PCMJ

Progress in Computer and Mathematics Journal (PCMJ)
volume 3 [November, 2025]
e-ISSN: 3030-6728
Website: fskmjebat.uitm.edu.my/pcmj

BANDWIDTH OPTIMIZATION IN MULTI-ACCESS POINT NETWORKS USING ADAPTIVE LOAD BALANCING BASED ON USER DISTRIBUTION

MUHAMMAD HAIQAL MOHD YAHYA
College of Computing, Informatics and Mathematics, Universiti Teknologi MARA,
2022753307@student.uitm.edu.my

NOOR ASHITAH ABU OTHMAN*
noor2106@uitm.edu.my

Article Info

Abstract

The research project "Bandwidth Optimization in Multi-Access Point Networks using Adaptive Load Balancing Based on User Distribution" establishes a dynamic bandwidth allocation system that depends on user numbers per access point (AP). The bandwidth distribution process will follow a ratio which splits 30% to AP1 and 70% to AP2 to achieve equitable resource distribution. The method works to solve wireless network bottlenecks along with fixing uneven bandwidth distribution. The project achieves its performance optimization through its implementation of weighted load balancing and dynamic bandwidth allocation methods. Network automation tasks run on Python but the web-based network data visualization relies on HTML. This system creates essential foundations that lead to improved bandwidth distribution stability in high-demand network environments through real-time monitoring and adaptive load balancing mechanisms.

Received: March 2025
Accepted: September 2025
Available Online: November 2025

Keywords: Bandwidth Allocation Based on the Number of Users

INTRODUCTION

The traditional methods of distributing fixed bandwidth often struggle to accommodate the evolving demands of modern, bandwidth-intensive applications (Alireza et al., 2021). This inadequacy results in either congestion or underutilization, ultimately diminishing the user experience and wasting resources. Therefore, to guarantee optimal resource utilization and quality of service (QoS) for end users, there is a pressing requirement for adaptive bandwidth allocation techniques capable of adjusting bandwidth distribution in real-time according to prevailing network conditions and application needs (Zhang et al., 2021). Employing an adaptive bandwidth access point system ensures a better environment for users due to its dynamic bandwidth allocation. For example, students in universities often rely on provided networks for assignments, but performance discrepancies occur when one user experiences faster access due to fewer users connected to the same access point (Jessica, 2022). This research aims to solve these issues and improve connectivity, especially in high density areas.

Problem Statement

In dynamic user environments, fluctuating connections make stable bandwidth distribution challenging. Traditional static methods are inefficient in adapting to real-time changes in user density and demand. Performance issues arise when users transition between access points, causing congestion, slow speeds, and unfair bandwidth distribution. An adaptive system is required to monitor and dynamically adjust bandwidth, ensuring balanced and efficient user experiences (Zhang & Wang, 2023). Current bandwidth allocation through access points instead of user numbers causes bottlenecks and hardware strain (Soudani et al., 2012). Overloaded access points slow down network speeds, increase latency, and risk long-term equipment damage. Implementing flexible bandwidth distribution helps manage traffic efficiently and ensures balanced access for all.

Objectives and Scope

This project addresses these issues by developing a real-time monitoring controller for dynamic bandwidth distribution among access points. Combining dynamic allocation with round-robin load balancing in a Peer-to-Peer Network optimizes performance, improves traffic distribution, and enhances user experience (Zhang & Wang, 2023). The project sets up a hierarchical wireless network, implements load balancing via a central controller, and compares performance metrics like latency and throughput with and without load balancing. The test bed includes five simulated users, representing typical small office or home environments. Cost-effective technology, including a laptop controller and access points, powers the implementation. The system dynamically allocates bandwidth based on user activities, ensuring fair distribution and efficient resource use.

Study Significance

The adaptive system minimizes bandwidth usage in crowded environments, preventing congestion and poor performance. It guarantees consistent connectivity by dynamically adjusting bandwidth during peak usage. This ensures reliable internet access, particularly in regions where connectivity is crucial. Finally, the system improves user experience by providing seamless Wi-Fi access, even in high-demand areas like computer labs and offices, ensuring smooth browsing, streaming, and work, with higher throughput and capacity.

LITERATURE REVIEW

This part represents the literature review section. It serves as a key section in a manuscript, summarizing past research and relevant studies that support the current work.

Network Set Up

A network setup refers to the arrangement and configuration of devices within a network to enable communication and resource sharing. This setup can follow different architectures, such as master-slave, where a central device (master) controls and manages other devices (slaves), or peer-to-peer, where devices communicate and share resources directly without a central controller.

Master-Slave Architecture

The master-slave architecture is a design where one central component (the master) controls and manages one or more subordinate components (the slaves). The master assigns tasks, coordinates operations, and oversees workflow, while the slaves carry out specific tasks and report back to the master. Commonly used in distributed systems, databases, and parallel computing, this architecture improves performance, ensures coordination, and balances workload by distributing responsibilities efficiently (Li & Ho, 2019).

Peer-to-Peer Architecture

The peer-to-peer (P2P) network architecture is a decentralized system where peers directly exchange resources and information without relying on a central server. Each peer shares equal responsibilities, acting as both client and server based on needs. Unlike client-server models, P2P networks allow fast resource distribution, efficient file transfers, and increased computational power and bandwidth by eliminating single points of control. Examples include BitTorrent for file sharing and Bitcoin for peer-verified transactions. P2P systems range from self-organized networks to more structured systems like Distributed Hash Tables (DHTs), supporting collaborative computing, content distribution, and decentralized decision-making (Hasimoto-Beltran, Lopez-Fuentes, & Vera-Lopez, 2019).

Comparison of Network Set Up

Table 1 Comparison of Network Set Up

Network Set Up	Characteristics	Advantages	Disadvantages
Master-Slave technique	**Architecture:** One master node in centralized control governs more than one slave node. **Communication:** such that the master node sends orders to the slave nodes, which in turn send information back. **Complexity:** It is easy to develop and oversee.	**Simplicity:** Easy to understand and implement. **Centralized Control:** Easier to manage and update the network from a single point. **Deterministic Behaviour:** Predictable and consistent performance	**Scalability:** Limited by the capacity of the master node, which can become a bottleneck. **Single Point of Failure:** If the master node fails, the entire system can be disrupted. **Limited Flexibility:** Less adaptable to dynamic network conditions

Peer-To-Peer Network Architecture	**Architecture:** It is a network where each node can serve both as a server and a client in a decentralized manner. **Communication:** There is no central controller in direct communication among peers. **Complexity:** It is more complex because of decentralized coordination and communication necessity.	**Scalability:** Highly scalable as each node contributes resources to the network. **Redundancy and Resilience:** No single point of failure; the network can adapt to node failures. **Resource Utilization:** Efficient utilization of network resources through direct peer-to-peer communication.	**Complexity:** More challenging to manage and coordinate, especially for tasks requiring centralized control. **Consistency:** Ensuring consistent network behaviour can be difficult in a fully decentralized system.

Load Balancing

Load balancing in network administration ensures that network traffic is distributed evenly across multiple access points, optimizing bandwidth usage and improving performance. It uses real-time data to allocate resources efficiently, reducing delays, preventing congestion, and enhancing system reliability. Strategies like bandwidth limiting, traffic shaping, and dynamic bandwidth allocation help the network adapt to changing user demands, ensuring a smooth and efficient connectivity experience (Arikuma & Kitano, 2021).

Weighted Round Robin Load Balancing

The Weighted Round Robin load balancing method distributes network traffic across multiple servers or access points (APs) based on their capacities, such as processing power, memory, or bandwidth. Unlike standard Round Robin, which treats all servers equally, Weighted Round Robin assigns different priorities or weights to each server or AP. Higher-capacity devices receive more traffic, ensuring efficient resource allocation for demanding tasks. This method enhances performance by preventing device overload, minimizing delays, and allowing networks to adapt to traffic changes without manual intervention (Ramesh Babu, 2023).

Least Connections Load Balancing

Least Connections load balancing distributes incoming network traffic by directing new connections to the server or access point (AP) with the fewest active connections. The load balancer continuously monitors active connections and dynamically allocates requests to prevent any single server or AP from becoming overloaded. This method improves system performance by minimizing bottlenecks, maximizing resource utilization, and ensuring even workload distribution. It is especially useful when traffic patterns fluctuate, offering scalability and resilience by automatically adapting to changing loads or server outages (Bhattacharya, 2022).

Comparison of Load Balancing Method

Table 2 Comparison of Load Balancing Method

Load Balancing	Description	Advantages	Disadvantages
Weighted Round Robin Load Balancing	An extension of Round Robin. Servers are assigned weights based on their capacity. Requests are distributed based on these weights.	More efficient than Round Robin for heterogeneous server environments. Allows for proportional distribution of requests according to server capabilities.	Still doesn't account for real-time server load or response times. Requires manual configuration of weights, which may need adjustments over time.
Least Connections Load Balancing	Distributes requests to the server with the fewest active connections. Aims to evenly distribute the load based on current server load.	Better load distribution than Round Robin in environments with variable request processing times. Adapts to real-time server load.	Can become inefficient if some connections are long-lived while others are short-lived. Does not account for server performance or response time directly

Bandwidth Management

Bandwidth management techniques refer to methods used to monitor, control, and optimize the distribution of network bandwidth among devices and applications. These techniques ensure efficient use of available bandwidth, prevent network congestion, and improve overall performance by prioritizing critical traffic, limiting non-essential usage, and dynamically allocating resources based on real-time demand. Common techniques include dynamic bandwidth allocation and traffic shaping, all aimed at providing a stable and reliable network experience.

Dynamic Bandwidth Allocation

Dynamic bandwidth allocation is a network management technique that adjusts bandwidth distribution in real time based on current usage patterns and operational needs. Unlike static allocation, which remains fixed until manually changed, this method continuously monitors network conditions, user activity, and application demands to dynamically direct bandwidth where it is most needed. It optimizes network performance by prioritizing critical applications during peak times, reducing delays, and preventing congestion. This approach enhances network flexibility and responsiveness, allowing administrators to efficiently manage resources and improve user satisfaction (Huang et al., 2019).

Traffic Shaping

Traffic shaping is a network management technique that controls data flow to improve efficiency and prevent congestion by regulating transmission rates based on policies or quality of service (QoS) parameters. It ensures fair bandwidth distribution among users and applications by prioritizing critical services like VoIP and video streaming while limiting less essential activities like file downloads. Traffic shaping helps prevent sudden data surges from overwhelming network capacity, maintaining stable performance and reliable, responsive network services even during high demand (Li et al., 2020).

Progress in Computer and Mathematics Journal (PCMJ)
volume 3 [November, 2025]
e-ISSN: 3030-6728
Website: fskmjebat.uitm.edu.my/pcmj

Comparison of Bandwidth Management

Table 3 Comparison of Bandwidth Management

Bandwidth Management	Description	Advantages	Disadvantages
Dynamic Bandwidth Allocation	Based on the current network circumstances and usage trends, the allocation of bandwidth to various users or apps is adjusted by the Dynamic Bandwidth Allocation in real time aiming at optimizing the general performance of a network through its continuous redistribution of bandwidth.	**Efficiency:** Maximizes the use of available bandwidth by reallocating it based on demand. **Flexibility:** Can adapt to changing network conditions and user requirements. **Fairness:** Ensures that all users get a fair share of bandwidth, especially in high-traffic scenarios.	**Complexity:** Requires sophisticated algorithms and real-time monitoring **Overhead:** May introduce additional processing overhead **Stability:** Frequent reallocation can cause fluctuations in network performance, which may not be ideal for certain applications.
Traffic shaping	Traffic shaping or Packet shaping refers to managing the data being sent and received within a network to establish an even and expected flow of traffic. Instead, certain forms of traffic are given precedence, and the quantity of bandwidth available for distinct applications is controlled.	**Predictability:** Provides consistent network performance by smoothing out traffic bursts. **Prioritization:** Ensures that critical applications **Control:** Allows network administrators to enforce policies and manage traffic effectively.	**Latency:** Can introduce delays, as traffic is held back to smooth out bursts. **Complex Configuration:** Requires careful planning and configuration to achieve desired outcomes. **Potential Inefficiency:** May lead to underutilization of available bandwidth if not properly configured.

Related Project

In this part, there will be a project or past work which is SDN-Based Load Balancing to compare them with this project.

SDN-Based Load Balancing

SDN-based load balancing for wireless networks improves network performance by separating the control plane, which makes decisions, from the data plane, which forwards traffic. SDN controllers manage dynamic wireless environments by monitoring network conditions and distributing resources based on current needs. This centralized approach optimizes resource utilization, reduces congestion, and enhances quality of service. It allows real-time adjustments, flexible scalability, and supports emerging technologies like 5G and IoT that require fast responses and efficient management (Adil et al., 2020).

Comparison of Related Project

Table 4 Comparison of Related Projects

Aspect	SDN-Based Load Balancing	Bandwidth Optimization in Multi-Access Point Networks using Adaptive Load Balancing Based on User Distribution
Goal	Centralized control of network traffic to reduce congestion and optimize performance.	Optimize bandwidth allocation and load balancing at access points (APs) based on real-time user demand.
Use of SDN	SDN controller manages resource allocation across network elements, such as APs and base stations.	Uses SDN to dynamically allocate bandwidth and balance load between APs in real-time.
Adaptive Bandwidth Allocation	Yes, resources are allocated based on current network state and traffic patterns.	Yes, dynamically adjusts AP bandwidth allocation based on user load and specific network requirements.
Focus on QoS	Indirect focus, QoS is enhanced through load balancing and congestion reduction.	Direct focus; seeks to maintain fair bandwidth allocation for optimal user experience and stable QoS in a high-traffic network.
Unique Features	Expands to multi-layered networks, managing various network elements beyond just APs.	Tailored for access point-based adaptive bandwidth, focused on user load and real-time network demands, suitable for IoT, 5G, and user-centric applications.
Application Areas	General wireless networks, 5G, IoT environments with varying traffic patterns.	Wireless environments with fluctuating user demand, AP-based load balancing for IoT, and adaptive services.

METHODOLOGY

There are six phases for completing the Bandwidth Optimization in Multi-Access Point Networks using Adaptive Load Balancing Based on User Distribution. Firstly, information gathering which is to research on the article that relates to the project. Secondly, planning which to Discover the hardware and software requirement. Thirdly, the design phase is to design the network setup, and the technique use. Fourth, development which implements the code into the hardware. Fifth, the testing phase is to test the success rate of the project. Lastly, the documentation phase is to compile the report.

The network set up used is peer-to-peer architecture which is suitable for this project to achieve its objectives. Next, the weighted round-robin load balancing is chosen as it is suitable to balance the load based on the number of users on its devices. The bandwidth management used for this project is dynamic bandwidth allocation which match the objectives of this project as its used a central controller to calculate and distribute the bandwidth.

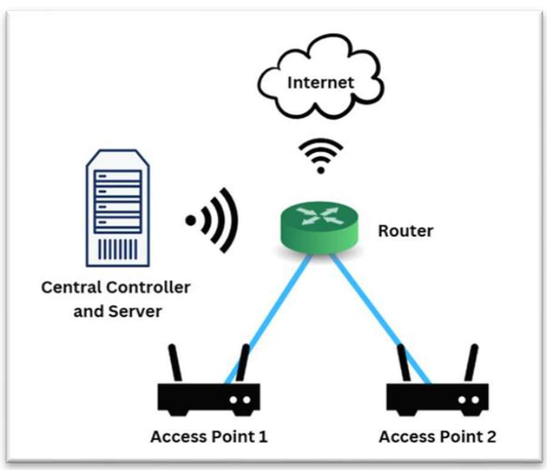

Figure 1 Peer-to-Peer Architecture

Figure 1 shows the physical diagram which used the peer-to-peer architecture network to make sure this project runs as its plan. Figure 2 shows the system flow of the project of how the central controller and the access point (AP) communicate to collect the number of users and how the calculation of the bandwidth distribution on each AP.

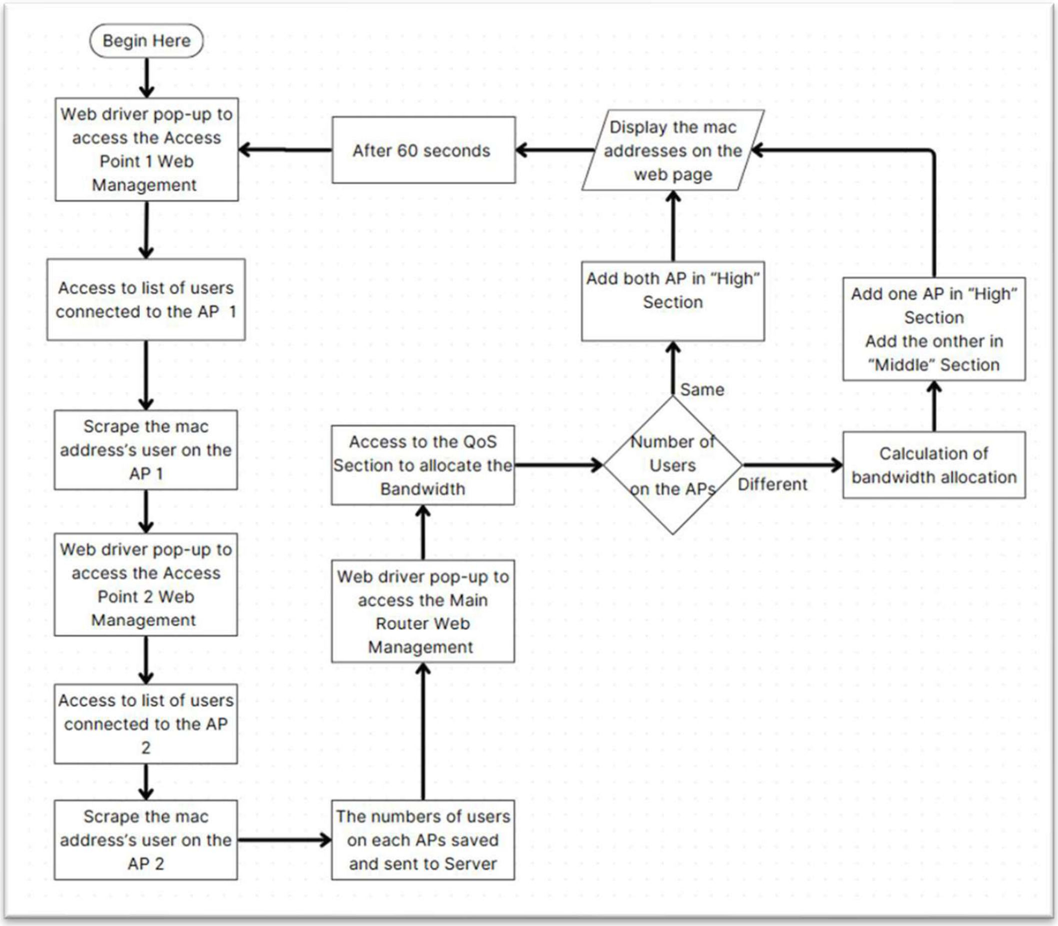

Figure 2 System Flow

RESULT AND DISCUSSION

The result of the load balancer test is discussed in this part. The latency and throughput are tested on testmy.net as it can test both parameters.

Table 5 Result of Test 1

Users Based on AP		AP1	AP2
		U1	U2, U3, U4, U5
Result	**Without Load Balancing**	The throughput of the users is not equal and have a huge difference	
	With Load Balancing	The throughput of the users is equal with a slight difference	

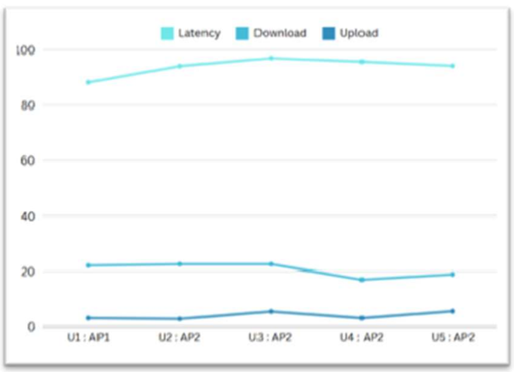

Figure 3 Before Load Balancing

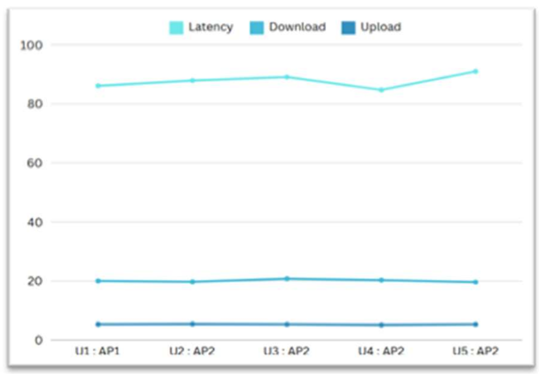

Figure 4 After Load Balancing

Table 6 Result of Test 2

Users based on AP		**AP1**	**AP2**
		U1, U2, U3, U4	U5
Result	**Without Load Balancing**	The throughput of the users is not equal and have a huge difference	
	With Load Balancing	The throughput of the users is equal with a slight difference	

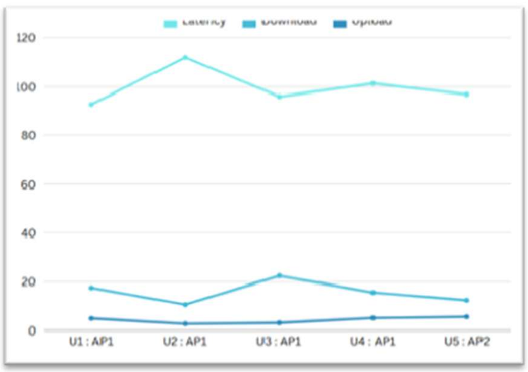

Figure 5 Before Load Balancing

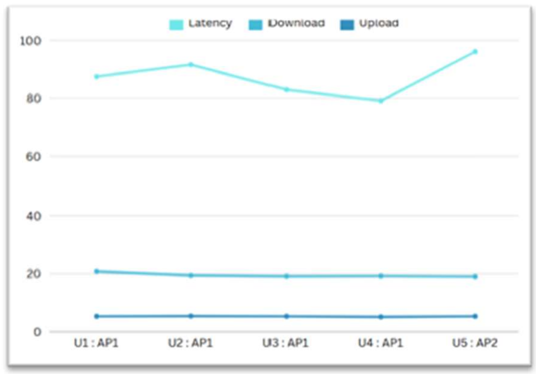

Figure 6 After Load Balancing

Table 6 Result of Test 3

Users Based on AP		**AP1**	**AP2**
		U1	U2
Result	**Without Load Balancing**	The throughput of the users is not equal and have a slight difference	
	With Load Balancing	The throughput of the users is equal	

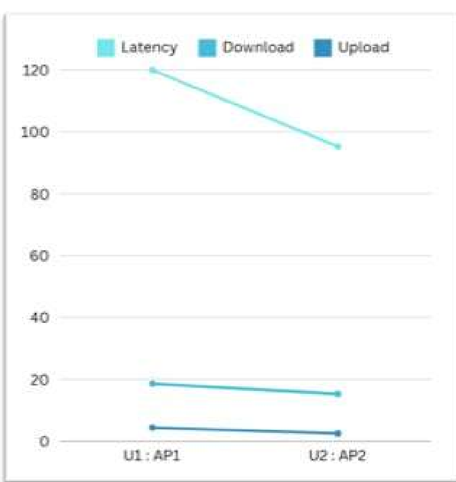

Figure 7 Before Load Balancing

Figure 8 After Load Balancing

Progress in Computer and Mathematics Journal (PCMJ)
volume 3 [November, 2025]
e-ISSN: 3030-6728
Website: fskmjebat.uitm.edu.my/pcmj

CONCLUSION

The Bandwidth Optimization in Multi-Access Point Networks using Adaptive Load Balancing Based on User Distribution led to satisfying results as it united advanced networking concepts between load balancing and dynamic bandwidth allocation. The combination of weighted load balancing with round-robin allocation distributed network bandwidth proportionally to current user numbers to maximize network operational effectiveness. Network performance became accessible in real-time through a central controller system that managed bandwidth and utilized Flask for server-side solutions to establish centralized control. The system demonstrated technical excellence through its ability to adapt to changing network conditions through its combined approach of multiple user data integration from different access points.

REFERENCES

Adil, M., Khan, R., Ali, J., Roh, B. H., Ta, Q. T. H., & Almaiah, M. A. (2020). Software-defined networking (SDN) for effective load balancing in wireless networks: A comprehensive survey. IEEE Access, 8, 190447-190467. https://doi.org/10.1109/ACCESS.2020.3036776

Alireza, Mojahed., Lawrence, A., Bergman., Alexander, F., Vakakis. (2021). Generalization of the Concept of Bandwidth. arXiv: General Physics

Arikuma, Takeshi., Kitano, Takatoshi. (2021). Load balancing system, load balancing device, load balancing method, and computer-readable medium.

Huang, L., Feng, X., Zhang, C., Qian, L., & Wu, Y. (2019). Deep reinforcement learning-based joint task offloading and bandwidth allocation for multi-user mobile edge computing. *Digital Communications and Networks*, *5*(1), 10-17.

Hasimoto-Beltran, R., Lopez-Fuentes, F. D. A., & Vera-Lopez, M. (2019). Hierarchical P2P architecture for efficient content distribution. *Peer-to-Peer networking and applications*, *12*, 724-739.

Jessica, Keiser. (2022). WiFi at University: A Better Balance between Education Activity and Distraction Activity Needed.. Computers and education open, doi: 10.1016/j.caeo.2021.100071

Li, J., Xue, K., Wei, D. S., Liu, J., & Zhang, Y. (2020). Energy efficiency and traffic offloading optimization in integrated satellite/terrestrial radio access networks. *IEEE Transactions on Wireless Communications*, *19*(4), 2367-2381.

Li, D., & Ho, C. N. M. (2019). A delay-tolerable master–slave current-sharing control scheme for parallel-operated interfacing inverters with low-bandwidth communication. *IEEE Transactions on Industry Applications*, *56*(2), 1575-1586.

Soudani, A., Divoux, T., & Tourki, R. (2012). Data traffic load balancing and QoS in IEEE 802.11 network: Experimental study of the signal strength effect.

Zhang, Y., & Wang, X. (2023). Adaptive Bandwidth Allocation in Dynamic Wireless Networks. *IEEE Transactions on Wireless Communications*, 22(3), 1500-1512.

Zhang, S., Wang, C., Jin, Y., Wu, J., Qian, Z., Xiao, M., & Lu, S. (2021). Adaptive configuration selection and bandwidth allocation for edge-based video analytics. *IEEE/ACM Transactions on Networking*, *30*(1), 285-298.