Report on 2.4 GHz IEEE 802.11 signal strength measurements inside a Boeing 737

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***Abstract*— Wireless access to the internet revolutionized our century and in recent years the rise of the internet of things brings new possibilities to collect data and interconnect the world. But these devices often rely on wireless communication to make the data they collect available. It is beneficial in different mediums to test how electro-magnetic waves and different protocols perform. A plane fuselage is a good place to test how 2.4 GHz WiFi react because it should be representative for all the similar plane models and with the same fuselage composition. The performance of the 2.4 GHz WiFi was analyzed by measuring the receiving strength in different parts of the plane and the number of packets lost.**

I. INTRODUCTION

This work is intended to show the collected data, its collection method, a visualization method and interpret it.

II. MEASURING METHODOLOGY

The measured information consists of the the received signal strength indication (RSSI) and the number of packets dropped. These were sampled in different spots in the plane as can be seen in Figure 1. The spots where reception antennas are represented by the hollow red circles and the transmission point is represented by the red filled square. The referencing of the measuring spots are as follows: $RXn-p$, where n is replaced by the index of the measurement line in reference to the plane axis and p is replaced by C, L or R (meaning center, left or right respectively). The reference point in the plane is $RX0-C$ represented in Figure 1 through the filled red circle at the tail of the plane which is on the center axis of the plane (which is also the Y axis). The left and right offsets from the central axis are 0.9 meters

The absolute positions of the measuring points can be seen in Table I.

The data measured is taken at 2 different heights in the same positions. Once the transmitter and the receiver was at 1 meter from the floor and in the other measurement of the entire plane they were at 0.5 meters from the floor, thus to penetrate through the seats.

Data was also collected in some special scenarios such as: in the baggage compartment, from an end of the airplane to another end and with the transmitter inside the airplane and the receiver outside with the door closed or open.

The 2.4 GHz WiFi transmitter was configured to transmit the beacon packets at intervals of 100ms and the receiver was capturing the beacon packets for 120 seconds and logging their arrival time and RSSI.

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TABLE I

TRANSMISSION AND RECEPTION ABSOLUTE POSITIONS IN THE PLANE. *IN METERS

point	position	point	position	point	position
RX0-C	(0,0)	RX4-C	-	RX8-C	(0,16.6)
RX0-L	(-0.9,0)	RX4-L	(-0.9,8.6)	RX8-C	(-0.9,16.6)
RX0-R	(0.9,0)	RX4-R	(0.9,8.6)	RX8-C	(0.9,16.6)
RX1-C	(0,2.6)	RX5-C	(0,10.6)	RX9-C	(0,19.1)
RX1-L	(-0.9,2.6)	RX5-C	(-0.9,10.6)	RX9-C	(-0.9,19.1)
RX1-R	(0.9,2.6)	RX5-C	(0.9,10.6)	RX9-C	(0.9,19.1)
RX2-C	(0,4.6)	RX6-C	(0,12.6)	TX	(0,8.6)
RX2-L	(-0.9,4.6)	RX6-C	(-0.9,12.6)		
RX2-R	(0.9,4.6)	RX6-C	(0.9,12.6)		
RX3-C	(0,6.6)	RX7-C	(0,14.6)		
RX3-L	(-0.9,6.6)	RX7-C	(-0.9,14.6)		
RX3-R	(0.9,6.6)	RX7-C	(0.9,14.6)		

III. MEASUREMENTS AND INTERPRETATION

I plotted the data spatially to see the RSSI values. The transmitter position is considered to have the RSSI 0dBm and is present at the absolute airplane position of $X = 0$ and $Y = 8.6m$.

1 meter height measurements

The first round of measurements when the transmitter and the receiver heights are 1 meter from the airplane floor can be seen in Figure 2. The obvious spike represents the transmitter's position and it can be clearly seen that as we move away from the transmitter the RSSI value decreases because of the propagation loss and the shadowing of the chairs. It can be seen that the shadowing does not have an effect for the measurements on the main corridor of the airplane as there is a direct line of sight between RX and TX.

In te plot it can also be observed that measurements $RX0-L$, $RX0-R$, $RX9-L$ and $RX9-R$ have a lower value than their center corresponding measurements($RX0-C$ and $RX9-C$ respectively), but not drastically different from the farthest measurements that were taken between the seats ($RX1-L$, $RX1-R$, $RX8-L$ and $RX8-R$). This could imply that the reflexions in the plane make up for the shadowing effect of the chairs and of the walls at the plane's ends.

One more interesting observation that can be made is that the RSSI values between the seats in the back of the plane (the portion with a Y value smaller than 8.6 meters) are smaller than the values in the front of the plane (the portion with Y value bigger than 8.6 meters) between the seats. This might be because some of the seats, as can be seen in Figure

1, are of a different material (the brown ones). Compared to the normal Boeing 737 seats, those were a mixture of fiberglass and wood and were shaped like a bench rather than a seat.

This measurement had an average beacon packet loss of 11.17%.

0.5 meters height measurements

For the second round of measurements, the transmitter and the receiver heights are 0.5 meters from the airplane floor, so that the seats would be more in the way of the signal (Figure 3). In these measurements, the RSSI values do not follow a constant decrease in value as the RX is getting further from the TX. This could be because the antenna used is a vertical one which has a cylindrical emission shape and in this scenario it is placed in line with the metal structure underneath the chairs which may cause more reflections and inconsistencies with a path loss signal strength model.

In this scenario it can be seen that the measured RSSI between the chairs is lower than the value on the main corridor (which has direct line of sight to the transmitter). The interesting part is that the RSSI value increases in the measurements taken at the ends of the plane ($RX0 - C$, $RX0 - L$, $RX0 - R$, $RX9 - C$, $RX9 - L$ and $RX9 - R$).

This measurement had an average beacon packet loss of 13.5%.

Differential view of the measurements

In order to compare the measurements at the different heights, I have created a differential plot where I subtracted from the RSSI values at 0.5 meters the ones taken at 1 meter above the airplane's floor (Figure 4). It is interesting to see that the difference is positive in the back of the plane (where the Y value is smaller than 8.6 meters and where the special airplane chairs are located), with a big spike in the region behind the walls in the back of the plane. In the front of the plane the RSSI value is bigger in the case when the transmitter and receivers were placed at 1 meter above the floor, with the exception of the receivers placed after the front wall (positions $RX9 - C$, $RX9 - L$ and $RX9 - R$). Also, there seems to be a bigger difference between the center RSSI values and the values between the chairs in the back of the plane ($RX2 - C$, $RX2 - L$ and $RX2 - R$) compared to the ones in the front ($RX7 - C$, $RX7 - L$ and $RX7 - R$).

Special measurements

Some special measurements were also taken. These include the following scenarios with the given values:

- outside airplane at position $(4.3, 16.6)$ with the airplane door closed: RSSI = -65.71 dBm and beacon packet loss of 16.16%;
- outside airplane at position $(4.3, 16.6)$ with the airplane door open: RSSI = -63.47 dBm and beacon packet loss of 15.83%;
- TX at $(0, 19.1)$ and RX at $(0, 0)$: RSSI = -43.19 dBm and beacon packet loss of 6.75%;
- TX at $(-0.9, 19.1)$ and RX at $(-0.9, 0)$: RSSI = -60.85 dBm and beacon packet loss of 7.41%;
- TX at $(-0.9, 19.1)$ and RX at $(0.9, 0)$: RSSI = -73.58 dBm and beacon packet loss of 10.58%;
- in bagage compartment with TX at $(0, 8.6)$ and RX at $(-0.9, 8.6)$: RSSI = -29.8 dBm and beacon packet loss of 6.41%;
- in bagage compartment with TX at $(0, 8.6)$ and RX at $(-0.9, 16.6)$: RSSI = -42.42 dBm and beacon packet loss of 9.83%.

IV. CONCLUSION

The measurements are publicly available at [2].

The difference in height of the 2 measurements sets proved to be bigger than anticipated and it might be because of the antenna design and the metal present underneath the seats. Another interesting observation is the higher RSSI power present between the benches present in the plane that are made out of a mixture of fiber glass and wood.

REFERENCES

[1] , "IEEE Standard for Information Technology–Telecommunications and Information Exchange between Systems - Local and Metropolitan Area Networks–Specific Requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications," *IEEE Std 802.11-2020 (Revision of IEEE Std 802.11-2016)*, vol. , no. , pp. 1–4379, 2021.

[2] Lică Robert-Mihai and Mick Koertshuis, "Boeing 737 2.4GHz WiFi RSSI measurements," , 2022.

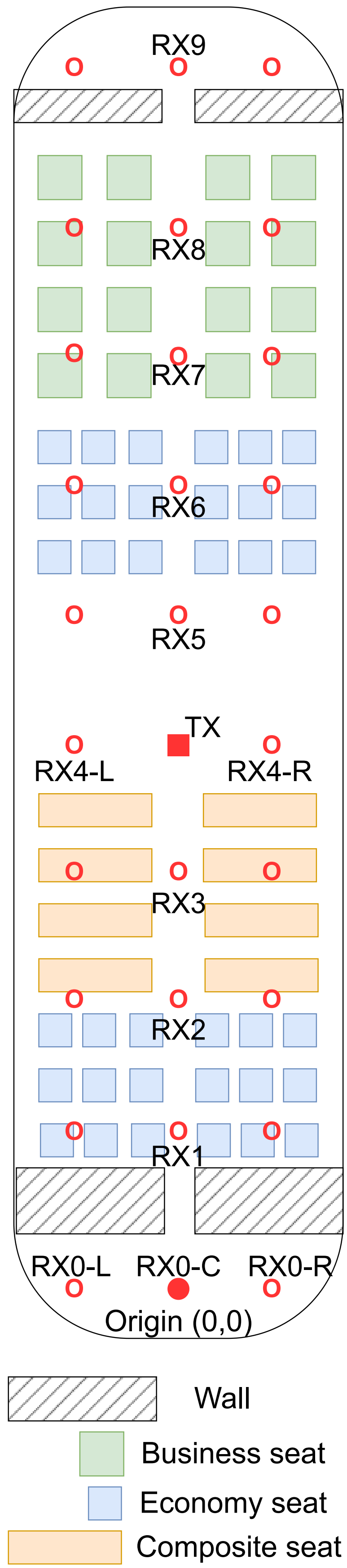

Fig. 1. Boeing 737 measuring locations. *proportions are not kept

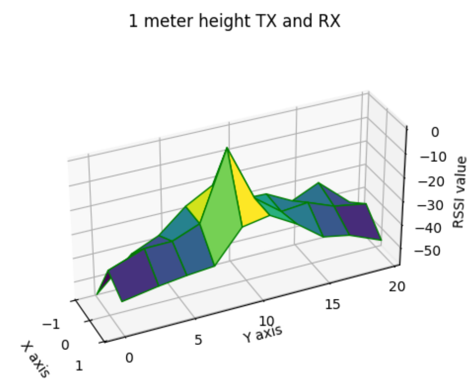

Fig. 2. 1 meter height TX and RX

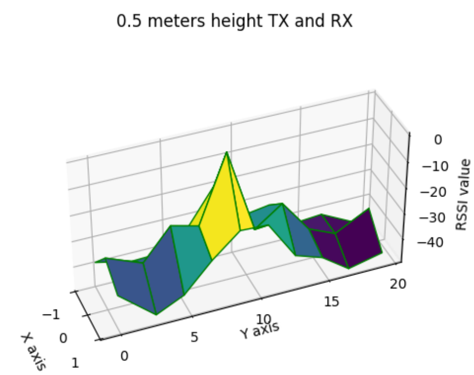

Fig. 3. 0.5 meters height TX and RX

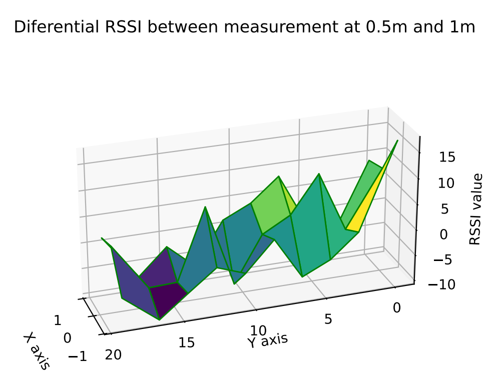

Fig. 4. Diferential RSSI beatween measurement at 0.5m and 1m