BLE Project

Evaluation of BLE Extended Advertising for Large Payload Transmission

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Abstract

This study investigates the feasibility of Bluetooth Low Energy (BLE) Extended Advertising for transmitting data payloads larger than 32 bytes without a connection. We developed a custom Android application for the Samsung S23 Ultra running Android 14 to capture BLE advertising packets from a sender EV kit operating at 50 Hz. Two experiments were conducted: a general capability evaluation under normal apartment conditions with over 10 active Bluetooth devices, and a maximum range test across multiple floors in an apartment building. In the first experiment, the sender's payload (limited to 230 bytes due to hardware constraints) was updated every 1000 packets, with data collection focused on round duration, throughput, and error counts. In the second experiment, we tested signal reception across distances up to 47 meters on the same floor and across multiple floors. Notably, no packet errors were observed in either experiment, demonstrating the reliability of BLE's Cyclic Redundancy Check (CRC) mechanism for error detection.

Introduction

BLE Extended Advertising extends the traditional 32-byte advertising limit, enabling larger payload transmissions. Our goal was to determine whether increasing the payload size impacts data transfer rates and to evaluate the maximum practical range for BLE Extended Advertising in real-world environments.

For our first experiment, we developed an Android application with multi-threaded processing to collect data from a target device broadcasting at 50 Hz. The experiment automatically tracked rounds of 1000 packets each, with the sender updating its payload between rounds. We discovered a practical limit of 230 bytes per payload, as larger sizes crashed the sender device.

Our second experiment focused on determining the maximum effective range of BLE signals, both on the same floor and across multiple floors of an apartment building, providing insights into how building materials and environmental interference affect transmission. We also investigated the Cyclic Redundancy Check (CRC) mechanism that ensures BLE packet integrity during transmission.

Methodology

Experiment 1 – General Capability Evaluation Setup Features:

- **Continuous Scanning:** The app continuously scans for BLE advertisements and filters packets from the target device ("scout_technologies").

- **Automatic Experiment Initiation:** The experiment starts when a valid round1 payload is received.
- **Real-Time Processing:** Using an 8-thread fixed pool and atomic counters, the app processes each packet in real time. Rounds advance when 1000 packets are received and the sender switches to the next expected payload.
- **Data Collection:** For each round, the app records:
  - **Total Packets:** The number of advertising packets received.
  - **Duration (s):** Time taken to collect 1000 packets.
  - **Throughput (p/s):** Calculated as Total Packets divided by Duration.
  - **Errors:** Packet validation errors (which were 0 in all experiments).
- **Storage of Results:** Detailed error logs and a round summary are saved as CSV files in a public folder (e.g., in Documents/experiment_data and Documents/experiment_summary).

Experiment 2 – Maximum Range Test Setup Features:

Scanning Procedure: BLE scanning is manually started using the same app, with the target device set to broadcast continuously. Packet reception is monitored and recorded without automatic round detection.

Test Setup: The BLE sender was placed in fixed positions—first on each floor's hallway (same floor as receiver), then on the top floor while the receiver was moved one floor down at a time. The environment featured regular background BLE traffic from smart appliances (e.g., Samsung ovens).

- Packet Collection: At each location, a 10-second scan captured all packets from the sender (broadcasting 40-byte payloads at 20 ms intervals) to measure reception reliability by distance or floor.
- Data Points Recorded:
  - Received Packets: Number of packets detected at each position.
  - Floor or Distance: Relative position between sender and receiver.
- Signal Reachability: Used to assess how far the BLE signal could travel under realistic indoor conditions.

Experiments

Experiment 1 - General Capability Evaluation

Experiments were performed in a typical apartment (normal room conditions) with more than 10 active Bluetooth devices present to emulate ambient noise. The receiving device was a Samsung S23 Ultra running Android 14. The sender EV kit transmits at 50 Hz, and its payload is updated every 1000 packets (yielding an approximate round duration of 20 seconds). Additionally, it was found that payloads must remain at or below 230 bytes; increasing beyond this limit causes the sender to crash.

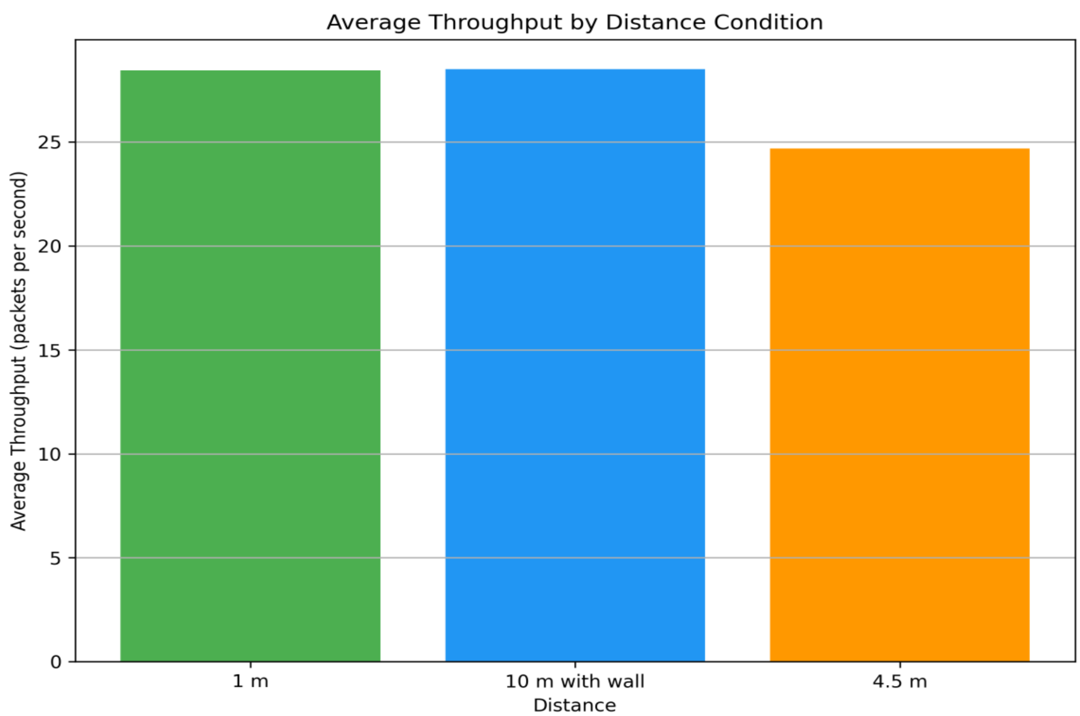
Data Analysis and Charts

The collected CSV summary files provided key performance metrics per round. For example, the summary file includes the following columns:

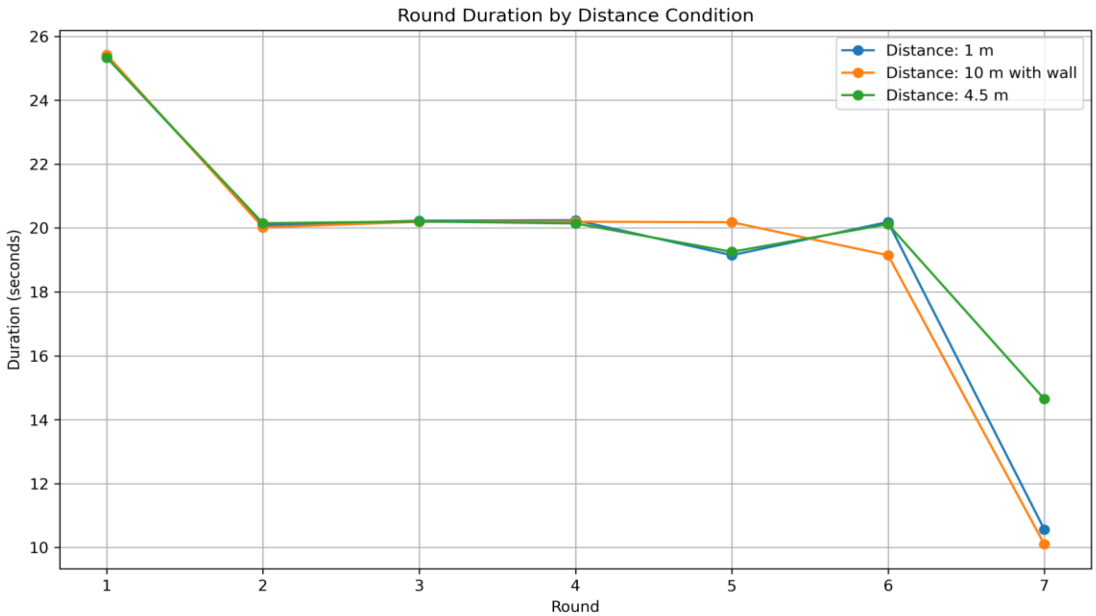
Round, TotalPackets, Duration(s), Throughput(p/s), Errors

The following charts have been generated from these data:

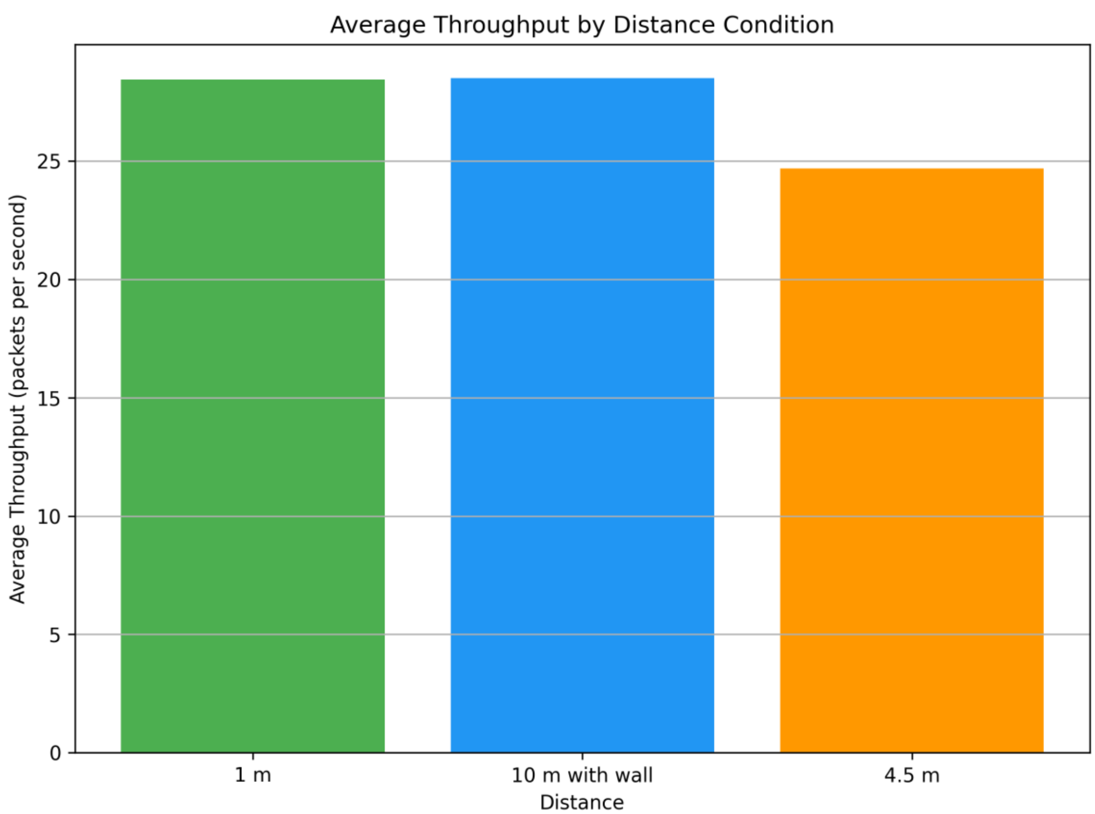
- **Figure 1 – Throughput per Round by Distance Condition:**
  A line chart comparing the measured throughput against the theoretical 50 p/s. This chart reveals that the actual throughput is lower due to processing overhead and environmental factors.



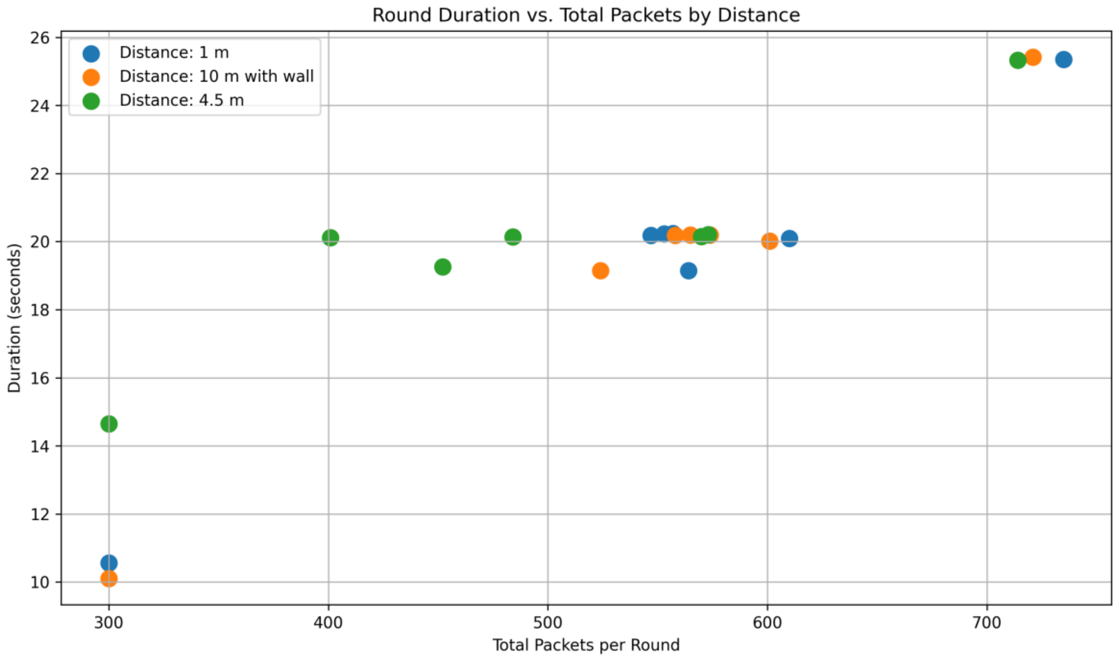
- **Figure 2 – Round Duration by Distance Condition:**
  A plot showing the duration of each round. Although rounds are designed to last 20 seconds, slight variations indicate system delays.



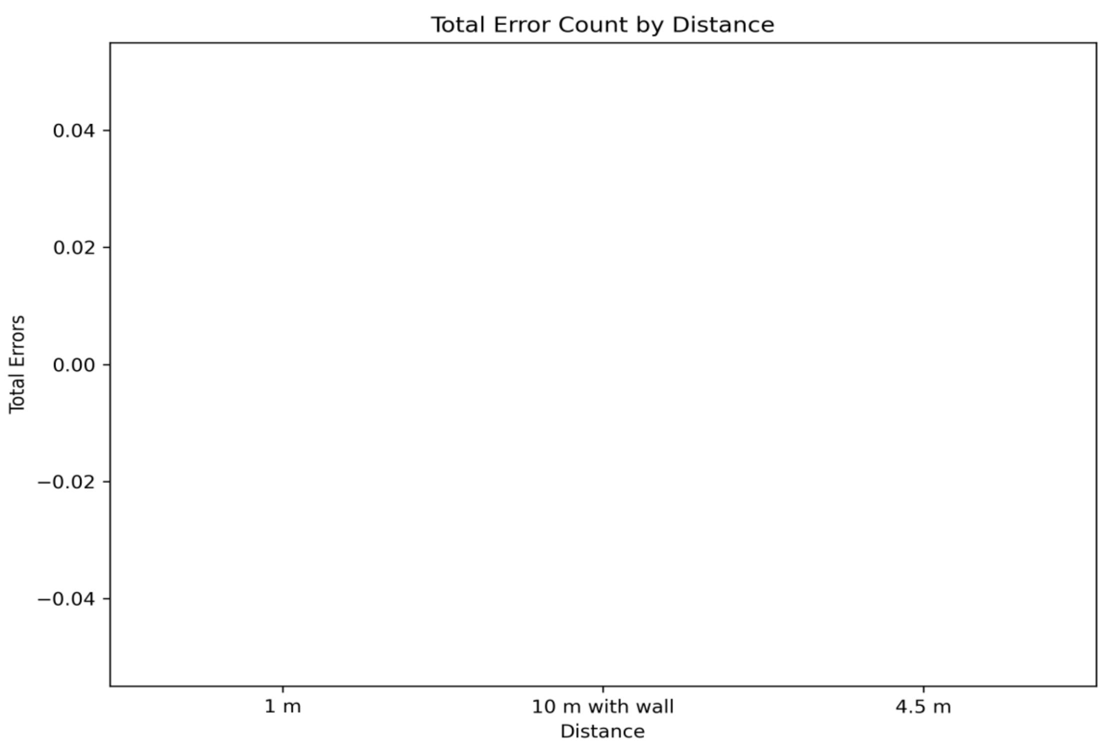
- **Figure 3 – Average Throughput by Distance:**
  A bar chart summarizing average throughput across different distance conditions.



- **Figure 4 – Round Duration vs. Total Packets:** A scatter plot illustrating the relationship between total packets received and round duration.



- **Figure 5 – Total Error Count by Distance:** Since no errors were recorded, this chart confirms the reliability of the payload validation.



Discussion

The experimental data indicate that although no packet errors were observed, the effective throughput is lower than the theoretical maximum of 50 packets per second. This reduction is likely due to processing overhead in the BLE stack and the application's real-time processing tasks. Moreover, the environment—with multiple active Bluetooth devices—introduces additional variability.

The fact that the sender EV kit crashes when payload sizes exceed 230 bytes highlights a practical limitation in current BLE hardware. For this experiment, staying below this threshold ensures stable operation.

Experiment 2 - Maximum Range Test

Experiments were conducted in a typical five-floor apartment building, where each unit contains at least one active EV kit/BLE device (e.g., Samsung smart oven). These devices broadcast 40-byte payloads at 20 ms intervals in 10-second bursts, contributing to consistent background BLE traffic. A Google Pixel Tablet running Android 15 was used as the receiving device. The experiment aimed to evaluate the maximum broadcasting range of our BLE sender under realistic multi-floor indoor conditions. Two setups were tested: first, placing both devices on the same floor in the hallway and measuring packet reception at various distances; second, placing the sender on the top floor and moving the receiver one floor down at a time to assess inter-floor signal strength. Packet counts at each location were recorded to determine the practical maximum range for reliable BLE Extended Advertising transmission.

Data Analysis and Tables

Table 1 – Testing range on the same floor

	Parking	Main	2nd Floor	3rd Floor	4th Floor
Distance (m)	47.24	44.72	41.15	40.56	42.21

Reception distance averaged 43 m; parking area had the longest at 47.24 m due to low RF noise. Other floors ranged from 40.56–44.72 m, showing stable reception with little variation.

Table 2 – Testing range on different floors

	Parking	Main	2nd Floor	3rd Floor	4th Floor
Trial 1	0	137	192	219	285

Trial 2	0	165	177	212	309
Trial 3	0	99	167	243	294
Trial 4	0	156	184	236	284
Trial 5	0	91	136	269	274
Average	0	~129	~171	~235	~289

No packets were received in the parking area, likely due to ceiling thickness blocking signals. On other floors, packet count increased with height: 4th (289), 3rd (235), 2nd (171), Main (129).

Discussion

From Table 1, we see that BLE advertising packets can travel reliably up to ~43 meters on the same floor, with minimal variation. The parking area performed best, likely due to a low-interference environment with fewer surrounding Bluetooth devices. In contrast, other floors had more RF noise from nearby devices, which may have slightly reduced the effective range.

Table 2 shows how signal reception is influenced by both building structure and environmental noise. The thicker ceiling in the parking zone completely blocked passive BLE signal reception across floors. In comparison, the upper floors—where ceiling construction was consistent (2.8m height, 0.3m thick)—still allowed packet reception across vertical separation. The trend also suggests that noise and signal obstruction from nearby devices could have affected packet counts, especially on lower floors.

Overall, both structural materials and environmental interference (from other devices) play key roles in determining how well BLE advertisements are received, often more so than the actual distance between sender and receiver.

Further Investigation

Based on both experiments, we found no packet errors—every received packet remained valid during transmission. This consistency led us to look into how BLE ensures data integrity. BLE uses a mechanism called Cyclic Redundancy Check (CRC) for error detection. CRC works by attaching a short "check value" to each packet, which is calculated from the packet's data using a polynomial algorithm. When a packet is received, the receiver performs the same calculation and compares its result with the attached CRC. If they don't match, the packet is discarded as corrupted. This lightweight but effective method helps BLE maintain reliable communication, even in environments with potential interference.

Conclusion

Our custom Android application effectively collected comprehensive performance data on BLE Extended Advertising with payloads up to 230 bytes. While our first experiment showed perfect transmission integrity (0 errors), we observed reduced throughput due to processing overhead and environmental interference. The second experiment demonstrated reliable transmission up to 43 meters on the same floor, with signal reception across floors varying significantly based on building structure. Our investigation into BLE's Cyclic Redundancy Check mechanism explained the consistent 0 error rate observed throughout testing. These findings provide critical insights for real-world applications of BLE Extended Advertising across various distances and environments. Future work will include detailed statistical analysis using R and exploring optimization strategies to improve cross-floor signal reception.

Reference

[1] M. Woolley, "Exploring Bluetooth® Core 5.0 - Going the Distance," Bluetooth SIG, Feb. 13, 2017. [Online]. Available: https://www.bluetooth.com/blog/exploring-bluetooth-5-going-the-distance/