Evaluating the Limits of Wi-Fi 5, and Wi-Fi 6 Networks for Industrial Video Applications

Jefferson M. O. das Mercês[1,2], José Silvestre da S. Galvão[1,2], Mikael M. Oliveira[1], Ruan D. Gomes[1,2], Marcelo P. Sousa[1] and Moacy Pereira da Silva[1]

[1]Instituto Federal de Educação, Ciência e Tecnologia da Paraíba (IFPB)

[2]Programa de Pós-Graduação em Tecnologia da Informação (PPGTI)

{jefferson.maxmiliano, jose.galvao, mikael.oliveira, ruan.gomes marcelo.portela, moacy.silva}@assert.ifpb.edu.br

Abstract. *This study evaluates the performance of Wi-Fi 5 and Wi-Fi 6 wireless networks, comparing them to a wired network. The analyzed metrics include throughput and packet loss. The tests were conducted in a controlled environment with 13 clients connected to an AP (Access Point), transmitting data corresponding to a video stream at varying resolutions. The results show that Wi-Fi 6 offers better performance, especially in scenarios with multiple devices, while Wi-Fi 5 presents limitations at higher resolutions. The wired network consistently demonstrated the highest stability, with limitations in higher resolution transmissions.*

1. Introduction

The Wi-Fi 6 (802.11ax) standard introduces significant improvements over its predecessor, Wi-Fi 5 (IEEE 802.11ac), addressing growing connectivity demands in high-density environments and real-time applications such as online gaming and high-resolution video streaming [Tokhirov, Ezozbek and Aliev, Ravshan 2023]. Furthermore, these improvements are relevant in the industrial context, where reliable and high-performance connectivity is crucial for operational efficiency and process automation [Fernandes et al. 2021]. However, although Wi-Fi offers greater operational flexibility, it does not guarantee the same level of reliability, stability, and high transmission rate provided by wired networks. Thus, despite the mentioned advances in wireless network standards, wired networks remain an essential part of infrastructure.

To enhance the analysis of Wi-Fi 5, Wi-Fi 6, and wired networking technologies within the context of computer vision applications, a testbed was constructed to independently assess each technology and compare their functionalities in various scenarios. Metrics such as throughput and packet loss ratio were analyzed. Those metrics are important in determining whether the applications used in Industry 4.0 can operate efficiently with each technology. This study aims to assist in decision-making regarding network implementation and optimization, ensuring effective and reliable connectivity in industrial environments. For the experiments, network traffic was generated from multiple clients using data rates corresponding to MJPEG (Motion JPEG) encoded video transmissions at different resolutions [Neto et al. 2024]. The network performance was evaluated for different channel widths, for both Wi-Fi 5 and Wi-Fi 6 networks. The transport layer protocol used was UDP (User Datagram Protocol).

This work was developed in the context of the EDGE 5G project, which is funded through a consortium of companies and EMBRAPII, aiming at developing and evaluating case studies for Industry 4.0 using private 5G networks and edge computing. Studies about other wireless technologies are important to understand the potential of using multiple network technologies in conjunction with 5G networks to meet the requirements of different industrial applications in a cost-effective manner.

2. Related Work

The article [Tokhirov, Ezozbek and Aliev, Ravshan 2023] explores the key innovations introduced by Wi-Fi 6 compared to its predecessor, Wi-Fi 5. The authors highlight that while Wi-Fi 5 still meets many organizational needs, Wi-Fi 6 offers significant improvements, such as MU-MIMO (Multiple User Multiple Input Multiple Output) technology, which enables simultaneous communication with multiple devices in both uplink and downlink directions. Although the article does not include any experiments on wireless technologies, it adds value to the research by presenting the similarities, advances, and features of the technologies.

The study in [Suer et al. 2022] conducted an experimental analysis of latency and reliability in Wi-Fi 5 and Wi-Fi 6 to assess the performance improvements of Wi-Fi 6. It examined periodic traffic patterns typical of industrial applications, evaluating uplink and downlink performance using OFDMA (Orthogonal Frequency Division Multiple Access). In addition, the impact of competing network traffic and varying signal levels was analyzed. The results indicated that Wi-Fi 6 can reduce latency compared to Wi-Fi 5, particularly in the uplink direction, as the number of users increases, highlighting its potential advantages in high-density environments.

A study in [Rady et al. 2024] evaluated Wi-Fi 6, 5, and 4 for robotic applications in shipyards with RF (Radio Frequency) interference and metal obstructions. Three parallel applications were tested: high-throughput streaming, real-time control via ROS (Robot Operating System), and clock synchronization with PTP (Precision Time Protocol). The results revealed that certain PHY configurations can make older Wi-Fi generations outperform Wi-Fi 6, highlighting trade-offs in channel width, transfer rate, and latency, which motivated further research on multi-PHY adaptation for industrial robotics.

Unlike previous works, we evaluated the performance in simultaneous video transmission at various resolutions, emphasizing limitations for Industry 4.0 applications. The inclusion of a wired network as a benchmark improves the relevance of the study for the deployment and performance assessment of Wi-Fi 5 and Wi-Fi 6 networks.

3. Experiment Methodology

The experimental study was conducted using 14 computers, one of them acting as a server. Figure 1 shows the architecture used in the testbed, where the server is connected to the AX 3600 EAP660 HD AP via an *Ethernet* connection, while clients are connected via Wi-Fi using the 5.8 GHz frequency band. To evaluate the performance of the wired network, a Huawei S5735-L48T4X-A1[1] switch is used to connect the computers through Cat 6 UTP cables (Unshielded Twisted Pair).

[1]https://support.huawei.com/enterprise/en/doc/EDOC1000013597/417a72d5/s5735-l48t4x-a1

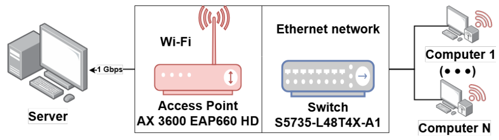


Figure 1. Architecture of the testbed to evaluate the Wi-Fi and Ethernet networks.

Table 1. Bitrates required for different video resolutions used in the experiment

Name	Video Resolution (px)	Bitrate (Mbps)
VGA (*Video Graphics Array*)	640 x 480	2.54
WVGA (*Wide Video Graphics Array*)	800 x 480	3.83
XGA (*Extended Graphics Array*)	1024 x 768	5.52
HD (*High Definition*)	1280 x 720	8.03
UXGA (*Ultra Extended Graphics Array*)	1600 x 1200	12.67
FHD (*Full High Definition*)	1920 x 1080	19.09
QUADHD (*Quad High Definition*)	2560 x 1440	109.84
DCI 4K (*Digital Cinema Initiatives 4K*)	4096 x 2160	185.02

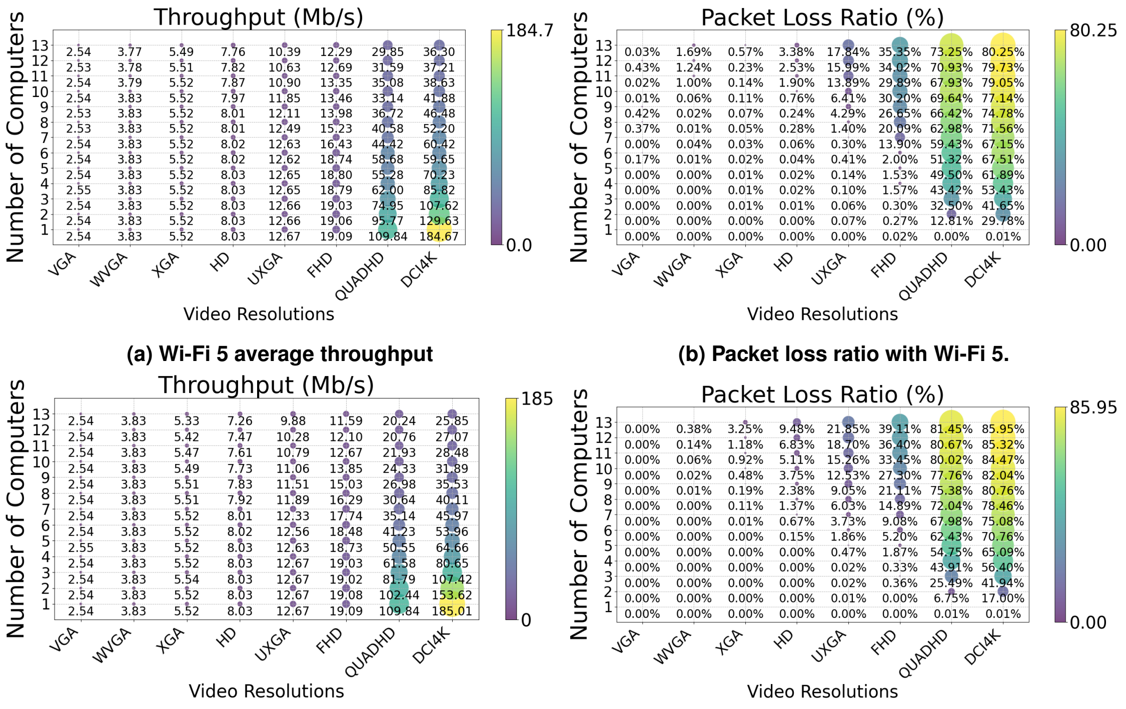
All tests were conducted on local networks without Internet access, eliminating external bandwidth competition. In the wireless network scenario, the computers and the AP were deployed to ensure a signal strength between -36 dBm and -55 dBm. The access point used allowed the channel width to vary between 20 MHz and 80 MHz, depending on the test, for both Wi-Fi 5 and Wi-Fi 6. Initially, a single client was responsible for server traffic generation. Each testing session was conducted for 5 minutes before stopping and adding an additional client, resulting in two clients concurrently transmitting data. This process continued until 13 clients were simultaneously transmitting data to the server.

Two programs in C language were developed to implement the experiment. The first, executed on the server, is responsible for configuring the logical ports for communication with the clients and saving the collected data in a CSV file (Comma-Separated Values). The second, executed on the clients, generates UDP traffic directed to the server at a constant bitrate, allowing the measurement of parameters such as throughput and packet loss ratio on the server.

A shell script was created to automate the experiment. Once the server is configured, a Python script establishes SSH connections to clients to initiate their code. The bitrates considered for the experiment are based on video transmission requirements for various resolutions, and were derived from encoding a 28 FPS (Frames per Second) MJPEG video stream, as detailed in Table 1 [Neto et al. 2024]. At the end of the experiments, the collected data were processed and analyzed using Python scripts. Graphs were generated to visualize and compare metrics such as throughput and packet loss ratio. Those graphical representations facilitated the interpretation of the results and enabled a detailed analysis of the performance of the tested networks, highlighting the differences between the evaluated technologies.

4. Results

Figure 2 shows the average throughput and the packet loss ratio for Wi-Fi 5 and Wi-Fi 6 with a channel width of 20 MHz for all combinations between the number of computers and the video resolutions. The video resolutions are represented on the X-axis (the bitrate for each resolution is shown in Table 1), while the number of computers used in the experiments is represented on the Y-axis. The bubbles represent the averages obtained in



(a) Wi-Fi 5 average throughput

(b) Packet loss ratio with Wi-Fi 5.

(c) Wi-Fi 6 average throughput

(d) Packet loss ratio with Wi-Fi 6.

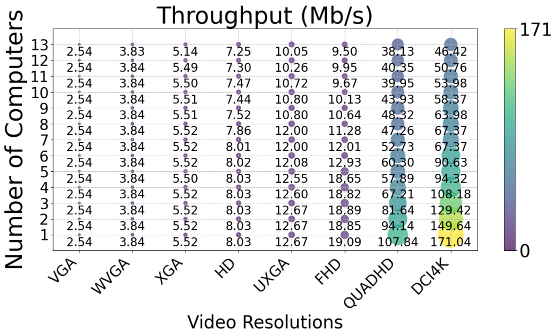
Figure 2. Throughput and packet loss with Wi-Fi 5/6 (20 MHz).

the experiments; the larger the bubble, the higher the value.

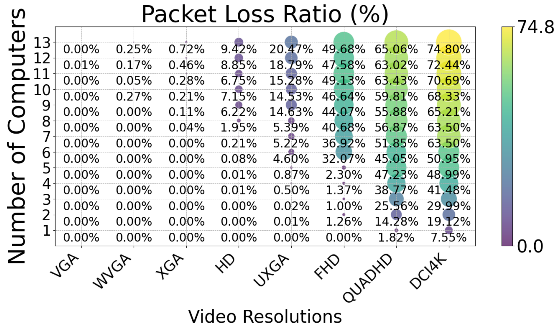
Wi-Fi 5 exhibits superior performance over Wi-Fi 6 in narrower channels due to the implementation of the OFDMA method in Wi-Fi 6, which is more effective with wider channels to optimize spectrum efficiency and handle multiple concurrent devices [Mozaffariahrar et al. 2022]. However, this benefit may be reduced in 20 MHz channels, as the limited number of subcarriers limits efficiency improvements. In general, with a channel of 20 MHz the packet loss ratio was significant for resolutions higher than HD using both Wi-Fi 5 and 6, when the number of clients increases.

Figures 3a and 3c show the throughput achieved with Wi-Fi 5 and Wi-Fi 6, respectively, when using channels of 80 MHz. Wi-Fi 6 consistently outperformed Wi-Fi 5 in all tested resolutions, demonstrating a 5.97% improvement in HD resolution, 10. 83% in UXGA, 39.02% in FHD, 11. 51% in QUADHD, and 23. 80% in DCI 4K. As illustrated in Figures 3b and 3d, starting with UXGA resolution, the packet loss ratio in both Wi-Fi technologies surpasses 10%, but it occurs with 9 computers for Wi-Fi 5 and with 12 computers for Wi-Fi 6. At HD resolution, Wi-Fi 5 registered a packet loss ratio of 9.42%, whereas Wi-Fi 6 recorded a mere 3.96% with 13 devices connected simultaneously.

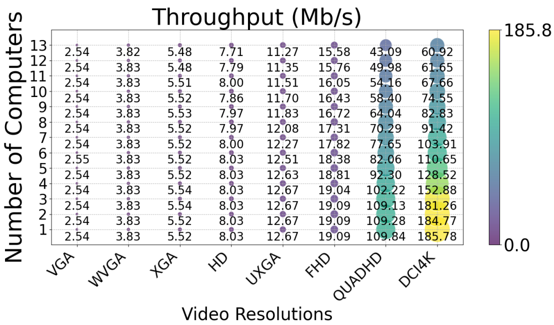
Finally, Figure 4 shows the maximum number of clients supported per network technology and configuration in various video resolutions. A packet loss threshold of 8%, allowing an average of 24 frames per second, was used, which can ensure a satisfactory visual experience [Monteiro et al. 2024]. Thus, the graph summarizes the behavior of each technology as the number of clients and data rates vary. The results demonstrate Wi-Fi 6's superior traffic management capabilities in dense settings when using broader channels. Advancements such as MU-MIMO and OFDMA in Wi-Fi 6 enhance spectral efficiency



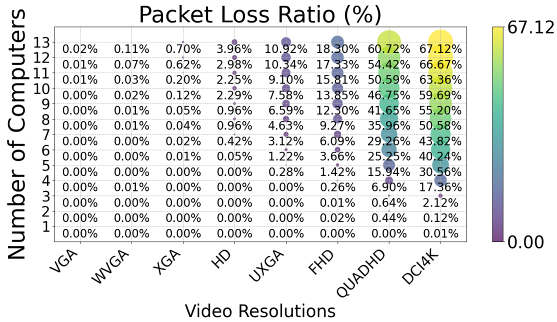
(a) Wi-Fi 5 average throughput



(b) Packet loss ratio with Wi-Fi 5.



(c) Wi-Fi 6 average throughput



(d) Packet loss ratio with Wi-Fi 6.

Figure 3. Throughput and packet loss with Wi-Fi 5/6 (80 MHz).

and device support. Specifically, Wi-Fi 6's MU-MIMO supports simultaneous connections with eight devices (two times more than Wi-Fi 5) [Mozaffariahrar et al. 2022].

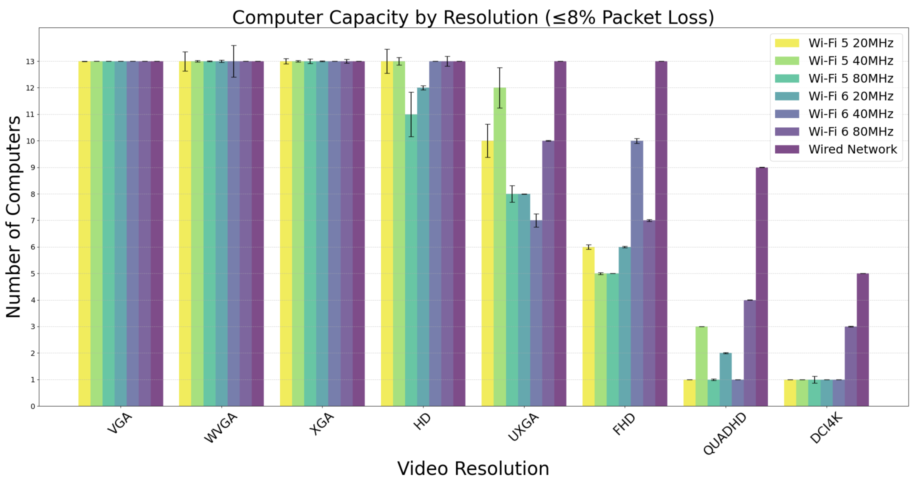


Figure 4. Number of clients supported by each video resolution.

5. Conclusion and Future Works

In a comparative analysis of Wi-Fi 5, Wi-Fi 6, and wired networks, a total of 2,184 experimental trials were performed. The findings indicated that although Wi-Fi 6 with 80 MHz channel widths shows enhanced efficiency and capacity, especially in environments with many computers, the wired network still retains a notable advantage in performance.

However, Wi-Fi 6 can be a viable alternative in scenarios with a lower client density per access point or when employing more efficient video codecs than MJPEG. The metrics collected serve as a reference for applications that require similar throughput levels, providing a benchmark for future deployments and research. Differences in observed performance highlight the necessity of strategically selecting the most suitable technology for each specific circumstance.

For future research, our aim is to evaluate the performance of real video applications transmitting over Wi-Fi networks, including experiments in industrial environments and assessments of various video codecs. Additionally, we plan to explore the 160 MHz channel width, currently limited by hardware constraints, and investigate Wi-Fi 6E and Wi-Fi 7. A comparison between Wi-Fi 6 and private 5G networks will also be conducted to identify how Wi-Fi can enhance and complement 5G, facilitating their integration in industrial scenarios.

6. Acknowledgments

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