Indoor Path Loss Measurements and Modeling in an Open-Space Office at 2.4 GHz and 5.8 GHz in the Presence of People

Samar Kaddouri, Marwan El Hajj, Gheorghe Zaharia, Ghaïs El Zein

Samar Kaddouri, Marwan El Hajj, Gheorghe Zaharia, Ghaïs El Zein. Indoor Path Loss Measurements and Modeling in an Open-Space Office at 2.4 GHz and 5.8 GHz in the Presence of People. IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), Sep 2018, Bologna, Italy. hal-01870223

HAL Id: hal-01870223
https://hal.science/hal-01870223v1

Submitted on 7 Sep 2018

Indoor Path Loss Measurements and Modeling in an Open-Space Office at 2.4 GHz and 5.8 GHz in the Presence of People

Samar Kaddouri, Marwan El Hajj, Gheorghe Zaharia, Ghais El Zein
Institut d'Electronique et de Télécommunication de Rennes - IETR - UMR CNRS 6164
INSA, 20 Avenue des Buttes de Coësmes, 35708 Rennes, France
samar.kaddouri@insa-rennes.fr

***Abstract*—This paper presents path loss models based on extensive propagation measurements performed at 2.4 GHz and 5.8 GHz in a modern indoor office layout typical of small and medium-sized businesses, namely: the open-space office. Measurements were conducted using a vector network analyzer which covers frequencies up to 6 GHz, and ultra-wideband omnidirectional vertically-polarized antennas. The data were recorded under the same conditions and with the same antennas for both 2.4 GHz and 5.8 GHz. 940 transmitter-receiver location and height combinations were studied, as well as antenna configurations in both line-of-sight and non-line-of-sight. A second measurement campaign was conducted to quantify the variation amount on the expected power loss in realistic scenarios that include the effect of people movement and showed that the mean path loss further increases by up to 4 dB due to people's presence and movement, with variations up to 9 dB when the activity level is high.**

***Index Terms*—Indoor propagation, propagation measurements, path loss modeling, office.**

I. INTRODUCTION

Indoor propagation research has been a topic of study for many years. However, the indoor environments, especially work-related ones, are constantly evolving. Propagation and path loss modeling are critical for successful planning and deployment of wireless communication systems, and are usually established empirically based on measurements. Since path loss is dependent mainly on the environment, the frequency, and the antennas, a propagation model can only be applied to sites similar to the one where the measurements were conducted. The already existing models may become obsolete as the offices architecture and layout change. With the evolving work environment, particularly in start-ups and small and medium businesses, investigating the propagation characteristics within the 2.4 GHz and 5.8 GHz WiFi bands is of particular interest to accommodate the new workplace trends.

The typical office environment evolved from enclosed private offices to partitioned cubicles, and most recently to open-space offices with no partitions. The open-office concept has taken off in the last decade and has spread from tech startups to more established enterprises in order to foster collaboration and optimize space. Since such environments are shared, increased pedestrian traffic within, as well as in and out can be expected. People in indoor propagation environments can cause a substantial amount of fading to the received signal. The variation of signal strength is the main reason that degrades the performance of an indoor system because of the rapid changes in signal level and previous studies [1] showed that at 1.8 GHz, fades with more than 10 dB magnitude were observed in measured data sets. In this context, providing a statistical distribution of the path loss to be expected in an open-office environment that takes into account the realistic movement of people in the workplace would be very useful, allowing for better network planning and deployment.

Several papers have been published on indoor propagation in the WiFi bands in an office environment. In [2], channel measurements were carried out at 5.6 GHz in a 6.6 m × 5.9 m furnished conference room. In [3], channel measurements at 5.25 GHz were performed on the third floor of a three-story office building consisting of 10 private offices with closed doors. In [4], the characteristics of the radio channel at 5.25 GHz were investigated using measurement data collected within a university building in a static configuration. The data resulting from [3], [4] and from some outdoor experiments were used to develop the ITU-R M. 2135 path loss model [5]. The TGn/ac channel models defined for 2.4 GHz and 5 GHz [6]–[8] consider open-space environments with line-of-sight (LOS) and non-line-of-sight (NLOS) configurations. However, the considered open-spaces where the measurements were conducted and from which the models were initially derived are not typical workplaces: one room was a staff canteen and the other room was a glass covered pedestrian street located between two buildings [9]. The impact of moving people on indoor channels has been studied at 1.8 GHz in [1] and static path loss model measurements for stairwells have been reported in [10] at 2.4 GHz and 5.8 GHz. However, to the best of our knowledge, no comparative analysis has been conducted in modern non-partitioned open-space environments at 5.8 GHz for both static and dynamic configurations.

In this paper, we report results for path loss channel measurements in the 2.4 GHz and 5.8 GHz bands for an open-space static environment in various situations using the same ultra-wideband omnidirectional antennas at the same positions for both frequency bands. The measurements cover LOS and NLOS propagation conditions and different antennas' heights. The obtained results are used to provide path loss models in a static open-space environment. We also study the effect of people movement on the path loss to quantify how strongly can the signal degrade in the case of a high activity level. We present the statistical characteristics of the path loss values to be expected in such an environment and compare the obtained values for the static and dynamic cases. These are the main contributions of this paper.

The rest of this paper is structured as follows: In Section II we describe the equipment and environments of the first measurement campaign to modelize the path loss in open-offices and present the results and analysis of these measurements. Section III provides the results of the second measurement campaign that aims at providing a statistical distribution of the power loss. Conclusions are drawn in Section IV.

II. PATH LOSS MEASUREMENTS AND MODELING

A. Setup

An HP 8753-D vector network analyzer (VNA) was used to sample the channel at 801 equidistant points in the 2.3-2.5 GHz and the 5.47 GHz-5.85 GHz WLAN bands [11]. The VNA corresponding sweep time is 400 ms, and four sweeps are performed and averaged for each S_{21} measurement. The S_{21} measurements were performed both in a static then in a dynamic channel where people were allowed to move freely and randomly. Fig. 1 shows the setup. A PC was used for VNA control and data acquisition. Ultra-wideband antennas operating from 800 MHz to 6 GHz were used at the transmitter and at the receiver. The antennas were mounted on a vertical post to control their height. The antennas are omnidirectional, vertically polarized, with a 2.0 dBi gain and a horizontal beamwidth of 75°. The transmit power measured at the VNA output is 8 dBm. A 17 m coaxial cable was used to connect the Tx antenna to the VNA whereas a 1 m coaxial cable was used for the Rx antenna. The complete measurement system, including the cables, was calibrated. Full 2-port calibration was used in order to remove the frequency response of these coaxial cables. It has to be noted that the effect of the two antennas was not included in the calibration.

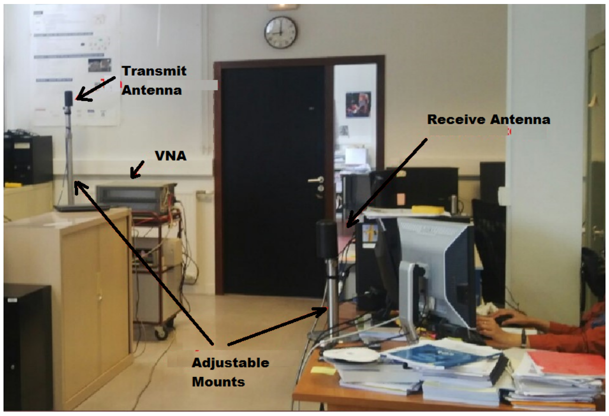

Fig. 1. Measurement setup.

B. Environment and Configurations

The measurements were performed in an L-shaped open-space non-partitioned office located in the ground floor of a typical work building. The measurement campaign was conducted during the day, hence the desks were occupied. The floor plan and Tx and Rx locations for the measurement campaign are shown in Fig. 2, where ”Pos-T” indicates the transmitter's position. ”Pos6” is chosen so that the direct path to the transmitter is obstructed by a pillar and a high metallic cupboard. Each of the receiver's positions indicates an occupied and furnished desk at the time of the measurement campaign. Other furniture, such as metallic cupboards, is also present.

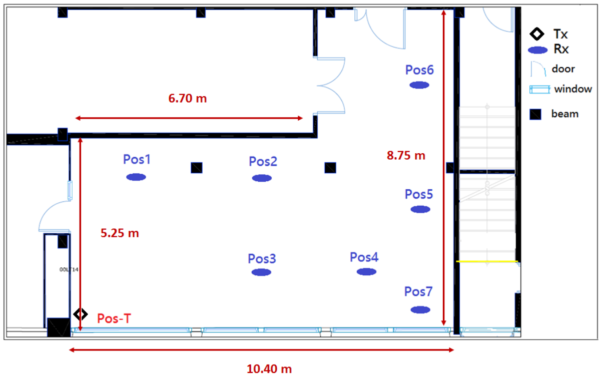

Fig. 2. Open-space office plan and Tx/Rx locations.

Three configurations for the antennas' heights were studied:

- Configuration 1: Both Tx and Rx are placed as high as possible. For our experiment, we chose the maximum height of the posts which was $h = 1.75$ m. While this height is suitable for the transmitter in a practical situation (on the top of a cupboard for example), it is hardly practical for the receiver.
- Configuration 2: Tx is placed at $h = 1.75$ m and Rx is placed at $h = 1.20$ m (standard height of a table/desk).
- Configuration 3: Both Tx and Rx are at $h = 1.20$ m.

To obtain measurements in a realistic environment, people were allowed to sit at their desks and to move freely in the room which makes the channel dynamic. The movements were random but still realistic, and other people could walk in and out of the office as well. Since the movements were random, 10 measurements were taken for each configuration and for each frequency band to compute an average path loss representative of a realistic open-space office scenario. Therefore, the average was taken twice: First over the 10 measurements to obtain an average of the frequency response of the channel over time for a certain Tx-Rx position, then over the 801 frequency points to obtain the average path loss in the considered frequency band. Path loss is modeled as:

$$PL(d)[\text{dB}] = PL(d_0)[\text{dB}] + 10n\log_{10}\frac{d}{d_0} + X_\sigma[\text{dB}] \tag{1}$$

where $PL(d_0)$ is the path loss at a reference distance d_0 from Tx, n is the path loss exponent, the term $PL(d_0)+10n\log_{10}\frac{d}{d_0}$ represents the deterministic path loss predicted at a distance d and X_σ is a normal distribution with zero mean and standard deviation σ that represents the range of deviation of the measured values from the predicted mean. In the presented results, the gain of the antennas was not considered.

C. Results and Discussion

In this section, the measured propagation characteristics as well as the derived path loss models are presented in terms of n, P_0 (i.e: $PL(d_0)$ at $d_0 = 1$ m) and σ. In Configuration 1, all positions of the Rx antenna, except for "Pos6", are in LOS. The measurement results are shown in Table I for 2.4 GHz in terms of relative path loss, which we define as the difference in dB between the measured path loss and the free-space path loss value. Negative relative values indicate losses lower than in free space.

TABLE I
RELATIVE PATH LOSS IN CONFIGURATION 1 FOR 2.4 GHZ

	Pos1	**Pos2**	**Pos3**	**Pos4**	**Pos5**	**Pos6**	**Pos7**
PL [dB]	-2.96	-5.89	-4.83	-3.86	-2.72	+1.03	-1.37

In Table I, we notice that all the LOS measurements show path loss lower than free space loss, except for the measure taken at "Pos6". This is explained by the fact that reflected and scattered multipaths by surrounding objects are added to the LOS path and contribute to the received power. In contrast, "Pos6" lacks the LOS component and the path loss is higher than in free space. We observe a similar trend at 5.8 GHz.

From these measured values, the parameters of the derived path loss models are determined through linear regression analysis. The correlation coefficient ρ is also calculated. The parameters for all three configurations and both frequencies are presented in Table II.

Both exponents are smaller than the free space exponent 2 due to constructive multipaths. These values are slightly lower than those given in literature for traditional office-type environments (for example, n between 1.6 and 1.8 for Configuration 1 [3], [5]). We also notice that P_0 values increased with frequency, as expected. The smaller σ value indicates that the path loss model at 5.8 GHz has a better accuracy than the model obtained at 2.4 GHz.

TABLE II
DERIVED PATH LOSS PARAMETERS IN CONFIGURATIONS 1, 2 AND 3

		n	P_0 [dB]	σ [dB]	ρ
Configuration 1	**2.4 GHz**	1.80	40.95	2.18	0.88
	5.8 GHz	1.35	45.49	1.5	0.90
Configuration 2	**2.4 GHz**	2.02	41.80	2.15	0.94
	5.8 GHz	1.9	43.63	1.01	0.91
Configuration 3	**2.4 GHz**	2.81	30.54	2.92	0.95
	5.8 GHz	2.3	33.15	2.6	0.98

In Configuration 2, because of the height difference between Tx and Rx, the direct path was obstructed for more Rx positions. Four receiver positions are in LOS (Pos1, Pos2, Pos3 and Pos5) and three are in NLOS (Pos4, Pos6 and Pos7). From Table II, we notice an increase in the path loss exponents for both 2.4 GHz and 5.8 GHz, which is consistent with the physical interpretation: Configuration 2 has more NLOS positions than Configuration 1. We also observe that the σ values are very close in both configurations, which indicates that the derived models in each case have similar accuracy.

In Configuration 3, both Tx and Rx are placed on the desks and the LOS paths are all obstructed due to furniture (e.g. computer monitors), except for ”Pos2”. From Table II, we notice that the path loss exponents again increased. We also observe that the σ values in this configuration are higher than the ones obtained in the previous configurations, which indicates that the accuracy of the models obtained for Configuration 1 and 2 is better.

To summarize, we present all the measured path losses and the resulting derived models in Fig. 3 and Fig. 4.

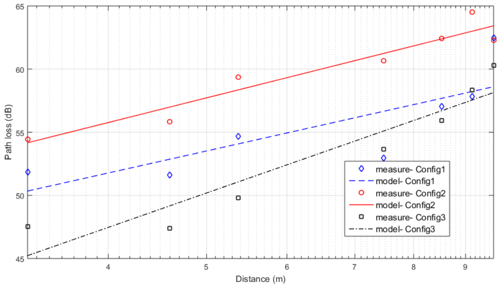

Fig. 3. Path loss results and the estimated model at 2.4 GHz.

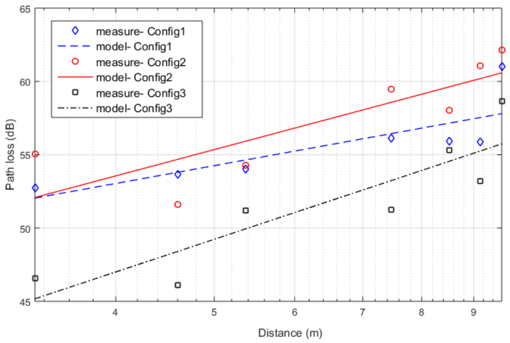

Fig. 4. Path loss results and the estimated model at 5.8 GHz.

Lastly, we compare the measured values to the ones provided recently by the ITU-R P.1238-9 [5]. Since no values for the path loss exponent n are provided for the frequencies and the environment considered in this paper, we used the available data at the closest frequencies which are 2.2 GHz and 4.7 GHz. Another limitation is that the recommendation document only considers the LOS case and a static channel.

The values presented for n were respectively 2.07 and 1.98. These values are very close to the free space path loss value of 2, so our measurement campaign and the resulting models provide a more specific discrimination based on whether the propagation is in LOS or not, and add to the data available for path loss parameters in open-space environment at the frequencies of 2.4 GHz and 5.8 GHz.

III. PATH LOSS STATISTICAL DISTRIBUTION IN THE PRESENCE OF PEOPLE

A. Environment and Configuration

For the second campaign, the measurements were conducted in the same open-space presented in Fig. 2. The retained positions were ”Pos2” for LOS close-range transmission, ”Pos5” for LOS far-range transmission and ”Pos6” for NLOS far-range transmission. ”Pos5” and ”Pos6” were placed at equal distance from Tx. For each position, power loss measurements were recorded every 10 seconds during the working hours, from 10 am to 5 pm, resulting in 2521 measures for each case. Configuration 2 was selected since it is the most realistic scenario. Since the measurements were time-consuming, we only considered the 5.8 GHz band. People (both the office occupants and outsiders) were not told measurements were recorded to keep their movement as natural as possible.

B. Results and Discussion

Fig. 5 presents the time evolution of the path loss for the considered positions.

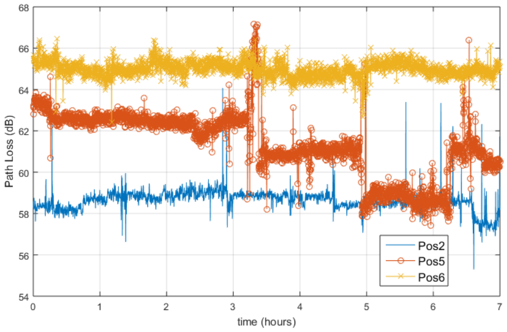

Fig. 5. Path loss evolution for ”Pos2”, ”Pos5” and ”Pos6”.

People activity during working hours affects the multipath signals. Therefore, the received signal level varies. This creates a path loss mean value that is different that the one obtained in static conditions. The static and dynamic mean path loss are presented in Table III.

TABLE III
PATH LOSS IN CONFIGURATION 2 FOR 5.8 GHZ

	Static PL [dB]	**Mean dynamic PL [dB]**
Pos2	54.7	58.5
Pos5	58.6	61.3
Pos6	62.5	65.0

We note that people activity impacts the mean path loss up to almost 4 dB, with ”Pos6” being the less affected. In addition, the received signal during working hours considerably fluctuates in the dynamic case. To illustrate, Fig. 6 presents the obtained result for ”Pos5” in a 30 minute time period (between 1 pm and 1.30 pm) where the path loss varies in a 9 dB range. The selected time interval corresponds to the lunch break where people's activity is noted to significantly increase.

We also notice in Fig. 6 that the mean path loss before the 3.2 h mark and after the 3.5 h mark changes. This indicates a more permanent change of the propagation channel than one caused by people movement. This is explained by an environment modification and is consistent with the occurrence of a furniture displacement.

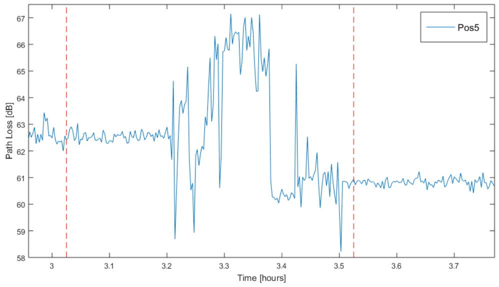

Fig. 6. Time evolution of the path loss for position ”Pos5” during lunch break.

We also notice larger and more frequent variations when the receiver is at ”Pos5” and ”Pos2” than in ”Pos6”, since the LOS components at ”Pos2” and ”Pos5” are directly affected by people's movement in the office, whereas ”Pos6” is already in an NLOS configuration.

Next, we compute the probability distribution function (PDF) of the path loss values obtained using the *histogram* function. The resulting PDF is presented in Fig. 7.

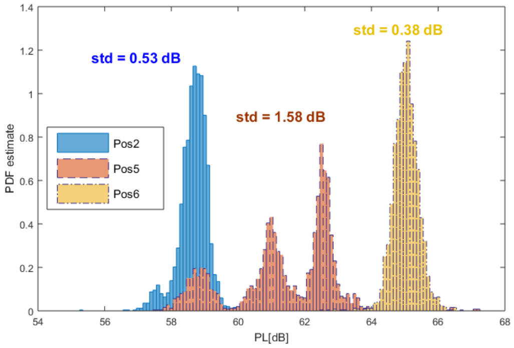

Fig. 7. PDF of the power loss values at ”Pos2”, ”Pos5” and ”Pos6”.

We observe that the PDF with the lowest standard deviation is the one obtained at ”Pos6”. This position being already in an NLOS configuration, it is less affected by people movement. The standard deviation in that case is due to contributing multipaths being blocked. In the case of ”Pos2”, the movement of people mainly blocks the LOS path and causes higher changes in the path loss, thereby generating a larger standard deviation. ”Pos5” has the highest standard deviation due to its location in the room. Much more people cross the Tx-Rx line, whereas for ”Pos2”, mainly the occupants of the desks at ”Pos1” and ”Pos2” move across it. As expected due to the absence of a LOS for ”Pos6”, the mean path loss at ”Pos6” is higher than in ”Pos5”, even though both positions are equidistant from Tx. However, since the people movement affects the LOS path in ”Pos5”, its deviation is higher than in ”Pos6”.

The cumulative distribution function (CDF) of the measured path loss values was also computed for the three positions. From Fig. 8, we obtain a $5\% \leq$ CDF $\leq 95\%$ for 57.63 dB $\leq PL \leq$ 59.17 dB at ”Pos2”, for 58.52 dB $\leq PL \leq$ 63.13 dB at ”Pos5” and for 64.43 dB $\leq PL \leq$ 65.58 dB at ”Pos6”. In these figures, the ”+” signs indicate the range of these PL values.

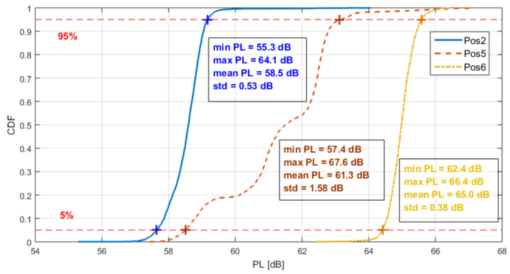

Fig. 8. CDF of the power loss values at ”Pos2”, ”Pos5” and ”Pos6”.

IV. CONCLUSION

This paper presented the results of two measurement campaigns conducted in an indoor office layout typical of small and medium-sized businesses, namely: an open-space office. The first measurement campaign studies the path loss obtained at 2.4 GHz and 5.8 GHz in three different Tx and Rx antennas configurations. This campaign brings new data for this type of environment and derives suitable path loss models that were not available at 2.4 GHz and 5.8 GHz. The second measurement campaign analyzes the time variation of the path loss in the case of moving people. People in indoor propagation environments can cause a substantial amount of fading to the received signal. The results analysis shows that the mean path loss is further increased by up to 4 dB due to people’s presence and movement, with variations up to 9 dB when the activity level is high. The standard deviation of the measured path loss correlates with the amount of people activity in the vicinity of the radio wave propagation. This measurement campaign allows us to provide a range of possible values around the path loss obtained using the usual statistical models. As a result, we provided a statistical characterization for the power loss experienced in realistic situations where the random movement of people should be taken into account to better manage effective WLAN network planning and deployment in open-space offices.

ACKNOWLEDGMENT

This work was supported by the French project FUI22 OptimiSME, Région Bretagne and Rennes Métropôle.

REFERENCES

[1] N. Papadakis, A. Economou, J. Fotinopoulou, and P. Constantinou, “Radio propagation measurements and modeling of indoor channels at 1800 MHz,” *Wireless Personal Communications*, vol. 9, no. 2, pp. 95–111, 1999.
[2] M. Peter and W. Keusgen, “Analysis and comparison of indoor wideband radio channels at 5 and 60 GHz,” in *IEEE 3rd European Conference on Antennas and Propagation. EuCAP*, 2009, pp. 3830–3834.
[3] D. Xu, J. Zhang, X. Gao, P. Zhang, and Y. Wu, “Indoor office propagation measurements and path loss models at 5.25 GHz,” in *IEEE 66th Vehicular Technology Conference. VTC Fall*, 2007, pp. 844–848.
[4] J. Zhang, X. Gao, P. Zhang, and X. Yin, “Propagation characteristics of wideband MIMO channel in hotspot areas at 5.25 GHz,” in *IEEE 18th International Symposium on Personal, Indoor and Mobile Radio Communications. PIMRC*, 2007, pp. 1–5.
[5] ITU- R, “ITU–R M. 2135: Guidelines for evaluation of radio interface technologies for IMT-Advanced,” 2008.
[6] V. Erceg, “IEEE p802. 11 wireless LANs TGn channel models,” *IEEE 802.11-03/940r4*, 2004.
[7] IEEE 802.11 Working Group, “TGac channel model addendum,” *Collaboration Project Proposal*, vol. 12, 2010.
[8] G. Breit, H. Sampath, S. Vermani *et al.*, “TGac channel model addendum,” *IEEE*, 2010.
[9] J. Medbo, H. Hallenberg, and J.-E. Berg, “Propagation characteristics at 5 GHz in typical radio-LAN scenarios,” in *Vehicular Technology Conference, IEEE 49th*, vol. 1, 1999, pp. 185–189.
[10] S. Y. Lim, Z. Yun, and M. F. Iskander, “Propagation measurement and modeling for indoor stairwells at 2.4 and 5.8 GHz,” *IEEE Transactions on Antennas and Propagation*, vol. 62, no. 9, pp. 4754–4761, 2014.
[11] FCC report, “Decision on the harmonised use of the 2.4 GHz and the 5 GHz frequency bands for the implementation of wireless access systems including radio local area networks (WAS/RLANs),” Federal Communications Commission, Tech. Rep. 16-181, 2017.