

Performance Evaluation in Ethernet and WiFi Scenarios

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ABSTRACT

This report examines the performance of wireless and device-to-device communication by comparing theoretical predictions with experimental results in three scenarios: WiFi-only, Ethernet-only, and a mixed configuration. Using iperf3 and Wireshark, we measured goodput and analyzed its variability under different conditions. The experimental data were contrasted with theoretical estimates based on protocol efficiencies and network overheads. Our findings underscore Ethernet's stability and highlight the challenges of WiFi's shared medium and half-duplex constraints.

1 BACKGROUND AND OBJECTIVES

- 1 This laboratory evaluates and compares the performance of wired
2 and wireless communication in a local area network by setting
3 up three scenarios: both devices on WiFi, both on Ethernet, and a
4 mixed configuration with one on each. The main objectives of the
5 lab are to:
- 6 • Measure performances using iperf3 and Wireshark [7, 8].
 - 7 • Analyze the variability and stability of the connection in each
8 scenario by collecting data over multiple test runs.
 - 9 • Compare the experimental results against theoretical predictions
10 based on protocol efficiencies and network overhead.
 - 11 • Investigate potential sources of performance degradation in wire-
12 less communication, such as interference, half-duplex operation,
13 and shared medium limitations.
 - 14 These experiments provide practical insights into the strengths and
15 limitations of both Ethernet and WiFi, crucial for optimizing mixed
16 network performance.

2 METHODOLOGY AND CONCEPTS

- 17 This section outlines the experimental setup, the tools employed for
18 the measurements, and the theoretical basis for estimating goodput.

19 2.1 Selected Tools

- 20 To evaluate the performance of Ethernet and WiFi connections, we
21 utilized several specialized tools:
- 22 • **iperf3**: Used to generate traffic and measure goodput in both TCP
23 and UDP modes. With repeated trials, iperf3 provides valuable
24 metrics such as minimum, maximum, average, and standard
25 deviation of the throughput.
 - 26 • **Wireshark**: For capturing and analyzing network traffic, Wire-
27 shark helped analyze data flows, identify frames, and confirm
28 results. It also generated useful charts for analyzing TCP streams.

^{*}The authors collaborated closely in developing this project.

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- **Automation Script**: A Python script was written to automate the entire measurement process. The script operates on both server and client modes of iperf3, logs output, and computes summary statistics. The script accepts a series of command-line flags, as described in the Appendix A.

2.2 Goodput Estimation

Goodput represents the rate at which useful data is delivered to the application layer, excluding protocol overheads and retransmitted packets. The theoretical estimation of goodput is based on the efficiency of the protocol and the capacity of the network link:

$$G \leq \eta_{\text{protocol}} \times C,$$

where C is the capacity of the bottleneck link and η_{protocol} is the protocol efficiency.

1. For **Ethernet** [1], the efficiency for TCP is computed as:

$$\eta_{TCP}^{Eth} = \frac{MSS}{MSS + \text{TCP headers} + \text{IP headers} + \text{Eth. overhead}},$$

with the Maximum Segment Size (MSS) defined as the MTU minus the headers. For a standard MTU of 1500 bytes, we obtain:

- $MSS \approx 1460$ bytes (after subtracting 20 bytes for the IP header and 20 bytes for the TCP header),
- An additional Ethernet overhead of approximately 38 bytes.

Thus, the efficiency for TCP over Ethernet is approximately:

$$\eta_{TCP}^{Eth} \approx \frac{1460}{1460 + 20 + 20 + 38} \approx 94.9\%.$$

Similarly, the efficiency for UDP is computed as follows. Since UDP has an 8-byte header, its MSS is given by:

- $MSS \approx 1472$ bytes (after subtracting 20 bytes for the IP header and 8 bytes for the UDP header).

Thus, the efficiency for UDP over Ethernet is given by:

$$\eta_{UDP}^{Eth} \approx \frac{1472}{1472 + 20 + 8 + 38} \approx 95.7\%.$$

2. For **WiFi** [2], there are additional considerations to account for due to its half-duplex nature and the overhead of the 802.11 protocol (e.g., control frames, retransmissions, and channel contention). For **TCP over WiFi**, the actual efficiency is typically around 80% under optimal conditions. This lower efficiency arises from the extra overhead of TCP's connection-oriented features—such as congestion control, flow control, and the guarantee of in-order delivery—which add depending on extra control packets and retransmissions.

Whereas, **UDP over WiFi** typically achieves the efficiency of around 85–90% by avoiding these mechanisms, leading to a simpler and faster data transmission process.

$$\eta_{TCP}^{WiFi} (\approx 80\%) \quad \text{and} \quad \eta_{UDP}^{WiFi} (\approx 85\%-90\%).$$

These theoretical estimates impose an upper bound on the amount of achievable goodput that our results are compared to. Discrepancies between theory and practice are primarily due to dynamic environmental variables, such as interference, channel variation, and nature's intrinsic constraint on wireless communications.

3 EXPERIMENTAL SETUP AND TEST CASES

3.1 Equipment and Configuration

In this section, we describe the hardware and software configuration used to perform our network performance measurements. Table 1 summarizes the main devices, their interfaces, and relevant specifications.

Device	Key Specifications
PC1	Victus 16-s1005nl Notebook <i>Operating System:</i> Ubuntu 24.04.2 LTS [11] <i>Ethernet Interface:</i> Realtek RTL8111/8168/8211/8411 [3] <i>Wireless Interface:</i> Realtek RTL8852BE (802.11ax) 2x2 [4]
PC2	Microsoft Surface Laptop Go 3 <i>Operating System:</i> Ubuntu 24.10 [11] <i>Ethernet Interface:</i> via Anker PowerExpand+ USB-C Hub [10] <i>Wireless Interface:</i> Intel Alder Lake-P CNVi (802.11ax) 2x2 [5]
Router	Vodafone Power Station Wi-Fi 6 <i>Ethernet Ports:</i> 4 × 1 Gbps <i>Wi-Fi:</i> Dual-band 802.11ax (2.4 GHz 2x2, 5 GHz 4x4) [12] <i>Default gateway ip:</i> 192.168.1.1
Cables	CAT.5E (up to 1 Gbps)

Table 1: Summary of Hardware and Network Configuration

Connection	Key Specifications			
Ethernet	<i>Cabling:</i> CAT.5E <i>Nominal Speed:</i> 1 Gbps <i>Client ip:</i> 192.168.1.12	<i>Protocol:</i> Ethernet II <i>Server ip:</i> 192.168.1.13		
Wi-Fi	<i>Standard:</i> 802.11ax <i>Nominal Speed:</i> 1200 Mbps <i>Bandwidth:</i> 80 MHz <i>Client ip:</i> 192.168.1.8	<i>Security Protocol:</i> WPA2-AES <i>Frequency:</i> 5 GHz <i>Channel:</i> 100 <i>Server ip:</i> 192.168.1.4 <i>Third host ip:</i> 192.168.1.13 (shared capacity scenario)		

Table 2: Ethernet and Wi-Fi Connection Specifications

This hardware setup allows us to compare Ethernet versus Wi-Fi performance under a consistent router and cabling environment. In the next section, we detail the evaluation scenarios and the measurement methodology.

3.2 Evaluation Scenarios

We considered three distinct network configurations to assess the performance differences between wired and wireless communications. For each scenario, the theoretical goodput is computed based on the nominal link capacity and protocol efficiency.

1. Both Ethernet:

In this scenario, both PC1 and PC2 are connected to the router via CAT.5E cables, providing a nominal link capacity of 1 Gbps. The efficiency for Ethernet is calculated as follows:

$$\eta_{TCP}^{Eth} \approx \frac{1460}{1460 + 20 + 20 + 38} \approx 94.9\%,$$

$$\eta_{UDP}^{Eth} \approx \frac{1472}{1472 + 20 + 8 + 38} \approx 95.7\%.$$

Thus, the expected goodput is:

$$G_{TCP}^{Eth} \leq 0.949 \times 1000 \text{ Mbps} \approx 949 \text{ Mbps},$$

$$G_{UDP}^{Eth} \leq 0.957 \times 1000 \text{ Mbps} \approx 957 \text{ Mbps}.$$

2. Both Wi-Fi:

For this configuration, both devices use their wireless interfaces (802.11ax) to connect to the router. Although the nominal Wi-Fi link speed is assumed to be approximately 1.2 GbEbps, the half-duplex nature of Wi-Fi effectively halves the throughput available for data transfer. Assuming a Wi-Fi efficiency factor of about 80%, the expected goodput for TCP is:

$$G_{TCP}^{WiFi} \leq 0.80 \times 1.2 \text{ Gbps} \times \frac{1}{2} \approx 480 \text{ Mbps},$$

and similarly for UDP, with a different efficiency factor:

$$G_{UDP}^{WiFi} \leq 0.85 \times 1.2 \text{ Gbps} \times \frac{1}{2} \approx 510 \text{ Mbps}.$$

3. Mixed Scenario:

In this configuration, one device (PC1) is connected via Ethernet while the other (PC2) uses its Wi-Fi interface. So the expected goodput is determined by the slower link, so we compute the min between the two. Since only one side is on Wi-Fi, the Wi-Fi estimated goodput has not to be halved. Thus, the theoretical goodput is:

$$G_{TCP}^{Mixed} \leq \min\{0.80 \times 1.2 \text{ Gbps}, 0.949 \times 1.0 \text{ Gbps}\} \approx 949 \text{ Mbps},$$

$$G_{UDP}^{Mixed} \leq \min\{0.85 \times 1.2 \text{ Gbps}, 0.957 \times 1.0 \text{ Gbps}\} \approx 957 \text{ Mbps}.$$

We can see that the Eth. link is the bottleneck in this scenario.

These calculations provide the theoretical upper bounds for goodput in each scenario. The experimental results, obtained via automated measurements using the provided Python script, are compared against these predictions to evaluate real-world performance.

4 ANALYSIS AND FINDINGS

4.1 TCP Performance

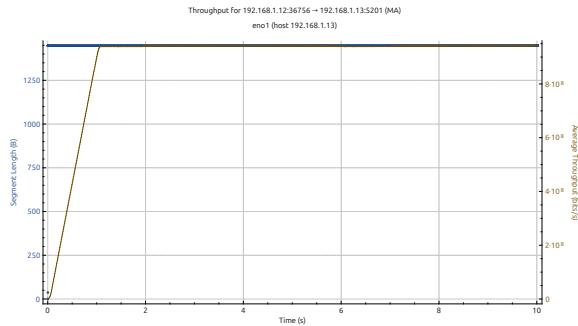
The performance tests using TCP reveal several noteworthy trends. The analysis for TCP performance in different scenarios is organized as follows:

Test	TCP: Goodput per flow (Mbps)				
	Prediction	Average	Min	Max	Std
Both Ethernet	949	939.6	938.2	942.7	1.5
Both WiFi	480	434.7	396.3	461.96	22.5
Mixed	949	663.7	619.2	698.86	26.6

Table 3: TCP Results (Client → Server)

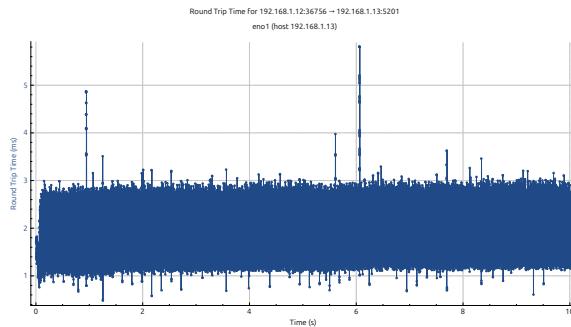
115 **1. Both Ethernet:**

116 Figure 1 shows the TCP throughput measured in the Ethernet scenario. The graph reveals a rapid ramp-up in throughput during
 117 the first few seconds, followed by a stable transmission rate that approaches the theoretical value. The **Maximum Segment**
 118 **Size (MSS)** reaches and remains stable at 1500 bytes, as defined by the TCP protocol. Additionally, the **bandwidth** is stable at
 119 **950 Mbps**, as indicated by the results and the low standard deviation.



120 **Figure 1:** TCP Throughput in the Ethernet Scenario.
 121

122 Figure 2 illustrates the round-trip time (RTT), which remains
 123 very low (typically within 1-3 milliseconds), highlighting the
 124 minimal latency in wired connections.



125 **Figure 2:** TCP Round Trip Time in the Ethernet Scenario.
 126

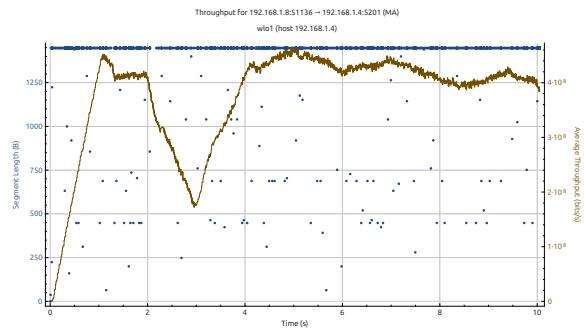
127 Overall, the Ethernet scenario demonstrates a near-ideal performance with high throughput and minimal latency, closely
 128 matching the theoretical predictions.

129 **2. Both WiFi:**

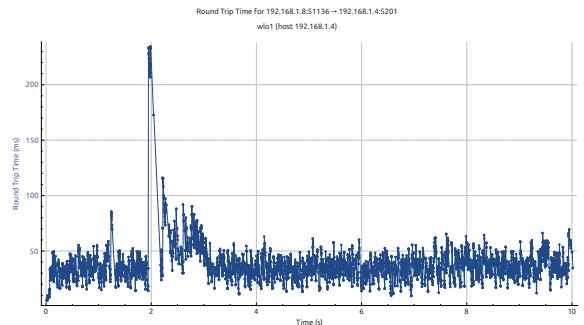
130 In the WiFi trace, the throughput plot (Fig. 3) shows an upfront
 131 ramp-up phase over the first 2 seconds, followed by a varying
 132 throughput about a mean of 434.7 Mbps. The up and down in these traces due to protocol overhead, some wireless inter-
 133 ference, and WiFi being half-duplex, reduces its performing
 134 capability.

135 RTT measurements (Fig. 4) show RTT in the range of around
 136 20-50 ms, with some delays probably caused by congestion and
 137 contention in the wireless medium.

138 Overall, while the theoretical limit for TCP over WiFi is approxi-
 139 mated to around 480 Mbps, experimental observation indicates
 140 that real-world factors does not reduce so significantly the ef-
 141 fective throughput of the WiFi network. This as the network



142 **Figure 3:** TCP Throughput in the WiFi Scenario.
 143

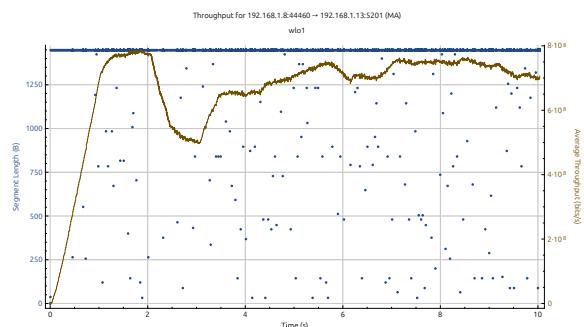


144 **Figure 4:** TCP Round Trip Time in the WiFi Scenario.
 145

146 was in a state of perfection, where there was just the server
 147 and client that were connected to the access point and no other
 148 computers were generating traffic.
 149

150 **3. Mixed:**

151 Figure 5 displays the TCP throughput for the mixed configura-
 152 tion. The graph shows that the throughput reaches a stable level
 153 after an initial ramp-up phase, although it remains below the
 154 Ethernet scenario and is consistent with the expected reduction
 155 due to the reliance on the wireless link.



156 **Figure 5:** TCP Throughput in the Mixed Ethernet/WiFi Scenario.
 157

158 The round-trip time (RTT) measurements, presented in Figure 6,
 159 indicate moderate latency, with RTT values generally remain-
 160 ing within a lower range compared to the pure WiFi scenario.
 161 This suggests that the wired segment helps in reducing overall
 162 latency.

163 **3a. Shared Capacity:**

164 In this scenario, a third host connected to the same access point
 165

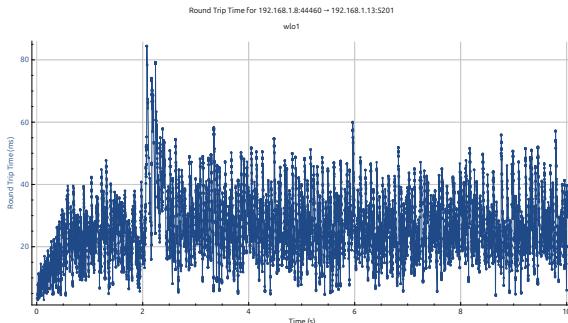


Figure 6: TCP Round Trip Time in the Mixed Ethernet/WiFi Scenario.

160 was concurrently downloading the film "Natale a Rio" [14] (directed by Neri Parenti), which introduced significant interference 161 during the tests. This additional traffic compromised the 162 available network capacity, leading to degraded performance. 163 As we can see in (Fig. 7), the other host starts the download 164 from the second test (~25 seconds). In fact the value of the 165 throughput, goes from the one of the standard Mixed Scenario 166 (~670Mbps), to a lower one (~500Mbps). This behavior is due 167 to the fact that the bandwidth is shared between the two hosts, 168 and the download of the movie is consuming useful bandwidth. 169

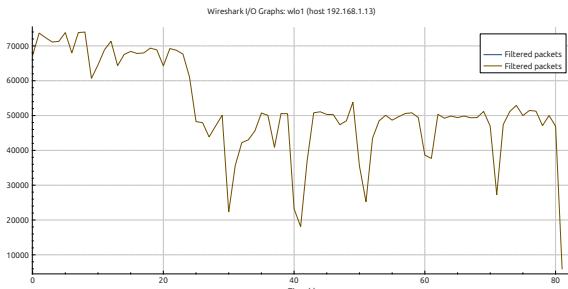


Figure 7: Wireshark I-O Graph for TCP in the Shared Capacity Scenario.

4.2 UDP Performance

171 The UDP tests offer an insightful comparison to the TCP results 172 by eliminating congestion control and acknowledgment overhead. 173 The analysis for UDP is structured as follows:

Test	UDP: Goodput per flow (Mbps)				
	Prediction	Average	Min	Max	Std
Both Ethernet	957	952.8	948.3	954.6	1.73
Both WiFi	510	487.8	453.1	499.9	15.8
Mixed	957	674.9	636.6	717.8	28

Table 4: UDP Results (Client → Server)

1. Both Ethernet:

174 In the Ethernet scenario, UDP achieves a near-theoretical throughput 175 of **952.8 Mbps** (vs. TCP's 939.6 Mbps), with minimal standard deviation (**1.73 Mbps**). The absence of retransmissions or 176 congestion control allows UDP to utilize the full wired capacity. 177 While TCP's latency remains marginally lower (1–3 ms RTT) 178 due to acknowledgment-based stability, UDP's lack of overhead 179 enables slightly higher throughput. 180

enables slightly higher throughput. 181

2. Both WiFi:

182 UDP averages **487.8 Mbps** (vs. TCP's 434.7 Mbps) in WiFi, 183 achieving a **~12% throughput advantage** by avoiding TCP's 184 congestion control. Despite outperforming TCP, UDP falls short 185 of the **510 Mbps theoretical maximum** due to WiFi interference 186 and contention. Moreover, it shows lower variability (std. 187 dev. **15.8 Mbps** vs. TCP's **22.5 Mbps**), indicating smoother 188 performance. This makes UDP preferable for real-time applications 189 prioritizing speed over error correction. 190

3. Mixed:

191 The mixed scenario shows UDP achieving **674.9 Mbps** (vs. 192 TCP's 663.7 Mbps). The wired segment reduces latency, but the 193 wireless link remains the bottleneck. UDP's performance aligns 194 closely with TCP here, as both protocols are constrained by 195 WiFi's limitations. UDP's throughput is **1.8% higher** than TCP, 196 reflecting its ability to bypass congestion control. 197

3a. Shared Capacity:

198 In the shared capacity test, UDP throughput drops significantly. 199 The third host's download introduces contention, reducing 200 available bandwidth. UDP's lack of congestion control leads 201 to aggressive transmission attempts, but packet drops result in 202 lower effective throughput. Unlike TCP, which degrades pre- 203 dictably due to its back-off mechanism, UDP's performance 204 becomes more volatile. This highlights TCP's adaptability in 205 shared environments, where fairness and resource allocation are 206 critical, while UDP's rigidity makes it less suitable for contested 207 networks. 208

5 CONCLUSION

209 This research compared TCP and UDP performance over wired, 210 wireless, and hybrid networks. Results affirm that **Ethernet environments** 211 optimize protocol efficiency, achieving near-theoretical 212 throughput with negligible latency. **WiFi**, on the other hand, 213 introduces variability because of interference and contention that 214 affects both protocols in spite of controlled scenarios. 215

216 **TCP** prioritizes reliability, making it resilient for file transfers and 217 web traffic, though its congestion control limits performance in 218 dynamic environments. **UDP**, although quicker in ideal circumstances, 219 struggles with packet loss and shared resources, making it 220 less suitable for congested networks. 221

222 Hybrid **Ethernet-WiFi setups** 223 focus attention on the ethernet portion 224 as the primary bottleneck, with both protocols also constrained 225 by WiFi's instability. Shared capacity configurations further reduce 226 performance, underlining the requirement for adaptive protocols 227 in contested networks. 228

229 These results suggest the importance of aligning protocol selection 230 with environmental constraints. Although theoretical models 231 provide benchmarks, real-world performance hinges on interference, 232 medium contention, and protocol design. Network planning 233 must balance throughput, latency, and resilience against dynamic 234 conditions. 235

A APPENDIX

234 Server Mode Initialization

```
235 def run_server():
236     """
237     Run iperf3 server with clean output handling.
238     """
239     server_logger.info("Starting iperf3 server...")
240
241     proc = subprocess.Popen(
242         ["iperf3", "-s", "-J"],
243         stdout=subprocess.PIPE,
244         stderr=subprocess.PIPE,
245         text=True,
246         bufsize=1,
247     )
248     # Handle server output and errors in a separate
249     # thread...
```

Listing 1: Excerpt for server mode initialization.

250 Client Mode Execution and Reporting

```
251 def run_client(server_ip, udp=False, bitrate="1M",
252                 iterations=10):
253     """
254     Run iperf3 client tests and generate reports.
255     """
256     for i in range(iterations):
257         cmd = ["iperf3", "-c", server_ip, "-J", "-t",
258                "10", "-i", "1"]
259         if udp:
260             cmd.extend(["-u", "-b", bitrate])
261
262         result = subprocess.run(
263             cmd,
264             capture_output=True,
265             text=True,
266             check=True
267         )
268
269         data = json.loads(result.stdout)
270         # Extract test data, compute statistics, and
271         log results...
```

Listing 2: Excerpt for client mode execution.

272 Logging and Output Management

```
273 def setup_logger(log_file, name):
274     logger = logging.getLogger(name)
275     logger.setLevel(logging.DEBUG)
276     handler = logging.FileHandler(log_file)
277     formatter = logging.Formatter(
278         '%(asctime)s - %(levelname)s - %(message)s'
279     )
280     handler.setFormatter(formatter)
281     logger.addHandler(handler)
282     return logger
```

Listing 3: Excerpt for logging setup.

283 These snippets illustrate how the script handles server mode ini-
284 tialization, client tests (both TCP and UDP), and logging. Error
285 handling, multithreaded stderr management, and CSV report gen-
286 eration are also included in the complete script.

All the code for the report and lab material is available on the repository [13]: <https://github.com/WDCSecure/LabWiFi.git> 287
288

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