Proceedings of the 5th International Conference on Signal Processing and Machine Learning
DOI: 10.54254/2755-2721/134/2025.22209

Research on Optimizing Wireless Mesh Networks for High Throughput, Large Scale Data Streaming Applications

Zhaotong Wang[1], Haokun Liu[2*], Xiaolu Zhou[3]

[1]*Shanghai United International School Gubei, Shanghai, China*
[2]*Xidian University, Xi'an, China*
[3]*Santa Monica College, California, USA*
**Corresponding Author. Email: 1587616970@qq.com*

Abstract: This paper explores methods for optimizing Wireless Mesh Networks (WMNs), with the primary goal of improving throughput and conducting simulation work to evaluate the effectiveness of wireless mesh networks compared to star topology networks in large-scale data stream applications. With the rapid development of wireless camera technology, the limitations of traditional wired cameras have become increasingly evident, while wireless cameras offer significant advantages in layout flexibility and installation complexity. This study analyzes how to achieve the maximum number of simultaneous streaming device connections by improving network architecture, routing algorithms, and optimization techniques. At the same time, it assesses the advantages of wireless mesh networks, particularly in application scenarios such as smart cities, industrial automation, and large-scale video surveillance systems. The research also points out that although WMNs have good scalability, they still face challenges such as interference, signal attenuation, network congestion, and latency. This study provides important references for future technological innovations and network optimizations.

Keywords: Wireless Mesh Networks, Throughput Optimization, Routing Algorithms, Data Streaming Applications

1. Introduction

Within modern society, there is an increased popularity in the usage of streaming devices, ranging from home surveillance cameras to smart home devices. in order to sustain these devices, the role of networks has become increasingly important. Flexible and scalable network solutions, Wireless mesh networks (WMNs) are beneficial in wireless networks with a large number of devices compared to traditional wired networks, providing more connection possibilities for streaming devices. In order to achieve the maximum number of simultaneous streaming devices in a mesh network, in-depth research and improvement of network architecture, routing algorithms, and optimization techniques are required. This article will explore the methods to optimize mesh networks to achieve the maximum number of simultaneous streaming devices, along with an analytical evaluation regarding the benefits of using a wireless mesh network compared to commonly seen Star topology networks.

Wireless camera technology started to rapidly advance with the transition from traditional analogue cameras to modern-day digital cameras. The advantage of digital data is that signals can not only be sent long distances over the wire but also transmitted wirelessly. Wired digital cameras yield significant limitations as they require both power and signal to be transmitted over wire, increasing the complexity of their installation process, as well as limiting their layout flexibility. Wireless cameras mitigate these disadvantages as they do not require a wired data connection and can even operate on battery power. Wireless cameras have demonstrated increasing popularity within various scenarios, including smart homes, commercial security systems, and public monitoring. These wireless cameras usually rely on central processing nodes or databases to complete artificial intelligence-related tasks such as image recognition and real-time analysis.

Wireless mesh networks have an advantage over star networks as they are able to dynamically route devices [1], use neighbouring devices as relays and aggregate data, making the network more flexible and scalable, increasing the spatial coverage of the network as well as increasing the efficiency of data transmission [2]. Wireless mesh networks are particularly suitable for applications that require a large number of devices to be connected, such as smart cities, industrial automation, and large-scale video monitoring systems.

Although wireless mesh networks perform well in many applications, there are still some challenges in practical applications. Interference and attenuation of wireless signals may affect the performance of the network, and network performance is limited by factors such as node layout, transmission range, and bandwidth limitations, which may lead to network congestion, packet loss, and increased latency, thereby affecting the use of streaming media devices. Load balancing has been a significant advancement, increasing the total throughput of the WMN, as compiled within the paper [3]. Various methods for load balancing have been researched, for instance, using a greedy algorithm, clustering network nodes and gateway load balancing algorithms.

ETX (Expected Transmission Count) and ETT (Expected Transmission Time) are also widely used. These routing metrics optimize route selection by evaluating the expected transmission count as well as transmission time. [4] WCETT (Weighted Cumulative Expected Transmission Time) builds on top of ETT, using weights to account for adjacent channel interference; further research also incorporated Load balancing WCETT-LB [5] and achieving increased throughput, but it is computationally complex and requires performance overheads.

Li, Jilong [6] proposed a clustering-based routing algorithm that groups nodes through clustering technology and forms a structure in which each member node is one hop away, reducing routing overhead and improving transmission efficiency. When optimizing wireless mesh networks to support the maximum number of simultaneous streaming devices, a comprehensive model needs to be established to consider various factors. The main optimization strategies include determining the ratio between relays and nodes, reasonably selecting relays to which nodes are connected, and calculating the packet loss rate and throughput of the network. Dynamic routing algorithms can consider relay load, distance to relays, and the number of hops each node passes. By comprehensively considering these factors, the optimal network configuration can be found.

Evaluating the performance of the system requires the use of specific calculation methods to analyze the probability of packet loss and throughput. By using tools such as Python, the probability of packet loss in each connection can be calculated, taking into account the bit error rate and packet length of the protocol used. Throughput is calculated by dividing the amount of data successfully sent by the time required, which depends on the number of shops and the amount of packet loss. Generating graphs to visualize the impact of each parameter on network performance can help determine the impact of different parameters on network performance and thus optimize the network configuration.

2. Simulation Initialization

Wireless mesh network routed with the ETT metric using centralized routing with Dijkstra's algorithm is compared to a similar system routed using the star topology.

Table 1: Simulation Parameters

Parameter	**Value**	**Description**
WiFi Standard	802. 11ax (WiFi 6)	WiFi standard
Modulation Scheme	256-QAM	Quadrature Amplitude Modulation with 256 levels
Area Size	100 units	The size of the simulated area where devices are distributed.
Base Station Position	Centered	The base station is positioned at the center of the simulation area.
Frequency	2.4 GHz	The operating frequency of the wireless network, common for WiFi devices.
Transmit Power	20 dBm	The power level at which devices transmit signals.
Noise Floor	-100 dBm	The level of background noise in the environment.
Bandwidth	20 MHz	The width of the frequency band used for transmission, affecting data rates.
Stream Rate	4 Mbps	The target data rate for each streaming device.
Path Loss Exponent	3.5	A factor indicating the rate of signal degradation in an obstructed environment.
Reference Distance	1 meter	The distance at which the reference path loss is measured.
Reference Path Loss	20 dB	The signal loss measured at the reference distance.
Throughput Threshold	0.5 Mbps	The minimum acceptable data rate for a connection to be considered effective.
Packet Size	1500 * 8 bits (1500 bytes)	The size of each data packet transmitted in the network affects transmission efficiency.

Table 1 lists the simulation parameters and their descriptions, which are used to simulate the performance of wireless AD hoc networks to evaluate the effectiveness of different routing algorithms.

ETT of the routes is calculated by:

$$\mathrm{ETT} = \frac{\text{Packet Size}}{\text{Link Speed (throughput)}} \times \text{Expected Number of Transmissions}$$

Which depends on the Link speed and Expected number of Transmissions (ETX):

$$\text{Link Speed (bps)=bandwidth} \times \log_2(1 + \mathrm{SINR})$$

$$\mathrm{SINR} = \frac{\text{signal\_power}}{\text{interference\_power} + \text{noise\_power}}$$

Which rely on the positional data of the devices and calculates the co-channel interference, as well as the path loss within a route:

$$\text{Interference Power (mW)} = \sum_{\text{transmitter}\neq\text{receiver}} 10^{\left(\frac{\text{transmit power}-\text{path\_loss}}{10}\right)}$$

$$\text{Path Loss (dB)} = \text{reference path loss} + 10 \times \text{path loss exponent} \times \log_{10}\left(\frac{\text{distance}}{\text{reference distance}}\right)$$

$$\text{Expected Number of Transmissions} = \frac{1}{1 - \text{Packetloss Probability}}$$

$$\text{Packetloss Probability} = 1 - (1 - \text{BER})^{\text{Packetsize}}$$

$$\text{BER} \approx \frac{3}{510} \cdot \text{erfc}\left(\sqrt{\frac{SNR}{170}}\right)$$

3. Algorithms Analyzed

The Star topology links every device spread within the area to the central base station without any device relaying. This method does not rely on any device processing to determine its route, which decreases latency. The simulation is conducted in an environment with-100dB of noise as a noise floor. It uses the 256 QAM modulation scheme and operates within a 20MHz band of 2.56GHZ WIFI 6. The base station is simulated to reside in the middle of the area, as well as the streamed packet size of the video feed is 1500 bytes. The stream rate of each device attempts to achieve 4Mbps and an exiting throughput threshold of falling below 0.5mbps. The ETT metric is calculated on the device for every other device in the network and connects to the device with the shortest result. For simulation purposes, The network was modelled by calculating ETT for all the possible routes between the devices, then by using Dijkstra's algorithm and ETT as an input weight, was able to determine the shortest routes between the devices.

The algorithm is repeated each time with n+1 devices, calculating routes and the summation of the wireless connections. This is done for both simulations, star topology and mesh network, to gauge their throughput performance.

4. Analysis Evaluation

A plot of the total number of devices within the network against their respective sum of throughputs is generated using the Python library Matplotlib

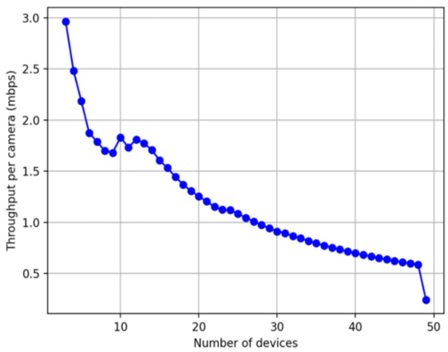

Figure 1: Direct connection of cameras to base station

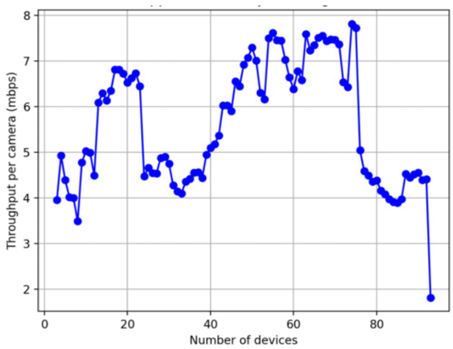

Figure 2: ETT approach with Dijkstra algorithm

Figure 1 shows how the throughput changes after each device is directly connected to the base station in a star topology. The horizontal coordinate represents the number of devices, and the vertical coordinate represents the total throughput.

Figure 2 shows the performance in a wireless routing network using ETT (expected transit time) metrics and Dijkstra's algorithm. The horizontal coordinate represents the number of devices, and the vertical coordinate represents the total throughput. The Simulation results show that a mesh network routed with ETT outperforms a network with star topology. by a significant margin. Within the network routed with ETT, the throughput slightly increases with the addition of the first 70 devices at less than 8mbps, whereas the network with star topology falls below the threshold at just slightly less than 50 devices. This aligns with the findings of the peer-reviewed papers, showing that mesh networks are more scalable as they can self-organize and route a number of short networks efficiently, compared to the star network, which may yield high congestion near the base station as every route is attempting to connect to that one device at the same time.

5. Conclusion

Optimizing wireless mesh networks requires not only technological innovation but also in-depth analysis of actual application scenarios. Future research can further explore more efficient algorithms and optimization methods to meet the growing demand for streaming devices and improve the overall performance of the network. In short, optimizing wireless mesh networks to support the maximum number of simultaneous streaming devices is a complex and important task. By comprehensively considering technological developments, deficiencies in existing technologies, improvement methods, and evaluation methods, significant improvements in network performance can be achieved to provide better support for streaming devices.

References

[1] *Naghian, S. "Mesh vs Point-To-Multipoint Topology: A Coverage and Spectrum Efficiency Comparison." 2004 IEEE 15th International Symposium on Personal, Indoor and Mobile Radio Communications (IEEE Cat. No.04TH8754), https://doi.org/10. 1109/pimrc.2004.1373858. Accessed 20 Sept. 2022.*

[2] *Shrestha, A., and Liudong Xing. A Performance Comparison of Different Topologies for Wireless Sensor Networks. May 2007, https:/doi.org/10. 1109/ths.2007.370059.*

[3] *Das, Banani, and Sudipta Roy. "Load Balancing Techniques for Wireless Mesh Networks: A Survey." IEEE Xplore, 1 Aug. 2013, pp. 247–53, https:/doi.org/10. 1109/ISCBI.2013.57. Accessed 11 Sept. 2023.*

[4] *Javaid, Nadeem, et al. "Performance Study of ETX Based Wireless Routing Metrics." ArXiv (Cornell University), Cornell University, Feb. 2009, https:/doi.org/10.1109/ic4.2009.4909163. Accessed 12 Mar. 2024.*

[5] *Ma, Liang, and Mieso K. Denko. "A Routing Metric for Load-Balancing in Wireless Mesh Networks." IEEE Xplore, vol. 2, 1 May 2007, pp. 409–14, https://doi.org/10. 1109/AINAW.2007.50.*

[6] *Li, Jilong, et al. "A Clustering Based Routing Algorithm in IoTAware Wireless Mesh Networks." Sustainable Cities and Society, vol. 40, July 2018, pp. 657–66, https://doi.org/10.1016/j.scs.2018.02.017.*