Impact of Wi-Fi Extenders on Performance and Coverage

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Problems

- Modern homes have WiFi dead zones and weak signal areas
- Signal degradation over distance affects user experience
- Multiple devices compete for bandwidth

Goals

- Evaluate the real-world impact of WiFi extenders on network performance and coverage

Equipments and applications

- Router FiberGateway
- Wifi extenders
- Computer/Phone
- Wifi Analyzer
- NetSpot
- Wavemon
- Wireshark
- Iperf3
- Ipfer3 Mobile Apllication

Metrics

- Downlink Speed (Mbps)
- Uplink Speed (Mbps)
- Latency (ms)
- RSSI - Signal strength (dBm)
- Frequency
- WiFi Channel
- Troughput
- Jitter (ms)
- Packet loss (%)

Results in a garage without extenders

Distance	RRSID	Freq	Download	Upload	Packet Loss
1m	-26 dBm	5500 MHz	51.5 Mbps	47.4 Mbps	0.00%
10m	-63 dBm	5500 MHz	49.8 Mbps	45.0 Mbps	0.00%
20m	-71 dBm	5500 MHz	31.6 Mbps	25.5 Mbps	0.00%
26m	-84 dBm	5500 MHz	7.72 Mbps	12.0 Mbps	0.86%

Important to note that these values were all from a 5G network
There was a second Access Point to 2.4G using channel 1, at 26m the RSSI was at –68 dBm

Multi-Hop Architecture

- We forced a linear topology to evaluate the cost of extending Wi-Fi indefinitely. As expected, we observed that the second hop dropped bandwidth and increased latency. This confirms that while Daisy Chaining extends range, it reduces capacity because the middle extender must share airtime to receive and re-transmit packets.

FiberGateway

Extender 1
(± 7 m)

Extender 2
(± 15 m)

Results with:

0 extenders

Distance	Down/Up	Ping (ms)	RSSI	Freq
0m	866/866	20	-13	5G
8m	520/390	21	-63	5G
15m	144/144	40	-67	2.4G
23m	7/7	76	-84	2.4G

1 extender

Distance	Down/Up	Ping (ms)	RSSI	Freq
0m	866/866	21	-13	5G
8m	866/866	23	-42	5G
15m	520/520	27	-67	5G
23m	28/28	47	-80	2.4G

2 extenders

Distance	Down/Up	Ping (ms)	RSSI	Freq
0m	866/866	23	-13	5G
10m	866/866	25	-44	5G
15m	866/866	38	-45	5G
23m	520/520	45	-64	5G

Analysis comparison

Speed Comparison (at 23m):

0 extenders: 7 Mbps (unusable)

1 extender: 28 Mbps (basic browsing)

2 extenders: 520 Mbps (excellent)

Signal Strength (RSSI at 23m):

0 extenders: -84 dBm (very weak, 2.4G)

1 extender: -80 dBm (weak, 2.4G)

2 extenders: -64 dBm (good, 5G maintained)

Methodology

- **Topology:** Linear Chain (Router → Extender 1 → Extender 2).
- **Server:** PC connected via Ethernet to FiberGateway (eliminating server-side wireless bottlenecks).
- **Client:** PC connected wirelessly to the specific Extender under test.
- **Protocol:** iPerf3 UDP Test (100 Mbps target load, 30s duration) to analyze stability and packet loss.

Results

Metric	Mid Extender (1 Hop)	Far Extender (2 Hops)	The "Cost" (Degradation)
Throughput (UDP)	**93.5 Mbps** (Stable)	**67.8 Mbps** (Struggling)	**-27.5% Speed Drop**
Latency (Ping)	33.88 ms	48.77 ms	**+44% Latency Increase**
Jitter	0.098 ms	0.178 ms	**~2x Instability**
Packet Loss	0.0008% (2 packets)	0.29% (510 packets)	**255x Loss Increase**

Key Technical Insights

- **Capacity Collapse:** Even under a controlled load of just 100 Mbps, the second hop failed to sustain the traffic, dropping to **67.8 Mbps**. This proves the middle extender is a bottleneck, unable to receive and re-transmit fast enough to keep up with the demand.
- **Reliability vs. Connectivity:** While the connection looks active on the Far Extender, the **255x increase in packet loss** (from 2 packets to 510) means that real-time apps like VoIP or Gaming would suffer from "micro-stutters".
- **Latency Accumulation:** Adding a single wireless hop added nearly **15ms** of delay, confirming that linear topologies should be avoided for latency-sensitive tasks.

Handover Methodology & Analysis

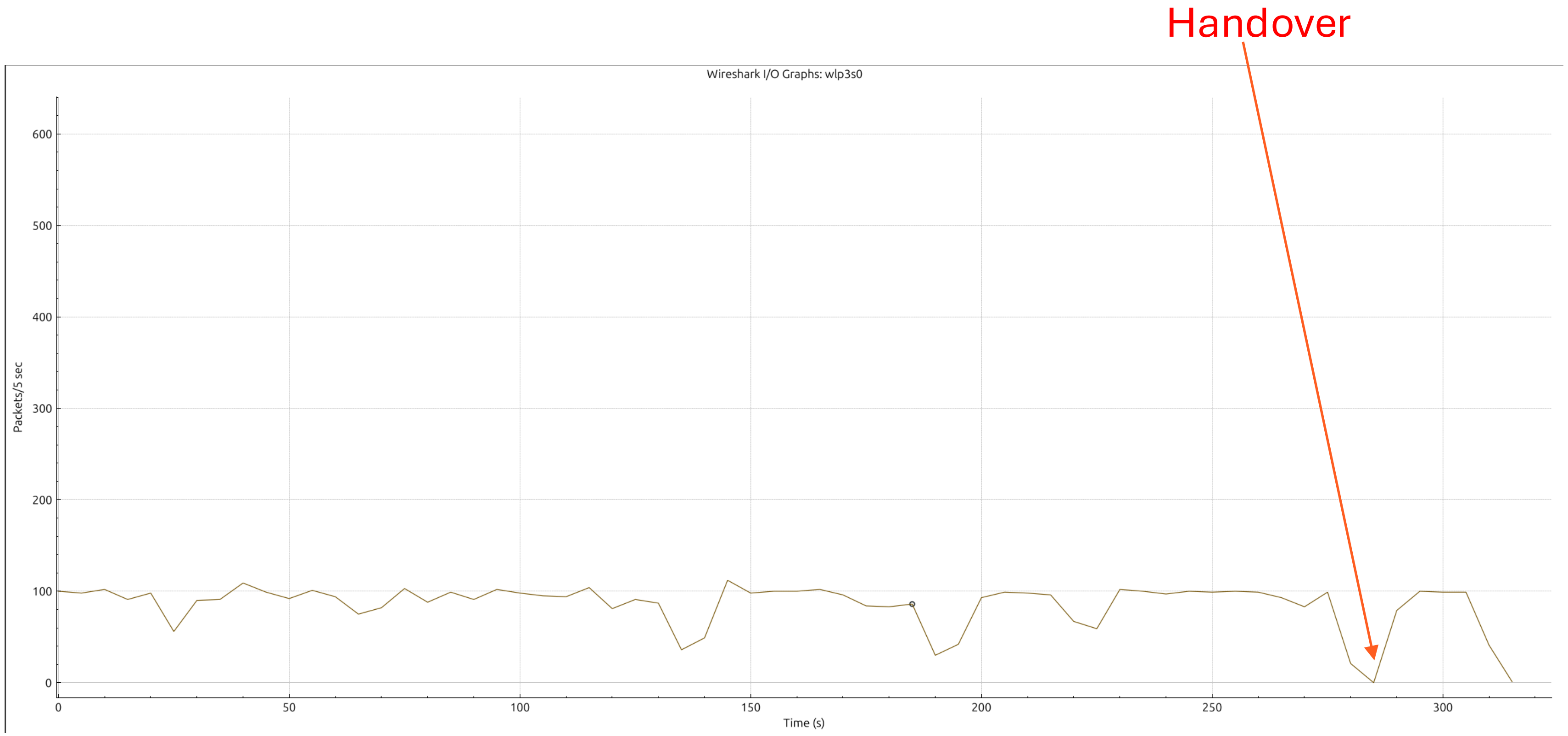
Test Scenario

- Performed a dynamic walking test from the Router to the Extender.
- Continuously pinged the Gateway IP to monitor connectivity stability.

Wireshark Packet Analysis

- Trigger: The handover event was signaled by the appearance of an ARP packet.
- Transition: Immediately followed by a sequence of continuous ICMP Requests (unanswered) as the device switched APs.
- Recovery: The procedure concluded when ICMP Replies resumed, confirming the connection to the Extender.

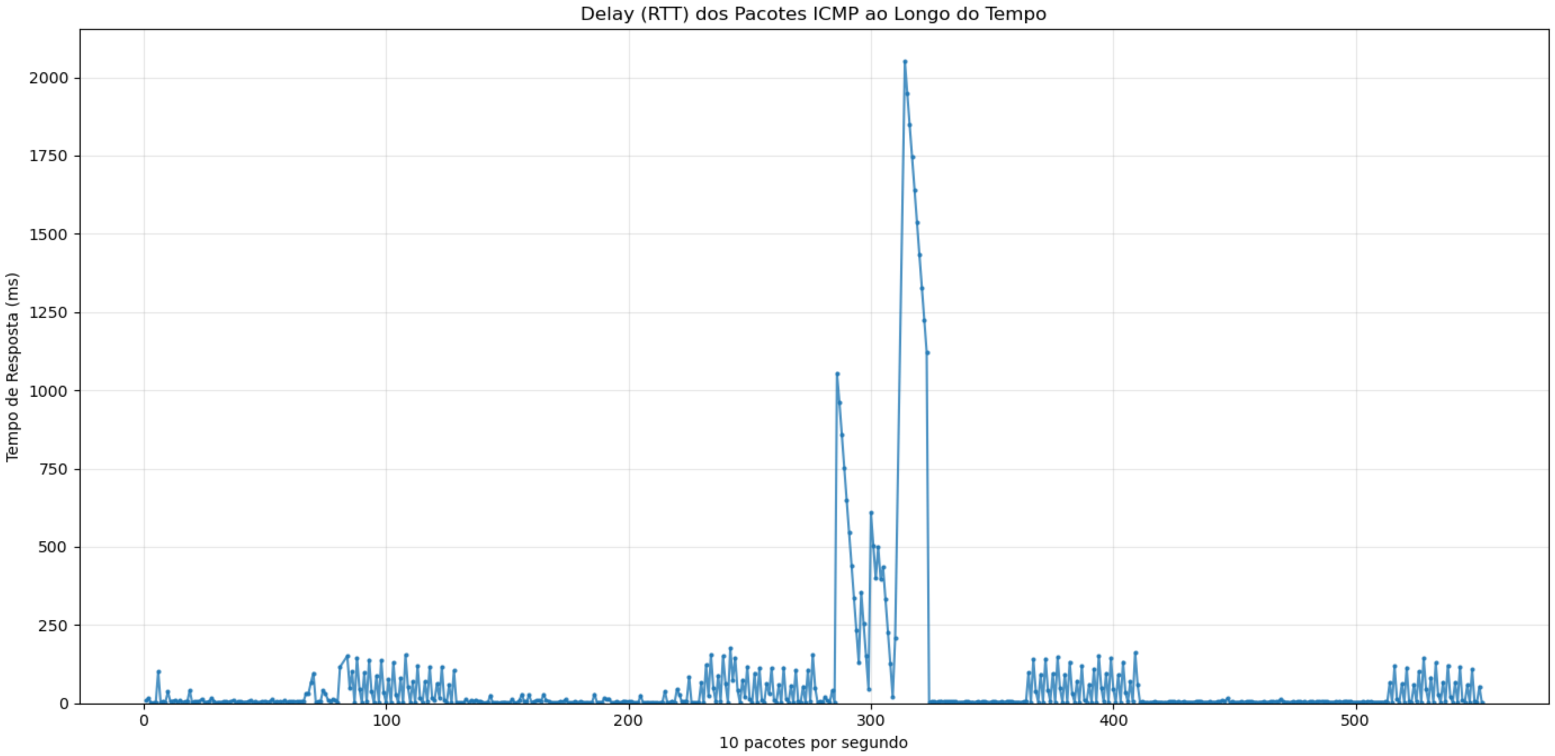
Results



Key Observations:

- Service Interruption: The Wireshark I/O graph shows throughput dropping to 0 packets/sec.
- Connection Gap: This "dead zone" corresponds to the period of unanswered ICMP Requests observed during packet analysis.
- Recovery: Traffic only resumes after the handover is fully completed.

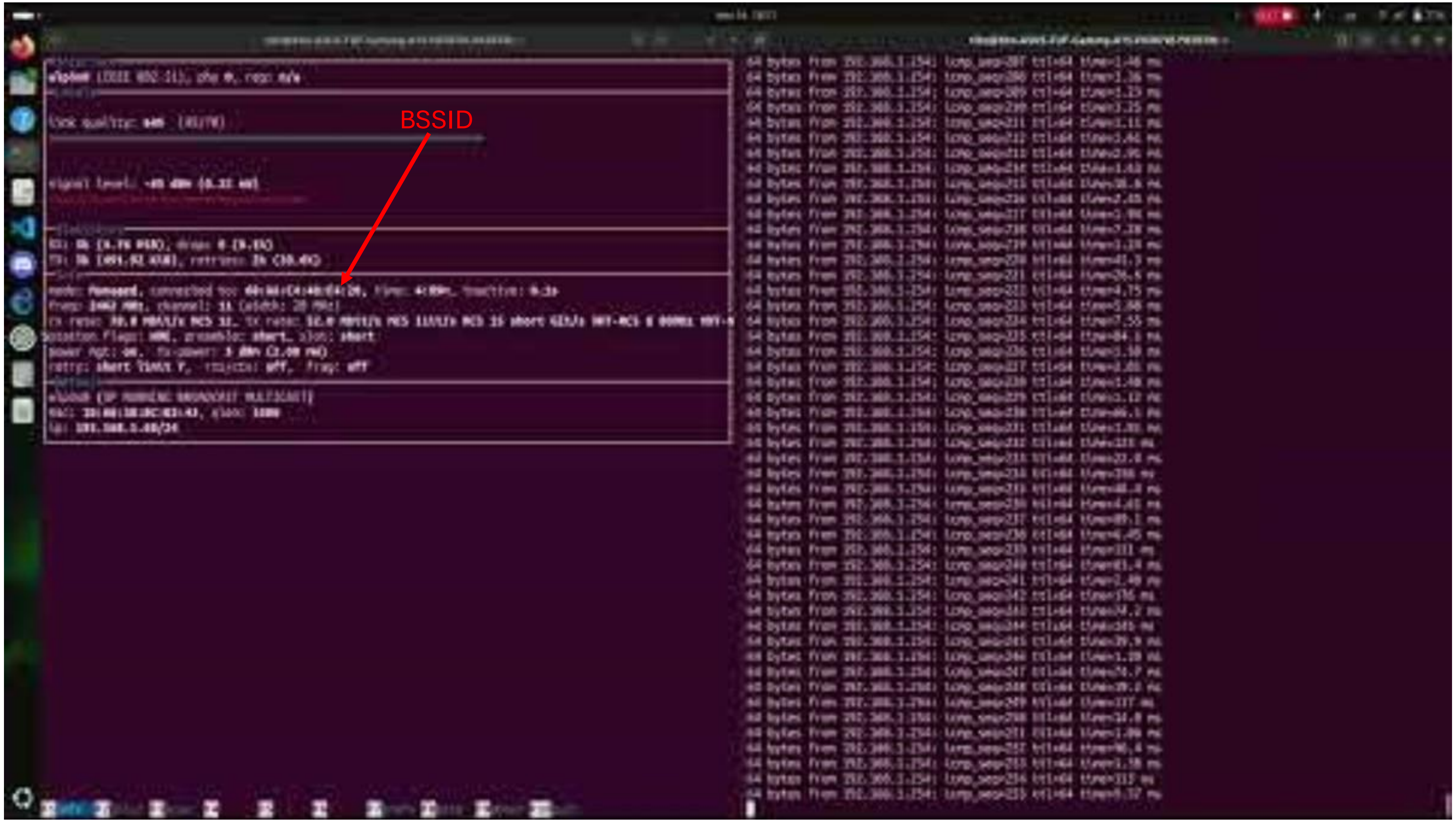
Results



Key Observations:

- Pre-Handover Instability: Before the switch, we observe a critical phase where RTT spikes drastically to ~2000ms.
- Cause of Latency: This is caused by a combination of signal degradation and the network scanning overhead as the device prepares to roam.
- User Experience: This lag indicates that the handover is triggered too late, destroying real-time performance before the switch happens.

Real-time Handover Monitoring



Impact of Placement & Obstacles

Test Scenario

- Objective: To measure signal degradation caused by physical obstacles and metal interference.
- Method: Compared signal metrics with the Extender in a Line-of-Sight (LoS) position vs. placing it inside a closed Refrigerator.

Results

- **Key Insight**
  - Material Attenuation: The metal chassis and insulation caused a massive signal power drop of 41 dBm.
  - Takeaway: Even over short distances, placing equipment inside cabinets or near metal appliances wastes nearly all the signal energy, degrading connection quality significantly.

Metric	Normal Position (LoS)	Inside Fridge (Obstructed)	Impact
Signal Level (RSSI)	-21 dBm (Excellent)	-62 dBm (Good)	~41 dBm Drop (Massive signal loss)
Link Quality	100%	79%	21% Quality Drop

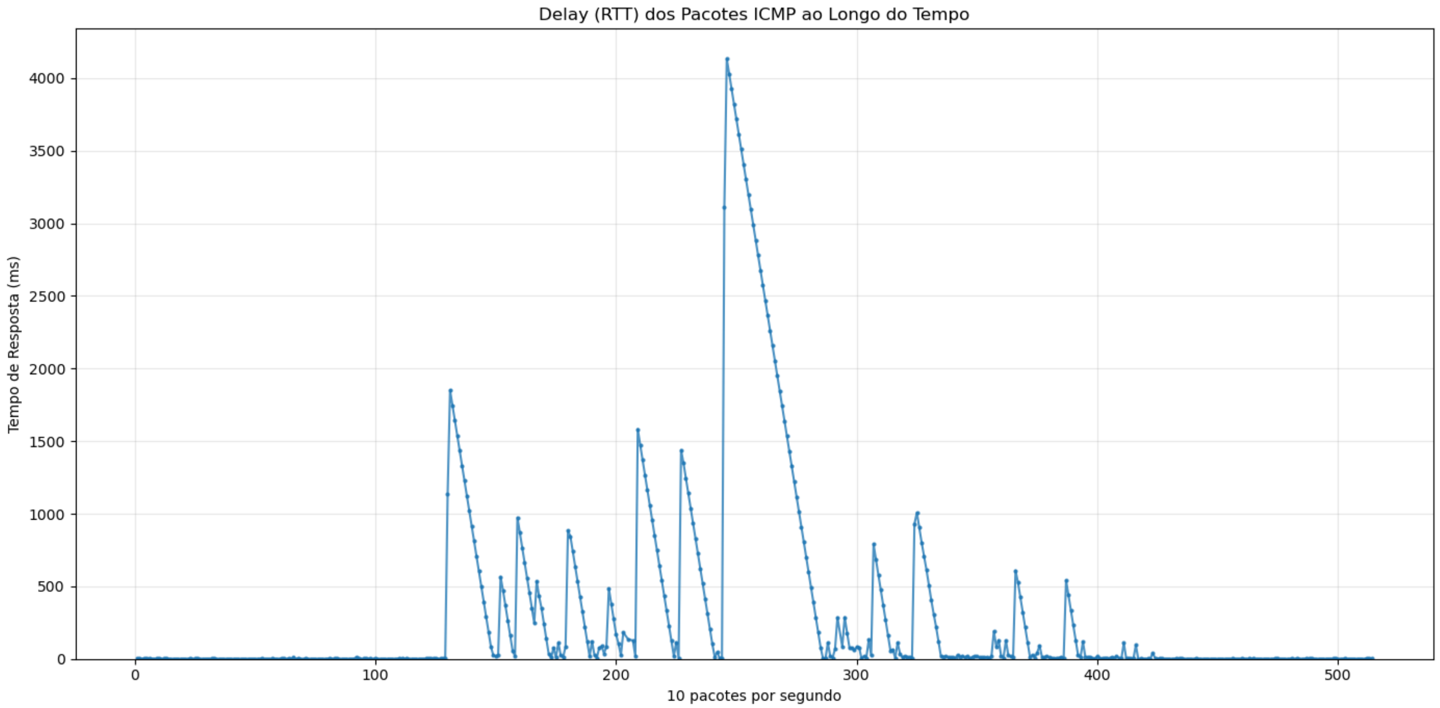
Congestion Stress Test (Multi-User Contention)

- To address the problem that *'Multiple devices compete for bandwidth'*, we designed a **Congestion Stress Test**. While single-device tests showed high speeds, we needed to verify how the Extender handles **concurrent loads** in a shared medium. Our goal was to measure the impact of a high-bandwidth user (the 'Aggressor') on a latency-sensitive user (the 'Victim') sharing the same wireless hop.

Methodology

- **Scenario:** Two clients (Phone and PC)connected to the same Extender (Shared Medium).
- **Aggressor (Phone):** Performing high-bandwidth download (iPerf3 TCP, 4 streams).
- **Victim (PC):** Performing latency monitoring (ICMP Ping) to measure stability.
- **Server:** A PC connected via ethernet to the FiberGateway

Results



- **Bufferbloat & Queuing:** The graph shows massive instability. The Extender is buffering the "Aggressor's" packets so aggressively that the "Victim's" small ping packets are stuck in the queue for up to 4 seconds.
- **The "Half-Duplex" Penalty:** Because the Extender cannot listen and talk at the same time, when one device demands high speed, the other device is effectively locked out, proving that **extenders do not handle concurrency well.**

Conclusion

- WiFi extenders effectively expand coverage but introduce performance trade-offs
- Single extender optimal for most home scenarios
- Strategic placement crucial for maximum benefit
- Direct router connection always provides best performance

Work done

- Luis -> Garage test, Packet loss, Speed tests, Data capture setup
- Simao -> Tests with extenders incorporated, Packet loss, Speed tests, Data capture setup
- Tiago -> Multi-hop, Handover, Congestion and Impact of Placemnet Tests
- Bruno -> Multi-hop, Handover, Congestion and Impact of Placemnet Tests

Everyone equally contributed to the analysis of results

Everyone contributed equally for the development of this project