The TMB path loss model for 5 GHz indoor WiFi scenarios: On the empirical relationship between RSSI, MCS, and spatial streams

Toni Adame, Marc Carrascosa and Boris Bellalta

Abstract—The WiFi landscape is rapidly changing over the last years, responding to the new needs of wireless communications. IEEE 802.11ax is the next fast-approaching standard, addressing some of today’s biggest performance challenges specifically for high-density public environments. It is designed to operate at 2.4 GHz and 5 GHz bands, the latter being rapidly adopted worldwide after its inclusion in IEEE 802.11ac, and with expected growing demand in the next 10 years.

This paper assesses empirically the suitability of the available IEEE 802.11ax path loss models at 5 GHz on some real testbeds and proposes a new model with higher abstraction level; i.e., without requiring from a previous in situ analysis of each considered receiver’s location. The proposed TMB path loss model, used in combination with generated data sets, is able to obtain an estimation of RSSI, selected modulation and coding scheme (MCS), and number of spatial streams in function of the AP configuration and the AP-ST A distance. We aim to use the model to compare IEEE 802.11ac/ax performance simulation results with experimental ones.

I. INTRODUCTION

IEEE 802.11ax is intended to replace both IEEE 802.11n and IEEE 802.11ac, targeting to improve the spectrum utilization efficiency, and working at both 2.4 GHz and 5 GHz frequency bands. The IEEE 802.11ax task group (TGax) [1], responsible for the design of the amendment named IEEE 802.11ax-2019, aims to improve PHY and MAC efficiency with modulation and coding schemes (MCSs) ranging from BPSK-1/2 to 1024-QAM-5/6.

TGax faces two main challenges: the ability of addressing dense scenarios and satisfying the increase of users’ throughput needs [2]. In fact, some of the main targeted use cases are indoors, such as crowded urban scenarios (apartment complexes, condominiums, and multi-dwelling buildings) or enterprise-class scenarios (next generation e-classrooms, colleges, and school campuses) [3].

To analyze the performance of this technology in such dense scenarios it is necessary to rely on simulators and analytical tools as realistic as possible. The use of these tools would then foster the design and development of advanced path loss / PHY models, statistical MAC protocols, as well as thorough access point (AP) deployment planning.

With this goal in mind, the current article evaluates the accuracy of the already available IEEE 802.11ax indoor path loss models at 5 GHz and compares it with the proposed empirical TMB model, which does not require from previous computation of traversed obstacles, unlike other similar models [4]–[7]. Besides, by combining it with other available data, the TMB model is able to provide the selected MCS and number of spatial streams for a given distance, in addition to the RSSI.

The contributions of this paper can therefore be summarized into three main points:

- The validation of the IEEE 802.11ax path loss models in the 5 GHz band.
- The proposal of a more general path loss model that averages the effect of the different obstacles between transmitter and receiver, also providing information about the achievable data rates at a given distance (i.e., MCS and number of spatial streams).
- The generated data sets, including measurements from multiple locations in an indoor scenario, and the implemented MATLAB functions to extract the information of interest.

The remainder of this paper is organized as follows: Section II introduces IEEE 802.11ax indoor path loss models. Section III describes employed technology and considered testbeds. Next, Section IV details the empirical process to obtain a new path loss model and compiles all obtained results from tests. Lastly, Section V presents the obtained conclusions and discusses open challenges.

II. IEEE 802.11AX INDOOR PATH LOSS MODELS

IEEE 802.11ax adopts the IEEE 802.11ac channel model and penetration losses for link and system level performance evaluation in indoor scenarios [8]. Specifically, IEEE 802.11ax standard defines 3 simulation scenarios [9], [10]:

1) Residential: In this environment, which models a 5-floor building with 20 apartments per floor, a large number of APs is installed in close vicinity, so that increased interference level can greatly affect devices performance within the network.

2) Enterprise: Similar to residential environment, enterprises are providing WiFi as their primary source of access to the Internet through a managed network. A large number of devices is considered in this office floor configuration, with 8 offices, 64 cubicles per office, and 4 stations per cubicle.

3) Indoor small basic service set (BSS): This scenario captures the issues of representative real-world deployments with high density of APs and STAs, where the BSS from each operator is deployed in regular symmetry.

Equations (1) and (2) obtained from [8] describe the path loss model for the residential and the enterprise scenario,

The indoor small BSS scenario has not been considered in the current study as it does not include the effect of typical surrounding walls in its corresponding path loss model.
respectively. Table I compiles the main technical parameters from both scenarios.

| Parameter | Description | Unit |
|-----------|-------------|------|
| $d_{i,j}$ | Distance to the AP | m |
| $f_c$ | Frequency | GHz |
| $W_{i,j}$ | Number of traversed office walls | walls |
| $p_{i,j}$ | Number of traversed floors | floors |

III. SCENARIO OVERVIEW AND TESTBEDS

The selected environment to validate the IEEE 802.11ax indoor path loss models at 5 GHz was the 2nd floor, right wing of the Tanger building at Universitat Pompeu Fabra (UPF) facilities. This space is characterized by a 50 m long transversal corridor with office rooms at both sides from 20 m$^2$ to 32 m$^2$ (see Figure 1).

Floors from offices and the corridor consist of ceramic tiles, while ceilings are made up of plaster. Space between offices is filled with plaster walls of 17 cm of thickness. As for doors and walls between offices and the main corridor, they have 8 cm of thickness and are made up of composite and plaster, respectively. The ceiling height of every room is 2.65 m. Furniture within offices mainly consists of cabinets, tables, chairs, and drawers, all of them made up of composite or aluminum with some metallic elements. In addition, offices contain varied computer equipment such as screens, computer towers, and printers.

Measurements were obtained during working hours with people performing their daily tasks (even occasionally walking along the corridor and in the rooms). Coexisting Internet wireless networks working at 2.4 GHz and 5 GHz were kept active.

A. Hardware

Due to the lack of available IEEE 802.11ax commercial hardware at the moment of writing this paper, tests were conducted on IEEE 802.11ac, as both standards operate at 5 GHz band and have equivalent channel models.

- AP TP-Link Archer C7 C1750 V4: This router supports IEEE 802.11ac standard delivering a combined wireless data transfer rate of up to 1.75 Gbps. Wireless speeds of up to 1300 Mbps over the 5 GHz band can be achieved.

- Laptop Dell Latitude E5580: It is worth noting here that while the AP has three antennas, employed laptops have only two, thus having access to two spatial streams for up to 866.7 Mbps when using 80 MHz channels.

B. Software

- Commercial firmware of the AP was replaced by the corresponding OpenWrt firmware.
- Laptops ran Ubuntu 16.04 TLS with Linux Kernel 4.13.0-36.
- iPerf 2.0.5 was the tool used in sender laptops to generate UDP traffic.
- Wireshark 2.6.1 was the application employed for the capture and analysis of transmitted packets.
- Aircrack-ng 1.2 Beta 3 was used for packet capturing of raw IEEE 802.11 frames.

C. Testbeds

- **Testbed #1**: Full deployment in 21 locations

  This testbed was made up of an AP and two laptops. The AP always maintained the same position on a table from a central office and was connected through an Ethernet cable to the sender laptop (laptop A). Measurements were taken in the receiver laptop, which occupied one of the $N_{t} = 21$ pre-selected locations in every test repetition (see Table III for position details and Figure 1 for device deployment), with the goal of covering a wide range of channel propagation cases.

- **Testbed #2**: Subset of locations

  This testbed maintained the same locations for the AP and the sender laptop (laptop A) from Testbed #1, and reused locations #7, #10, and #18 for the receiver laptop (see Figure 1 for device deployment). Again, measurements were taken in the receiver laptop.

- **Testbed #3**: Subset of STAs and close locations

  Again, this testbed maintained the same position for the AP and the sender laptop (laptop A) from Testbeds #1 and #2, and reused locations from Testbed #2 for the receiver laptop. In addition, a 3x3 grid with a separation of 10 cm was created around each of the 3 selected locations, as shown in Figure 1.

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2UPF Communication campus website: [https://www.upf.edu/web/campus/tanger](https://www.upf.edu/web/campus/tanger)

3TP-Link Archer C7 C1750 V4 datasheet: [https://static.tp-link.com/Archer%20C7%20Datasheet%204.0.pdf](https://static.tp-link.com/Archer%20C7%20Datasheet%204.0.pdf)

4Dell Latitude 5580 owner’s manual: [https://topics-cdn.dell.com/pdf/latitude-15-5580-laptop_owners_manual.pdf](https://topics-cdn.dell.com/pdf/latitude-15-5580-laptop_owners_manual.pdf)

5OpenWrt Firmware for TP-Link Model Archer C7 AC1750: [https://openwrt.org/toh/hwdata/tp-link/tp-link_archer_c7_v4](https://openwrt.org/toh/hwdata/tp-link/tp-link_archer_c7_v4)

6Ubuntu Linux kernel image for version 4.13.0-36: [https://packages.ubuntu.com/xenial/linux-image-4.13.0-36-generic](https://packages.ubuntu.com/xenial/linux-image-4.13.0-36-generic)

7iPerf main website: [https://iperf.fr/](https://iperf.fr/)

8Wireshark main website: [https://www.wireshark.org/](https://www.wireshark.org/)

9Aircrack-ng main website: [http://www.aircrack-ng.org/](http://www.aircrack-ng.org/)
TABLE II: Configuration summary of the different experiments.

| Experiment                  | Testbed | Number of positions | Frequency channel | BW (MHz) | TX (dBm) | TX duration per repetition (s) | Number of samples per repetition |
|-----------------------------|---------|---------------------|------------------|----------|----------|-------------------------------|---------------------------------|
| A. Signal variance          | T #2    | 3                   | 36               | 20       | 23       | 600                           | ≈ 50000                         |
| **Time effect**             | T #3    | 3 x 9               | 36               | 20       | 23       | 10                            | ≈ 850                           |
| **Space effect**            | T #2    | 3                   | 36, 40, 44       | 20       | 23       | 10                            | ≈ 1700                          |
| B. Path loss                | T #1    | 21                  | 36               | 20, 40, 80| 4, 10, 23| 10                            | ≈ 850                           |
| C. Modulation and coding scheme (MCS) | T #2 | 3                   | 36               | 20, 40, 80| 4, 10, 23| 10                            | ≈ 850                           |
| D. Spatial streams          | T #1    | 21                  | 36               | 20, 40, 80| 4, 10, 23| 10                            | ≈ 850                           |

Fig. 1: Scenario floor plan and device deployment in Testbeds #1, #2, and #3.

TABLE III: Summary of analyzed locations in Testbed #1.

| Location | Height (m) | Distance to the AP (m) | Traversed office walls |
|----------|------------|------------------------|------------------------|
| AP       | 0.740      | -                      | -                      |
| 0        | 0.740      | 1.000                  | 0                      |
| 1        | 0.505      | 0.934                  | 0                      |
| 2        | 0.740      | 3.084                  | 0                      |
| 3        | 0.740      | 4.266                  | 0                      |
| 4        | 1.680      | 2.717                  | 0                      |
| 5        | 1.970      | 2.899                  | 0                      |
| 6        | 1.680      | 3.995                  | 0                      |
| 7        | 0.740      | 2.945                  | 0                      |
| 8        | 0.505      | 5.778                  | 2                      |
| 9        | 1.800      | 9.286                  | 1                      |
| 10       | 0.740      | 11.141                 | 4                      |
| 11       | 1.970      | 10.569                 | 3                      |
| 12       | 1.970      | 13.884                 | 4                      |
| 13       | 0.740      | 15.801                 | 4                      |
| 14       | 1.970      | 17.579                 | 5                      |
| 15       | 1.800      | 18.508                 | 3                      |
| 16       | 0          | 22.020                 | 2                      |
| 17       | 0.505      | 24.304                 | 2                      |
| 18       | 0.740      | 8.975                  | 3                      |
| 19       | 1.970      | 7.267                  | 2                      |
| 20       | 0.740      | 4.623                  | 1                      |

D. Extraction of data sets

Once deployed a testbed, measurements were obtained as follows: firstly, a bandwidth-transmission power level (BW-PTX) combination was set in the AP by means of the OpenWrt firmware. Then, the sender laptop (which was connected through an Ethernet cable to the AP) used iPerf to inject a determined UDP traffic load at 1 Mbps. Lastly, the receiver laptop running Wireshark captured several metrics from each received packet and stored them into .txt files.

IV. EXPERIMENTATION AND RESULTS

Four different experiments were defined to study the behaviour of different IEEE 802.11ax parameters on the aforementioned testbeds: signal variance, path loss, MCS, and spatial streams. Table III compiles the main features of experiments, which are fully described in the following lines.

A. Signal variance

Prior to the in-depth analysis of path loss, effects of time, space, and frequency on received signal were studied. This quantification and assessment of signal variance was aimed to validate the procedure followed to get the measurements that would be used to obtain the TMB path loss model.

- **Time effect** on signal variance was studied by sending a 10-minute continuous data stream to receiver locations from Testbed #2. The full set of collected received signal strength indicator (RSSI) values over time is shown in Figure 2. Except from some signal variance in the first minutes, channel maintained its stability.
for the whole test duration in all considered locations. Besides, computed standard deviation kept below the \( \sigma = 5 \text{ dB} \) of inherent shadowing defined in the IEEE 802.11ax simulation scenarios [9], with values of 0.92 dB, 0.94 dB and 2.26 dB in locations #7, #10 and #18, respectively.

- **Space effect** on signal variance was studied after injecting a 10-second continuous data stream per each 9-point grid of the 3 selected locations from Testbed #3. Figure 3 shows the averaged RSSI value in every 9-point grid, where the reference value (i.e., the one in grid’s central position) is always contained between the maximum and the minimum RSSI of its corresponding grid. More specifically, the maximum absolute difference observed with respect to the reference value is 3.96 dB, 3.38 dB and 3.11 dB in locations #7, #10 and #18, respectively. As these values were below the \( \sigma = 5 \text{ dB} \) of inherent shadowing, it was assumed that any future measurement taken within a 20 cm x 20 cm squared area would correspond to the same location.

- Lastly, **frequency effect** was analyzed by sending a 10-second continuous data stream to receiver locations from Testbed #2 at three adjacent frequency channels: 36 \( (f_c = 5.180 \text{ GHz}) \), 40 \( (f_c = 5.200 \text{ GHz}) \), and 44 \( (f_c = 5.220 \text{ GHz}) \). Table IV shows how RSSI differences with respect to the reference value from channel 36 were again confined below \( \sigma = 5 \text{ dB} \), reflecting no significant influence of frequency channel on collected RSSI.

### B. Path loss

With the goal of quantifying the channel propagation losses at 5 GHz and assessing the suitability of the residential and enterprise channel models proposed in the IEEE 802.11ax standard, a comprehensive study on the path loss was performed.

In each of the \( N_L = 21 \) considered locations from Testbed #1 in which the receiver laptop was placed, the sender laptop continuously sent it data packets through the AP for 10 seconds at a rate of 1 Mbps. This operation was repeated 9 times, one per each possible BW-\( P_{TX} \) combination from Table II. RSSI values at the receiver laptop were used to compute the corresponding path loss (PL) according to

\[
\text{PL} = P_{TX} - P_{RX} = P_{TX} - \text{RSSI},
\]

where \( P_{TX} \) and \( P_{RX} \) correspond to the transmitted and received power, respectively.

Figure 4 shows path loss measured values together with a representation of IEEE 802.11ax path loss models for residential and enterprise scenarios by means of (1) and (2), respectively. Similarity between both models and the actual measured values is noticeable even in the three furthest locations (#15, #16, and #17), where the path loss is less than in closer locations, due to the low number of traversed office walls and the effect of the corridor. The \( W_{ij} \) factor, specific to the number of traversed walls for each location, makes the models suit to the current scenario.

By taking into account the measured values in Testbed #1, the following lines elaborate on the design of a generalizable path loss model. Firstly, the log-distance model

\[
\text{PL}_{\text{ld}}(d_{ij}) = L_0 + 10 \cdot \gamma \cdot \log_{10}(d_{ij})
\]

11Available RSSI values from different bandwidths (BW) were averaged and grouped into a single model, as no significant differences were found except from edge cases (i.e., close to the sensitivity level of the receiver), where higher BW values were slightly prone to signal loss.

### TABLE IV: Averaged RSSI and difference with the reference value in the frequency study performed in Testbed #2.

| Channel 36 (reference) | Location #7 | Location #10 | Location #18 |
|------------------------|-------------|--------------|--------------|
| -44.74 dBm             | -78.43 dBm  | -58.81 dBm   |
| +1.34 dB               | +1.29 dB    | +0.90 dB     |
| -40.96 dBm             | -77.84 dBm  | -59.56 dBm   |
| +3.78 dB               | +0.59 dB    | -0.75 dB     |

10From that moment on, tests were conducted over channel 36.
is obtained after applying a robust regression on path loss measured values from locations with no traversed walls (i.e., from #0 to #7), where $L_0$ is the path loss intercept and $\gamma$ is the attenuation factor.

Then, and as in [7], a new $k \cdot W_{i,j}$ factor is added to the previous model to define the wall factor path loss model

$$PL_{wf}(d_{i,j}) = L_0 + 10 \cdot \gamma \cdot \log_{10}(d_{i,j}) + k \cdot W_{i,j}, \quad (5)$$

being $k$ the attenuation of each wall, and $W_{i,j}$ the number of traversed walls. $k$ is chosen as the value which minimizes the root mean square error (RMSE) with measured values.

Lastly, with the goal of avoiding the use of a location-specific value like $W_{i,j}$, the TMB model

$$PL_{TMB}(d_{i,j}) = L_0 + 10 \cdot \gamma \cdot \log_{10}(d_{i,j}) + k \cdot \overline{W} \cdot d_{i,j} \quad (6)$$

is proposed. In this case, $W_{i,j}$ value is replaced by the distance-dependent expression $W(d_{i,j}) = \overline{W} \cdot d_{i,j}$, where $\overline{W}$ is the average number of traversed walls per meter in the $N_L$ analyzed locations [11].

Additionally, and for comparison purposes, the ITU-R indoor site-general model

$$PL_{ITU}(d_{i,j}) = 20 \cdot \log_{10}(f_c) + N \cdot \log_{10}(d_{i,j}) + L_f - 28, \quad (7)$$

is considered [12], where $f_c$ is the employed frequency, $N$ is the distance power loss coefficient (in our particular case and according to the model guidelines, $N = 31$), and $L_f$ is the floor penetration loss factor (which was removed as experimentation was performed on a single floor).

Figure 3 compares the aforementioned path loss models with measured values in Testbed #1. While the ITU-R and specially the log-distance model are not able to reflect the effect of walls on indoor propagation, the wall factor model (due to the introduction of the $W_{i,j}$ value for each location) better matches with real behavior. The TMB model, for its part, also characterizes channel propagation better than the log-distance and the ITU-R models, thanks to the introduction of the averaged wall attenuation factor $\overline{W}$.

Table V compiles all parameters introduced in the aforementioned models as well as the obtained RMSE when comparing them to the path loss measured values from Testbed #1. Low error is achieved in location-specific models (i.e., residential, enterprise, and wall factor), specially in the wall factor one, but it is necessary to know the number of traversed walls for each receiver’s location.

As for the continuous models (i.e., log-distance, TMB, and ITU-R), it is worth noting the behavior of the TMB model, which outperforms IEEE 802.11ax residential and enterprise models, thus proving its suitability in indoor scenarios.

C. Modulation and coding scheme (MCS)

The dynamic selection by the AP of the most appropriate MCS in function of the node location was analyzed in Testbed #2. The receiver laptop was alternatively placed in locations #7, #10, and #18, receiving a 10-second data flow from the AP at a rate of 1 Mbps. This operation was repeated 9 times, one per each possible BW-PrX combination from Table II. At every repetition, the MCS value of every packet was examined and stored.

Figure 4 shows the appearance of each MCS (in %) in every possible combination. The BW impact on the selected MCS follows a downward trend in most of the analyzed combinations (when not, it is due to a different number of

Table V: Main parameters and RMSE of path loss models analyzed in Testbed #1.

| Path loss model | Parameters | RMSE (dB) |
|-----------------|------------|-----------|
| Residential     | $L_0, \gamma, k$ | 7.9932    |
| Enterprise      | see Equation (2) | 7.8431    |
| Log-distance    | $54.1200, 2.06067, -$ | 13.3454   |
| Wall Factor     | $54.1200, 2.06067, 5.25, -$ | 4.8237    |
| TMB             | $54.1200, 2.06067, 5.25, 0.1467$ | 7.7283    |
| ITU-R           | see Equation (2) | 11.5772   |
spatial streams, as it will be studied in the next subsection). As expected, the AP tends to select greater MCSs when using higher $P_{TX}$ levels (specially in locations #7 and #10). As for location #18, it does not completely follow this pattern, for example when using BW = 80 MHz (see Figures 5c, 5f, and 5i). In this case, the highest MCSs are selected with $P_{TX} = 10$ dBm, where only 1 spatial stream is used (unlike $P_{TX} = 23$ dBm with 2 spatial streams).

In this sense, this confirms that the MCS selection in IEEE 802.11ac (and therefore in IEEE 802.11ax) is no longer tied to the number of spatial streams, as it was in 802.11n. As already known, higher modulations pack more data into each transmission, but at the cost of requiring much higher signal-to-noise ratio (SNR). To boost SNR in poor-quality wireless channels, the AP makes use of its antennas to send redundant information using a single spatial stream, thus eluding spatial correlation. Basically, when the AP reduces the number of spatial streams, the antennas are used to increase the diversity gain at the cost of reducing the spatial multiplexing gain.

D. Spatial streams

As noted in the previous section, the MCS selection process conducted by the AP cannot be detached from the number of employed spatial streams. This issue was analyzed in depth in Testbed #1, where the receiver laptop stored the RSSI value, the number of spatial streams, and the MCS of each received packet.

Data obtained from the $N_L = 21$ analyzed locations is aggregated and presented in Table VI offering the outcomes of the developed $TMBmodel5GhzWIFI$ MATLAB function, a representation of the most selected MCS (i.e., the statistical mode) and its associated number of spatial streams together with its appearance frequency (in %) in function of the BW-$P_{TX}$ configuration of the AP and the collected RSSI in the receiver (here aggregated in 5-dB groups). Due to the non-homogeneous distribution of measurements along the receiver’s RSSI range, there are some RSSI bands with fewer samples than others or even none, the latter case being represented with an empty cell.

Results show how MCSs with a single spatial stream are mainly below -72 dBm, while MCSs with two spatial streams are chosen in better channel conditions. However, the threshold between one and two spatial streams is not clearly defined, as shown with the two outliers located at RSSI bands between [-82, -78] dBm and [-77, -73] dBm.

As expected, the index of the most selected MCS grows together with the RSSI in each analyzed AP configuration, covering all available modes except from the lowest ones using two spatial streams, which are less often used than those with a single stream and higher indexes. For a given RSSI band, however, there is no discernible tendency in the impact of BW and $P_{TX}$ on the selected MCS, even less in low RSSI values, where higher index diversity is observed.

Consequently, in the internal process of the AP to select the most appropriate MCS, the commercial character of the employed AP should be taken into consideration with respect

12Note the avoidance of MCS #9 among tests run with BW = 20 MHz due to its unavailability in IEEE 802.11ac employed hardware.

13The $TMBmodel5GhzWIFI$ MATLAB function is able to provide a vector of MCS probabilities in function of the AP-ST A distance, the BW and the $P_{TX}$. It is available (together with the data sets obtained from described experimentation) in the following GitHub repository: https://github.com/wn-upf/TMBmodel5GhzWIFI
to the conducted experimentation, as the actual MCS selection algorithm could contain some other rules and variables apart from BW, $P_{TX}$, and RSSI.

V. CONCLUSIONS

IEEE 802.11ax is an important step forward for WiFi, bringing many features and improvements to support multi-user and high-throughput application requirements. However, the inherent signal propagation characteristics of the indoor scenarios in which these networks are planned to be deployed complicate prior planning and physical network dimensioning.

Accurate indoor path loss models could help researchers to better understand IEEE 802.11ax PHY and MAC layers, which would lead to the development of better tools to simulate their behaviour, detect inefficiencies, and propose novel technological improvements. Similarly, operators and installers could also benefit from these advanced tools prior to network planning and deployment operations.

This article provides the new TMB path loss model for 5 GHz indoor IEEE 802.11ac/ax scenarios. Designed as a continuous model, the TMB model does not require from previous computation of traversed obstacles to provide the path loss value for a given AP-STA distance, in contrast to existing location-specific models. In fact, the model suitability in indoor environments has been proved by means of extensive experimentation in a typical office floor configuration with multiple room partition walls.

A comprehensive study on the empirical relationship between RSSI and MCS has shown how low BW and high $P_{TX}$ levels configured in the AP lead to larger modulation indexes. As for the number of spatial streams, they grow together with the RSSI in all studied cases. Both facts are considered in the developed $TMB_{model5GhzWIFI}$ function, which returns the MCS and number of spatial streams distribution according to the AP-STA distance and the BW-$P_{TX}$ configuration.

Multi-floor environments and technical implications of upcoming commercial IEEE 802.11ax devices (for instance,
The use of MU-MIMO technology stand as the two main issues to be integrated into the TMB model in the near future. Additionally, the current study paves the way of an in-depth analysis of the channel occupancy rate (COR) in a WLAN in function of the receiver’s location.

**Acknowledgement**

This work was partially supported by the Cisco University Research Program fund (Project CG No. 890107, Towards Deterministic Channel Access in High-Density WLANs), a corporate advised fund of Silicon Valley Community Foundation. It also received funding from the Catalan government through projects SGR-2017-1188 and SGR-2017-1739, and from the Spanish government under the project TEC2016-79510-P.

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| RSSI (dBm) | 20 MHz | 40 MHz | 80 MHz |
|-----------|--------|--------|--------|
| 4 dBm     | 10 dBm | 23 dBm | 4 dBm  |
| [-97, -93]|        |        |        |
| 82.42%    | 54.57% |        |        |
| [-92, -88]|        |        |        |
| 31.62%    | 74.76% |        |        |
| [-87, -83]|        |        |        |
| 33.10%    | 55.00% |        |        |
| [-82, -78]|        |        |        |
| 45.33%    | 27.27% |        |        |
| [-77, -73]|        |        |        |
| 35.76%    | 29.85% |        |        |
| [-72, -68]|        |        |        |
| 44.44%    | 36.17% |        |        |
| [-67, -63]|        |        |        |
| 77.39%    | 54.10% |        |        |
| [-62, -58]|        |        |        |
| 60.70%    | 86.00% |        |        |
| [-57, -53]|        |        |        |
| 50.33%    | 99.13% |        |        |
| [-52, -48]|        |        |        |
| 97.92%    | 95.97% |        |        |
| [-47, -43]|        |        |        |
| 98.51%    | 97.89% |        |        |
| [-42, -38]|        |        |        |
| 97.25%    | 96.00% |        |        |
| [-37, -33]|        |        |        |
| 99.55%    | 99.12% |        |        |
| [-32, -28]|        |        |        |
| 64.42%    | 97.21% |        |        |
| [-27, -23]|        |        |        |
| 97.82%    | 97.21% |        |        |