Journal of Information Systems Engineering and Management
2025, 10(11s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

Enhanced IEEE 802.16 Network Performance Utilizing Directional Antennas and Resource Allocation

Aydin M. Saeed[1], Mustafa M. Jasim[2], Fidha Ezzaldin Mohammed[3]
[13]University of Telafer, Mosul, Iraq
aydin.m.saeed@uotelafer.edu.iq
fidha.e.mohammed@uotelafer.edu.iq
[2]Nineveh Education Directorate, Mosul, Iraq
tecmustafa90@gmail.com

ARTICLE INFO

Received: 15 Nov 2024

Revised: 27 Dec 2024

Accepted: 15 Jan 2025

ABSTRACT

This paper investigates the performance enhancement of WiMAX (IEEE 802.16) networks through the integration of directional antennas and innovative resource allocation algorithms. Two main methods are presented: a load-balancing technique to guarantee fair traffic distribution among relay stations (RS) and a multi-level search approach for the best communication path selection. When compared to baseline designs, simulations using OPNET software show notable performance gains, such as a 34% increase in throughput and a 26% decrease in delay. These results underscore the potential of the proposed approach in optimizing multi-hop wireless networks, with practical applications in different network scenarios such as WiMAX-based Networks for 5G and IoT.

Keywords: WiMAX, Directional Antennas, Load-Balanced Algorithm, Throughput, Delay

INTRODUCTION

A wireless network is a category of computer network in which data is transferred between network elements via wireless connections. Wireless networks transmit data and information via radio waves. The primary advantage of wireless networks over stationary ones is the avoidance of expensive and time-consuming cable installations within buildings. Furthermore, wireless networks provide better flexibility and scalability, making it easier to expand and adapt to changing needs. Mobile communication systems have typically been classified by generation, beginning with 1G in the 1980s as the first mobile analogue radio system. This was IP followed by 2G, the first digital mobile system, and then 3G, which enabled broadband. This nomenclature distinguishes between consecutive generations of mobile phone systems by emphasising their functions and evolution. However, ensuring that 4G wireless technologies, such as WiMAX, met the requisite service quality standards was critical to provide users with a satisfactory Internet experience. [1]. WiMAX satisfies present and forthcoming quality-of-service standards, thereby elevating the significance of the quality-of-service concept WiMAX addresses both present and future quality-of-service needs, emphasising the growing importance of quality. Broadband Wireless Access (BWA) is successfully supported by the physical (PHY) and medium access control (MAC) layers, which improve all-IP broadband wireless access technologies and provide more users with better data rates, availability, and coverage. WiMAX was designed by the IEEE 802.16 VoIP standard and is based on the Wireless Metropolitan Area Network (WMAN) concept. It combines various techniques, including mobile cellular access and point-to-point communication, to provide wireless connectivity across great distances. In addition to the Forward Error Correction (FEC) system included in the original specification, the Physical Layer (2–11 GHz) specification provides an option to use Automatic Return Requests (ARQ). These include improvements also to the media access control (MAC) layer of the 802 16-2004 standard, such as support for (Multi-hop Mesh Networking), which enables nodes to forward signals and contributes to expanding the coverage of WiMAX base stations[2]. As this technology has generally improved the omnidirectional antenna, there is still a requirement for bias in the antenna to enhance the coverage of service areas on a wide scale. Additionally, operation in the frequency range(2–11GHz) with adaptive beamforming techniques is allowed, which enhances scalability and interference management. These specifications include security improvements in wireless local loop applications. The use of scalable OFDMA, as opposed to the non-scalable version of the fixed WiMAX specification, is a significant improvement in IEEE 802.16-2005. Proponents assert that this improves the technology's resilience to network congestion and permits graceful performance degradation in the presence of interference. Modern technologies like hybrid automated retransmission requests, sophisticated FEC coding methods like turbo codes and low-density parity-check codes, and support for multiple-input multiple-output (MIMO) are among the other noteworthy developments. [3]. This paper introduces a dynamic, fair, multi-user resource allocation algorithm for IEEE 802.16 WiMAX networks to enhance energy efficiency and network performance. The suggested method takes into account factors including node lifetime, transmission power, outage likelihood, and power gain while allocating resources according to fairness standards. Simulation results showed that considerable increases in throughput resulted in lower end-to-end latency and higher delivery ratios for real-time and non-real-time traffic. The approach outperforms current techniques like Dynamic Distributed Resource Allocation (DDRA) and Particle Swarm Optimization (DPSO) by effectively balancing resource usage and energy conservation. To further increase network efficiency, future research will investigate resource allocation techniques that are optimized [4]. WiMAX provides data rates of up to 75Mbps within a 100km radius and serves a large geographic area with licensed and unlicensed spectrum frequencies between (10 and 66 GHz). It also provides multiple services to support quality of service(QoS) for real-time and non-real-time traffic [5][6]. IEEE 802.16, is a wireless digital communication system designed for Metropolitan Area Networks (MANs). It provides Broadband Wireless Access (BWA) with coverage of up to 50 kilometres for fixed stations and 5 to 15 kilometres for mobile stations. Unlike the Wi-Fi/802.11 wireless local area network standard, which is typically limited to a range of 30 to 100 meters (100 to 300 feet), WiMAX offers significantly extended coverage and supports similar data rates with reduced interference. By enabling broadband connections without the need for physical cables or wires, WiMAX significantly reduces the cost-of-service deployment. This makes it particularly valuable in regions where installing or upgrading landlines is prohibitively expensive, such as in developing countries. WiMAX, a second-generation protocol, enhances bandwidth efficiency, minimizes interference, and supports higher data rates over greater distances [7]. WiMAX is available in two fundamental varieties: 802.16-2004 (Fixed WiMAX), which is designed to function with stationary devices, and 802.16e or 802.16-2005 (Mobile WiMAX), which provides enhanced data capabilities, supports mobile voice-over IP, and allows users to communicate while in motion [8]. WiMAX has several advantages over Wi-Fi, including the capacity to accommodate a greater number of users, a vaster coverage area and superior speed rates. Additionally, the ability to support end-user devices with WiMAX wireless controllers (receivers) rather than Wi-Fi interface cards due to the network architecture's relative simplicity. The main innovations and contributions of this paper can be summarized as follows:

- The WiMAX network was implemented in a multi-hop configuration. Each relay node was equipped with two radio directions: one directed toward the base station (BS) and another toward the user (SS). It was proposed that relay stations be equipped with directional antennas featuring a 45 dBi beamwidth and a gain of 20 degrees. The algorithm is designed for scenarios where all SS subscribers have access to a fixed data rate, and resources are allocated in a fair and equitable manner.
- Communication channels are assigned to each user to ensure connection with the base station BS through the most efficient path. This is accomplished by adjusting the direction of the radiation beam from relay station antennas, enabling the user to connect to the BS in a multi-hop scenario according to tree topology.
- A multi-level search algorithm was proposed to select the optimal connection path, enhancing service quality and achieving balanced load distribution at each relay station along the path with minimal inter-channel interference.

RELATED WORK

The IEEE Standards Board introduced and developed Broadband Wireless Access Standards in 1999, paving the way for the global deployment of Wireless Metropolitan Area Networks. The IEEE 802.16 family, also known as WiMAX or wireless broadband, includes both IEEE 802.16-2004, also known as "fixed WiMAX," and IEEE 802.16-2005 (or 802.16e), also known as "mobile WiMAX." provides broadband connectivity by connecting users to Internet Service Providers even when they are away from home. WiMAX networks are an excellent alternative to 3G and other wireless networks because they provide broad coverage, inexpensive deployment costs, and high-speed data rates. It provides data rates of up to 70 Mbps across lengths of 50 km and mobility at automobile speeds. Notably, WiMAX is the only wireless technology that can provide high-quality service at high data rates to IP networks. One of the primary applications of IEEE 802.16 is Voice over Internet Protocol (VoIP), which allows for bidirectional voice communication[9][10]. WiMAX (IEEE 802.16) presents high-speed wireless connectivity (up to 100 Mbps) with a coverage of 50 km, supporting VoIP technology for flexible and inexpensive communication. However, there are difficulties in guaranteeing dependable voice communication. Using OPNET 14.5, performance parameters such as bandwidth and MOS were examined for VoIP codecs in a four-cell WiMAX network. With a bandwidth of 1600 packets/sec at 15 dB and 1300 packets/sec at -1 dB, the multiband channel model performed better than the CSE pedestrian model, according to the results. Compared to the ITU pedestrian model, the multipath cancellation model produced higher MOS values [11]. The paper uses OPNET Modeller to assess VoIP performance across WiMAX networks. Major parameters like bandwidth and multipath channel models were investigated using a star trajectory topology with four cells. The results indicated that increasing bandwidth improved throughput and MOS, with the "disabled" multipath channel model producing the best results. Throughput reached 1600 packets/sec at 15 dB, while MOS exceeded 3.5, confirming the significance of bandwidth and channel model selection for optimal network performance [12]. WiMAX networks are an effective substitute for 3G and wireless networks in terms of delivering high-speed data at low deployment costs and across expansive coverage areas. In comparison, most 3G networks have lower maximum speeds (typically 2-3 Mbps) and shorter coverage distances, making them better suited to smaller, urban, or densely populated locations. Furthermore, WiMAX's support for Quality of Service (QoS) ensures more constant data throughput, whereas 3G networks may encounter increased latency and slower speeds, particularly under heavy loads. This makes WiMAX appropriate for users who need high-speed, dependable connectivity over large areas, often at a reduced cost per user[13]. The IEEE 802.16 standard supports multiple physical (PHY) layers, each with unique characteristics. The Wireless MAN-SC (Single Carrier) PHY, for example, is designed for operation in the 10 to 60 GHz spectrum. Although IEEE has standardized this PHY, it is not widely implemented due to its requirement for line-of-sight (LoS) communication and its susceptibility to rain attenuation and multipath interference, which affect reliability at these high frequencies. Particularly in non-line-of-sight (NLoS) environments, the Orthogonal Frequency Division Multiplexing (OFDM) technology of the IEEE 802.16 standard leverages the sub-11 GHz spectrum to enable (NLoS) communication, hence improving WiMAX performance. Based on OFDM technology to enhance WiMAX reliability in congested areas (with high population density) In addition to, the presence of many obstacles such as high buildings, mountains, etc. by reducing interference from signal fading caused by reflections from building surfaces. which is achieved by distributing data across multiple parallel sub-waves. Additionally, the (OFDM)system improves spectral efficiency, allowing many available frequencies to be shared by a larger number of users without compromising quality of service (QoS). These features make it ideal for using challenging locations and enhancing WiMAX performance in terms of spectrum efficiency, reliability, and adaptability to changing conditions [14]. The PHY-layer is intended for stations with particular subscribers. Several profiles are used in the physical layer of WiMAX technology. The vast majority of WiMAX equipment available today uses this PHY. Many sub-subscribers utilized Time Division Multiple Access(TDMA) to distribute media in this PHY. The OFDM is a multi-band transmission system in which users have complete control over all sub-bands. the better to limit the number of sub-bands for mobile users since it allows the subscriber station to utilize more transmission capacity per sub-band while improving signal-to-noise-ratio(SNR). Orthogonal frequency division multiple access(OFDMA), often known as OFDM, is used in conjunction with time division multiple access and frequency[15][16][17]. The researchers used simulation tools such as OPNET to evaluate WiMAX (802.16e) performance of the throughput, Block Error Rate (BLER), and network load. According to studies, WiMAX is appropriate for broadband networks because of its rapid speeds, wide coverage, and high QoS capabilities. study reveals how network load and adaptive modulation impact performance, implying that WiMAX performs successfully under circumstances differently by enhancing QoS and using adaptive ways. [18]. WiMAX technology is ripe to suit the increasing request for high-speed internet access, particularly in places without wired infrastructure. WiMAX is based on the IEEE 802.16 standards, which enable high-speed wireless broadband access across large distances. "It provides a viable alternative to wired connections such as DSL and cable, and it has grown to incorporate both fixed and mobile applications, putting it on par with other technologies such as 3G and Wi-Fi, particularly in terms of coverage and connection speed". WiMAX uses cutting-edge technology such as "OFDMA (Orthogonal Frequency Division Multiple Access) and MIMO (Multiple-Input Multiple-Output)" to enhance spectrum efficiency and signal coverage, making it appropriate for urban and rural applications. WiMAX technology has played an important role in defining and certifying global standards to assure interoperability amongst WiMAX devices, hence driving wider use. WiMAX provides wider coverage and faster speeds than Wi-Fi and LTE (Long Term Evolution), making it a good alternative for regions that need fast and efficient internet access[19]. New wireless technologies such as WiMAX, 3G, and 4G have emerged as a result of horizontal communication system development. However, due to variations in frequency, protocols, and management, Wi-Fi and WiMAX cannot communicate directly. To enable communication across several technologies, this work provides a private synchronization system that properly synchronizes at the microsecond level using the CPU clock. A thin layer is added between the MAC and PHY layers to manage both systems' synchronization and coordination duties. [20]. A WiMAX system consists of three primary components: the subscriber station (SS), the relay station (RS), and the base station (BS). A BS can be connected to one or more nodes, which serve as subscriber units. A point-to-multipoint (P2MP) cell can be produced through the collaboration of base stations (BSs) and subscriber stations (SSs). The IEEE 802.16j standard enables multi-hop relay capabilities in WiMAX networks, which increases signal strength and reduces building-induced shadow fading. One of the primary areas of contemporary research is resource allocation. The use of directional antennas for resource allocation in IEEE 802.16j networks is investigated in this study. In response to user bandwidth requests, resources are modified via the proposed Dynamic Resource Allocation (DRA) method. The frequency of division is equal across sectors when compared to alternative methods[21][22]. The paper presents a compact reconfigurable patch array antenna specific for broadside and directional, solving the need for high data rates, interference resilience, and low bit error rates in modern wireless communication. The antenna achieves effective radiation patterns and adaptive beam steering for both directed and broadside applications by using a spiral feed construction and PIN diode switches. In terms of half-power beamwidth and spurious reduction, its small 100x100 mm design performs better than traditional antennas, operating at 2.37–2.41 GHz with a peak gain of 6.4 dB and 85.97% efficiency [23].

RESOURCE ALLOCATION ALGORITHMS

A. Determine the best path

The main base station (MBS) and relay stations (RS) use the algorithm described in Figure 1 for downlink communication, which is primarily responsible for delivering content, applications, and services to users. Downlink communication is the transfer of data from the base station (or another higher-level network element) to the mobile device or user equipment. It is an important component of communication systems because it directly affects the user experience by defining how quickly and reliably data can be transmitted. When a mobile phone requests contact with the base station, the base station returns the appropriate communication parameters to the subscriber, allowing the link to be created using the optimum path between them, as determined by the research algorithm. The specified base station serves as the principal node, commencing the process that uses the following equation as the focal point:

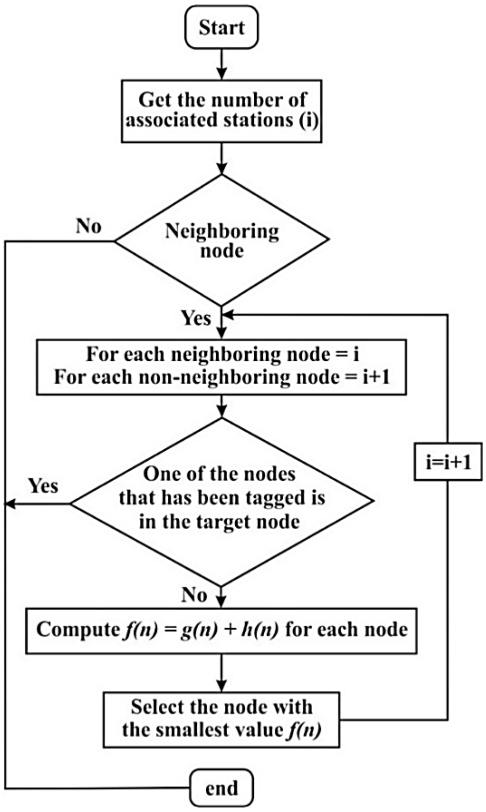
$$f(n) = g(n) + h(n)$$

Here, n represents the node number at the end of a path between two nodes, g(n) is the cumulative cost of the paths leading from the starting node to the node n , h(n) is a heuristic function that estimates the cost of the best path between node n and the target node. This heuristic is finely tuned to reflect key parameters, such as crowding or interference levels.

Resource Allocation: Effective downlink communication necessitates the best allocation of resources (e.g., time slots, bandwidth, and power) to ensure data transmission to users while minimizing interference and congestion. This is crucial for ensuring adequate network capacity, especially in crowded areas with several concurrent users.

b. Load-Balanced Algorithm

This mechanism limits the number of nodes (SS) that can connect to each node (RS) in the structure of the tree, hence spreading load evenly across the nodes. The goal of load distribution in WiMAX is to improve network stability and performance. The system distributes passing fairly between relay stations (RS) to reduce latency, eliminate crowding, and ensure equitable resource allocation. This strategy avoids overloading any single node, hence increasing dependability and reducing delays. It enhances energy efficiency and scalability, guaranteeing, that the network can manage increased traffic and extend while maintaining service quality. Thoroughly, the load distribution guarantees a high performance reliable, and efficient WiMAX network. Figure 2 shows the flowchart of a load-balancing algorithm for managing traffic through Relay Stations(RS) or access points (APs) in a network.



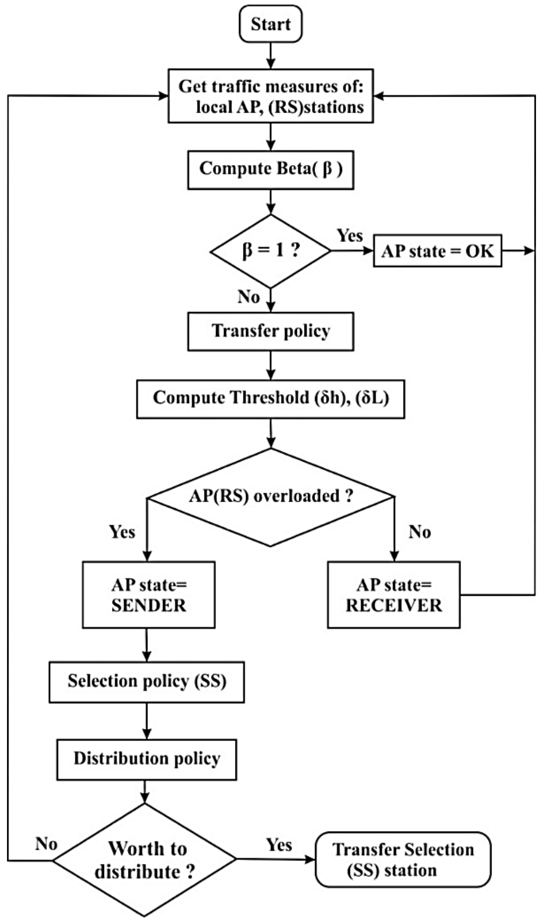


Figure 1. Flowchart of the Best Search Algorithm Figure 2: Flowchart of the Load-Balanced Algorithm (LBA)

The algorithm in Figure 2 allows any node of type (SS) to switch to the second node (RS) provided that it is located within the same hop-level, and is from the new node (RS) and vice versa. The proposed algorithm is implemented by the controller in several steps to ensure a balanced load distribution. This ensures optimal use of resource distribution, reduces congestion, and gives stability to the network.

First Step: Data Traffic Calculation and Balance Index

The initial step determines the data traffic value (Ti) for each relay station (RS), which is the sum of data traffic from all connected subscriber stations (SS) at that moment:

$$T_i = \sum_{j=1}^{m} T_{STAj}$$

where T_{STAj} represents the traffic from each connected SS.

Next, the balance coefficient or balance index (β) is calculated to measure load distribution:

$$\beta = {(\sum_{i=1}^{n} T_i)^2} / {n * \sum_{i=1}^{n} T_i^{\ 2}}$$

where Ti is the data traffic at RS station i, and n is the number of RS stations within the same hop level. The balance index β ranges from ($1/n - 1$), where a value of 1 indicates ideal load-distribution across RS stations. For example, if there are RS stations (n=5) with equal data traffic, β =1. However, if traffic is heavily loaded at one RS station (e.g.,$T1 >> T2, \ldots, T5$), β approaches the minimum value ($1/n$), indicating an imbalance. Balanced data traffic reduces congestion, thus enhancing network stability and performance.

B. Second Step: Threshold Calculation

The algorithm evaluates each RS station's load status relative to (average network load (ANL)) and predefined thresholds to decide if it needs to relinquish, accept, or maintain connections.

1. Average Network Load-(ANL): The average data traffic across RS stations at the same hop level:

$$ANL = {T_1 + T_2 + T_3 + \cdots}/{n}$$

2. Upper and Lower Thresholds (δh and δL): These thresholds define acceptable traffic ranges for balanced operations:

$$\delta h = ANL + \alpha * ANL$$

$$\delta L = ANL - \alpha * ANL$$

where α is a tolerance parameter that controls solution quality by adjusting the boundaries of the balance region. A higher α increases solution quality but can lead to more handovers, which may raise latency, affecting real-time applications.

Threshold Roles: Overloaded Stations: RS stations with traffic above δh must offload one or more SS connections to reduce their load.

Balanced Stations: Stations with traffic within the thresholds (($\delta L \leq Ti \leq \ \delta h$, δL≤Ti≤δh) accept only new SS connections but not transferred ones.

Underloaded Stations: Stations with traffic below δL can accept both new and transferred SS connections.

C. Third Step: Selection Policy for Load Transfer

This step calculates the traffic differential between the overloaded RS and the ANL to pick the optimal SS station candidate for transfer after recognizing an overloaded station.

$$\Delta = T_{Bs} - ANL$$

B_{cj} is computed based on the data traffic of the SS and Δ as follows:

$$B_{cj} = \left| T_{B_{cj}} - \Delta \right|$$

This reduces the difference in load distribution, as the station (SS) has a lower value than B_(cj) it represents the ideal transportation. The selection policy is influenced by ensuring the traffic is better routed while maintaining network performance by avoiding an undue load on any station RS.

D. Fourth Step: Distribution Policy

to compute a new balance index βnew, this stage enhances the effectiveness of the selection SS transfer. The system begins with the delivery procedure and confirms the transfer decision if β new > β old, where β new > β old is the pre-transfer index. This leads to the transfer operations, this helps to avoid the switching of the transfer between stations (SS) frequently to the congested relay station (RS), This leads to may cause instability and inefficiency.

CONTROL INTERFERENCE ALGORITHM

The channels are allocated as efficiently as possible using a specific interference control algorithm. This algorithm requests to optimize channel allocation by minimizing interference and balancing demand distribution across the network. The channel set is carefully chosen based on parameters that minimize interference, with low-pressure channels being used. This method reduces signal interference across active lines, improving communication reliability and quality, particularly in busy network conditions. The following are the primary repercussions of selecting the optimal choice of channels.

Reduce interference(To ensure that neighbouring stations can continue to operate properly, the algorithm prioritizes channels that do not interfere with other active stations). Improving network efficiency (In high-density locations where interference is widespread, optimising the channel selection procedure results in constant data transfer rates and significantly improved communication quality). Load balancing (The method seeks to alleviate congestion on a given channel by focusing on channels with low transmission traffic and limited usage, and then adds to the network's overall stability and efficiency by spreading data flows equally). Optimal resource utilization (The approach allows the network to use available spectrum resources more efficiently, resulting in increased overall capacity and throughput by selecting channels that are less susceptible to interference).

SIMULATION AND RESULTS

The multi-hop scenario was chosen for WiMAX networks because it improves coverage and signal quality while increasing capacity and energy efficiency. Multi-hop communications use relay stations to reduce the stress on the base station by increasing network range, decreasing interference and blockages, and assuring balanced traffic delivery. Additionally, this situation improves the network's scalability, allowing it to adapt to changing conditions, whether in terms of user density or support for varied applications such as disaster response or remote connectivity.

The efficacy of the proposed methods in increasing network performance metrics such as throughput, latency reduction, and load balancing may also be assessed by simulating a realistic environment representative of this scenario.

Simulation Scenario: Based on IEEE 802.16e, a Wi-MAX network's multi-hop scenario consists of seven subscriber stations, four relay stations, and one base station. The network model as shown in Figure 3 was created according to the IEEE 802.16e standard specifications. The simulation process was carried out following the application of the proposed algorithms to the network structure.

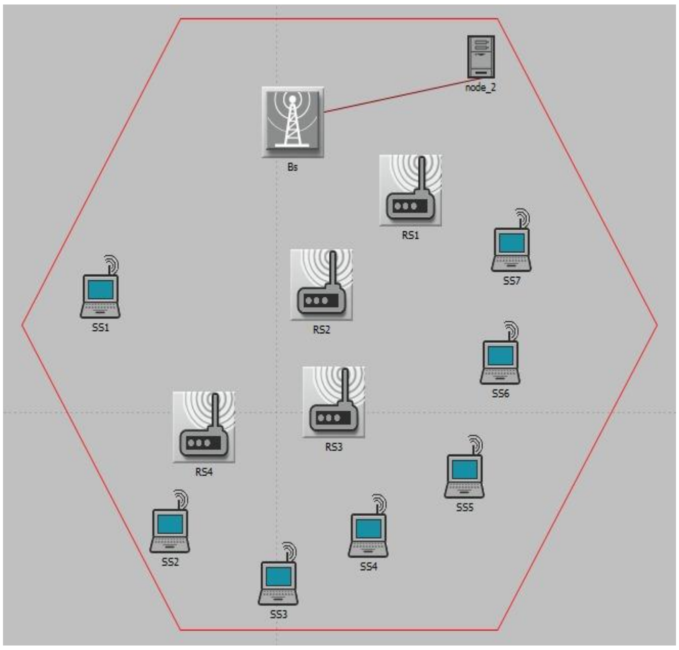


Figure 3. The Network model

1. Simulation Before Applying the Proposed Algorithms

The antennas provided by the 802.16e standard were used, which are omnidirectional antennas. The proposed algorithms were not integrated into the relay stations and base stations. Parameters were configured according to the IEEE standard, with the values specified in Table 1.

Table 1. Simulation Parameters

Parameter	Value
Request packet size (Bytes)	1500
Response packet size (Bytes)	500
Requests per second	10
Transport protocol	UDP
Frame duration (ms)	5
Symbol duration (μs)	100.8

BS transmitter power (W)	0.158
SS transmitter power (W)	0.1
Number of channels	5
Spectrum band (GHz)	5.0
Duplexing technique	TDD
Bandwidth of a channel (MHz)	20
UL/DL frame boundary	75 % UL / 25% DL
UL / DL usage mod	Pusc / Fusc

Figure 4 illustrates a multi-hop for WiMAX network scenario with one base station (BS), multiple subscriber stations (SS) and several relay stations (RS1, RS2, RS3, RS4): The relay stations extend the coverage area of the BS. They are used to relay data from the BS to more distant subscriber stations. The relay path from the BS goes through RS1, RS2, and RS3 to RS4, forming a multi-hop network.

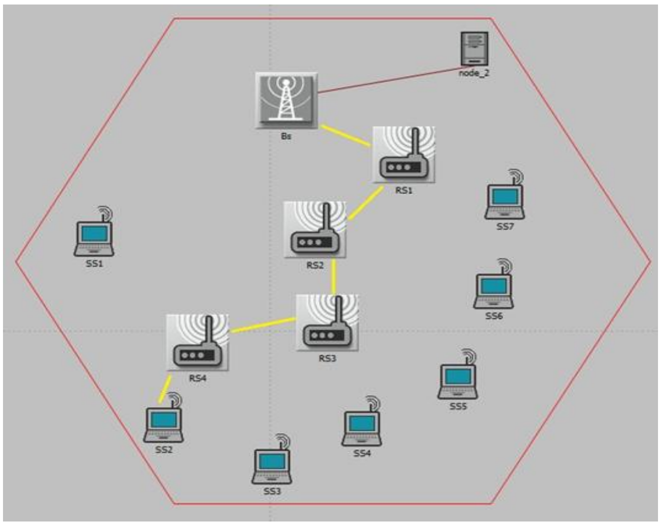


Figure 4. Scenario1 (The connection path between SS2 and BS)

Figures 5, and 6 present the results of a WiMAX network simulation conducted in OPNET over 15 minutes. The figure specifically shows the throughput performance, measured in bits per second (bps) and the average delay in the network. where the throughput rate rises sharply to approximately 450 kbps, accompanied by an increase in average delay over time. This rapid rise indicates that the network swiftly attains a steady-state condition shortly after the simulation begins. Once the throughput reaches this level, it stabilizes with minimal fluctuations, demonstrating consistent data transmission and effective network management.

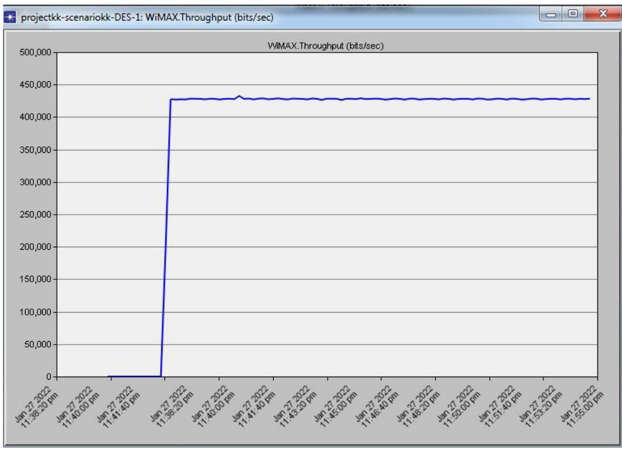


Figure 5. Throughput before applying the proposed algorithm

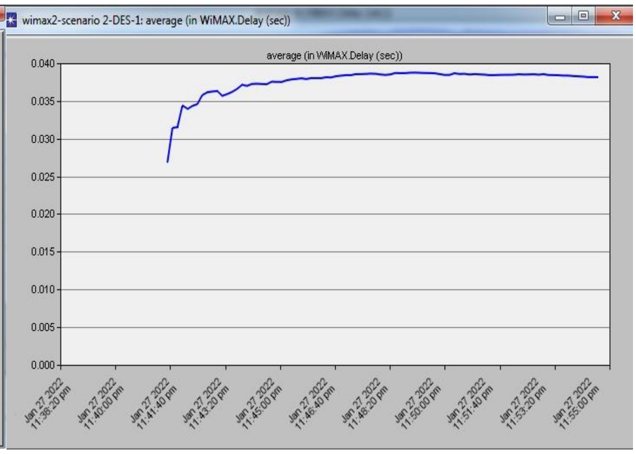


Figure 6. Delay before applying the proposed algorithm

2. Simulation After Applying the Proposed Algorithms

The proposed algorithm was applied to the network topology of a WiMAX multi-hop scenario illustrated in Figure 7. Directional antennas with a 45-degree beam width and a 20 dBi gain were installed in the base and relay stations. In the Figure, user devices are represented by a single Base Station (BS), four Relay Stations (RS1, RS2, RS3, RS4), and multiple Subscriber Stations (SS1 to SS7). The connecting path is established in a multi-hop manner through intermediate relay stations. The blue lines indicate the main communication path from the base station to (RS2, RS4, and SS2). The red lines represent alternate or auxiliary links to other SS devices via nearby RS nodes, indicating potential paths for load balancing or alternative routing.

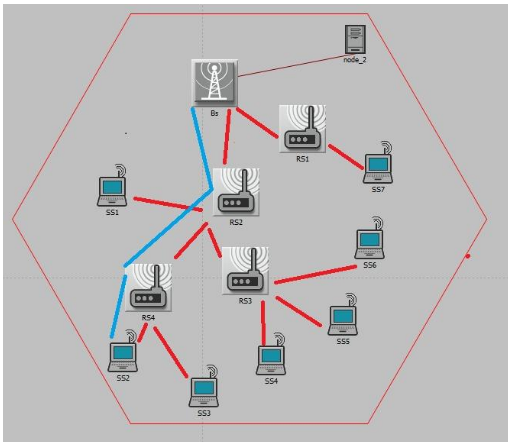


Figure 7. Scenario2 (Multi-hop WiMAX network with improved path selection)

Algorithm-Guided Path Selection: the suggested algorithm is used to configure the connections and relay paths in a way that maximizes load distribution and path selection throughout the network. Network resources are effectively managed by this method, particularly for SS devices that are the furthest away from the base station. After applying the proposed algorithm for Figure 7, the simulation results were conducted in OPNET over 15 minutes. The results showed the following:

Figure 8 illustrates that the throughput rapidly increases to around 580,000 bits/sec shortly after the simulation starts and stabilizes at this value. This indicates that once the network reaches its peak throughput, it maintains a stable transmission rate.

Figure 9 shows that the delay remains relatively constant at around 0.013 seconds throughout the measured period. This stability suggests that the network experiences minimal latency variations and maintains a low and consistent delay.

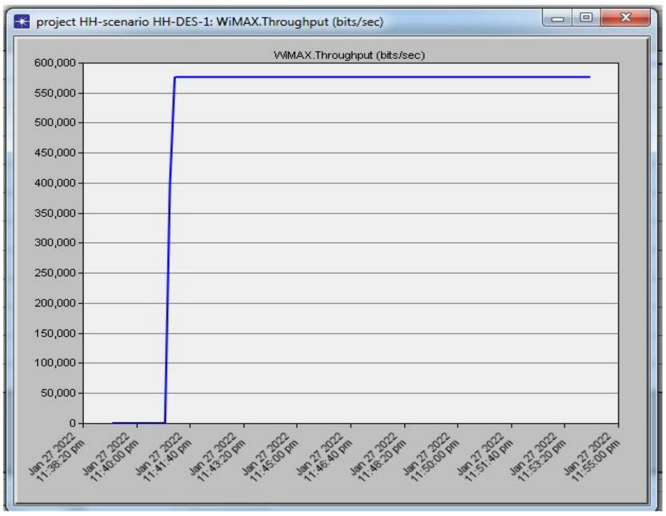


Figure 8. WiMAX Network Throughput Performance After Applying the Proposed Algorithm

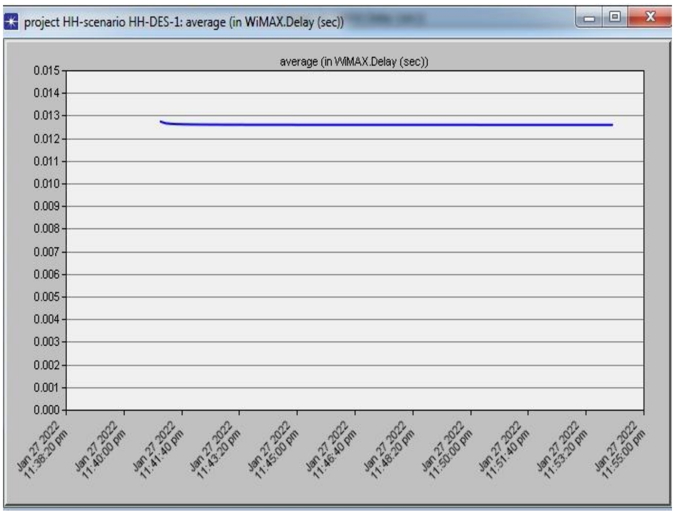


Figure 9. WiMAX Network Delay Stability After Applying the Proposed Algorithm

RESULT AND DISCUSSION

The simulation results before and after applying the proposed algorithm showed. figure 10 illustrates a comparison of throughput performance, the (scenario before applying the Algorithm) shows a rapid increase but stabilizes at a lower value of approximately 450 kbps. however, showing that the "scenario After Applying the Algorithm" achieves higher and more stable throughput than the " scenario Before Applying the Proposed Algorithm". the throughput rapidly increases to approximately 580 kbps within the first two minutes and then remains stable at this value for the rest of the simulation period. This demonstrates that the proposed algorithm significantly improves the performance of the network, it shows that throughput improved by over 130 kbps.

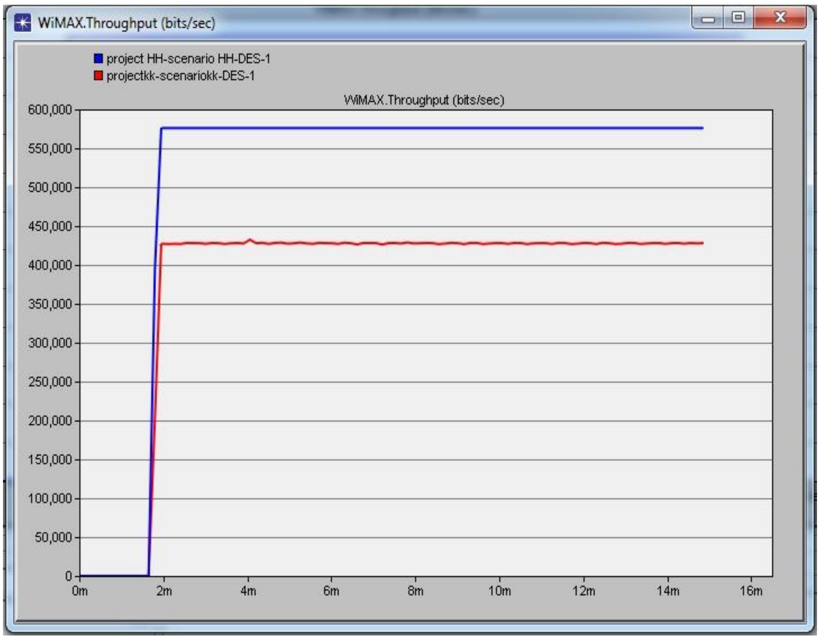


Figure 10. Throughput Performance Comparison Between Before and After Applying the Proposed Algorithm Scenarios in a WiMAX Network

Figure 11 compares the delay in a WiMAX network before and after applying the proposed algorithm. In the case of "Before Applying the Algorithm", the delay starts at a lower value but increases rapidly during the first two minutes of the simulation, stabilizing at approximately 0.035sec. In contrast, in the case of "After Applying the Algorithm", the delay remains consistently low at around 0.013sec throughout the simulation period.

Figure 11. Delay Performance Comparison Between Before and After Applying the Proposed Algorithm Scenarios in a WiMAX Network

Significant improvements were observed when applying the proposed algorithm and utilizing directional antennas, compared to the traditional design of WiMAX networks under the IEEE 802.16 standard. These improvements were achieved through increased throughput, reduced delay, and a reduction in the number of hops required for users to connect to the base station.

CONCLUSION

This study introduced innovative resource allocation and load-balancing algorithms integrated with directional antenna technology to enhance the performance of multi-hop WiMAX networks. The following results confirm the effectiveness of the proposed methods:

- Improved Throughput a 34% increase in data throughput demonstrates the efficiency of the algorithms in optimizing resource allocation and minimizing interference.
- Reduced Delay decreased by more than 26% after implementing the proposed solutions, enhancing the quality of service (QoS) and supporting real-time communications, such as VoIP.
- Load Balancing the proposed algorithms distributed traffic more effectively, reducing bottlenecks and improving network stability.
- Scalability and Efficiency the reduction in the number of hops required for user connectivity fosters scalability and minimizes interference.

Future studies can focus on using WiMAX networks in environments requiring wide coverage and low latency, such as rural regions or emergency communication networks. The proposed algorithms can work in real-world environments to evaluate their performance under practical conditions.

REFRENCES

[1] Alqaysi Manhal K., Behadili Suhad Faisal, Alqaysi M. K. and Behadili S. F. (2022). Gravity Model for Flow Migration Within Wireless Communication Networks. Journal of Science, 6310, (pp. 4474–4487). Iraqi.

[2] Ahson Syed, Ahson Mohammad Ilyas S.A., And Ilyas M. (2018). WiMAX: applications: CRC press.

[3] Yarali Abd., Rahman S. and Mbula B. (2008) WiMAX: The Innovative Broadband Wireless Access Technology. Journal of Communications.

[4] Meyyappan G., Govindan M., Chikkannan E. (2017). Dynamic Power Efficient Resource Allocation for 802.16 WiMAX Networks. International Journal of Intelligent Engineering and Systems. 10(4). 2017 DOI: 10.22266/ijies2017.0831.28

[5] Haeeder M. N., Mohammed A. H. and Ali A. A. (2023). WiMAX Network Design and Simulation for Middle Technical University Campus Using OPNET Modeler. Journal of Science. 64(12) (pp: 6586- 6595). Iraqi.

[6] Augustine A. and Georgethomas G. (2018). Advance Features and Mobility Management of Mobile WiMAX. International Innovative Research Journal of Engineering and Technology. 4(2). (pp. 17-21).

[7] Haider T. H. (2010). Wireless Communication using WiMAX technology. Journal of Engineering and Development, 14(3).

[8] Najah Abu N. A., & Hossam S. H. (2007). IEEE 802.16 standards and amendments. In WiMAX: Standards and Security (pp. 19-34). CRC Press.

[9] Adhicandra I. (2010). Measuring Data and VoIP Traffic in WiMAX Networks. Journal of Telecommunications.

[10] Anouari T., Haqiq A. (2012). Performance Analysis of VoIP Traffic in WiMAX using various Service Classes. International Journal of Computer Applications. (0975 – 8887). 52(20).

[11] Noorulden Basil, (2023), WITHDRAWN: Trajectory Path Calculated for WiMAX Network Implemented on High Coverage Area. Research Square, https://doi.org/10.21203/rs.3.rs-2478790/v1.

[12] Alfaisaly N. N., Naeem S. Q., Neama A.H. (2021). Enhancement of WiMAX networks using OPNET modeler platform. 23(3). (pp. 1510~1519).

[13] Nuaymi L. (2007). WiMAX: technology for broadband wireless access. John Wiley & Sons.

[14] Jakhar N., Kuldeep A., Vats and Suman (2014). OPNET based Performance Evaluation of WIMAX Network with WIMAX Management using Different QoS. IJCSMC3(6). (pp.862 – 872)

[15] Halepovic E., Ghaderi M. and Williamson C. (2009). Multimedia application performance on a WiMAX network. Proc. SPIE 7253. Multimedia Computing and Networking.

[16] Hammoshi, M. (2011). WiMAX Simulation Model to Investigate Performance Factors. Journal of Convergence Information Technology. 6(1). (pp. 266-276).

[17] So-In C., Jain R. and Al Tamimi A. (2010). Capacity Estimation of IEEE 802.16e Mobile WiMAX Networks. Hindawi Publishing Corporation Journal of Computer Systems, Networks, and Communications. Article ID 279807.
[18] Kamini J., Jyoti and Kuldeep V. (2014). Performance analysis of WiMAX (802.16e) on different-sized networks using OPNET. International Journal of Current Research, 6(6). (pp.7073-7076).
[19] yadav A., Mulik V. and Kasar M. (2023). Overview of WiMAX. Journal for basic sciences. 23(4).
[20] Ali Al-Sherbaz, Chris Adams & Sabah Jassim, (2008) Private Synchronization Technique for Heterogeneous Wireless Network (WiFi and WiMAX), Proceedings of SPIE - The International Society for Optical Engineering.
[21] Proceedings. Mobile Multimedia/Image Processing, Security, and Applications 2008. https://doi.org/10.1117/12.777580
[22] Wu1 J., Hwang W., Liang H. and Shieh C., (2011). Dynamic Resource Allocation of IEEE 802.16j Networks with Directional Antenna. IEEE 17th International Conference on Parallel and Distributed Systems. (pp 528-533).
[23] Jusoh M., Jamlos M. F., Kamarudin M. R., and Sabapathy T. (2013). A Reconfigurable WiMAX Antenna for Directional and Broadside Application. International Journal of Antennas and Propagation. 20.