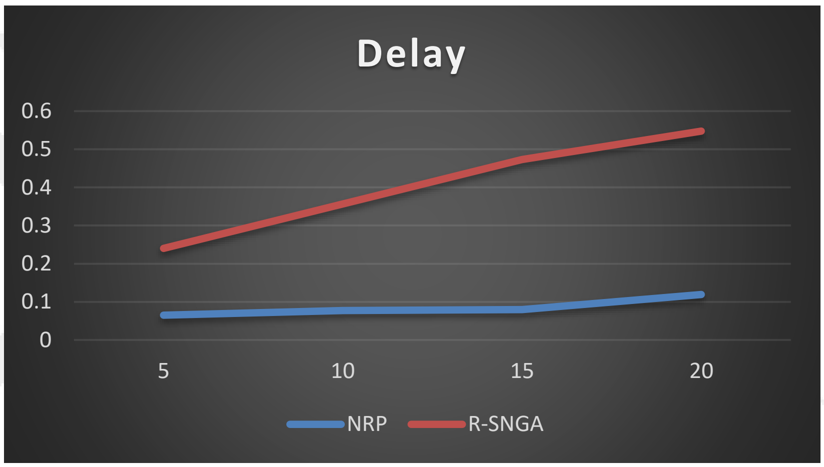

Figure 4.5 : Comparison between our methods according to speed.

Here in figure 4.5 and table 4.1 we notice that the delay rate is less in our proposed method compared to the other method, as the delay rate increases when the mobility rate increases.

Table 4.2: Comparison between our methods according to number of nodes.

Number of Nodes	NRP	R-SNGA
20	0.119167	0.286109
40	0.319618	0.550193
60	0.631827	1.11684
80	1.073915	1.865091
100	1.466071	2.861907

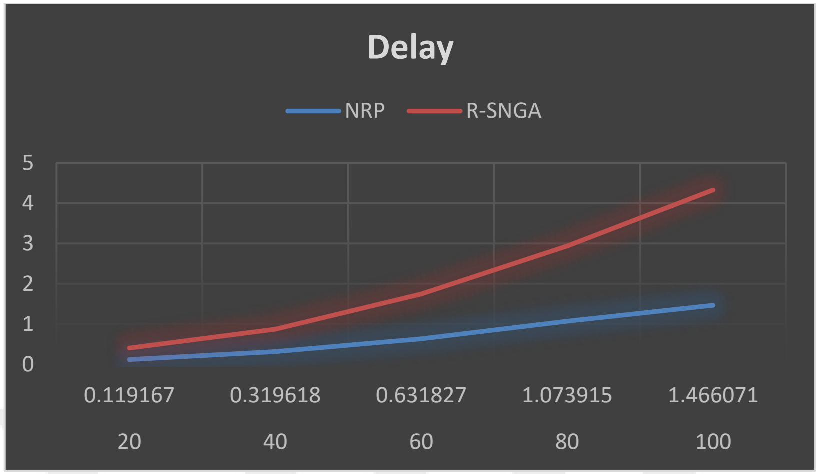

Figure 4.6 : Comparison between our methods according to number of nodes.

In each simulation, we utilized several numbers of nodes, including 20, 40, 60, 80, and 100, and we note that in figure 4.6 and table 4.2 the results are different according to the simulation. As the number of nodes used increases, the delay rate increases. We note that our method used gives better results than the other method in terms of delay and the number of scattered nodes.

Table 4.3: Comparison between our methods according to throughput.

Throughput	NRP	R-SNGA
5	0.062	0.065
6	0.06	0.064
7	0.058	0.064
8	0.057	0.062
9	0.056	0.06
10	0.055	0.058
11	0.053	0.057
12	0.053	0.056

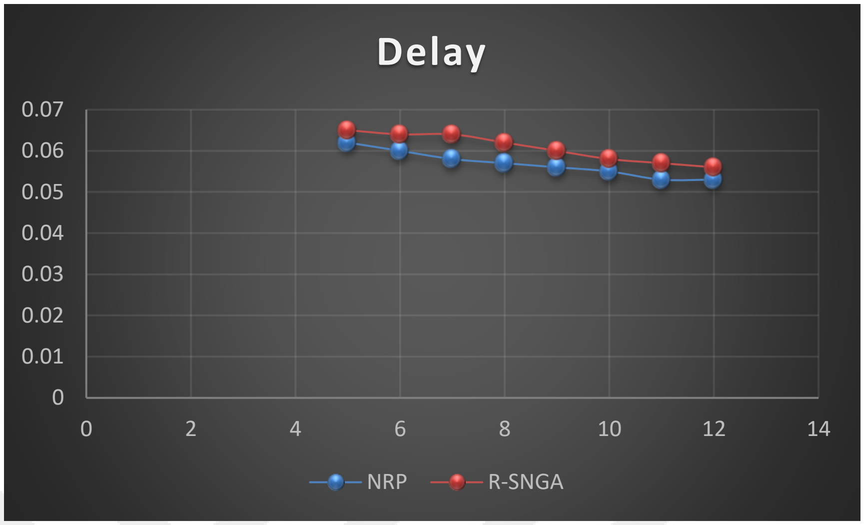

Figure 4.7 : Comparison between our methods according to throughput.

The Throughput in terms of sending and receiving data and the delay rate between the two methods in figure 4.7. We note that the proposed method gave better results in terms of Throughput.

Table 4.4: Comparison between our methods according to spread.

Scenarios	NRP	R-SNGA
scen1	0.44	0.57
scen2	0.56	0.61
scen3	0.52	0.55
scen4	0.68	0.77
scen5	0.42	0.51
scen6	0.72	0.78
scen7	0.7	0.83
scen8	0.61	0.8
scen9	0.76	0.81
scen10	0.72	0.83

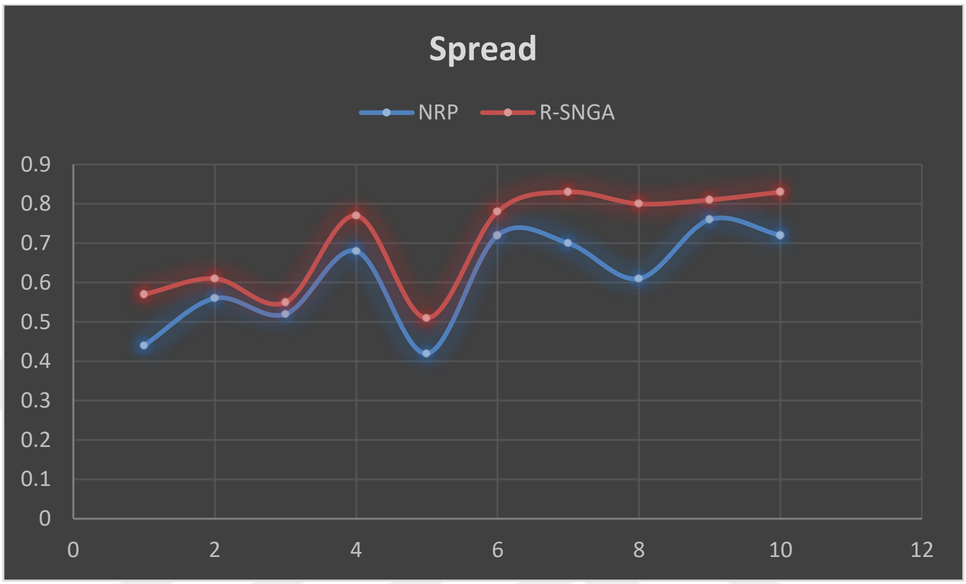

Figure 4.8 : Comparison between our method according to spread.

As can be seen from Figure 4.8, the proposed method has a significant difference in the number of covered users compared to the R-SNGA method. Due to placement of routers in such a way that it covers the entire surface of the network, if the clients in the network have a uniform distribution, many users are covered. The non-coverage of the remaining clients can be due to one of the following two reasons: the network clients are located in an area of the network where there is no routing, because there are more routers to cover the entire area. The network was needed. Secondly, the clients are located in an area where the traffic density is high, and using the number of routers in that area, it is not possible to support all of them, and for dividing the traffic load A number of routers should be added to the network in the mentioned area.

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5. CONCLUSIONS AND FUTURE WORKS

5.1 CONCLUSIONS

Recently, the use of wireless mesh networks has become very popular due to the provision of broadband services and the possibility of accessing the Internet for all mobile or stationary users. In order for a WMN to support a suitable and acceptable level of service to users, it must be properly established. One of the most important steps in WMN design is to locate mesh routers inside this network, because unplanned and random placement of routers causes problems such as increasing interference and creating hotspots. Network resources are running low. Therefore, the proper and effective performance of WMN It is highly dependent on the strategic placement of routers inside the network environment.

In this thesis, the methods of determining the location of routers in the wireless mesh network have been investigated. As mentioned, a suitable placement of routers should be created with the approach of determining the number of routers required by the system to obtain the maximum possible coverage, while considering the environmental and traffic limitations of the mesh network, along with the network connection. to be This thesis considers the design of a method for placing routers with these approaches.

After examining the existing methods of determining the location of routers in the mesh network, a need assessment for the existence of a method that, while considering the necessary limitations, determines the number of routers used and reduces this number as much as possible in order to design and develop It was mentioned that the mesh network is economical.

Inspired by PP problems, a GA was provided and designed to resolve the issue of determining the location of routers. A special example of PP, i.e., CPP, was used and after customizing for the desired problem, it became CCP. The CPP result was used as the initial state of the genetic algorithm. Using this model, by minimizing the number of routers, It was located in such a manner that it provides the most network coverage feasible. The proposed method results in a placement in which the routers are as far apart as possible to cover more of the network surface, while also overlapping each other to establish a connection. The environmental and traffic restrictions of the network were also considered in the placement, so that by forming a relay tree, for each of the routers, the amount of traffic that must be transferred is calculated, if it exceeds the capacity of the router. That area is marked as a critical area and that area is reinforced with additional or stronger routers so that network traffic can be sent to the IGW.

Comparing the results with previous works demonstrates the efficiency of the suggested approach with respect to the above criterion. In terms of the number of routers used, it shows a good reduction because it is inspired by the CCP model. Regarding the number of users covered, depending on the type of placement, it can cover a significant number of users. Especially when the location distribution of users in the network is close to uniform or normal distribution.

5.2 RECOMMENDATIONS

Several suggestions for the continuation of this research can be made, which are given below:

i. In this thesis, the problem was investigated offline, and environmental and traffic restrictions were considered, and the goal was to obtain the maximum amount of network coverage. It was assumed that the channel allocation was done ideally and without interference, while in reality it is usually not like this and there is a certain amount of interference in the network, in other words, the type of channel allocation and the amount of interference in the network. The network is also effective in the network efficiency. Therefore, while considering environmental and traffic restrictions, the type of channel allocation and the interference of channels in the communication between routers can be considered in placement, so that while meeting this restriction, the amount of network interference is also minimal. in online mode.

ii. Wireless routers can use several radio interfaces. In this thesis, we considered the case where the same routers use the same data transfer rate. Each of these interfaces is capable of operating at different transmission rates, if this mode is considered, and it is possible to estimate dense traffic areas in the network, using a suitable algorithm (heuristic or fuzzy), you can choose an interface with a suitable transfer rate for each connection (connection between two routers or connection between client and router). As a result, in addition to the effect it can have in reducing network interference, it can reduce the number of routers needed by the network to cover users and their traffic load.

iii. Another idea is to use a method to determine the location of the IGW or IGWs in the network, along with determining the location of the routers. In this research, we assumed the location of the IGW to be predetermined and optimal. Since determining the optimal location of IGW affects the efficiency and capacity of the network, using a method to determine its optimal location next to routers can make the design more efficient.

iv. As we have shown in the evaluations, the type of placement is such that, if the distribution of clients in the network is uniform, a large number of users are covered. Because the goal of placement was to obtain the maximum coverage of the network area, while in some networks, the distribution of clients and their related traffic is uneven, and in some areas, the density is higher than in other areas of the network. There are many clients and as a result traffic density is much higher. If you know the type of distribution of clients, you can change the placement plan in such a way that it uses more routers in the area with higher client density in order to balance the load in the network and avoid placing routers in areas with low traffic load. In this way, placement is done based on the priority of network areas.

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